High resolution diffusion tensor imaging of human hyaline articular cartilage

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In view of osteoarthritis, diffusion tensor imaging (DTI) was used to analyze the microstructure of human hyaline articular cartilage. The experiments were performed on two high-field MRI systems with a maximum resolution of 35×70µm². Cartilage-on-bone samples were measured unloaded and under local compressive strain. Using a self developed software package, maps of diffusion tensor trace, anisotropy, eigenvalues, and eigenvectors were visualized. DTI experiments seem applicable to articular cartilage structural analysis. The various maps show a zonal arrangement for unloaded cartilage. This pattern is strikingly modified under loading. These findings are in good agreement with current literature about the collagenous fiber architecture of cartilage.

Introduction

Hyaline articular cartilage is an anisotropic structure of various zones, defined mainly by the arrangement of the collagenous fibers. Changes within this fiber network are regarded to be a hallmark of early degeneration in cartilage subject to osteoarthritis (1). DTI has been demonstrated to be effective in analyzing internal structural anisotropy in brain and intervertebral disc tissue (2,5). However, today no data are available about DTI of hyaline articular cartilage. Therefore, this work presents a first investigation of hyaline articular cartilage using DTI.

Materials & Methods

The measurements were performed on cartilage-on-bone samples of human patellae (cylindrical, 7mm diameter) in pseudo-physiological conditions. These samples were tested unloaded and under local compressive strain through a solid and not porous indentor (maximum strain about 25%, Fig. 1a and 2a). The DTI data were acquired on two Bruker Microimaging Systems with 400MHz and 500MHz. On the 400MHz system (maximum gradient strength 1T/m), we obtained a resolution of 39×78µm² (Matrix 256×128, FOV 10×10mm², slice thickness of 1.5mm) with 18 averages, b-value of 1000s/mm², TR/TE=2000ms/11ms, Δ=3.7ms, δ=2.1ms. On the 500MHz system (maximum gradient strength 2T/m), we obtained a resolution of 35×70µm² (Matrix 256×128, FOV 9×9mm², slice thickness of 1.5mm) with 16 averages, b-value of 1000s/mm², TR/TE=2000ms/8.5ms, Δ=2.7ms, δ=1.2ms. 12 different diffusion gradient directions were applied.

DTI data are evaluated using a self developed software package based on the visualization system AVS. We determined the diffusion tensor eigenvalues and eigenvectors and visualized the results as trace maps, anisotropy maps based on different definitions (3,4), eigenvalue maps, and the eigenvectors using color map and their projections on arbitrary planes.

Results

The mean diffusivity map (Figures 1b and 2b) show zonal variations. Figures 1c and 2c give a schematic quantitative evaluation of the mean diffusivity: the values vary between 0.0014mm²/s in the tangential zone and 0.0004mm²/s at the tide mark. The fractional anisotropy varies between 0 and 0.2. The projection of the largest eigenvector on the image plane (Figure 3) has different directions in the unloaded case and in the loaded case. There are marked changes in distribution of map parameters between unloaded and loaded case.

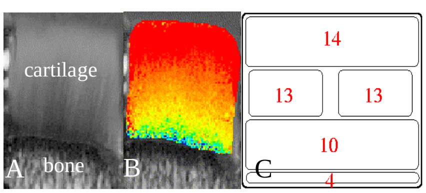

Figure 1. Unloaded cartilage. A: diffusion image with b=1000s/mm². B: mean diffusivity. C: quantitative scheme of the mean diffusivity (100µm²/s).

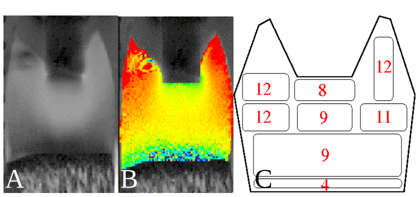

Figure 2. Loaded cartilage. A: diffusion image with b=1000s/mm². B: mean diffusivity. C: quantitative scheme of the mean diffusivity (100µm²/s).

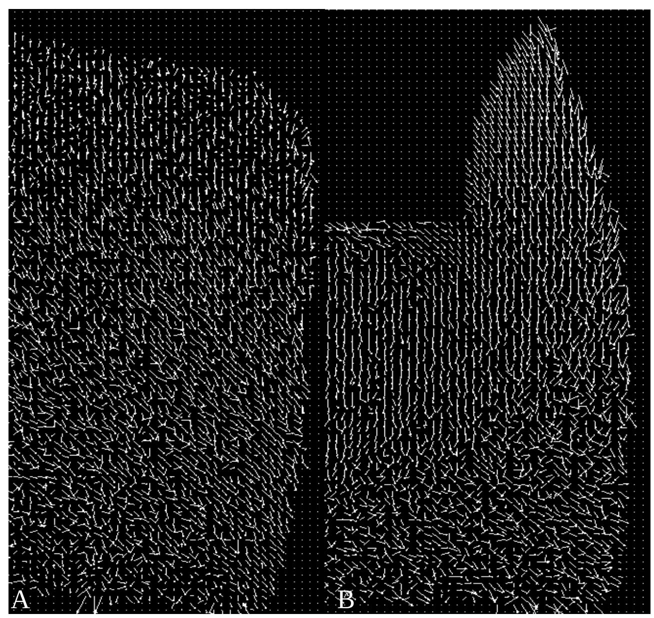

Figure 3. Projections of the largest eigenvector on the image plane. The projection directions change between the unloaded (A) and the loaded case (B).

Discussion and Conclusion

Our results demonstrate the feasibility of DTI experiments for structural analysis of hyaline articular cartilage. The technique holds high potential for monitoring the zonal arrangement of the cartilage and its change between unloaded and loaded case. The observed zonal pattern is in good agreement with current literature about the collagenous fiber architecture of cartilage (1).

References

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