

In vivo diffusion tensor imaging (DTI) of articular cartilage of healthy and osteoarthritis (OA) subjects with coverage of all cartilage plates

Jose G Raya¹, Mike Notohamprojo², Svetlana Krasnokutsky³, Soterios Gyftopoulos³, and Christian Glaser³

¹Radiology, New York University Langone Medical Center, New York, New York, United States, ²University of Munich, ³New York University Langone Medical Center

Introduction: Diffusion tensor imaging (DTI) of articular cartilage is sensitive to both the proteoglycan content through the mean diffusivity (MD) and to the collagen network through the fractional anisotropy (FA) [1–4]. Hence, DTI has potential as a biomarker for the early diagnosis of osteoarthritis (OA). In vivo DTI of articular cartilage has been shown high diagnostic accuracy for OA in the patellar cartilage (sensitivity, specificity greater than 80% [5]). The aim of this study was to demonstrate the feasibility, repeatability and potential for diagnosis of in vivo DTI in all knee cartilage plates (patella, tibia lateral and medial, and femur).

Methods: DTI was performed on a whole body 7-T scanner (Siemens Healthcare, Erlangen, Germany) with a dedicated birdcage transmit, 28-channel receive knee coil (QED, Cleveland OH). Images have been acquired on the right knee of 10 healthy volunteers (mean age 30.9±2.3 y, no episodes of knee pain in the last three years, and no history of surgical intervention) and 3 OA-diagnosed patients from the NYU-HJD OA cohort [6] (mean age 65.3±8.5 y, Kellgren-Lawrence grade II ($n=1$) and III ($n=2$)). Three volunteers and one OA subject were imaged two times in the same imaging session with knee repositioning for repeatability assessment. Imaging protocol included a line scan diffusion tensor imaging (LSDTI) sequence (TE/TR/TR_{eff} = 46/180/2890 ms, FOV = 154×86 mm², matrix = 256×144, in-plane resolution = 0.6×0.6 mm², rotation angle (α) = 20°, 10 slices, slice thickness = 3 mm, slice gap = 2 mm, b -values = 0, 450 s/mm², 6 directions, bandwidth = 500 Hz/Pixel, acquisition time = 28:03 min) and a 3D fat-saturated T1-weighted gradient echo (T1w-GRE) sequence for cartilage segmentation with the same slice orientation as the LSDTI images but higher resolution (TE/TR = 6.12/44 ms, flip angle = 20°, in-plane resolution = 0.25×0.25 mm², 88 slices, slice thickness = 1 mm, bandwidth = 210 Hz/pixel, parallel imaging acceleration factor (iPat) = 3, acquisition time = 10:14 min). All images were acquired in the sagittal plane, covering the whole knee joint. For each LSDTI image there was a T1w-GRE image with the same position.

Femoral, tibial (lateral and medial) and patellar cartilage plates were segmented in the T1w-GRE images and superimposed on the LSDTI images.

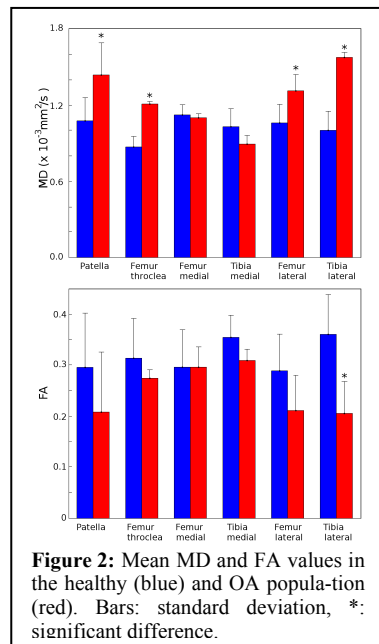


Figure 2: Mean MD and FA values in the healthy (blue) and OA population (red). Bars: standard deviation, *: significant difference.

(Healthy: $(0.87 \pm 0.10) \times 10^{-3}$ mm²/s, OA: $(1.21 \pm 0.07) \times 10^{-3}$ mm²/s), the lateral femoral condyle (Healthy: $(1.06 \pm 0.14) \times 10^{-3}$ mm²/s, OA: $(1.31 \pm 0.13) \times 10^{-3}$ mm²/s) and the lateral tibia (Healthy: $(1.00 \pm 0.16) \times 10^{-3}$ mm²/s, OA: $(1.58 \pm 0.07) \times 10^{-3}$ mm²/s). Significantly increased MD was accompanied with a decrease in FA, which was, however, only significant for the lateral tibia (Healthy: 0.36 ± 0.08 , OA: 0.21 ± 0.06).

