Generalized Diffusion Tensor Imaging of Excised Rat Brain

E. Ozarslan[1], B. C. Vemuri[2], T. H. Mareci[3]

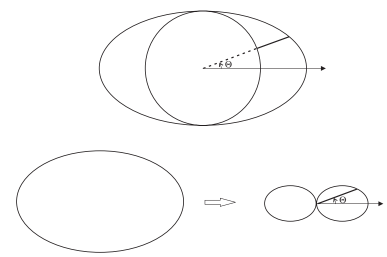
[1]Department of Physics, University of Florida, Gainesville, FL, United States, [2]Dept. of Computer and Information Science and Engineering, University of Florida, Gainesville, FL, United States, [3]Dept. of Biochemistry and Molecular Biology, University of Florida, Gainesville, FL, United States

INTRODUCTION

Application of diffusion sensitizing gradients along different directions in a pulsed gradient spin echo experiment has provided a way to observe anisotropic diffusion that occurs within fibrous tissues like muscle and white-matter. In addition to quantification of anisotropy, a natural and very important application of anisotropic diffusion imaging has been fiber orientation mapping that enables one to visualize the anatomical and functional connections in the brain. The simplest method in modeling anisotropic diffusion has employed a rank-2 diffusion tensor (1), which assumes a Gaussian displacement profile. Although this model is successful in extracting fiber orientations in relatively simple systems in which the fibers are orientationally coherent, it fails when there is orientational heterogeneity in the voxel of interest. To overcome this difficulty, diffusion tensor imaging has been generalized so that the signal attenuation observed by the application of diffusion gradients along many directions is better quantified (2). The generalized (higher-rank) diffusion tensor is a totally symmetric tensor and has (r+1)(r+2)/2 distinct elements, where r is the rank of the tensor. The choice of r is typically done based on the number of orientations along which the signal is measured. In this work, we present the application of generalized diffusion tensor imaging to an excised rat brain and demonstrate that this technique is capable of producing orientation maps even in complex fiber structures.

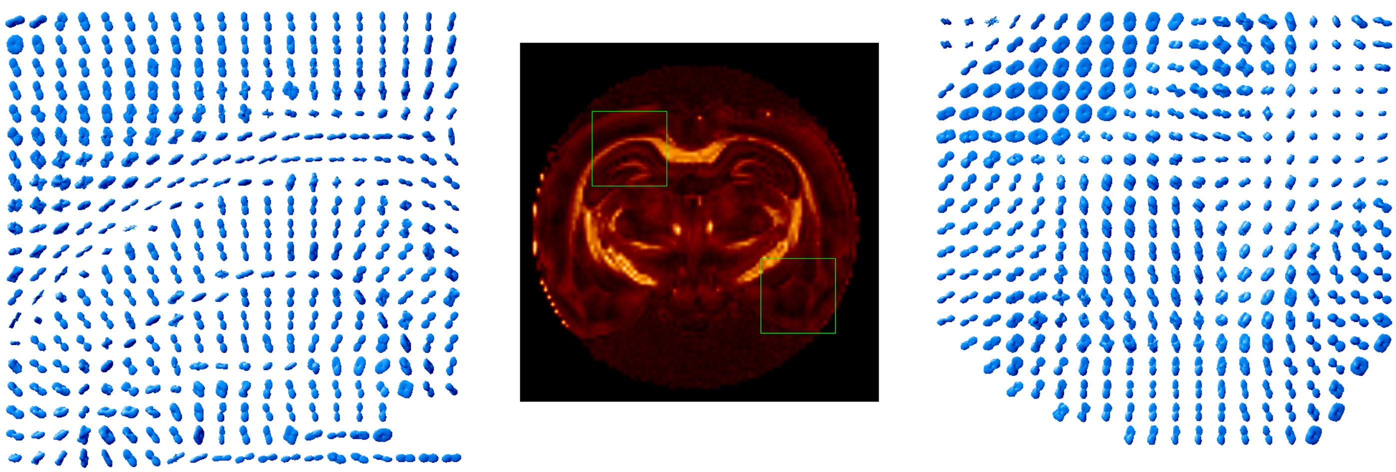
METHODS

A series of diffusion weighted images of an excised rat brain in phosphate-buffered saline was acquired at 17.6T using a Bruker Avance imaging system. The imaging parameters were TR=2500ms, TE=28ms, Δ=17.8ms, δ=2.2ms, resolution=150µmX150µmX300µm. Diffusion-weighted images were acquired along 81 directions specified by the tessellations of an icosahedron on the hemisphere, with a b-value of 1500 s/mm^2, along with a single image acquired at b≈0. The images were fitted to the generalized Stejskal-Tanner relation (2)



$$S = S_0 \exp\left(-b \sum_{i_1=1}^{3} \sum_{i_2=1}^{3} \cdots \sum_{i_r=1}^{3} D_{i_1 i_2 \ldots i_r} g_{i_1} g_{i_2} \ldots g_{i_r} \right),$$

to yield the components of a rank-8 Cartesian tensor with 45 distinct elements. In this equation, b is the b-value, $D_{i_1 i_2 \ldots i_r}$ is the rank-r diffusion tensor, S_0 is the non-diffusion weighted signal and g_{i_n} is the i_n-th component of the gradient direction. Then signal values on a Cartesian grid whose points correspond to different gradient values (q-space) were calculated assuming that signal will be exponentially decaying along each radial line. This way a 32 X 32 X 32 q-space image covering a region up to b=80000 s/mm^2 was constructed whose Fourier transform estimated the probability displacements. The isosurfaces of these displacement probabilities were transformed using the transformation depicted in the figure above. These surfaces were examined at selected slices and several regions of interest (ROIs).



RESULTS

The figure above shows the fiber structure in two different ROIs as shown on a fractional anisotropy (3) map constructed from a rank-2 diffusion tensor. It is apparent on the maps on the sides that using generalized diffusion tensor imaging it is possible to infer information about geometries more complicated than those that can be inferred from traditional (rank-2) diffusion tensor imaging. In addition to mapping of the structure in the coherent fibers of white-matter, generalized diffusion tensor imaging can be used to examine more complicated structures like gray-matter.

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References

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