MEDINFO 2007
HISA Ltd Australia
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Extraction of White Matter Connectivity in the Human Brain Using the Projected Diffusion-Tensor Distance

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Abstract

Diffusion tensor imaging (DTI) has become a powerful tool for analyzing the structure of white matter. We have already developed a novel method to assess white matter connectivity using diffusion tensor distance between neighborhood voxels. Diffusion tensor distance is defined as the length from the center to the surface of the diffusion tensor. In the proposed method, we use directional diffusion measurements to infer regional white matter connectivity. To assess the connectivity, we investigate the method using the iterative algorithm. By the algorithm, we can segment typical white matter trajectories such as Corpus Callosum. Compared with other algorithms using eigenvalues of the diffusion tensor, our approach has flexibility in selecting connected regions by using basic characteristics of the diffusion tensor shape.

Keywords:

diffusion tensor, MRI, anisotropy, white matter, connectivity

Introduction

Recently, the study of brain function has received much attention and in vivo detection of the structure of deep brain white matter has become more important. Conventional Magnetic Resonance Imaging (MRI) methods, however, cannot detect them. With the development of the devices and techniques of MRI, we can measure the diffusion of water molecules. This technique is called Diffusion Weighted Imaging (DWI). In DWI, the area where the degree of diffusion is large shows as dark and where the degree of diffusion is small shows as bright. Using such images, we can obtain MR diffusion tensor maps. Particularly in white matter, the diffusion varies very much. The value and orientation of the diffusion are directly related to the interaction between nerve bundles and magnetic gradients. This is known as the diffusion anisotropy. Namely if the nerve bundles are perpendicular to the magnetic gradient, we can obtain the minor diffusion coefficient. Conversely if the nerve bundles are parallel to it, we can obtain the major one.

In this study, directional diffusion measurements are used to infer regional white matter connectivity. The connectivity is determined as a function of distance between the origin of the tensor and the surface for each voxel. With the iterative algorithm, we can segment typical white matter trajectories such as Corpus Callosum and Internal Capsules. This approach is different from other methods that use the principal eigenvector or full tensor. Here, a novel method for labeling and segmenting white matter connectivity using DT-MRI is described.

Methods

Diffusion tensor images are acquired on a 1.5 T Signa MRI system (GE). Echo planar images are acquired on a subject in the axial plane at 36 slice locations. The six dimension weighting was done and the maximum b value was 1014 sec/mm2. Other parameters were Echo Time (TE) =78 msec, Repetition Time (TR) =7000 msec, slice thickness=3 mm, image matrix=256x256 pixels (zero filling), in plane resolution=1 mm.

First, the algorithm is started from a specified point in a slice. Second, an iteration method is used to select multiple neighborhoods

We consider the normalized distance potential by multiplying the in-coming and out-going distance divided by trace (D),

$$\varphi_i = \vec{x}_i^{\,t} D_i \vec{x}_i FA_i \vec{x}_j^{\,t} D_j \vec{x}_j FA_j \Big/ TRACE(D_i) TRACE(D_j) \quad (1)$$

where i indicates the reference, j indicates the neighborhood.

In Fig. 1, the searching algorithm is performed for all eight 2-D neighborhoods (26 neighborhoods in 3D). In this case, we start from the center as a reference. Left-up, up, down, right-down voxels are the subsequent references. We continue searching until visiting the previous reference.

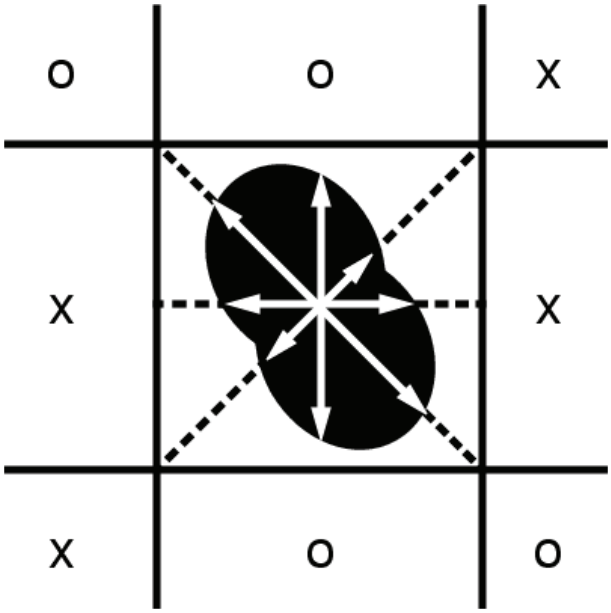

Figure 1 - Concept of threshold distance and iterative searching (o are candidates of next step (to be references) and x are discarded)

Results

In Fig. 2, we show the result of iterative algorithm superimposed on corresponding FA images for a single subject. The starting point is on major fiber trajectories such as Corpus Callosum and Internal Capsule.

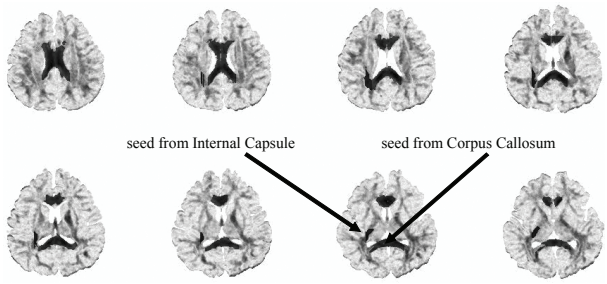

Figure 2 - Result of an iterative algorithm superimposed on corresponding FA images (8 contiguous slices: dark regions are seeding from Corpus Callosum and Internal Capsule)

Discussion

The result of the algorithm depends on the threshold value. For example, we used threshold 2.1 in Fig. 2. It is important to determine the value statistically and automatically. And the anisotropy of voxel size should also be improved. We are now investigating the effect of interpolation on the accuracy of the results.

We also have a plan to verify the feasibility of our method by way of adding noise simulation. The estimation of the effect of noise will be important before using the method in clinical studies.

These results are promising for connecting and segmenting specific white matter regions. The segmented volume may be used to constrain white matter tracking algorithms. The results here are preliminary and will require more work. We show that the iterative algorithm is refined further considering the interaction between the outgoing and incoming directions.

Conclusion

In this study, we propose methods to assess the white matter connectivity using projected diffusion tensor distance. This algorithm is different from other tracking methods and has potential to be used in combination with traditional tracking algorithm. The algorithm is iterative and consists of two steps. We can also use the result to analyze the connectivity quantitatively and statistically. Information derived from the result is important and necessary to obtain the structure of the white matter and it will enhance the study of human brain function.

Acknowledgments

This research was partially supported by the Ministry of Education, Science, Sports and Culture, Grant-in-Aid for Young Scientists (B), 16700360.