Residual Dipolar Coupling - A Fundemental Tissue Parameter

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Introduction

Residual dipolar coupling (RDC) provides an important contrast mechanism when imaging fibrocartilage. The behavior of water imbedded in collagen was first described fifty years ago in a seminal paper by Berendsen where the NMR spectrum of bovine Achilles tendon displayed three discrete broad lines(1). The two outer lines were found to depend on the fiber to static magnetic field orientation, providing direct evidence of residual proton-proton dipolar coupling. When imaging tissues containing fibrocartilage, the details of the NMR spectrum are not given much consideration. The presence of RDC, however, produces change in T_2^* values and gives rise to the magic angle effect, providing angle dependent contrast between fiber structures. RDC should be viewed as a fundamental measureable tissue parameter, similar to a diffusion rate or T_1 value. We have developed an imaging technique allowing the evaluation of this parameter on a per voxel basis. The RDC value provides a sensitive indicator reflecting the structure of fibrocartilage tissue, e.g. direction and distribution of fibers, how much collagen is present and state of hydration.

Methods

Images of tissue specimens were obtained in multiple equally spaced orientations relative to B_0 using a GE 3T HDx scanner with small custom receiver coils. Images were registered using FLIRT software (FSL, Oxford) and intensity fluctuations computed on a per voxel basis using macros written in ImageJ. Simulations were performed in MatLab evaluating the number of sample orientations necessary to achieve a stable value for the coefficient of variation (related to RDC) for an arbitrary voxel.

Results

In our previous work with dipolar anisotropy fiber tracking(2) we reported intensity fluctuations for each voxel as a coefficient of variation (cv) parameter. Fig. 1 shows the expected intensity changes vs. orientation for a dipolar model. Computation of a cv value was done from the intensities indicated by the vertical lines. For a 2D distribution of fibers (requiring only one rotation axis to investigate) six equally spaced orientations provided a stable cv value. For a full 3D investigation at least 16 equally spaced orientations were found to be necessary.

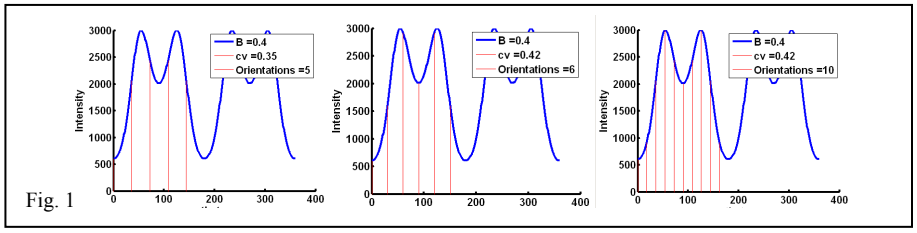

Fig. 1

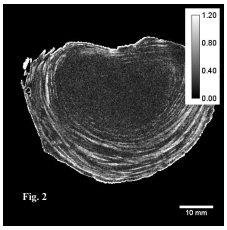

Fig. 2 is an intervertebral disk "cv image" that in situ would correspond to an axial plane. It was obtained with 6 specimen to field orientations involving rotation about an axis orthogonal to the plane of the image. Fibrous tissue within the disc appears with high values of cv which arise from the large intensity changes on the individual images, while extra-fibrillary matrix has a very low cv. This results in high contrast between lamellae and the interspersed matrix.

Discussion

The magnitude of the intensity fluctuations observed with specimen to field orientation depends strongly on RDC. The exact behavior depends on how water is trapped in the collagen(3) as well as the distribution of fiber directions within a voxel. A model that faithfully describes the observed NMR lineshape needs to include additional contributing mechanisms such as microscopic susceptibility, chemical shift anisotropy of the water molecule, anisotropic motion effect on T_2, and dipolar coupling to ^{14}N. RDC plays a major role and provides a parameter that is independent of magnetic field strength or choice of TE. RDC effects are also the basis for multiple quantum filtering approaches to imaging(4). Although clinically it might not always be possible to do this sort of multi orientation study in horizontal field magnets, they would become more practical in vertical field systems. From the full array of data it is possible to understand contrast between tissues containing two or more fiber groups and to select orientations of preference to demonstrate particular structures.

References

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