BY NATHAN HAGEMAN

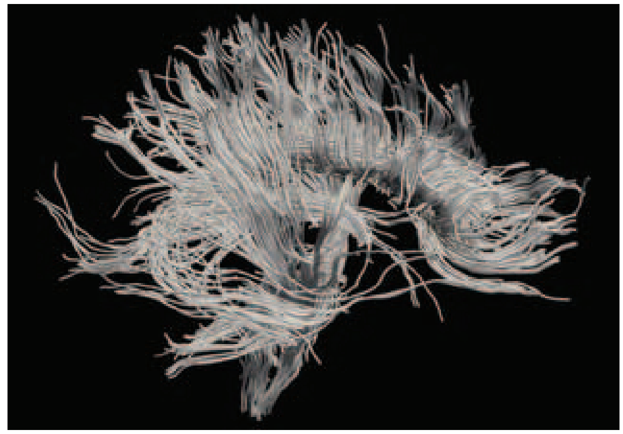
Diffusion Tensor Imaging Tractography: Revealing Connectivity in the Living Brain

One of the major obstacles to studying the human brain has always been gaining access. Until relatively recently, almost all of what we knew about the brain was obtained through post-mortem examination. Few techniques were available for obtaining a clear picture of the structure and function of the living human brain at work. Recent imaging methods, such as MRI, fMRI, and PET, have been partially successful at overcoming this obstacle.

However, while structural methods, such as MRI, allow us to differentiate tissue types, and functional methods, such as PET and fMRI, allow us to characterize regional brain blood flow and metabolism, we still had no clear way of looking at how different parts of the brain connect to each other via the white matter in vivo. The development of diffusion tensor MRI changed that.

Diffusion tensor imaging (DTI) is a non-invasive magnetic resonance imaging based technique used to measure the in vivo local diffusion of water within tissues. This is useful because water molecules move unevenly within fibrous tissues. In the white matter of the brain, the movement of water molecules along axons is much freer than perpendicular to them. DTI, therefore, gives us the local diffusion profile of the brain, which is linked to the local axonal integrity and orientation. Computerized tractography methods have been created to determine likely connection paths through the white matter between different parts of the brain based on this local orientation information. These methods use varied and sometimes sophisticated mathematical techniques to generate regional connectivity maps.

The earliest DTI tractography algorithms were streamline methods that generated discrete paths through the white matter by following the local major diffusion direction at each voxel, point by point, through the image volume. There are several disadvantages to this approach. In particular, random noise in the image causes perturbations in the diffusion tensor, which can have significant effects on the reliability of these streamline methods. More sophisticated techniques have been created to try to correct for the weaknesses in the original streamline model. Others have attempted to reconstruct the connectivity information using entirely different mathematical approaches. For example, some techniques use partial differential equation based models to generate a connectivity map by simulating the movement of some physical substance based on the DTI data. One such method involves simulating a fluid flow through the DTI image volume guided by a pressure force at each voxel identical to its diffusion profile [1]. The fluid dynamics then are directly related to the underlying local axonal orientation and can provide a metric of regional connectivity.



Segmentation of major white matter tracts in the brain using a fluid mechanics-based DTI tractography method. Courtesy of Nathan Hageman.

Probably the greatest limitation of tractography methods currently is due to the resolutions at which DTI data can be acquired. Current voxel resolutions for DTI are about 1-3 millimeters. However, the typical axonal diameter is 1000 times smaller—approximately 1 micron; this disparity can lead to averaging of different fiber populations within the voxel. The fiber architecture within a single voxel can be extremely complex and not well modeled by a single fiber direction. Therefore, even the best tractography methods provide only probable connection paths, and we can not assume that they correctly reflect the true underlying fiber architecture. However, DTI tractography remains a powerful and promising technique. Perhaps one day it will help us reveal the true fiber architecture of the living brain. □

DETAILS

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REFERENCES:

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