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Dependence of the MR lineshape for white-matter on the orientation of the B_0 field: Insights from a three-phase model

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The phase maps obtained via gradient echo imaging exhibit exquisite contrast in the brain due to a frequency shift of the MR signal [1]. This observation has prompted interest in its biophysical mechanisms. An interesting finding is the dependence of the frequency shift on the direction of the main magnetic field [2-4]. We consider a simple, three-phase geometry to represent the myelinated neural cells. We obtained exact expressions for the component of the induced magnetic field along the direction of B_0 for an arbitrary orientation of the axon with respect to B_0. We use this formulation to study the entire MR spectrum.

Figure 1 shows the unit cell (assuming hexagonal packing) in which the axon resides. To have realistic volume fractions, we used a_0:b_0:d_0=0.7:1:1.25. The magnetic susceptibility values were chosen to be 2, 0.33 and 10 ppm relative to that of water for intracellular space, extracellular matrix, and myelin, respectively. The relatively high susceptibility of the myelin assumes that iron–rich oligodendrocytes can be taken to be a part of the myelin sheath [2]. The T_2 values were taken to be 60, 20, and 200 ms, respectively. Figure 2 shows the component of the magnetic field parallel to the main field when the axon makes 0, 30, 60 and 90 degrees with B_0. In Figure 3, we show the proton MR spectrum (in a logarithmic scale) for different values of the angle. Note that there is a significant broadening of the myelin and extracellular space peaks as the angle is increased while the peak due to the intracellular space remains sharp owing to the field being constant inside, independent of the orientation. Note that the frequency at which this peak is observed shifts slightly when angle is increased.

The findings of the paper suggest that valuable information could be obtained if the full MR spectrum is acquired, e.g., using localized spectroscopy or spectroscopic imaging methods. The developed model can be employed in many different contexts, e.g., in and around blood vessels and in numerous material science applications.

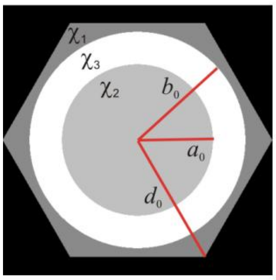

Fig. 1: The geometry considered in this study.

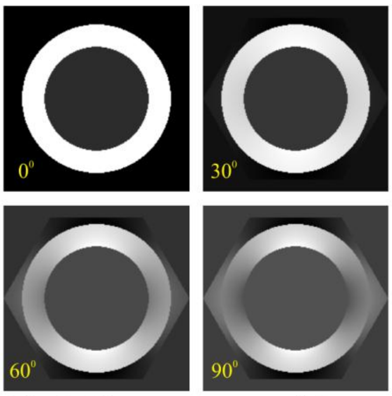

Fig. 2: The z-component of the magnetic field for different angles between the axon and B_0.

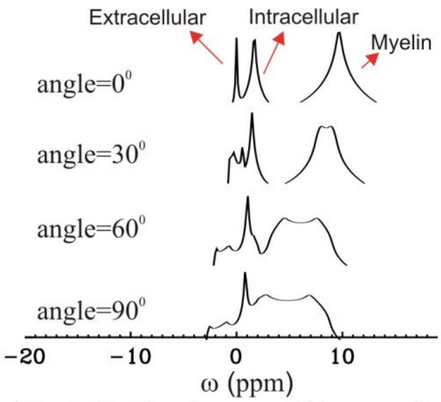

Fig. 3: Predicted proton MR spectra for different values of the angle the axon makes with the main field.

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References:

[1] Duyn et al., Proc Natl Acad Sci USA,104:11796-11801, 2007. [2] He and Yablonskiy, Proc Natl Acad Sci USA,106:13558-13563, 2009. [3] Liu, Magn Reson Med, 63:1471-1477. [4] Lee, Proc Natl Acad Sci USA,107:5130-5135, 2007.