Correlation of diffusion tensor and strain imaging in ex vivo bovine spinal cord

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Abstract

Both diffusion and q-space imaging have been used to study tissue microstructure by probing the molecular motion of water. Recently, magnetic resonance elasticity imaging has begun to describe the macroscopic mechanical properties of tissue. However, the underlying relationship between tissue microstructure and macroscopic mechanical characteristics is not well understood. Additionally, previous work has been limited to skeletal muscle which demonstrates a small diffusion anisotropy (<10%). Here we present diffusion and strain imaging data for *ex vivo* bovine spinal cord.

Introduction

Little work has been done to find an underlying relationship between tissue microstructure—which may be studied with diffusion imaging [1]—and macroscopic mechanical properties revealed by MR elasticity imaging [2]. Although a correlation between diffusion anisotropy and mechanical anisotropy has been demonstrated [3], much work remains to be done to further characterize the relationship that exists between the two levels of tissue organization. We believe that tissue mechanical properties relate to tissue organization at the microscopic scale. White matter is known to exhibit large diffusion anisotropy (FA~0.7-0.8) and can serve as a good surrogate for fibrous tissues. To further study this, we have imaged the diffusion characteristics of *ex vivo* spinal cord and the mechanical properties of the sample using magnetic resonance strain imaging.

Methods

Bovine spinal cord was obtained at a local butcher shop from which two samples were cut for imaging, each measuring approximately 3cm in length and 1cm in diameter. We poured 10% by weight gelatin in a rectangular form measuring 8cm on a side and approximately 12cm in length. In this block (8cmx8cmx12cm) of gelatin we suspended at right angles with respect to each other the two spinal cord samples. The samples were centered side to side and positioned about 4cm apart. The gelatin/spinal cord phantom was allowed to chill overnight to solidify. Imaging was done at an ambient temperature of 10^{o}C. The placement of the two pieces of spinal cord was done to measure strain parallel (1^{st} piece) and perpendicular (2^{nd} piece) to the white matter fiber orientation. The gelatin serves as both an isotropic diffusion and mechanically isotropic background.

Diffusion tensor imaging (256X64, 9.0x7.5cm FOV) was done with fast spin echo readout on a Bruker/Varian 2T animal imaging system (TE=46ms, echo spacing=10ms, echo train length=8). Diffusion lobes were of δ=16 ms and Δ=21 ms at a strength of 3.66 G cm^{-1}, the b-matrix (Tr(b)~780 s mm^{-2}) was numerically calculated [4]. A total of 6 non-colinear directions were used for calculation of the tensor components, with 3 averages for diffusion-weighted images and 11 averages for T2 images.

Two-dimensional strain imaging was performed using a stimulated echo/fast spin echo acquisition [2] over a 128x128 matrix. Two sets of 2D displacement-encoded data were acquired with the spinal cord aligned with the vertical deformation, and perpendicular to the vertical deformation.

Results

Figure 1 shows the tensor imaging results as well as the strain images. Mean FA for the samples was measured to be 0.48 +/- 0.18 and 0.51+/-0.18 for the vertically and horizontally placed samples respectively. The reduction of FA compared to what might be expected is most likely due to partial volume effects (grey matter, with little or no fractional anisotropy is interior to the white matter in spinal cord). The strain imaging shows analogous results to those presented previously [3]. In panel C we see that the spinal cord exhibits relatively high absolute strain compared to the gelatin (i.e., it is softer than the gelatin), while panel D shows that the spinal cord exhibits relatively low absolute strain compared to the gelatin (i.e., it is harder than the gelatin).

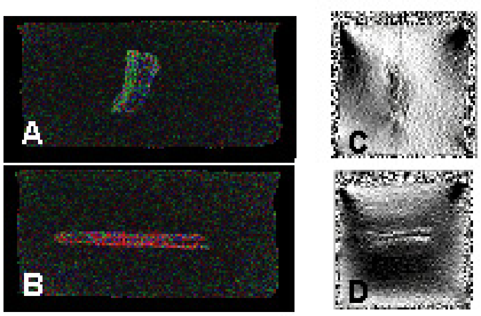

Figure 1. Panel A is the directionally-color-encoded (DEC) fractional anisotropy (FA) map [5] for the sample with fibers parallel to applied strain, while B is the DEC FA map with the spinal cord perpendicular to the applied strain. Purely green indicates fiber vertical fiber orientation, red is horizontal orientation and blue is orientation into the page. Panel C shows the vertical longitudinal strain, and D the horizontal longitudinal strain. Both are presented on a scale from –5% (black) to +1% strain (white). The change in strain contrast in the spinal cord in the two orientations indicates a mechanical anisotropy.

Conclusions

The strain imaging and diffusion tensor imaging clearly show the correlation with the white matter fiber orientation. These data illustrate that certain macroscopic mechanical characteristics may be indirectly probed via diffusion tensor imaging.

References

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