Discussion/Conclusions: Our results provide first in vivo DTI of the articular cartilage in all knee cartilage plates on healthy and OA subjects. In the healthy population our data indicate homogeneous diffusion properties among all cartilage plates. In OA subjects, significantly increased MD and a trend of reduced FA identifies knee compartments affected by OA. DTI of the cartilage is feasible, putting into scene a new promising biomarker for early diagnosis of OA.

References: [1] Filidoro L et al. MRM 2005;53:993–998; [2] Meder R et al. Osteoar. Cartil. 2006;14:875–883; [3] de Visser et al. Osteoar. Cartil. 2008;14:875–883; [4] Raya JG et al. Invest Radiol 2011;46:401–409; [5] Raya JG et al. Radiology 2011;in press; [6] Attur M et al. Ann Rheum Dis 2010;69:856–861.

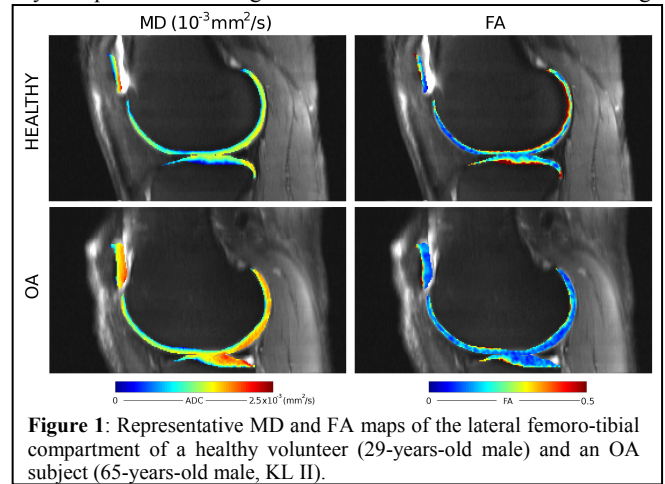


Figure 1: Representative MD and FA maps of the lateral femoro-tibial compartment of a healthy volunteer (29-years-old male) and an OA subject (65-years-old male, KL II).

All images were acquired in the sagittal plane, covering the whole knee joint. For each LSDTI image there was a T1w-GRE image with the same position.

DTI parameters MD and FA were calculated on the segmented cartilage. All segmented cartilage was automatically divided into 2 layers (deep and superficial) parallel to the bone-cartilage interface. Additionally, the femoral cartilage was divided into trochlea, lateral condyle, and medial condyle. The repeatability of the DTI parameters was assessed globally and for each layer using the root mean square of the coefficient of variation (i.e. standard deviation divided by the mean times 100%).

Non-parametric tests were used to detect significant differences in diffusion parameters between the different cartilage plates as well as between the healthy and OA populations. For binary comparisons within healthy population (e.g. deep versus superficial layers), the two-sided paired Wilcoxon test was used. Differences between the healthy and OA populations were assessed using the two-sided unpaired Wilcoxon test. For comparisons of more than two groups (e.g. all cartilage plates), the two-sided Kruskal-Wallis test with Bonferroni correction was used. Overall a significance level of 0.05 has been assumed.

Results: Fig. 1 shows an example of the DTI parameter maps of the lateral femorotibial compartment of a healthy volunteer and an OA subject. In the healthy population there was no difference in MD or FA among the different cartilage plates, neither globally (Fig. 2) nor by layers. However, in all cartilage plates, MD in the superficial layer was significantly higher, $(1.28 \pm 0.16) \times 10^{-3}$ mm²/s (average over all cartilage plates in all subjects), than in the deep layer, $(1.01 \pm 0.12) \times 10^{-3}$ mm²/s. FA was significantly higher in the deep layer, 0.43 ± 0.12 , than in the superficial layer, 0.25 ± 0.12 . In the patellar cartilage, MD and FA values $((1.08 \pm 0.18) \times 10^{-3}$ mm²/s and 0.30 ± 0.11 , respectively) were in the range of previously published in vivo data [5]. The repeatability of global MD/FA was, respectively, 6.9%/7.8% in the patella, 8.2%/9.1% in the femur, 9.3%/10.1% in the lateral tibia, 9.2%/11.1% in the medial tibia.

MD and FA values in the OA subjects (mean and standard deviation) are summarized in Fig. 2. In highly-resolved T1w-GRE images, OA subjects showed signs of OA in the patellofemoral ($n=2$) and lateral femorotibial compartments ($n=3$ OA subjects). This is reflected by the significantly increased MD values in the cartilage of the patella (Healthy: $(1.08 \pm 0.18) \times 10^{-3}$ mm²/s, OA: $(1.43 \pm 0.18) \times 10^{-3}$ mm²/s), the trochlea