

Diffusion Goes Mad

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Title: From Diffusion Weighting to the Diffusion Tensor Indices

Highlights

- Water molecules, whether in a glass of water or in the brain, undergo a random motion known as diffusion; MR sequences can be sensitised to this, allowing diffusion to be quantified.
- In the brain, diffusion values differ depending on the direction in which they are measured, providing an insight into tissue structure.
- The *Diffusion Tensor* is the simplest description of the three dimensional diffusion process; many useful indices can be extracted from it, but these can sometimes be misleading, as the tensor model is not able to fully encapsulate all the complexity of brain tissue.

Target audience: Physicists/technologists/clinicians who wish to understand the basics concepts of diffusion weighted imaging in general, and diffusion tensor imaging (DTI) in particular.

Objectives: Following this lecture, audience members should be able to:

- Discuss the basic concept of diffusion weighted imaging (DWI) and diffusion tensor imaging (DTI)
- Recognise the limitations of DTI and the need for more complex diffusion models

PURPOSE: To provide the information necessary to allow audience members to appraise the applicability of DWI and DTI, and to apply them appropriately in their own clinical or research work.

METHODS: In a liquid, collisions between molecules lead to any particular molecule undergoing a 'random walk', with its mean square displacement from its initial position increasing with time according to $r.m.s = \sqrt{\langle r^2 \rangle} = \sqrt{6Dt}$, where D is the diffusion coefficient. (Einstein's equation). In an MR experiment, this motion leads to a loss of signal in the presence of magnetic field gradients given by $S = S_0 e^{-bD}$, where b is a function of the applied gradient strength, and duration and separation. If diffusion is restricted or hindered (as is always the case in tissue, due to cell membranes and other structures), Einstein's equation is not valid anymore and changing the observation time (diffusion time) can change value that we measure, which we then refer to as the *Apparent Diffusion Coefficient* (ADC). In a test tube, diffusion is largely isotropic, and is characterised by a single diffusion constant; in the brain diffusion may be anisotropic, as barriers to diffusion (e.g. axon walls and cellular microstructures) are oriented, and the system is characterised by different ADCs in different directions. The simplest description is then given by the diffusion tensor; the *eigenvalues* of the tensor describe the degree of diffusion along three perpendicular axes, while the *eigenvectors* indicate the orientation of these axes relative to the magnet coordinate system.

RESULTS: Examples of the parameters that can be extracted from the diffusion tensor – including fractional anisotropy (FA), mean diffusivity (MD), plus the radial and axial diffusivities (RD and AD, respectively) – will be defined and explained.

DISCUSSION: While FA and MD can be interpreted as measures of tissue integrity, results must be interpreted with caution in areas of crossing fibres and other areas in which the simple Gaussian diffusion process assumed by the diffusion tensor model is not valid. Similarly, RD and AD results can be misleading if the context in which the data were collected is not taken into account.

CONCLUSION: DTI data are relatively straightforward to collect and process, and can give useful information about tissue microstructure; results must be interpreted with caution, however, and more complex models are required in order to more fully describe brain (and other) tissue.