Diffusion in biological tissue: a theoretical approach

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ABSTRACT

This PhD dissertation originates from the Faculty of Health Sciences of the University of Aarhus, and is the result of work performed at the Danish National Research Foundation's Center of Functionally Integrative Neuroscience, the University of Aarhus, and at Department of Diagnostic Radiology, Medical Physics, the University Hospital Freiburg.

The PhD work deals with the study of water diffusion in biological tissue using magnetic resonance (MR) scanners. The MR signal derives from the magnetic properties of water molecules, which move randomly around (diffuse) in the brain tissue. By applying so-called diffusion weighted pulse sequences, the MR signal can be brought to reflect the motion of water molecules. Diffusion combined with MR opens up the possibility of gaining microstructural information about biological tissue in a non-invasive manner, which is very important in e.g., neuro-radiology.

Diffusion-weighted imaging is already well-established in the clinic, primarily as a tool to diagnose acute stroke (ischemia). Following stroke, the signal shows a significant increase from the region of infarcted tissue. The origin of the sudden signal increase after stroke is still uncertain. Knowledge about the mechanisms behind the signal change would be a valuable tool to estimate the survival potential of the tissue and thereby selecting the best treatment for individual patients. In general, a physical theory to relate the diffusion weighted signal to important spatial parameters of the underlying tissue is still lacking.

In biological tissue, the logarithm of the diffusion weighted signal (ln S) depends non-linearly on the b-value (a measure for the strength of the diffusion weighting). In this PhD work the restricted diffusion is studied using the so-called cumulant expansion of the signal, which is valid ab initio and yields ln S in the form $\ln S = -Db+Ab^2+Cb^3+ \ldots$ For a simple model system we have found that for practically relevant b-values it can be approximated by its first two terms with a good accuracy. Furthermore, we have developed a technique for calculating the coefficients in the cumulant expansion, which are given by the so-called velocity-cumulants. This technique has been used to study the first two terms of the cumulant expansion.