# MR DIFFUSION TENSOR IMAGING AND FIBER TRACKING TECHNIQUE

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**ABSTRACT**

Magnetic Resonance Diffusion Tensor Imaging (DTI) is a neuroimaging method for detecting and representation of water diffusion properties of nervous tissues. Fiber tracking technique uses DTI data and reconstructs nervous fibers and significantly enhances the knowledge about the in vivo configuration of white matter. Using sophisticated algorithms and specialized software, DTI and fiber tracking detect in patients pathological changes of nervous system. The white matter tracts can be investigated not only by simple observation, but also through analyzing water diffusion coefficients, magnitudes of anisotropy and fibers parameters.

**Key words:** diffusion tensor imaging, DTI, fiber tracking, neuroimaging

## PRELIMINARY CONCEPTS – WATER DIFFUSION IN NERVOUS TISSUES

The molecules of any substance in a continuous media have a random movement determined by their thermal energy. The motion takes place over a distance in space which is determined by the diffusion coefficient (D), in accordance with Stokes-Einstein's law:

$D=kT/f$,

where k represents Boltzmann constant, and f depends on particle dimensions and fluid viscosity.

The **diffusion** can be either:

- **isotropic**, when there are no hinders to diffusion, being statistically the same in all directions in space, or,
- **anisotropic**: when has barriers against diffusion for some directions (1).

In biological tissues the physical obstacles to diffusion could correspond to cell membranes or organelles. The three-dimensional structures may well be represented through their anisotropy characteristics related to the geometry of the barriers.

The central nervous system (CNS) white matter is organized in bundles of myelinated axonal fibers with similar direction. It connects various grey matter structures. For the nervous system, the microstructures, which impose hindrances to diffusion and determine an unequal flow for some directions in space, are the axonal membranes, cytoskeleton and the myelin sheaths. The myelin sheath composed of lipids and proteins limits the water permeability for the direction across the fibers. However, systematic studies have shown that even non-myelinated nerves, with intact cell membranes, preserve their anisotropic diffusion, with changes only of diffusion coefficients. Consequently, myelin

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could be considered more like a modulator of the degree of anisotropy. The microtubules which are linked with fast axonal transport and the neurofibrils have little impact on this process. (2)

## MR DIFFUSION TENSOR IMAGING (DTI)

A three-dimensional model of isotropic diffusion could be envisioned as a sphere and for anisotropic diffusion the representation comprises an ellipsoid. This ellipsoid could be mathematically determined by calculating the tensor matrix for diffusion, a system with 6 variables. In a much simpler way, the axes of the ellipsoid represent the values and spatial directions (x, y, z) of water diffusion. (3)

By applying at least 6 sensitizing magnetic field gradients to MR Imaging, this method could detect the random water molecules motion. The recognition of molecules' trajectories is linked with Magnetic Resonance signal attenuation as a result of loss of spin coherence. The rapid diffusion produces large signal intensity attenuation:

$$S=S_0e^{-bD}$$

($S_0$ is the initial signal, D represents the diffusion coefficient of the analyzed nervous tissue and b is a property of the gradients of magnetic fields). In fact, the MRI works with voxels – volume elements larger than 1 $mm^3$ and the acquired data are a mediation of local diffusion parameters.

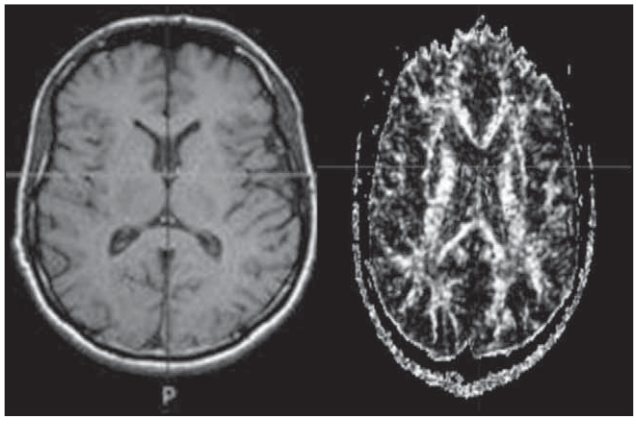

***FIGURE 1.*** *The classic MRI (left), and the representation of diffusion map (right)*

The DTI information could be analyzed for certain specific characteristics:

- mean diffusivity (MD) – generally estimates the amplitude of diffusion for a specific voxel and it has no spatial connotations. It is used for quantifying the changes in terms of barriers to diffusion (e.g. in demyelization or neuronal destruction MD increases). Also, MD distinguishes well between white and grey cerebral matters.
- fractional anisotropy (FA) – expresses on a scale from 0 to 1 how preferential to a single direction (linear) is the diffusion. A high value suggests an increased degree of anisotropy due to myelination (as in corpus callosum).
- other methods identify the magnitude of diffusion for each of the three main spatial directions. (4)

Generally, we should observe augmentation of mean diffusivity and declining of fractional anisotropy whenever pathological changes disrupt the normal structure of fibers or myelin sheaths.

