DTI Fiber Volume Measurement Using a Wrapping Algorithm

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Introduction

Diffusion tensor imaging (DTI) (1,2) is sensitive to the directionality of water diffusion and is used to study the white matter anisotropy in the brain. An important applications of DTI is white matter fiber tracking. The resultant fiber tracts can potentially lead to quantitative assessment of brain development and pathology, provided that the size and volume of the neuronal fibers can be accurately measured. One of the most commonly used methods to estimate the fiber volume from tracked fibers is voxel counting, which sums up the number of voxels where tracks pass through. However, the relatively low resolution of DTI makes the voxel counting technique less accurate because it introduces strong partial volume effect (Fig. 1). In this report we propose a more accurate volume measurement based on a fiber wrapping algorithm.

Methods

A simulated curvature phantom was generated to demonstrate the algorithm, due to the lack of a gold standard for fiber volume quantification in human DTI. The phantom is a band of circular arches with outer radius of 50 mm, inner radius 45 mm and 5 mm thickness (Fig. 2). To assess the accuracy of volume estimation, a second phantom with the top compressed was also generated which simulates fibers deformed by external objects. These two phantoms were then imaged at $128 \times 128 \times 64$ matrixes with cubical voxels in $2 \times 2 \times 2$ mm^3. Each voxel inside the band had the same assigned FA value at 0.34, and the fiber orientation was in the tangential direction of the circle. The voxels outside the band were simulated as gray matter with FA of 0.1. The intensity of gray matter and white matter in the base image was the same. The SNR of the base image was approximately 100 after adding Gaussian noise. We assumed that diffusion weighted images had the same level of noise but lower SNR in comparison to the base image because of signal attenuation. The b factor was set to 800 s/mm^2. The diffusion tensor was then computed back from the noisy diffusion weighted images with the Levenberg-Marquardt nonlinear fitting algorithm. The tensors were decomposed into eigenvectors and eigenvalues for DTI fiber tracking.

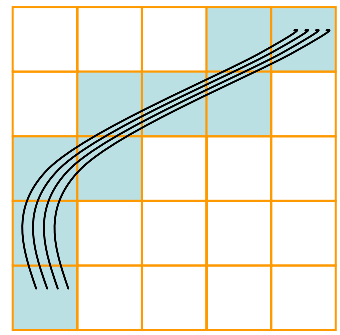

Fig. 1: The schematic illustration of the voxel counting estimation in the volume measurement.

The simulated fibers were tracked from the tri-cubic interpolated primary eigenvector field of diffusion tensors with the 4th order Runge-Kutta algorithm. High sampling density of seeds in ROIs, approximately 20 seeds randomly sampled in each voxel, was used for better fiber shape delineation in 3D space. When fiber tracks were given, three consecutive steps were implemented for the volume calculation: clustering fibers, wrapping boundaries and volume integration. The tracts were first clustered into tight bundles to avoid possible false wrapping among different fiber groups (3). Then, the non-convex hull algorithm was used to find the boundary fibers of each clustered fibers (4). For better accuracy and tight wrapping of the region where a fiber bundle located, the radius parameter in the alpha shape algorithm was weighted by the local point density. The volume wrapped by the boundaries was integrated along the fiber trajectory with thin slices perpendicular to the trace of the center of mass of the transverse intersection region with adaptive integral steps based on the local fiber curvature. In the end, the total volume was equal to the summation of all classified bundles.

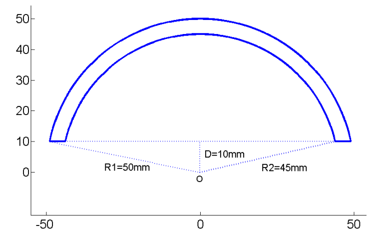

Fig. 2: A white matter phantom with fiber orientation in the tangential direction of the circle.

Results

Table 1 shows the volume calculated with the direct voxel counting method and the volume calculated by the proposed fiber wrapping method. The percentage errors of the voxel counting and track wrapping are 58% and 20% respectively. The volume difference before and after compression can also be estimated. The percentage errors of voxel counting and track wrapping of estimating the volume change are 36% and 23% respectively.

Table 1: The volume of fibers (rounded to 1 mm^3)

	Exact Volume	Voxel Counting	Track Wrapping
Circular Band	3227	5112	3868
Compressed Band	3039	4992	3637

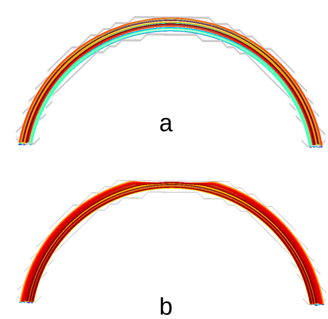

Fig. 3: a) tracts in a circular band; b) tracts in a top-compressed band.

Discussions and Conclusions

For any given fiber tracts determined by various tracking algorithms, our new method demonstrates better accuracy in neuronal fiber volume quantification in comparison to the voxel counting method. It is hoped that such an improved volume determination can allow DTI fiber tracking procedure to be more applicable in quantitative assessment in white matter development and pathology.

References and Acknowledgements: 1. Basser, P.J., et al., Magn. Reson. Med. 39, 928–934, 1998.; 2. Mori, S., et al., Neuron 51, 527–539, 2006.; 3. Ding Z., et al., Magn. Reson. Med. 49, 716-721, 2003; 4. Edelsbrunner H, et al., IEEE Trans. on Info Theory 29, 551-559, 1983. The authors thank Dr. Ding for providing the program of fiber clustering.