Invited Commentary

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In the preceding article, one can find a true tour de force of diffusion-tensor imaging (DTI) fiber tractography in patients with congenital central nervous system anomalies. In the past 2 years, DTI has bridged the chasm between creating astounding color-coded images of the normal white matter tracts in the brain to a technique that can graphically depict the impact of disease on the white matter.

DTI developed as a specialized form of diffusion-weighted imaging (DWI) in multiple dimensions. The concept of DWI is to assess the local environment of the cell to determine the ease of water diffusion. As cells swell (as in cytotoxic edema), the ability of water protons to diffuse extracellularly is restricted. This may be on the basis of a decrease in the extracellular space, a change in membrane permeability, or active transport restriction. The restriction of diffusibility corresponds to high signal intensity on diffusion-weighted images and a reduction in the apparent diffusion coefficient (ADC) of local water. The mechanism for the increased intracellular water is believed to be the failure of the sodium-potassium pump at the cell membrane. DWI interrogates the water diffusion at a cellular level.

The concept behind diffusion-tensor tractography or white matter mapping is a more global view of the brain in terms of the macroscopic diffusivity of water. There is rigid organization to the white matter structure in the brain that can be characterized by a three-dimensional asymmetry, since the water protons cannot diffuse equally in all directions, bounded by the structure of the white matter tracts. This is termed diffusion anisotropy. DTI is a means to obtain ADC values along many orientations and map white matter tracts from such measurements (1–8). To perform this study, diffusion gradients are placed in at least six independent directions and calculations of the tensor in three-dimensional space are performed. From these studies, one can determine white matter orientation and, by extension, possible injuries. The connectivity of white matter tracts, a parameter thought to be disrupted in many diseases, can now be assessed with DTI.

Imagine, if you will, the ultimate set of maps used by the neurosurgeon removing an astrocytoma. The surgeon has a representation of the surface features of the scalp and skull that allows accurate delineation of the boundaries of the craniotomy for tumor removal. Deep to this map, as the surgeon begins to raise the flap, he or she has an MR venogram that allows one to avoid inadvertent puncture of the superficial veins of the meningeal surface. Next, as the surgeon contemplates the corticotomy, he or she finds overlain in the surgical microscope not only the three-dimensional representation of the tumor but also functional MR imaging cortical maps outlining the eloquent areas of the brain to avoid. Avoiding the motor strip displaced by the neoplasm, the surgeon must determine the approach to resecting the mass.

The surgeon flips the lens of the microscope and can visualize the corticospinal tract derived from the DTI pulse sequence and sees that the white matter tracts are displaced posteriorly by the tumor (6,9). The surgeon adjusts the plan to pulverize the mass from an anterior approach. As the surgeon begins the resection, the margins of the enhancing portions of the tumor are represented in the scope at the same time additional “danger zones of functional significance” are projected for the nearby gray and white matter. If the patient is to wake up with a deficit, it will be an informed decision that the surgeon makes in an effort to achieve gross total removal. Finally, probing the depths of the tumor, the surgeon switches to three-dimensional virtual reality to obtain (a) the location of middle cerebral artery branches from MR arteriographic data and (b) deep gray matter functional maps from previously performed functional MR imaging analyses.

Some academic centers are close to achieving this ultimate scenario (6,10–21). Heretofore, it was the white matter mapping that was the stumbling block. In the preceding article, Lee et al, in demonstrating quite elegantly the facility of using DTI in demonstrating abnormal fiber tracts, have
provided encouragement to the neuroradiologic community that this hurdle can be overcome. For patients with congenital gray matter disorders, Lee et al have shown that the underlying white matter may also be affected. In cases of resecting seizure foci due to cortical dysplasias, the white matter fibers can now be visualised for surgical planning. This is the first step in the elucidation of how the white matter disease may produce the clinical signs and symptoms that plague the child. Determining the severity of tract disease may allow more accurate prognostication for families of children with leukopathies (22,23).

As discussed by Lee et al, this technique is very much operator dependent. DTI fiber tractography is not a push button solution yet and still requires active participation by physicians familiar with white matter anatomy. To produce the global brain maps gracing many journal covers these days requires the input of physicians, technologists, and PhDs who donate their various expertise to the mission. Congratulations are offered to the Yonsei University College of Medicine team for providing a glimpse into the promising future.

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References

Authors’ Response

From:
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We greatly appreciate Dr Yousem’s complimentary comments and completely agree with his future prospect for DTI in the clinical field. As Dr Yousem mentioned, presurgical planning is one of the most attractive fields of clinical DTI application because precise localization of important white matter tracts to avoid inadvertent injury has high clinical impact. If DTI is used with a classic method such as intraoperative cortical stimulation, one can achieve a good postoperative result and less surgical morbidity (1). Combination with multimodality approaches such as functional MR imaging, positron emission tomography (PET), and three-dimensionally reconstructed anatomic data will help in the diagnosis, treatment planning, and surgical management of space-occupying lesions in the brain. Therefore, collaboration with physicians, technologists, and experts in image processing is important to maximize the power of DTI.

In the preceding article, we showed aberrant fiber pathways in the case of cortical dysplasia located at the precentral gyrus. Usually, the epileptogenic foci do not exactly match the structural abnormality in malformation of cortical development and sometimes they are much larger than the dysplastic cortex. Therefore, the surgical resection margin can contain normal-appearing cortex and underlying white matter. From this point of view, detailed information about the aberrant white matter connections adjacent to the dysplastic cortex is important before surgery and DTI is the only way to provide such information.

As suggested by Dr Yousem, we have to consider the limitations of DTI and be careful in the interpretation of DTI results. More active collaborations with neuroscientists and technologists, broadening of the clinical applications of DTI, and obtaining a better understanding of white matter changes in various pathologic conditions will be the cornerstones of DTI in clinical neuroimaging.

Reference