Mapping of Neural architecture with Multi-Lines Diffusion Tensor First Eigenvector Field

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Abstract

Diffusion tensor image is capable of mapping neural fiber orientation accurately. However, the relationship between neural fiber density and diffusion tensor has not been quantified. Here we simulate diffusion tensor image with different ratios of white matter within a voxel and calculate the diffusion indices, i.e. Fractional Anisotropy, Rational Anisotropy, and Linear Case. Our result shows that these indices are proportional to neural density within a voxel. Based on this relationship, neural architecture of rat hippocampus has been "line drawing" with multi-lines of first eigenvector field, which is consistent with known histology.

Introduction

Numbers of reports have demonstrated that neural fiber density is highly correlated with normal brain function as well as brain abnormalities, e.g. neural degeneration [1-3] and development [4], using diffusion tensor imaging (DTI) and scalar indices. However, the relationship between neural density and diffusion tensor has not been resolved. To evaluate the relationship between neural density and scalar indices, i.e. Fractional Anisotropy (FA), Rational Anisotropy (RA), and Linear Case (CL) [5-6], two-compartment simulation with non-exchange assumption was studied. Our result shows that these indices are proportional to neural density. Based on this relationship, DTI first eigenvector field is visualized using multi-lines, which is proportional to indices. Neural architecture of rat hippocampus has been "line drawing" with this method, which is highly consistent with histology map.

Materials and Methods

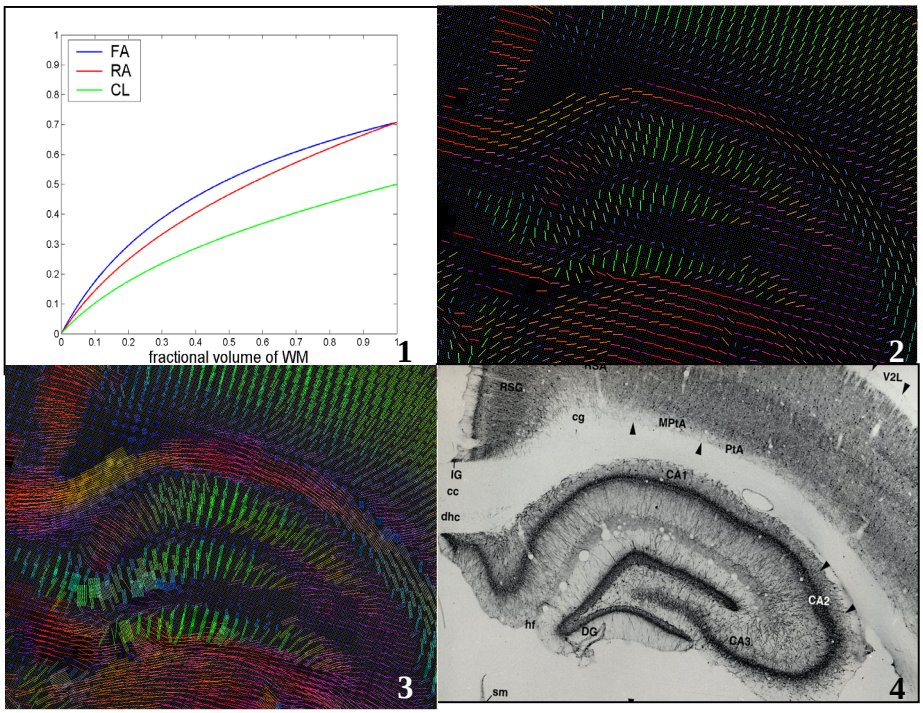
The non-exchanged model and two-tensor compartment system was adopted in this investigation. The signal can be modeled by $S(b) = S_0 \{f \times \exp[-bgD_1g'] + (1 - f) \times \exp[-bgD_2g']\}$, where f is the fractional volume of white matter component, D_1 and D_2 are the diffusion coefficients of two components, and g is the unit vector of diffusion gradient orientation. The two compartment DT model is simulated in the case which two DTs [λ_1, λ_2, λ_3] (unit: 10^{-3} mm^2/sec) were considered that white matter of [1.4, 0.35, 0.35] and isotropic parts of [1, 1, 1]. The simulation was repeated for f between 0 and 1 and the b-value of 100-3000 sec/mm^2. DTI encoding schemes was adopted the oblique double encoding (ODG): g = 0.707 {(1, 1, 0), (1, 0, 1), (0, 1, 1), (-1, 1, 0), (1, 0, -1), (0, -1, 1)}. Three scalar indices (FA, RA, and CL) and their relationships between fractional volumes of white matter were calculated.

Adult Wistar rats were euthanized under deep general anesthesia with intra-peritoneal injection of sodium pentobarbital, 100 mg/kg. Rat brains were dissected from the cranium and were placed fixedly in an acrylic holder filled with 4% formaldehyde solution. MR experiment was performed in a 9.4T MRI system (Bruker, Germany). Images of DTI were acquired using spin echo diffusion sequences with ODG diffusion-encodings with TR/TE of 2000/19.3 ms and voxel size = 0.1 × 0.1 × 1.2 mm^3. Δ = 8.11ms, δ = 4.5ms, and g = 36 g/cm yields b value of 1200 sec/mm^2.

"Line drawing" of rat brain was performed using multi-lines first eigenvector of DTI. The number of multi-lines within each voxel is proportional to the scalar index. Multi-lines first eigenvector field is color-coded according to its Cartesian orientation.

Results

Figure 1 shows the relationship between white matter compartment and scalar indices using b of 3000 sec/mm^2 under two-compartment diffusion simulation. b value of 100 – 3000 sec/mm^2 shows almost the same result. Among the scalar indices, RA shows highly linear relationship with neural density. Figure 2 and 3 shows the result of DTI first eigenvector field with single- and multi-lines, respectively. Multi-lines first eigenvector field shows clear neural architecture, which is in consistent with histological result in figure 4.



Conclusions

There are lots of factors will affect the value of scalar indices, i.e. neural density, demyelination, and crossing fibers. Within white matter or in high resolution case, crossing fiber effect can be ignored. The absence of myelin results in increasing of $\lambda 2$, $\lambda 3$ is only about 20% [7], which will slightly modify the scalar range but no influence on linear relationship. Our result shows that the neural density plays the most important parts in scalar indices and is almost linear proportional to scalar indices. Under this relationship, order of neural degeneration can be evaluated. In addition, multi-lines first eigenvector filed can demonstrate neural architecture clearly, which shows "line-drawing" effect and is consistent with histological image.

Figure 1-4 are the relationship between scalar indices and white matter compartment (Fig. 1), single-line and multi-lines first eigenvector field (Fig. 2, 3), and chemoarchitectnoic atlas of the rat forebrain from Paxinos (Fig. 4).

Reference

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