

# Relationships Between MRI-observed Patellar Motion and Knee/Lower-limb Tissue Characteristics in Hypermobile Ehlers-Danlos Patients and Healthy Controls

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**INTRODUCTION:** Hypermobile Ehlers-Danlos syndrome (hEDS) patients have a higher incidence of patellar maltracking/instability and poorer treatment outcomes compared to people without any form of EDS<sup>1-4</sup>. A better understanding of why these differences exist could inform more effective treatments. We obtained biomechanical and MR measurements related to soft-tissue properties, muscle function, and joint and limb alignment and evaluated between-group differences in hEDS versus controls and relationships to patellar kinematics.

**METHODS:** We collected data for 7 female participants without self-reported knee injuries on the imaged side (4 healthy controls, ages 21-39 years; 3 hEDS patients, ages 26-39 years). Recruitment was open to all genders, but 70% of individuals with hEDS are female, contributing to inclusion of only female participants in this pilot sample. MR imaging of the knee (anatomic, T<sub>2</sub>\* mapping, and diffusion (Fig. 1A-B)) and lower limbs from ankles through pelvis (Dixon imaging) was acquired at rest, and during knee extensor contraction (anatomic series of pelvis/hip and knee during isometric contraction at 20° and 0° of knee flexion, cine series during knee extension from 30° knee flexion to full extension (Fig. 1C)). Beighton hypermobility scores and knee extension maximum voluntary isometric contraction (MVIC) force measurements were also collected. A custom-built MR-compatible knee dynamometer, inspired by a previously published device<sup>5</sup>, was used for extension force measurements and isometric knee extensor contraction and knee extension MR imaging. Patellar displacement from maximum knee flexion to full extension was measured on the cine images. Median apparent diffusion coefficient (ADC) and T<sub>2</sub>\* were calculated for the knee articular cartilage, meniscus, anterior and posterior cruciate ligaments (ACL, PCL), medial patellofemoral ligament (MPFL), and patellar tendon (PT). Vastus medialis and lateralis (VM, VL) maximum anatomical cross-sectional area (ACSA) was measured on the Dixon series. Knee and hip internal/external rotation angles during isometric contraction and at rest, and measurements relevant to patellofemoral alignment at rest (Insall-Salvati ratio, patellar angle, congruence angle, tibial-tuberosity-trochlear-groove (TT-TG) distance, Q-angle, hip-knee-ankle angle), were measured. Control versus hEDS between-group differences and Spearman correlations between MR-based patellar displacement and other reported measures were evaluated.

**RESULTS:** All hEDS patients and 1 control exhibited generalized joint hypermobility (Beighton score ≥5). In all participants, median T<sub>2</sub>\* in the articular cartilage<sup>6</sup>, meniscus<sup>7</sup>, ACL<sup>8,9</sup>, PCL<sup>10</sup>, and PT<sup>8</sup> and ADC in the articular cartilage<sup>11,12</sup>, ACL<sup>13,14</sup>, PCL<sup>14</sup>, and PT<sup>14</sup> were in similar ranges as previously reported values. To the authors' knowledge, T<sub>2</sub>\* and ADC in the MPFL and ADC in the meniscus have not been previously reported. The hEDS patients had similar VL and VM ACSA but produced lower MVIC force normalized to body mass than controls. MPFL and PT median T<sub>2</sub>\*, TT-TG distance, and Beighton score were positively correlated with maximum patellar displacement (Fig. 2). Body-mass-normalized MVIC force and femoral neck angle (positive angle indicating external angle relative to medial-lateral axis of pelvis) at rest and during isometric contraction at 0° and 20° of knee flexion were negatively correlated with maximum patellar displacement (Fig. 2).

**DISCUSSION:** These pilot results suggest differences between hEDS patients' and controls' tissue properties that may correlate with patellar displacement during knee extension. The hEDS versus control differences in body-mass normalized maximum knee extension force are consistent with previously reported results<sup>15</sup> and may be related to lower stiffness in the patellar tendon in hEDS patients<sup>16</sup>. The relationship between patellar alignment (as indicated by TT-TG distance) and maximum patellar displacement may be due to the role of the PT in constraining the patella. The negative correlation between external femoral rotation and maximum patellar displacement may be related to altered forces on the patella with hip internal rotation<sup>17</sup>. The T<sub>2</sub>\* results are consistent with known roles of the MPFL and PT in patellar kinematics and indicate that T<sub>2</sub>\*, which is known to correlate with collagen organization/content and tissue mechanical properties<sup>18-22</sup>, may be a useful biomarker of altered collagen properties and function in these structures.

**SIGNIFICANCE/CLINICAL RELEVANCE:** The results suggest that the tissue properties that impact function of the MPFL and PT during patellar motion correlate with T<sub>2</sub>\*, highlighting a potential biomarker relevant to abnormal patellar kinematics in hEDS patients.

**REFERENCES:** 1. Castori. ISRN Dermatol. 2012 2. Heighes et al. J Orthop. 2024 3. Rombaut et al. Clin Rheumatol. 2010 4. Stern et al. J Pediatr. 2017 5. Brisson et al. Z Für Med Phys. 2022 6. Williams et al. Osteoarthritis Cartilage. 2011 7. Williams et al. Osteoarthritis Cartilage. 2012 8. Chu et al. Orthop J Sports Med. 2019 9. Schmitz et al. Muscle Ligaments Tendons J. 2019 10. Wilms et al. Quant Imaging Med Surg. 2022 11. Raya et al. Radiology. 2012 12. Duarte et al. Eur Radiol. 2019 13. Liu et al. J Magn Reson Imaging. 2020 14. Van Dyck et al. Eur Radiol. 2020 15. Rombaut et al. Arthritis Care Res. 2012 16. Wang et al. Int J Mol Sci. 2025 17. Meira et al. Sports Health. 2011 18. Beveridge et al. J Orthop Res. 2018 19. Biercevicz et al. J Orthop Res. 2015 20. Emanuel et al. Osteoarthritis Cartilage. 2021 21. Pownder et al. Quant Imaging Med Surg. 2021 22. Figueroa et al. Am J Sports Med. 2025

**ACKNOWLEDGEMENTS:** This work was supported by the Stephens Family Clinical Research Institute Innovations in Medical Research Award. We thank the University of Illinois Mechanical Engineering senior design students who designed and fabricated the knee extension dynamometer.

