Dipolar Anisotropy Fiber Imaging Reveals Structure in a Meniscus Specimen

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Introduction

In a recent publication we described how unaveraged dipolar interactions cause marked MRI intensity changes in fibrocartilage as the tissue-to-static-field angle is varied. A systematic exploration of orientations allowed dipolar direction maps and dipolar anisotropy maps to be constructed, resulting in a technique described as Dipolar Anisotropy Fiber Tracking (DAFI)[1]. Here we describe how useful information is contained in subsets of these oriented measurements and how high contrast images can be obtained allowing visualization of fiber structures previously not appreciated on MR images. An example of a knee meniscus specimen revealing internal fiber structure is demonstrated.

Methods

The knee meniscus specimen was submerged in a cylindrical container containing perfluorinated polyether (Fomblin) to reduce macroscopic magnetic susceptibility effects. A small 5 cm diameter Helmholtz receiver coil was used with a G.E. 3T HDx scanner. 3D SPGR images were obtained with 0.16 x 0.16 x 0.20 mm^3 resolution with TR=25 ms, TE=4.0 ms, and FA=15. Eight orientations of the specimen were imaged with rotations about a single axis (y-magnet axis). Each 3D image was registered to the initial dataset using a 6 parameter rigid body fitting algorithm (FLIRT, FSL software, FMRIB Group, UK). Minimum intensity and coefficient of variation (CV) maps were computed from the registered datasets using ImageJ software. The high resolution 3D images were collected with a voxel size of 0.065 x 0.065 x 0.20 mm^3.

Results

Large variations in intensity (up to a factor of 10) were observed for certain voxels as the specimen was rotated. Intensities ranged from a baseline low signal intensity when fibers were aligned with B_0, to a maximum when fiber-to-field angles approached 54.7^o (the magic angle effect). The meniscus contains multiple fiber types with varying directions. Using an appropriate tissue orientation, rotation axis, and some post processing, it was possible to suppress signal intensity of certain fiber structures, while retaining uniform high signal intensity from others. Fig. 1 is the minimum intensity projection through a set of data obtained from 8 orientations. The circumferential fiber intensity was reduced, allowing the other structures to stand out with high contrast. A measure of the intensity variation with reorientation was computed as a coefficient of variation parameter (Fig 2.). Tissues with strong unaveraged dipolar couplings (fibers) that were affected by the rotation of the specimen had high CV values. Unstructured tissue or tissue having fibers parallel to the axis of rotation had low CV values. Fig. 3 plots the intensities of ROIs in regions corresponding to various tissues as the specimen was rotated. Fig. 4 is from another meniscus specimen and illustrates that high contrast images showing internal fiber structures can, in certain cases, be obtained in a single measurement if the tissue-to-field angle and voxel size are carefully chosen.

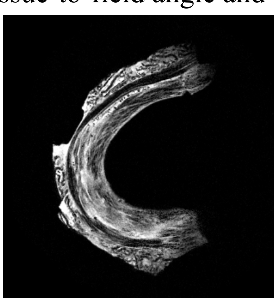

Fig 1. Human knee meniscus minimum intensity map.

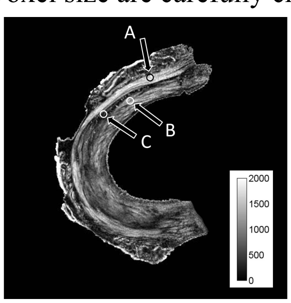

Fig 2. Human knee meniscus coefficient of variation map.

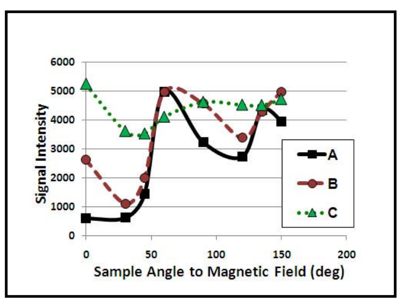

Fig 3. Plot of signal intensity vs. orientation. ROI A=intermeniscal ligament; B=circumferential fibers; C=radial sheet/fiber.

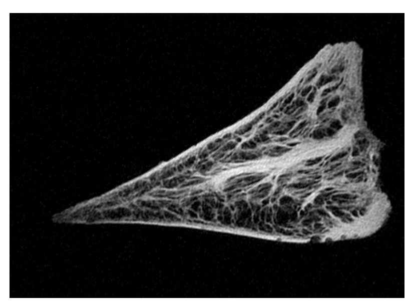

Fig 4. High resolution image of a meniscus specimen. B_0 is perpendicular to image plane reducing circumferential fiber signal. Radial sheets/fibers are high intensity signals providing excellent contrast.

Conclusion

A reduced sampled version of our DAFI technology, rDAFI, is demonstrated and provides a new approach for visualizing ordered structures in fibrocartilage. It requires multiple measurements with the appropriate choice of tissue-to-B_0 orientations, but can produce images reducing selected fiber signals and revealing high contrast details. The CV values are meaningful parameters that can characterize healthy and diseased tissues. This ex-vivo study examines (and describes how one might exploit) the dipolar effects in fibrocartilage which also must occur in clinical images.

References

1. Szeverenyi NM and Bydder GM.. Dipolar Anisotropy Fiber Imaging in a Goat Knee Meniscus. Magn Reson Med 2010 (November in press).

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