Practical Quantitative Imaging: Diffusion Measures

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Target audience: Researchers (in particular clinicians, technologists and biological scientists) with an interest in, but little practical experience of, diffusion imaging.

Overview

Diffusion MRI is uniquely sensitive to tissue microstructure at the micron scale, providing a unique window into cellular structures. In brain white matter and other fibrous tissues, this can be used to infer two different types on information:

- the orientation of the fibers;
- microstructural properties (e.g. myelination, axonal diameter & density, etc.).

The orientation information can be used to perform so-called *fiber-tracking*, which aims to delineate the white matter pathways through the brain, and hence study the connectivity of the brain; diffusion MRI is unique in providing this type of information in-vivo non-invasively. This can be used to identify white matter tracts of interest, with a range of applications from neurosurgery planning to quantitative investigations of specific white matter tracts.

Measures of microstructural properties can be used to investigate changes in the properties of the white matter fibers in a range of conditions, ranging from acute stroke to psychiatric disorders. Such measures include the mean diffusivity (MD), the diffusion anisotropy (i.e. is there is directional preference to the motion of water molecules), the radial and axial diffusivities (i.e. the rate of diffusion across and along the fiber axis respectively), and more advanced measures with more demanding acquisition requirements, such as diffusion kurtosis, axonal diameter distribution, and apparent fiber density.

The model most commonly used to characterise diffusion MRI data is the diffusion tensor model, as used in diffusion tensor imaging (DTI). Many parameters can be obtained using this framework, and much of the existing diffusion literature is based on this model. There is however growing recognition of the limitations of this model, particularly in crossing fiber voxels where multiple fiber orientations co-exist; such voxels are now widely acknowledged to be widespread in brain white matter, particularly given the limited spatial resolution typical of diffusion MRI. This introduces biases in the results provided using DTI, with a potentially profound impact on both fiber-tracking results as well as measures of microstructure. An understanding of these limitations is essential for DTI results to be reliably interpreted.

Much of the recent research in diffusion MRI has been devoted to overcoming these limitations, by developing improved, more realistic models of white matter architecture. While too numerous to present in detail, these models do share certain aspects. In particular, they generally require denser orientations sampling of the DW signal, and a larger amount of diffusion sensitization (i.e. higher b-values) than would typically be used for DTI, with correspondingly longer scan times. Nonetheless, these methods are now beginning to be used for routine clinical imaging, and have been shown to provide much more reliable information.

Further reading:

Johansen-Berg H, Rushworth MFS. Using diffusion imaging to study human connectional anatomy. Annu. Rev. Neurosci 2009;32:75–94.

Jones DK, Knösche TR, Turner R. White matter integrity, fiber count, and other fallacies: The do's and don'ts of diffusion MRI. NeuroImage 2012;

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