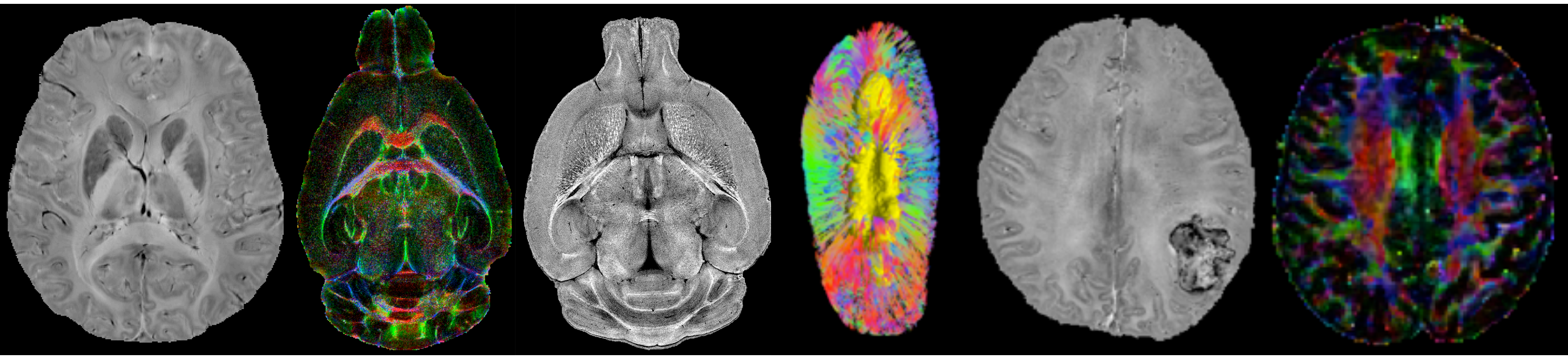
Program

3rd International Workshop on MRI Phase Contrast & Quantitative Susceptibility Mapping



October 6-8, 2014

Great Hall of the Mary Duke Biddle Trent Semans Center

Duke University, Durham, NC USA

www.biac.duke.edu/qsm2014

Calculation of the Anisotropic Magnetic Field Around a Myelinated Axon During MRI

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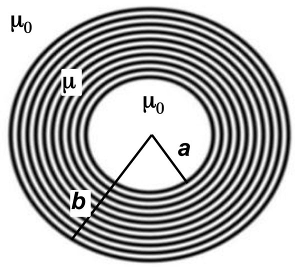
Introduction: Water trapped between layers of myelin contributes significantly to the MR signal from neural tissue. This myelin water may contain clinically useful information about diseases caused by demyelination, such as multiple sclerosis. One factor influencing the MR signal is susceptibility heterogeneities caused by the periodic wrapping of the myelin layers around a nerve axon. Our goal is to calculate the magnetic field perturbations caused by the myelin susceptibility, and to determine how the MRI signal varies with axon orientation.

Methods: The axon is represented as a cylinder of inner radius a and outer radius b. The axoplasm ($r < a$) and extracellular space ($r > b$) have magnetic permeability μ_o. The region of the myelin sheath ($a < r < b$) has a permeability $\mu = \mu_o (1+\chi)$, where the susceptibility χ is periodic and approximated by $\chi = \chi_o \sin^2(\omega(r-a)/2)$, with $\omega = n\, 2\pi/(b-a)$. The magnetic field is solved using a perturbation expansion in powers of χ_o. Because $\chi_o << 1$, only the zeroth and first order terms are considered.



Results: *Perpendicular Field*: When the applied magnetic field B_o is perpendicular to the axon, the intracellular magnetic field ($r < a$) is unaffected by the myelin. Outside ($r > b$) an additional dipolar contribution to the magnetic field falls off as r^2. Within the myelin ($a < r < b$) the magnetic field oscillates with the susceptibility. Most MR measurements average over many axons within a macroscopic voxel, so to determine the influence on the MR signal we find the spatial average of the component of the magnetic field parallel to the applied field for a single axon (including extracellular space out to a distance R, where $a < b < R$). The average magnetic field is

$$B_o\left(1+\frac{\chi_o}{4}\frac{b^2-a^2}{R^2}\right).$$

Parallel Field: When the applied magnetic field is parallel to the axon, the field is unchanged both inside and outside the myelin. Within the myelin, the magnetic field oscillates with the susceptibility. The average magnetic field parallel to the applied field is $B_o\left(1+\frac{\chi_o}{2}\frac{b^2-a^2}{R^2}\right)$.

Discussion: The deviation of the local magnetic field from the applied field is given by the second term in the two equations above, and is proportional to χ_o and to the volume fraction of the myelin. The magnetic field deviation is twice as large when the axon is parallel to the applied field compared to when it is perpendicular it, resulting in an anisotropic signal. The magnetic field at an arbitrary angle to the axon can be found from a linear combination of the parallel and perpendicular cases. In the myelin sheath, the magnetic field oscillates, being larger within the myelin itself and smaller between the layers where the myelin water is present.