ALTERNATIVE METHODS FOR TRANSFORMING T2 ANISOTROPY OF MRI INTO COLLAGEN ARCHITECTURE OF ARTICULAR CARTILAGE – THE EFFECT ON KNEE JOINT MECHANICS – DATA FROM THE OSTEOARTHRITIS INITIATIVE (OAI)

Lasse P. Räsänen[1,2], Mika E. Mononen[1], Miika T. Nieminen[3,4], Eveliina Lammentausta[3], Jukka S. Jurvelin[1], and Rami K. Korhonen[1]

[1]*Department of Applied Physics, University of Eastern Finland, Kuopio, Finland,* [2]*Department of Clinical Radiology, Kuopio University Hospital, Kuopio, Finland,* [3]*Department of Diagnostic Radiology, Oulu University Hospital, Oulu, Finland,* [4]*Department of Radiology, University of Oulu, Oulu, Finland*

Target Audience

Radiologists, Medical personnel associated with the diagnostics of MRI and articular cartilage.

Purpose

Two alternative methods were applied to transform T2 relaxation data of tibial articular cartilage into the depth-dependent collagen architecture. This structural information was used in a computational model of a knee joint and differences in the mechanical response of knee cartilage, resulting from the different architectural appearances of cartilage, were evaluated.

Methods

The knee joint tissues were manually segmented from mid-lateral sagittal slice of a healthy joint (3.0T, Siemens Trio, Erlangen, Germany, T2 weighted MESE, TR = 2.7 s, seven TE's between 10.0 and 70.0 ms, in-plane resolution 0.322 mm, Osteoarthritis Initiative (OAI) database, image dataset 0.E.1, http://www.oai.ucsf.edu/, Fig. 1a). Superficial, middle and deep zones of the tibial cartilage were determined in the segmented cartilage area by using two alternative methods for the analysis of depth-wise T2 profiles, indicating the collagen architecture. In *Method I* the middle zone was located in between the half-maximum point of the rising part and descending part of typically bell-shaped T2-profiles (Fig. 1b).[1] In *Method II* the superficial-middle zone boundary was evaluated similarly as in *Method I*, but the boundary between the middle and deep zones was determined from the corresponding signal intensity in the descending profile (Fig. 1c).[2] The determined collagen architectures (Fig. 2a,b) were implemented into a 2D computational model of the knee joint[2,3]. In the models, cartilage and menisci were considered as biphasic tissues (solid and fluid) reinforced with collagen fibrils.[2,3] The models were used to simulate cartilage mechanics under impact loading of 846N, corresponding the body weight of the subject.[2]

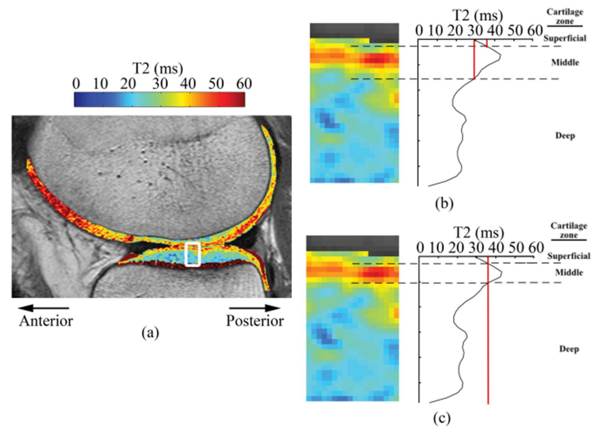

Fig 1: (a) T2 map of segmented cartilage, (b,c) the zoomed T_2 map from (a) and a depth-wise T2 profile of the zoomed tibial cartilage. The half-maximum limits illustrated with the red lines. The laminar boundaries obtained with (b) *Method I* and with (c) *Method II* illustrated with dashed lines.

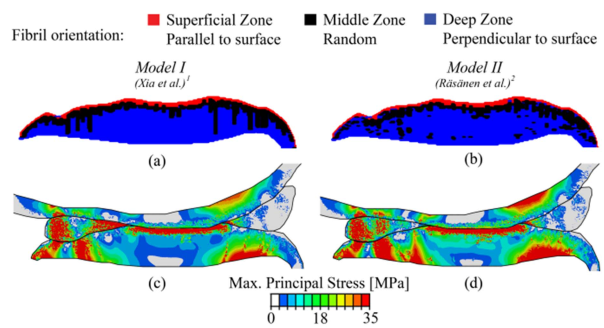

Fig 2: Collagen architectures of the tibia evaluated with (a) *Method I* and with (b) *Method II*. (c,d) Stress distributions.

Results

The obtained thickness (mean ± SD) of the middle zones were 21.1 ± 17.9 % (*Method I,* Fig. 2a) and 20.2 ± 15.2 % (*Method II,* Fig. 2b) of the total tibial cartilage thickness. Thickness of the superficial zone was 11.5 ± 6.7 % in both cases (Figs. 2a,b). In the cartilage-cartilage contact area, *model II* produced up to 18 % higher maximum principal stresses in the middle zone of tibial cartilage. Below the meniscus, in the anterior area, stresses were up to 49 % higher in *model II* (Fig. 2d) compared to *Model I*.

Discussion and Conclusion

Importance of the variation in the thickness of the middle zone of cartilage, as caused by different methods for evaluating collagen architecture[1,2], on tissue stresses and strains was evaluated. Due to the reduced tensile stiffness of the cartilage in *model II*, as caused by thinner middle zone, tissue strains were increased. This led to higher fibril strains and maximum principal stresses in the superficial layer of tibial cartilage, both in the cartilage-cartilage contact area and under the menisci. This result was surprising since the average middle zone thicknesses were only 0.9 % (20.2 vs. 21.1 %) different between the models. However, local changes in the zone thickness between the models was substantial, increasing the differences in stresses in some specific anatomical locations. The imaging resolution is therefore crucial in order to identify the collagen architecture of cartilage. The present results emphasize that the method for determining the collagen architecture of cartilage should be chosen carefully for optimal evaluation of cartilage mechanics and possible failure sites in knee joints.

References

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