

**3T Diffusion Tensor Imaging (DTI)**

**Overview**
3 Tesla (3T) MRI is clearly the next generation in imaging with detail never before possible and the ability to visualize the flow of water in the brain called Diffusion Tensor Imaging (DTI), which holds great promise. DTI is a revolutionary way to visualize the white matter tracts in the brain and is the next generation in neurological imaging. This technology is far more advanced than just visualizing the T1 and T2 of hydrogen atoms as occurs with standard MRI. DTI evaluates the complex diffusion (motion) of water molecules in the brain by determining their direction and flow. This allows noninvasive visualization of the white matter tracts’ (axons’) integrity which just a few years ago would have been considered impossible. The DTI technique holds great diagnostic potential, especially for neurological diseases such as normal pressure hydrocephalus (NPH), dementia, amyotrophic lateral sclerosis (ALS), trauma, and many other processes.

**How DTI Works**
To understand how DTI works, a short review of the anatomy and physiology of the brain is appropriate. In the brain, water diffusion is restricted from moving freely in all directions by the surrounding tissues, thus creating preferred directions for water diffusion. In the white matter, the neuronal axons form fiber tracts imposing directionality on water diffusion causing water to flow in the direction of the fiber’s tracts. Physicists describe this motion as anisotropic diffusion. That is, the way the nerve tracts are oriented determines the direction of water diffusing within white matter tracts. The diffusion of the water in these tracts tends to be in one direction, because the myelin sheath, cell membranes, neurofilaments, density of the fibers, etc. of the axon presents a barrier to the motion of water molecules that is not parallel to the orientation of the fibers. Therefore, this direction of maximum diffusivity is consistent with the white matter tracts’ orientation.
The degree of motion in a particular direction is called fractional anisotropy (FA). Simply, FA is the percent of the water that is traveling in the direction of the fibers. Therefore, with DTI we determine not only the directions of the fiber tracts in the brain, but also the density, myelination, and integrity of the membranes associated with these tracts. **DTI provides an amazing view inside the architecture of the brain, which holds great promise for early and accurate diagnosis of numerous neurological maladies.**

### The DTI Image

DTI is a quantitative MR technique that measures the three-dimensional diffusion of water in the brain, by evaluating the interaction of water molecules with cell membranes, myelin sheath, macromolecules and other tissues. The construction of DTI tracts (called tractography) involves advanced image processing and requires an experienced MRI technologist. **State of the art software calculates and colors the direction of the water diffusion, revealing a 3D image of the axonal tracts.** This mathematical model is called tensor. The standard for coloring the tracts is as follows: Green - anterior to posterior; Red - transverse, left to right; and Blue - superior to inferior, such as the cortico-spinal tracts. This helps greatly in evaluating the white matter tracts. Additionally, these tracts are presented in three dimensions from “seeds” that are positioned in areas of the brain and from those areas the specific tracts of interest are “grown” by the computer. For instance, if one wishes to see the cortico-spinal tracts, the “seeds” are “grown” from the cerebral peduncles. If one positions the “seeds” along the corpus callosum, the callosal radiations are then “grown” out from that point.

In DTI, another parameter that is evaluated is called FA. FA is fractional anisotropy that is the percentage of water going in the direction of the fiber tracts. In general, healthy fiber tracts have high FA where unhealthy (i.e. MS, neurodegenerative diseases, etc.) fiber tracts have a decreased FA. In certain neurological situations these values can be more predictable and offer more information than tractography. The FA values are shown as a gray scale in images called FA maps.

DTI tracts (tractography) can be presented in two ways. The tracts can be overlayed on top of a standard MRI image of the brain. The sagittal T2 weighted images are the most common, as seen in this newsletter. However, our radiologists prefer a simpler technique of putting the tracts over a black background. This allows easier visualizations of abnormal tracts.

### What is DTI used for?

DTI can determine white matter tract involvement of, and preoperative planning for, brain tumors. It is crucial that neurosurgeons understand exactly where certain tracts lie so they can be avoided during surgery. DTI helps determine if a tumor is invading into the white matter tracts or simply displacing them, providing a surgical “roadmap.”

The 3T MRI Advantage
High Field & Open MRI’s radiologists are particularly interested in the **use of DTI to differentiate disease processes** such as normal pressure hydrocephalus from early onset of Alzheimer’s disease, or other progressive neurodegenerative diseases. DTI can also determine the degree of white matter involvement in patients with multiple sclerosis as well as help determine their future disability. DTI can be used in the diagnosis of neurological trauma, specifically diffuse axonal injuries (DAI) that are often missed on standard MRIs. **DTI holds great promise in the early diagnosis of normal pressure hydrocephalus (NPH)**. There are three basic findings seen on DTI in patients with NPH. While each finding by itself is non-specific, the combination of all three with increased velocity of flow through the aqueduct seen on 3T CSF flow studies are strong evidence for NPH in older patients with hydrocephalus. The first is elevated FA values in the posterior limb of the internal capsule with decreased values in the anterior limb. Second, is where the callosal radiations are seen to “jump” to the cortico-spinal tracts, forming the classic “heart sign.” The third is densely packed cortico-spinal tracts which can differentiate from neurodegenerative disease that has decreased density of the cortico-spinal tracts.

**Multiple sclerosis (MS)** can often be difficult to diagnose. Standard MRI shows focal lesions of inflammation and tissue injury; however, it does not project the degree of tissue damage, possibility of recovery, chronic degeneration, as well as response to therapy. DTI has the potential to show changes to the white matter much earlier than standard MRIs, thus allowing earlier diagnosis and a better understanding of the extent of the disease. Even a subtle change in myelin will cause an alteration in the flow of water along the nerves. In contrast, it takes a significant change over a focal area to be seen on standard T2 FLAIR images, currently the gold standard in identifying MS plaques.
The use of DTI in traumatic brain injury has been advocated in many parts of the country. DTI was used in a recent study of military personnel who experienced blast injuries in Iraq and Afghanistan to assess the middle cerebellar peduncle. Trauma often results in diffuse axonal (shear) injuries which are due to unequal or acceleration / deceleration forces causing a shear effect at the junction between the grey and white matter. Axonal shear injury is the primary mechanism of damage in mild cases of traumatic brain injury. This results in decreased microstructural integrity of the white matter. There also tends to be decreased myelination as well as increased permeability in the cell walls, all leading to decreased directional diffusion, i.e., FA. Tractography also reveals that many of the white matter tracts will simply be missing in areas of axonal injury. The majority of the time these injuries are below the resolution of standard MRIs. Therefore, these patients with real injuries are often misdiagnosed as normal simply because the proper sequence was not done.

Conclusion
Diffusion Tensor Imaging is clearly the next generation in imaging of the brain. Just as MRI, using the T1 and T2 of hydrogen atoms, revolutionized the evaluation of the brain, DTI holds the promise of using the flow of water in the white matter tracts to diagnose disease processes that currently are a diagnostic dilemma. Tractography is in the early stages of development, but the promise of this new technology is so important that even though “growing” the white matter tracts and interpreting the DTI takes significant time and training, High Field & Open MRI currently incorporates tractography in every brain MRI performed on our 3 Tesla MRI at no additional charge to the patient or insurance company. Our goal is to develop and utilize the most advanced state of the art medical imaging technology to assure doctors and patients in Kentuckiana the highest quality and most accurate diagnosis possible.