The actual phenomenon is 3D. For a two-dimensional representation is used a color code: a red pixel depicts the left-right main direction of diffusion, green is for an anterior-posterior path, blue indicates superior-inferior.

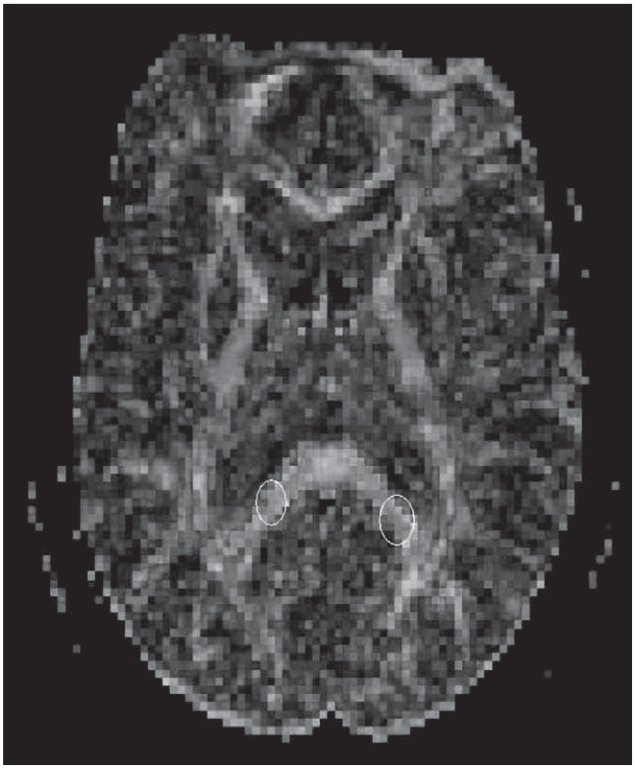

***FIGURE 2.*** *The water diffusion map using the color coding*

## FIBER TRACKING FOR CNS

For each voxel, DTI acquires data about diffusion direction and magnitude. The really remarkable application of these data is the representation of white matter axonal bundles. This is the single

available method for studying in vivo the organization of cerebral white matter.

Fiber tracking uses complex algorithms to check if two neighbor voxels are connected (meet precise requirements: the diffusion coefficient is approximately the same and the angle between diffusion vectors is not straight). If the voxels are linked then a small local tract is drawn and the software continues the operations until the image is completely analyzed. (5, 6)

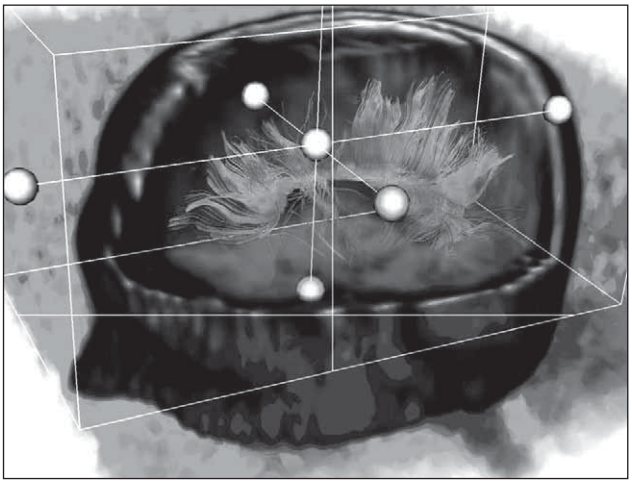

***FIGURE 3.*** *Corpus callosum reconstruction*

The tracking of nervous system fibers may be achieved either by:

- starting the testing in each voxel of the brain and proceeding to the neighbor voxels and finally keeping only the fibers of the region of interest (ROI), or by:
- beginning with the ROI and simply observing the local tracts

Possible errors could emerge when the axonal bundles are crossing in a voxel (in this case the MD and FA are actually averages). Errors may appear when trying to illustrate the white – grey matters boundary. Furthermore artificial fibers, not existing in reality may be described. (7)

