3D Visualization of the Diffusion Tensor Ellipsoid in Mouse Brain

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Synopsis

The goal of the present study is to propose a new 3D visualization method which can simultaneously extract and display diffusion tensor size, shape and orientation. The results demonstrate that the proposed method is a promising technique for the evaluation of morphologic phenotype and can be used as an effective diagnostic tool for white matter diseases.

Introduction

Diffusion-tensor MRI (DT-MRI) provides unique microstructural and physiological information [1] and can be used to characterize diffusion isotropy, anisotropy, similarity and fiber tract organization. In the analysis of tissue pathology, it is imperative to extract and display all of the aforementioned information in three-dimensional (3D) manner. Several methods have been previously proposed for visualizing the 3D information contained in DTI data [2-5], however, all of them only utilize the part of the information of DTI data to display the integrity of the white matter tract. The aim of this study is thus to propose a novel 3D visualization technique with a combination of foregoing visualization methods. A well-established cuprizone-induced mouse model of experimental demyelination in corpus callosum (CC) in a mouse brain was used to evaluate the capability of our proposed 3D visualization method.

Material and Methods

Animal

A male (8-week-old) C57BL/6 mouse was treated on a diet of 0.2% cuprizone through mixed into milled chow and was maintained on the cuprizone diet until 10 weeks.

DTI data acquisition

Mouse was anesthetized with isoflurane/oxygen mixture (isoflurane at 5 % for induction and 1% for maintenance) and examined on a 4.7T Biospec 47/40 spectrometer. A spin echo imaging sequence was employed for acquisition of the required series of diffusion weighted images with TR of 1.5 s, TE of 36.5 ms, Δ of 15 ms, δ of 8 ms, 8 averages, slice thickness 0.8 mm, FOV of 2 cm, data matrix 256x256 and b values of 0 and 1100 mm^2/s applied along six directions:[Gx, Gy, Gz] = [1,1,0],[1,0,1],[0,1,1],[-1,1,0],[0,-1,1], and [1,0,-1]. Images were acquired before and at 4^{th}, 6^{th}, 10^{th} week after treating with cuprizone diet.

3D tensor ellipsoid visualization with color coding

The diffusion tensor was derived by matrix diagonalization, and three pairs of eigenvalues and eigenvectors were calculated for each pixel. The tensor ellipsoid for each pixel was constructed according to the eigenvalues on each axis and is located on the center of the pixel. Relative anisotropy (RA) map was obtained form the diffusivity of each axis and used for quantification of the anisotropy. The major axis of each ellipsoid was oriented in the direction of the principal eigenvector. The ellipsoids were colored by combining the principal eigenvector and RA into RGB coding. The RGB components of each ellipsoid were defined by the ratio of the absolute value of x, y and z components of the principal eigenvector, and the intensity was proportional to the RA value. Red was assigned to the left-to-right axis, green to the superior-to-inferior, blue to the anterior-to-posterior. All codes were written on the UNIX platform with C++ language running on a SGI Fuel work station with Open Inventor version 2.1.

Results and Discussions

3D color-coding of the DT ellipsoid and RA map with normal mouse brain were shown in Fig. A1 and Fig. B, respectively. Figs. A2-A5 show the series of 3D view of the DT ellipsoid focused on the CC in 0 week, 4 weeks, 6 weeks and 10 weeks of cuprizone model, respectively. The DT within CC in 0 week, exhibited the well-organized structure regarding the elliptical size, shape and orientation. In 4 weeks, the thicker of CC was observed and the size of ellipsoid was reduced due to the decrease of diffusivity, which were probably attributed to the formation of edema and in 6 weeks, the size of ellipsoid was recovered to the normal but the shape of ellipsoid was changed to sphere, indicating the reduction of anisotropy due to the demyelination. In 10 weeks, the thinner of CC and the disordered structure in relation to the elliptical size, shape and orientation were observed suggesting the demyelination and axonal damage. The extracted information of our proposed method was well-correlated with the histological staining using Luxol Fast Blue (LFB) as shown in Figs. C1-C4.

Conclusion

The proposed 3D visualizing method is able to simultaneously demonstrate the DT size, shape and orientation that can be used to characterize microstructure of the fiber tract. The advantage of using 3D DT ellipsoid visualization with DT-MRI is the ability to perform rapid and detailed whole-brain phenotype analysis of mutant strain. In addition, the proposed 3D method is expected to be a useful tool for white matter diseases diagnosis and follow-up in clinical applications.

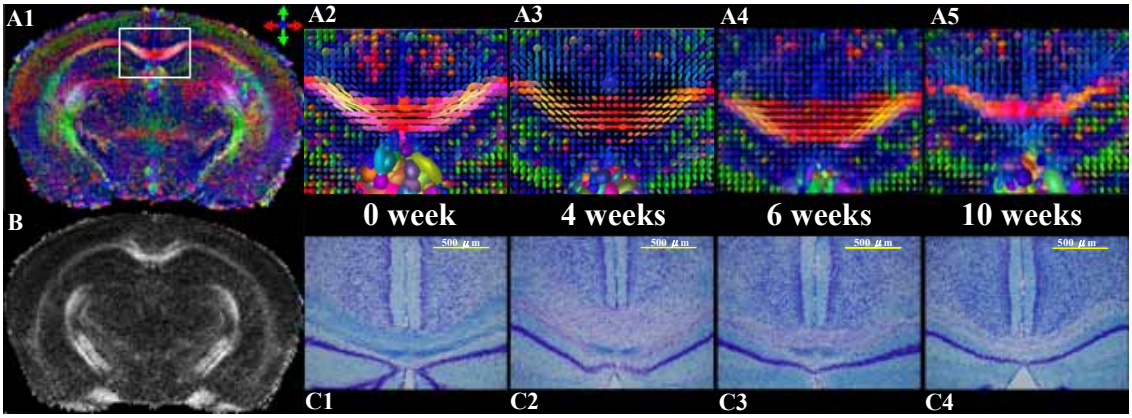

Fig. A. 3D diffusion ellipsoid with color-coding for the axial section. The colors represent the principal diffusion direction with red: left-right; green: superior-inferior; blue: anterior- posterior. A1: An overview of 3D diffusion ellipsoid; A2-5: Enlarged view of corpus callosum from 0 week to 10 weeks of cuprizone animal model. Figure B. RA map. Figure C. Representative LFB histological staining at the indicated time points, respectively.

References

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