DTI of the human patellar cartilage ex vivo at 1.5T: comparisson with 17.6 T and patterns of disease

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Introduction: DTI has a great potential for assessing the integrity of the matrix of the articular cartilage, since it is sensitive to the proteoglycan content through the mean diffusivity (ADC) and to the integrity the collagen network through the fractional anisotropy (FA) and the first eigenvector (1st EV) [1–3]. However, due to the low T2 values in articular cartilage and the high resolution necessary to depict the structure of the cartilage, DTI of the cartilage has been performed exclusively at ultra-high fields (>7 T) and therefore restricted to small samples. Aim of this work was to demonstrate the value of DTI of the cartilage performed on a 1.5-T scanner and to characterize the patterns of pathology, which can be observed when imaging the whole articular cartilage.

Methods: DTI of human excised patellae (n = 25, n = 13 with age under 35 y (mean age 24.7±8.5 y) and n = 12 with age over 35 y (mean age 60.4±21.2 y)) was performed on a 1.5-T scanner (Magnetom Sonata, Siemens Healthcare, Erlangen, Germany) with a four channel small extremity coil using an in-house developed multi-slice diffusion-weighted navigated spin-echo (SE) sequence (TE/TR = 53/1400 ms, FOV = 14×14 cm², matrix = 128×128 zero filled to 256×256, in-plane resolution = 0.54×0.54 mm², 20 slices, slice thickness = 3 mm, b-values = 0, 550 s/mm², 6 directions, 5 averages, bandwidth = 130.0 Hz/Pixel, acquisition time = 1:45 h). To keep the patella fixed during MRI a Plexiglas device was designed which fits tightly into the small extremity coil. The cartilage was segmented on DTI images and maps of ADC, FA and the 1st EV were calculated for each sample. Some samples (n = 6) underwent additionally DTI at 17.6 T (Bruker Advance, Bruker, Rheinstetten, Germany). Cylindrical cartilage-on-bone samples (diameter = 14 mm) were drilled from the lateral facet of the patellar cartilage and imaged using a 20 mm birdcage coil with a single-slice diffusion-weighted SE sequence (TR/TE = 1000/16 ms, FOV = 16×16 mm², matrix = 256×64, in-plane resolution = 62×250 µm², slice thickness = 1.5 mm, bandwidth = 130 kHz, repetitions = 32, acquisition time = 4 h).

Results: Fig. 1A shows an example of the DTI parameter maps for a healthy patella. The 1st EV at 1.5 T demonstrates a spatial dependence on the cartilage depth, which corresponds with the expected orientation of the collagen network [1–3] (Fig. 1A). Underneath the articular surface (AS) the 1st EV is principally oriented parallel to the AS. In the deep cartilage the 1st EV turns to be perpendicular to the bone-cartilage interface (BCI). Similarly as by 17.6 T, ADC continuously decreased from the AS to the BCI. Measured ADC values are slightly larger at 1.5 T, (1.17±0.35) mm²/s, than at 17.6 T (1.06±0.22) mm²/s. This difference can be well explained by the difference in temperature at which the experiments in the two scanners were performed (approx. 22 °C at 1.5 T and 18 °C at 17.6 T). Increased FA from the BCI to the AS was observed at both gradient strengths. However, average FA was higher at 1.5 T (0.35±0.21 at 1.5 T and 0.18±0.17 at 17.6 T). Possible explanations for this difference are the different diffusion times (30 ms by 1.5T and 5.85 ms by 17.6 T) and the lower resolution of the images at 1.5 T.

The average ADC measured on the samples older than 35 y, (1.27±0.35) mm²/s, is significantly larger than in the samples with ages lower than 35 y, (1.12±0.35) mm²/s. No significant difference was observed for the FA. Patterns of degradation of the articular cartilage include focal lesions of increased ADC (n = 8), alterations of the subchondral bone (n = 2) and osteophytes (n = 2). Focal lesions were seen on ADC and were sometimes accompanied by changes in FA and reorientation of the 1st EV (Fig. 1B). Alterations of the subchondral bone were observed in the lateral facet and were characterized by a high ADC and reduced FA. Osteophytes (one found in the periphery (Fig. 1B) the other in the medial facet) had a low ADC and produced increased FA with reorientation of the 1st EV, thus evidencing the deformation of the surrounding cartilage.

Conclusions: DTI of the cartilage at 1.5 T is demonstrated to lead to reliable DTI parameters. Imaging of the whole cartilage allows a more complete characterization of the pathological processes occurring in OA.

References:

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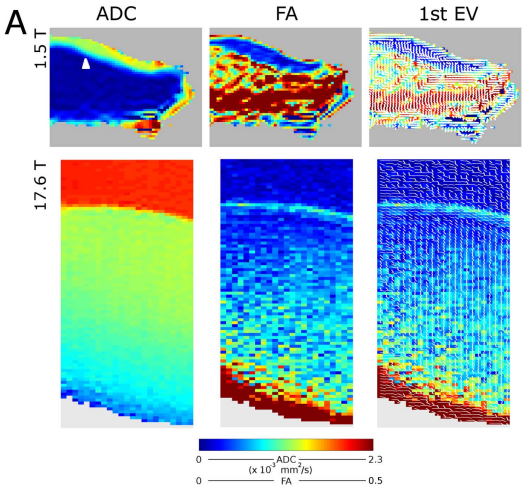

Figure 1. 1A. Top. Example of the DTI parameters (ADC, FA and 1st EV) on a healthy sample (23 y). Cartilage can be identified as the tissue with high ADC and low FA The white arrow indicates the approximate position of the sample drilled for imaging at 17.6 T. Bottom. DTI maps obtained at 17.6 T, in this case cartilage was immersed in Physiologic saline, hence the high ADC above the AS. **1B.** Details of the DTI maps of an osteophyte and a focal lesion. The osteophyte (not imaged because of the short T2) produces increase of the FA, reduction of the ADC and reorientation of the 1st EV. The focal lesion is characterized by an increase in the ADC near to the AS. In this lesion an abnormal high FA was found near to the BCI, which also involves a reorientation of the 1st EV. The same scaling has been used in all images.