

Valgus bracing alters cartilage stresses in medial knee osteoarthritis: a neuromusculoskeletal–finite element analysis

Joose P. J. Peitola¹, Amir Esrafilian¹, Atte S. A. Eskelinen¹, Scott C. Starkey², David J. Saxby³, Laura E. Diamond³, Michelle Hall⁴, Rami K. Korhonen¹
¹University of Eastern Finland, Kuopio, Finland, ²Centre for Health, Exercise and Sports Medicine, The University of Melbourne, Melbourne, Australia,
³Australian Centre for Precision Health and Technology (PRECISE), Griffith University, Gold Coast, Australia, ⁴Sydney Musculoskeletal Health, The University of Sydney, Sydney, Australia
joose.peitola@uef.fi

INTRODUCTION: Valgus knee bracing may benefit patients with medial knee osteoarthritis (KOA) by reducing medial tibiofemoral contact loading^{1,2}. Previous research has demonstrated variable effects of knee bracing on joint moments and contact forces/pressures, as well as KOA-related pain^{1,3}. Computational musculoskeletal models have shown valgus bracing may shift the center of knee contact pressure^{1,4}. However, the effects of valgus bracing on cartilage-level mechanics, relevant to cartilage failure, remain unexplored. In knee cartilage, the collagen fibril network provides tensile stiffness and structural integrity, and its organization combined with fluid pressure largely governs tissue deformation and stress⁵. Investigating tensile stresses along the primary fibril direction using a fibril-reinforced material model may offer more realistic insights into how bracing may influence cartilage and collagen failure risk, tissue degeneration, and KOA-related pain. The aim of this study was to examine effects of valgus knee bracing on tibiofemoral cartilage stresses during walking compared to unbraced walking using subject-specific neuromusculoskeletal–finite element (NMS–FE) analysis with fibril-reinforced poroelastic and -viscoelastic (FRPE, FRPVE) material models for both cartilage and menisci.

METHODS: 20 individuals (aged ≥ 50 years) diagnosed with varus-malaligned medial KOA (Kellgren–Lawrence grade ≥ 2) participated in data collection at the University of Melbourne approved by the Ethics Committee, where motion analysis data from each participant was acquired from both unbraced and braced (Unloader One©, Össur, Reykjavik, Iceland) walking trials⁴. An MS model with 3 degrees of freedom (DoF) at the hip, 12 DoF at the knee, and 1 DoF at the ankle joint, was developed for each participant. Geometries of bones, cartilages, and ligaments were created with a machine learning-based segmentation algorithm⁶ using each participant’s magnetic resonance imaging scan (Fig. 1A). Next, an EMG-informed Concurrent Optimization of Muscle Activation and Kinematics (COMAK) pipeline⁷ was used in OpenSim (V. 4.5) to estimate knee kinetics and kinematics⁴. Then, the above-mentioned cartilage and meniscus geometries were imported in an FE model⁶, which was split into medial and lateral compartments. Cartilage and menisci were modeled as FRPVE and FRPE materials, respectively (Fig. 1B), and meshed with hexahedral pore pressure elements (type C3D8P). Ligaments were excluded since we used mostly kinematic parameters, obtained from the COMAK pipeline, to drive the model (Fig. 1B). We used soils consolidation analysis (Abaqus V. 2023) and present here the results for maximum principal stresses, which are linked to potential cartilage overload, collagen damage, and degradation⁸. Wilcoxon signed rank -tests were used for statistical analysis.

RESULTS: Overall, compared to unbraced walking, braced walking significantly reduced maximum principal stresses (mean -1.23 ± 1.10 MPa standard deviation, $p = 0.03$) in the medial tibial cartilage (Fig. 1C) at the second peak of ground reaction force (~80% stance phase) but not at the first peak (~20% stance phase, -0.28 ± 0.96 MPa, $p = 0.24$). During the first ground reaction force peak, medial cartilage maximum principal stresses decreased for 9 participants by a mean of 1.20 MPa (12%, range 0.6–1.9 MPa), increased for 6 participants by a mean of 0.85 MPa (11%, 0.4–1.5 MPa), and had minor changes for 5 participants (change < 0.1 MPa). During the second peak of ground reaction force, cartilage maximum principal stresses decreased for 13 participants by a mean of 2.13 MPa (19%, 0.2–8.6 MPa), increased for 4 participants by a mean of 0.77 MPa (11%, 0.4–1.3 MPa), and had minor changes for 3 participants.

