Analysis of fiber arrangement in knee cartilage of younger and older volunteers with 7-T MRI

Nikita Garnov[1], Wilfried Gründer[2], Gregor Thörmer[1], Robert Trampel[3], Robert Turner[3], Thomas Kahn[1], and Harald Busse[1]

[1]*Diagnostic and Interventional Radiology, Leipzig University Hospital, Leipzig, Germany,* [2]*institute of Medical Physics and Biophysics, Leipzig University, Leipzig, Germany,* [3]*Neurophysics, Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany*

Introduction

Osteoarthritis is a widespread joint disease, which may occur after trauma, infection or with age, and may eventually lead to irreversible cartilage damage. An early sign for cartilage degeneration is the increased loss of structural order in the collagen fiber network starting at the surface layer. It has been shown that intact cartilage features a thicker layer of radial structures than arthritic tissue [1]. Therefore, the anisotropy of the cartilage layer is considered to be a sensitive indicator for early degenerative changes. Assuming an analytical fascicle model of the cartilage ultrastructure, angle-sensitive MRI of cartilage (ASMRIC) [2, 3] can be used to quantify the anisotropic architecture of knee cartilage [4]. The purpose of this study was to evaluate the feasibility of ASMRIC at 7 T in human volunteers and to compare the quantitative results between two different age groups (younger vs. older).

Methods and Materials

Twenty healthy volunteers were divided into two equally sized groups with younger (9 m, 1 f; 21–30 [mean 25.1] y.o.) and older (6 m, 4 f; 55-76 [mean 65.3] y.o.) subjects. The lateral condyles of the right knees were examined in a 7-T whole-body MRI (Siemens Healthcare) using an 8-channel phased-array birdcage coil (Rapid Biomedical) and a sagittal T2w multi-echo sequence (TR/TE: 2,500/12-96 ms, 8 echoes, FOV 130×130 mm^2, four 1.0-mm thick slices with 3.0 mm gap, matrix size 448×448). Regions of interest (ROI) were defined near the joint contact point in both femoral and tibial condyles (perpendicular to the respective bone-cartilage interfaces) with a width of 3 pixels and the height of the individual cartilage thickness (Fig. 1a). T2-maps were calculated from the echo-time dependence of the signal intensities.

Profiles of T2 and signal intensity (SI) were calculated as a function of cartilage depth by averaging over the width of the ROIs. The depth was normalized with 0 and 1 corresponding to the bone-cartilage interface and cartilage surface, respectively. For further analysis, MR images were selected for those TE times where the depth-dependent SI profile best matched the corresponding T2 profile. The resulting SI profiles were then fitted to a dose-response curve with variable slope (Fig. 1b). The fascicle model (Fig. 2) describes the fiber distribution in a voxel as a function of mean fiber orientation θ and opening angle α [4]. Curves were normalized according to the minimum and maximum values of the simulated intensity for varying opening angles α at a given initial mean fiber orientation angle θ. Using the analytical function of the fascicle model [4], the normalized intensity profiles were then converted to depth-dependent profiles of α (Fig. 2). The relative depth position of the R/T boundary was defined at α =35° (Fig. 2, Fig. 1c). A significance level of 0.05 was used for all t-tests.

Table 1. Relative positions of R/T boundary.

Subjects	*Femur*	*Tibia*
Younger	0.51 ± 0.12	0.65 ± 0.11
Older	0.41 ± 0.10	0.57 ± 0.09

Data are mean ± SD

Results

Sample 7-T MR image and derived results are given in Fig 1. In 90% of the cases, MR images with a TE of either 60 ms (20/40) or 72 ms (16/40) showed a similar intensity variation with depth as that in T2 maps. The relative depth positions of the R/T boundary (Tab. 1, Fig. 3) in the tibia were significantly higher than those in the femur for both younger and older subjects. Between groups, differences in the relative R/T boundary were significant in the femoral cartilage and did not reach significance in the tibia (p=0.12).

Conclusions

In-vivo ASMRIC at 7 T and analysis using the fascicle model allows for a reliable quantification of the cartilage ultrastructure in human adults. These preliminary results suggest that the position of the femoral R/T boundary could be a potential factor to evaluate the "biologic age" of the cartilage. This method also holds promise to potentially detect or monitor early osteoarthritis because disorganization of the anisotropic network is also a hallmark of arthritic changes in cartilage.

References

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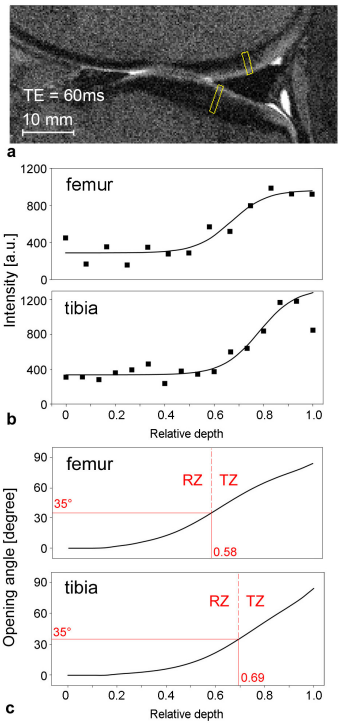

Fig. 1. a: T2w knee MRI of a 30 y.o. male with selected cartilage ROIs. **b:** Depth dependence of signal intensities over the ROIs and corresponding curve fits. **c:** Computed depth dependence of opening angle α in the fascicle model and resulting R/T boundaries.

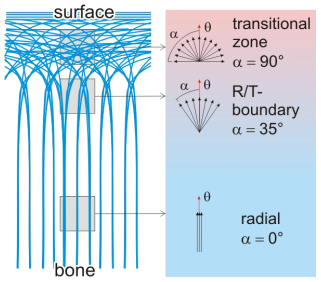

Fig. 2. Collagen fiber arrangement in adult cartilage according to the fascicle model [4].

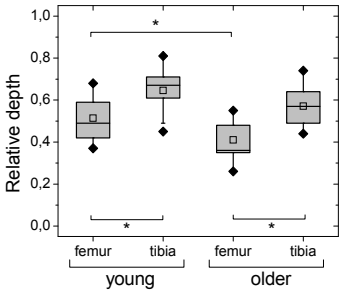

Fig. 3. Comparison of the relative positions of the R/T boundaries (0=bone-cartilage interface, 1=cartilage surface) in the ultrastructure of femoral and tibial cartilage between younger and older volunteers (asterisks indicate significant differences).