Fiber Tracking of Dipolar Directions in the Meniscus

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Introduction

Unaveraged dipolar interactions can give rise to "magic angle effects" in ordered tissues, such as in tendon, cartilage and meniscus. When the dipolar interactions of fibers are oriented at 54.7 deg to the external magnetic field, T2 and T2* values increase, and tissue is seen with increased signal intensity[1]. When the orientation becomes collinear with the field, the dipolar interactions are maximized and hypo-intense signals are observed. It would be useful to "invert" the imaging intensities information in order to determine the dipolar interaction directions – similar to what is done in diffusion tensor imaging. Conceptually this could be done by aligning the tissue at a large number of orientations with respect to the external field and noting the specific orientation which minimizes a particular voxel's intensity, corresponding to the direction of maximum dipolar interaction. This may not be feasible because of the long imaging times required to carry out such a large number of measurements. What we propose is to measure a subset of orientations and perform computations that extract the dipolar directions from this reduced dataset.

Methods

A goat meniscus was used in this experiment, due to its substantial thickness but otherwise compact dimensions. The meniscus was fixed in 10% formalin and imbedded in a 45 mm diameter epoxy sphere to minimize susceptibility effects and provided a rigid mechanical structure that could be easily reoriented in a 3T General Electric scanner; an 8 cm diameter surface coil was used for signal detection (Fig. 1). 3D GRE images were obtained with 0.4 mm isotropic resolution having TR=25ms and TE=9ms. Twelve orientations of the meniscus were obtained representing a distribution of directions on a hemisphere. Image intensities were corrected for surface coil sensitivity profile variations and then registered to the initial reference orientation dataset using a 6 parameter rigid body fitting algorithm (FLIRT, FSL software, FMRIB Group, Oxford, UK). The translation matrices required for this registration were retained as these provided a sensitive measure of the angular orientation of the sample and were used in subsequent calculations.

Results

Large variations of the signal intensity were seen as a function of the various orientations (Fig. 2). A Matlab program was written which examined a bouquet of initial test directions covering a hemisphere (Fig 3) and compared intensities of the simulated dipolar effects for each choice of initial direction under the identical 11 rotations, to what was observed in the meniscus sample. The one direction that best fitted the observed data was taken to be the direction of the unaveraged dipolar interaction for that particular voxel. This process was repeated for every voxel in the meniscus image. The resulting directional data were made into a directional vector map and the fluctuations of intensity into a map representing the anisotropy of the dipolar interaction (i.e. analogous to a fractional anisotropy map). DTI Studio software (F.M. Kirby Research Center, KKI) was used to visualize these maps and fiber tracts were grown as is done with diffusion data in the brain. Fig. 4 shows the color coded directional map and Fig. 5 the resulting fiber tracts.

Fig 1. Goat meniscus in epoxy ball. on surface coil.

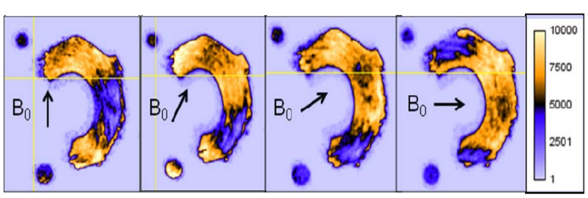

Fig 2. Intensity variations in meniscus with different orientations relative to external magnetic field.

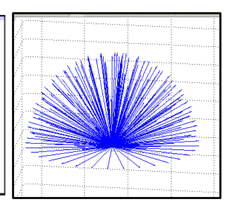

Fig 3. Bouquet of test directions, used to identify dipolar direction.

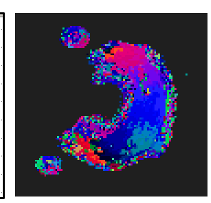

Fig 4. Color map of dipolar directions in meniscus

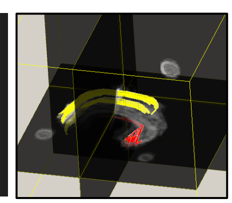

Fig 5. Fiber tracks computed in meniscus sample.

Conclusion

Although this method cannot easily be applied to patient studies, it does allow characterization of tissue samples. It also provides a methodology to extract dipolar direction information in ordered tissues with a minimum number of measurements, and should appeal to the MRI community, who have had experience with DTI calculations.

References

1. Krasnosselskaia LV, Fullerton GD, Dodd SJ, Cameron IL. Water in tendon: orientational analysis of the free induction decay. Magn Reson Med 2005;54(2):280-288.