DISCUSSION: This study presented important insights into the effects of valgus knee bracing on estimated cartilage mechanics for individuals with medial KOA. The results suggest that valgus knee bracing can reduce cartilage tensile stresses and failure risk in many individuals with KOA, especially during the push-off phase (~80% stance phase, Fig. 1C), and may therefore help mitigate KOA progression. The reduction in tensile stresses may be explained by reduced knee adduction moments caused by the brace, especially for participants with large varus-malalignment⁴. However, individual responses varied, with some participants showing negligible changes or even an increase in stress. This highlights the potential need to personalize application of valgus bracing. To draw more general conclusions regarding how neuromuscular and anatomical differences affect the role of knee bracing on modulating cartilage failure risk and degeneration, more patients should be enrolled. Such studies could also clarify how biomechanical modification with knee bracing may mitigate pain.

SIGNIFICANCE/CLINICAL RELEVANCE: This study provides new information about the effects of knee bracing on tibiofemoral cartilage stresses. Ability of the brace to reduce cartilage loading may mitigate further tissue damage and degradation for certain individuals with medial KOA.

REFERENCES 1 Shelburne *et al. Clin. Biomech.* 23, 814–821 (2008); 2 Hall *et al. PLoS One* 17, 1–18 (2022); 3 Moyer *et al. Arthritis Care Res.* 67, 493–501 (2015); 4 Starkey *et al. Clin. Orthop. Relat. Res.* 1–14 (2025); 5 Mononen *et al. J. Biomech.* 45, 579–587 (2012); 6 Esrafilian *et al. IEEE Trans. Biomed. Eng.* 72, (2024); 7 Esrafilian *et al. J. Biomech.* 147, (2024); 8 Mononen *et al. Ann. Biomed. Eng.* 47, 813–825 (2019).

ACKNOWLEDGEMENTS: Novo Nordisk Foundation, The Research Council of Finland, Sigrid Jusélius Foundation, Finnish Ministry of Education and Culture (pilot project DREAM), Vilho, Yrjö and Kalle Väisälä Foundation, the National Health and Medical Research Council of Australia, the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie actions, Finnish Cultural Foundation, the Australian Department of Industry, Innovation and Science, and Ossur Orthopaedic Solutions.

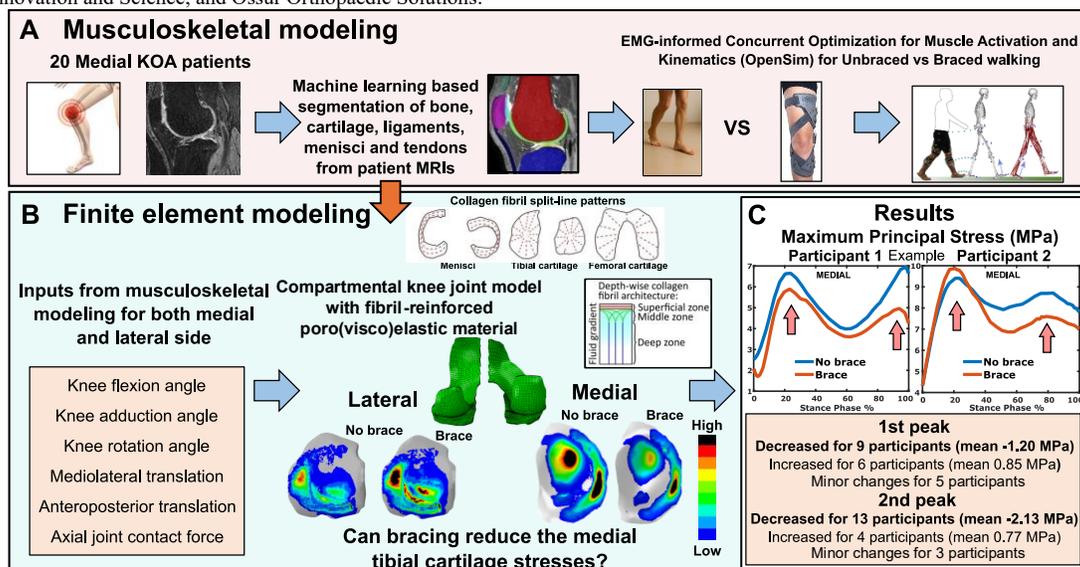


Fig 1: Overview of the study investigating the effect of valgus knee bracing on cartilage mechanics for individuals with medial knee osteoarthritis.