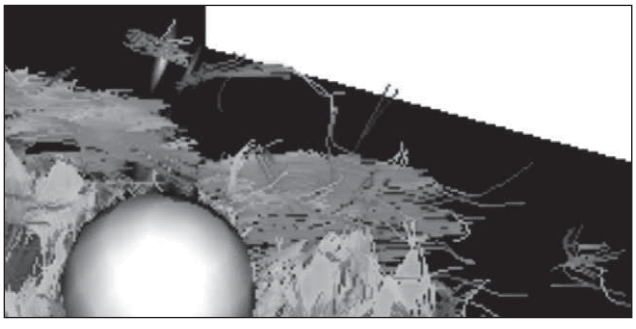

***FIGURE 4.*** *Example of error: fibers reconstructed outside of the head*

## CLINICAL APPLICATIONS OF DTI AND FIBER TRACKING

So far, various studies on this neuroimaging field showed the broad range of clinical applications that DTI promises. Some examples:

- in brain ischemia: DTI is sensitive to changes of the tracts due to axonal degeneration after strokes. Modifications of the evaluated parameters can be detected. For example decreasing of the magnitude of Fractional Anisotropy following an acute stroke and also remote from the incident. (8)
- multiple sclerosis: affects myelination processes and DTI could detect earlier changes in the white matter (decrease in FA and increase in Mean Diffusivity) in acute lesions and also globally. (9)
- for brain tumors: there are multiple patterns of possible involvement of fibers. When the tumor completely disrupts the tracts the diffusion is almost isotropic. In other case, the tumor may result in displacement of the fibers, with no other alteration of parameters. The third possibility is when Fractional Anisotropy decreases, but the tracts have normal directions. This knowledge gained could be useful when preparing for a brain surgery (10)
- the brain malformations: can be detected with great accuracy. Moreover, in normal brain development the FA of the frontal lobe white matter is lower in children than in adults (11).
- in Alzheimer's disease: DTI revealed early in the course of the disease interruptions of normal white mater connections.

Brain injuries, epilepsy, ALS as well as other neurological pathologies are the instances that had also a closer approach with DTI (see Figure 5) (12).

At the Department of Neurology of Emergency University Hospital Bucharest we take advantage of this neuroimaging technique to study how neurological pathologies affect nervous fibers. We are using a GE Signa Excite 1.5 T MRI equipment, with 6 or 25 gradients, with NEX 1-3, 128x128 matrix, b = 1000 s/mm2. For our voluntary patients we start with a classic MRI exam which has a better spatial resolution, and then we apply the pulsed gradients of DTI, with exposure times that vary from 10 to 15 minutes. After the acquisitions of

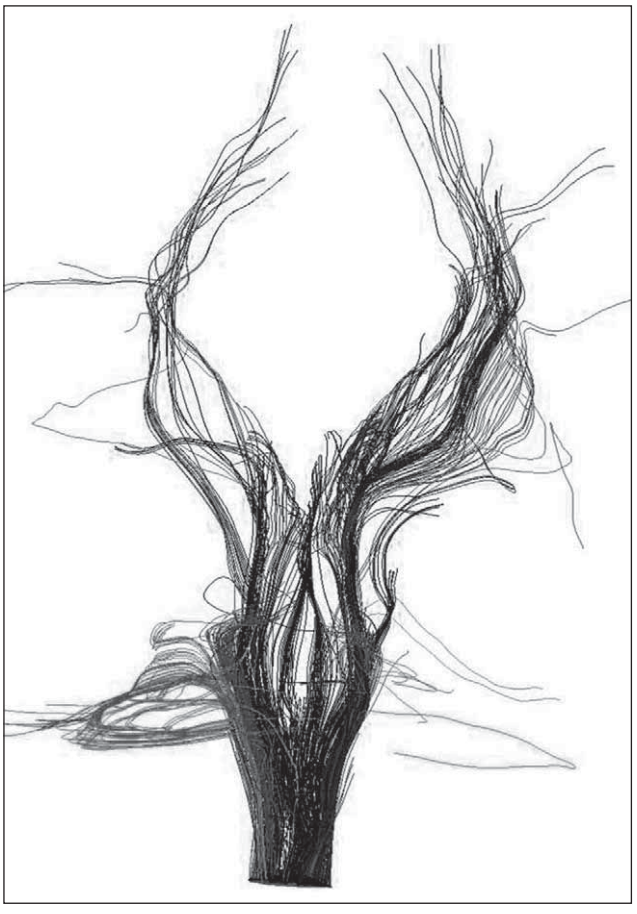

***FIGURE 5.*** *Cortical-spinal tracts*

DTI data we further process them using sophisticated software in terms of generating fibers and analyzing the parameters of the diffusion. Moreover we process the statistical data acquired and try to correlate the results with the patient complaints and diagnosis.

*MR Diffusion Tensor Imaging and Fiber Tracking Technique are the means for better understanding the cerebral white matter configuration and the different pathologies that could influence it.*

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