Quantitative Imaging and Modeling

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Highlights

- Quantitative T_2 studies require acquisition of the complete T_2 decay curve
- In wood, T_2 relaxation yields amount of cell wall water and the distribution of cell lumen diameters
- In central nervous system tissue, T_2 relaxation yields the myelin water fraction

Modeling Structure with Relaxation: T_2

Target Audience: MR Scientists

Introduction: Conventional MR imaging using T_2 – weighting, which makes key contributions to patient diagnosis and management in the health care system, relies on the use of images acquired at a single TE time. This is a qualitative use of T_2 relaxation. If the complete T_2 decay curve is acquired, using many TE times, it should be possible to obtain more quantitative information about the contents of the MR voxel. The starting point for a quantitative T_2 relaxation study is the T_2 distribution, which is a plot of T_2 amplitude vs time. The goal of this presentation is to show how tissue structure can be investigated by T_2 relaxation. We shall look at two biological systems: 1) wood, an ideal 'model' tissue system and 2) central nervous system tissue, which is much more complex than wood.

Wood- a simple natural model system: Wood is made up of long cylindrical cells that have cell wall thicknesses of a few microns and cell lumen diameters of 10's of microns. For most wood cells, lumen water contains few solutes and hence can be treated as free water. T_2 distributions from wood consist typically of two broad peaks: one at a short T_2 time which is from water trapped within the cell wall and the other at a longer T_2 from lumen water. By applying the Diffusion Bloch equation to lumen and cell wall water simultaneously (1), it is possible to generate an analytical expression (a sum of Bessel functions) which enables accurate estimation of the lumen water T_2 in terms of lumen diameter, the relative concentrations of water in the cell wall and cell lumen, the diffusion coefficients of lumen and cell wall water and the T_2 of the cell wall water. Hence, T_2 relaxation can be used to determine the amount of cell wall water and also the wood cell diameter distribution in solid wood samples.

Brain- a complex inhomogeneous system: Unfortunately, the microscopic structure of central nervous system tissue is much more complex than that of wood. However, there are come common characteristics. For example, water trapped between myelin bilayers has a shorter T_2 time than the rest of the water. CNS tissue is substantially more inhomogeneous than wood; while neuronal axons are somewhat similar to wood cells in that they provide a significant barrier to water diffusion, glial cells, possessing a single plasma membrane and the presence of significant amounts of solutes in the cytoplasm complicate relaxation behavior, make structural modeling very challenging.

The analog between cell wall water in wood and myelin water in brain and spine holds; hence the fraction of signal from myelin water has been used as a measure of tissue myelination (2). The rest of the water in CNS tissue is located in the intra cellular and extra cellular spaces. E*x vivo* studies have managed to separate the MR signals from intra and extra- cellular T_2 components (3),

however, it seems unlikely that it will be possible to do this *in vivo*. To date, the most medically valuable information available from the T_2 distribution in white matter is the use of the fraction of signal from myelin water as a measure of myelination in the brain and spine. Very few studies have extracted structural information from the MR signal from the intra and extra-cellular water.

Two approaches have been used to model T_2 relaxation in white matter - a two or three pool model for MR signals from tissue water compartments and a four pool model for proton MR signals from two water and two non- aqueous compartments. The main applications of these modeling studies have been to estimate the influence of water movement between pools on the accuracy of the measured myelin water fraction. These modeling studies have shown that in rodent spine, water movement between the myelin water pools and other water pools leads to artifactual reduction in the measured myelin water fraction which depends upon the thickness of the myelin sheath (4).

Conclusion: Accurate measurement of the T_2 distribution from white matter enables estimation of myelin water fraction which is expected to be proportional to myelin content. More research is required before we will know what additional medically useful information is available from T_2 in white matter.

References

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