A First-Principles Approach for Diffusion Tensor based Fiber Tracking

Daniel Gembris*, Helmut Schumacher†, Dieter Suter‡, Karl Zilles*

**Institute of Medicine, Research Center Jülich, D-52425 Jülich, Germany*

†Central Institute for Applied Mathematics, Research Center Jülich, D-52425 Jülich, Germany

‡Institute of Physics, University of Dortmund, D-44221 Dortmund, Germany

Introduction:

MR diffusion imaging provides information about brain structure and function on a microscopic level. Diffusion-tensor imaging in particular allows to determine the anisotropy of water diffusion and hence the local orientation of nerve fiber bundles. To study of neuronal connectivity it is desirable to derive the (continuous) course of these fiber bundles from the (discrete) diffusion tensor data. For this purpose several algorithms have been developed recently (1-9). We describe here a novel approach based on a physical simulation which combines advantages of the existing techniques while avoiding some of their problems (e.g. the choice of arbitrary parameters).

Methods:

The measured diffusion tensor data are used to compute the spreading of a 'virtual' (water) concentration peak in the brain according to the following diffusion equation

$$\frac{\partial C}{\partial t} = \sum_{i,j=1}^{N} D_{ij} \frac{\partial^2 C}{\partial x_i \partial x_j},$$

where C denotes the concentration and D_{ij} the tensor components. Due to the spatial heterogenity of D_{ij} analytical solutions can not be obtained for the above partial differential equation and a finite element method (FEM) was used instead. We found the software package "femlab" (www.femlab.com) suited for our purposes. The actual fiber tracking is performed by placing the initial concentration distribution (peak) into a start region, e.g. near a cortical area, and analyzing how the iso-lines or iso-surfaces of the concentration distribution evolve over time. It is assumed that the course of a fiber bundle is determined by the path along which the iso-line/-surface grows fastest. To restrict the diffusing water to the fiber bundles the diffusion tensor is set to zero in regions with a negligibly low diffusion anisotropy, specified in terms of the Fractional Anisotropy (FA) index in our case. Diffusion tensor data were acquired on a Magnetom Vison 1.5T using diffusion-weighted single-shot EPI.

Results:

The main component of our method, the computation of the concentration has been implemented and applied to both 2D and 3D data sets. On a PC equipped with a Pentium III clocked at 700MHz and with 512MB RAM the computations typically needed several minutes to complete, e.g. 4 minutes for a 3D simulation with about 20000 knots and 20 time points.

Discussion:

Two major advantages of our fiber tracking approach are that the full information contained in the diffusion tensors (of the fiber tracts) is used and that it accounts for the inherent sign ambiguity of each eigenvector (10). This ambiguity can cause failures of the known methods. Instead of tracing the spreading of a single concentration peak it might computationally be more effective to perform this computation separately for overlapping subvolumes of the brain.

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