Human Medial Femoral Condyle Cartilage Has More Compliant And Viscoelastic Superficial Tensile Properties Than Tibial Cartilage

Aapo Ristaniemi[1], Ervin Nippolainen[1], Isaac O. Afara[1], Mika E. Mononen[1], Rami K. Korhonen[1], Janne T. A. Mäkelä[1]
[1]University of Eastern Finland, Kuopio, Finland
aapo.ristaniemi@uef.fi

Disclosures: None.

INTRODUCTION: The tensile properties of the superficial articular cartilage in the human tibiofemoral joint have only been characterized within the femoral condyles (Kempson, 1982; Temple-Wong et al., 2009). As of our current knowledge, the tensile properties of human tibial cartilage remain unexplored. Therefore, it is also not known how the tensile properties compare between these two sites. We hypothesize that femoral and tibial cartilage exhibit site-specific tensile properties, given to the typical disparity in loading patterns (Halonen et al., 2016). To study this, we characterize the tensile properties of the superficial zone of human tibial plateau and femoral condyle articular cartilage.

METHODS: Knee joints from human cadavers (*N*=5, Fig. 1a) were obtained from a biobank (Science Care, USA) and processed and used according to the local ethical committee approval. OARSI-grading showed mostly healthy tissues (58 % of samples were grade 0 or 1, 27 % were grade 2 and 15 % were grade 3). Cartilage-on-bone blocks (*n*=37, Fig. 1b) of the lateral and medial femoral condyles (LFC, MFC) and lateral and medial tibial plateaus (LTP, MTP) were extracted, with the longest dimension oriented in the split-line direction. A ~300 µm thick slice was cut from the superficial zone to a dogbone-shaped tensile test specimen. The tensile test (Fig. 1c) consisted of a four-step stress relaxation test (steps at 3-6-9-12 % strain, 30 min relaxation), followed by a sinusoidal test (1 % strain amplitude, frequencies from 0.01 to 3 Hz) and finally an ultimate test until tissue failure (0.1 %/s velocity). Relaxation was characterized by peak-to-equilibrium stress ratio (a measure of the relaxation), the sinusoidal test with phase difference (indicating viscoelasticity), and the stress-strain response with Young's modulus of the linear region and ultimate strength and strain. Comparisons between the sites (LFC, MFC, LTP, and MTP) were made with a linear mixed model with the knee as a random subject variable and the site as a fixed variable and statistical significance was set to $p=0.05$.

RESULTS: No differences in the peak-to-equilibrium stress ratio were observed between the sites (Fig. 2b). At frequencies 0.1, 0.2, 1 and 1.25 Hz, the MFC cartilage exhibited significantly higher phase differences compared to all other surfaces ($p<0.05$, Fig. 2a). Additionally, at frequencies 0.05, 0.5, 0.75 and 1.5 Hz, the phase difference in MFC was higher than in LFC and MTP ($p<0.05$), and at 2 Hz, it was higher in MFC than in MTP ($p<0.05$). Young's modulus was lower in MFC than in MTP ($p<0.05$, Fig. 2c), and the ultimate strain was higher in MFC than in MTP ($p<0.05$, Fig. 2d). Although MFC showed a trend towards lower ultimate strength than the other surfaces, this difference was not statistically significant.

DISCUSSION: The MFC cartilage exhibited higher viscosity (damping) in tension compared to other surfaces, and lower Young's modulus and higher ultimate strain relative to its contacting MTP. These adaptations could be linked to the higher loading experienced in the medial side (Halonen et al., 2016) potentially resulting in heightened tensile strains in the superficial zone of the femoral cartilage. Combination of high straining and damping suggests effective damping of rapid loads. We acknowledge that cartilage degeneration can impact the results. However, the majority of the tissues were healthy, and the statistical model considers the variations between the knees.

SIGNIFICANCE/CLINICAL RELEVANCE: The results of this study improve the understanding of site-specific biomechanical properties of cartilage and aid in the development of more accurate computational knee joint models. Consequently, these advancements could facilitate better-informed clinical decisions and treatment strategies for knee-related conditions, such as guiding the design and optimization of allotransplantation and tissue-engineered cartilage constructs.

REFERENCES: Kempson (1982), *Ann. Rheum Dis. 41*, 508-511. Temple-Wong et al. (2009), *Osteoarthr. Cartil. 17(11)*, 1469-1476. Ebrahimi (2022), *Dissertation 486, University of Eastern Finland*. Halonen et al. (2016), *J Biomech Eng 138*, 1-11.

ACKNOWLEDGEMENTS: This study received funding from Research Council of Finland (grant No. 315820, 324529, 324994, 348410, 352666, 357787), Instrumentarium Science Foundation and Sigrid Jusélius Foundation.

IMAGES:

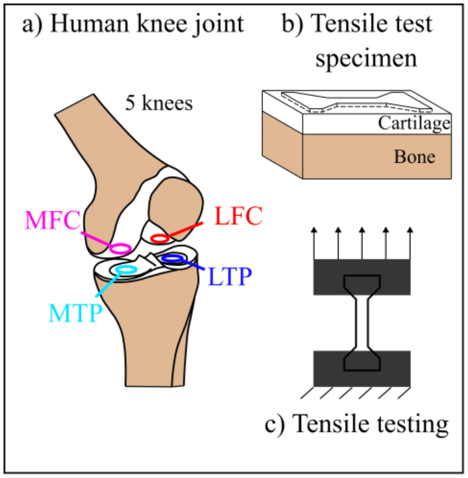

Fig. 1. a) Lateral and medial femoral condyles (LFC, MFC) and tibial plateaus (LTP, MTP) were obtained from five human knee joints. b) Superficial zone tensile test specimens were cut from cartilage-on-bone blocks and c) subjected to tensile testing.

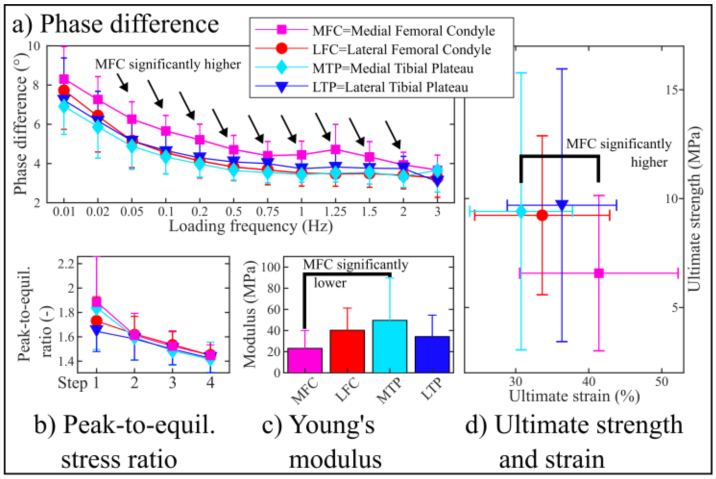

Fig. 2. a) Phase difference, b) peak-to-equilibrium stress ratio, c) Young's modulus and d) ultimate strength and strain for the different surfaces in tensile loading in the split-line direction.