Diffusion Tensor Imaging and Tractography Made Easy.

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Background

Diffusion tensor imaging (DTI) is an advanced form of diffusion weighted imaging in magnetic resonance imaging (MRI) with useful clinical applications. However, understanding it can be challenging since the technology is dependent on highly complex mathematics and physics. Learning the basic concepts of tensor analysis is key to interpreting DTI and tractography.

Diffusion imaging is based on the inherently random motion of water molecules known as Brownian motion. DTI exploits Brownian motion of water molecules in tissues allowing characterization of molecular diffusion in three dimensions of space.

Diffusion anisotropy effects can be fully characterized and utilized to provide exquisite detail on tissue microstructure. The two most common scalar metrics are fractional anisotropy (FA) and mean diffusivity (MD), which are used to generate images of the diffusion data.

Tractography can also be performed using data from diffusion tensor imaging to allow the mapping of the white matter fiber tracts in the brain.

Physics of Diffusion Tensor Imaging

By adding two magnetic field gradient pulses to a conventional spin echo pulse sequence, the signal of moving water molecules can be diminished, and the signal of stationary or “restricted” water molecules can be relatively increased. This method of imaging is known as Diffusion Weighted Imaging (DWI).

The two gradient pulses must be equal in magnitude and timing before and after the 180 degree pulse of the spin echo pulse sequence. The effects of the two gradient pulses on the phases of stationary water molecules are cancelled out, permitting the remainder of the pulse sequence to elicit a strong signal from the stationary water molecules. Moving water molecules on the other hand demonstrate loss of signal because they are most influenced by one of the gradient pulses without the phase reversal of the second.

DTI complies data from numerous DWI acquisitions, each with a different orientation of the diffusion sensitizing gradient pulses, to generate vectors representing the rate of diffusion and preferred direction of diffusion at various points in space.

Diffusion is predominantly anisotropic in the white matter fiber tracts. The direction of maximum diffusion coincides with fiber tract orientation and is contained within a 3x3 matrix of diffusion measurements known as a diffusion tensor, which can be graphically depicted as an ellipsoid (Fig. 2). The ellipsoid is characterized by an eigenvector and its eigenvalues.

Eigenvectors (v): direction of the ellipsoid (orientation)
Eigenvectors (λ): shape of the ellipsoid (difficulties)

Diffusion Tensor Imaging (DTI) and Tractography

Tractography uses various mathematical algorithms to bidirectionally track the course of white matter fiber tracts passing through a selected region of interest. The most commonly used tracking algorithms follow the principle directions of diffusion (the principle eigenvectors of adjacent voxels) so long as the fractional anisotropy is above a set threshold and the principle direction of diffusion is within a given angular range (some of probability).

Note that tractography based on DTI data has limited angular resolution and diffusivity reorienting crossing fiber tracts.

Clinical Applications

Stroke

DTI can be used to detect early ischemic changes in the setting of acute stroke.

Neoplasms

DTI offers additional functional information in the setting of acute stroke.

Demyelinating disease (Multiple Sclerosis)

Mean diffusivity in the corpus callosum may be the market imaging finding of MS, leading to better identification.

Dystonia

Diffusion tensor imaging (DTI) in dystonia demonstrates low fractional anisotropy and increased mean diffusivity in the affected areas.

Tractography

Tractography in brain tumors can be used to map the location of the tumor, its extent, and its relationship to critical brain structures.

Normal anatomy and connectivity

Functional anatomy and tractography

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