# Anatomical and movement-related factors influencing knee joint in loading in osteoarthritis: Insights from a population-based approach

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INTRODUCTION: Over the last two decades, comprehensive datasets describing how subjects of different populations move during various daily activities have been collected. Additionally, rich imaging datasets detailing musculoskeletal geometry have become available. While this data is commonly analyzed on a patient-by-patient basis, it represents only specific subsets of the entire population. To address this limitation, we have explored two emerging methods for population-based modeling: The first approach focuses on evaluating the role of movement characteristics based on joint angles from motion capture data, therefore using a principal component analysis technique to establish representative population gait kinematic patterns. The second approach describes knee joint alignment and anatomical shape variations via a Statistical Shape Model (SSM). Combining these parameters with advanced musculoskeletal modeling enables us to explore wider insights into knee joint loading in knee OA. With this population-based approach, we can effortlessly identify geometric anatomical features and alignment variations, along with kinematic walking patterns that predispose the knee joint to altered loading variations, in casu local over- or underloading, interfering with joint homeostasis and thereby predisposing to cartilage degeneration.

METHODS: A workflow was developed to incorporate population-specific tibiofemoral joint geometry in a musculoskeletal model with a detailed 12 DOF knee joint [1]. Anatomical geometries derived from an existing SSM [2], built from MRI-images of 524 patients with knee osteoarthritis were included. In addition, a principal component analysis technique [3] was used to describe the variation in OA gait patterns based on 2 minutes treadmill gait data of 17 OA subjects (5 ♂ and 12 ♀; age: 66.6 ± 7.3 yrs.; height: 1.65 ± 0.12 m; weight 80.5 ± 15.3 kg; BMI: 29.86 ± 6.28 kg/m$^2$, Kellgren-Lawrence score 2-4). We then ran dynamic gait pattern simulations using MSK models representative for the different standard deviations (+/- 1,2,3) on the mean of each of the first eight modes of SSM combined with the first 14 components for the gait pattern variation (explaining 95% of variation). Mean knee contact pressures during the first and second peak of knee joint loading were then evaluated. In this abstract, we have chosen to highlight specific cases (first 8 modes of SSM) and 2 different walking patterns (first mode and fifth mode of variation)) which have been frequently observed in studies on joint variations and are believed to hold significant clinical relevance in the context of knee OA progression but whose role in altered knee joint loading were not confirmed so far.

RESULTS: When examing the isolated effect of anatomical variation using an average OA walking pattern, compressive medial compartment load progressively increased with increasing varus alignment (mode 1 SSM). Similarly, a reduction in femoral condyl size (mode 6) and increased anterior positioning of the tibia with respect to the femur (mode 3) increased medial compartment loading. When combining these anatomical variations with a stiffer walking pattern (characterized by a decrease in hip and knee joint flexion and identified by the first mode of variation), medial compartment contact pressure further increased on average with 29.4%. In contrast, when combining the anatomical variations with a kinematic pattern (increased contralateral sidebending (5°) + internal hip rotation (5°), identified as mode 5), no changes in medial compartment loading could be observed.

DISCUSSION: In agreement with previous studies on MSK variation associated with knee joint OA, a larger varus alignment resulted in an increase in medial compartment contact pressure [4]. Impact of other anatomical variations described in remaining modes (2-8), were previously never investigated. Given the finding that other modes related to tibiofemoral alignment and condylar geometry have an impact on medial compartment loading. This is an important consideration which further emphasizes the need to not only focus on frontal plane knee alignment in clinical assessments. The increase in contact pressure when adopting a stiffer walking pattern, has also been well established in previous research [5]. Uniquely, our population-based, dynamic simulation approaches allow studying undocumented interaction effects between musculoskeletal geometry and movement characteristics on knee joint loading. Although, the impact of anatomical variation within mode 1,3 and 6 becomes particularly distinct when combined with a stiffer walking pattern, is adopted, there is a more limited effect when adopting a kinematic pattern with focus on contralateral side-bending and internal hip joint rotation, as often integrated in gait retraining protocol for knee OA patients. , This seems to suggest that correcting for sagittal plane gait characteristics is potentially more powerful to impact knee joint loading and that the impact of gait retraining interventions is minimal when not correcting for skeletal malalignment.

SIGNIFICANCE/CLINICAL RELEVANCE: It has been widely acknowledged that mechanical joint loading plays a key role in the onset and progression of knee osteoarthritis, therefore this work aims to identify the factors that are causing the under- and overloading of the knee joint during daily life activities in particular walking. Using this population-based approach we can easily identify geometrical anatomical features and alignment variations as well as kinematic walking patterns that predispose the knee joint to either under- or over-loading. Moreover, it possesses the potential to synergistically integrate the interaction of both factors hence allowing to evaluate the tradeoff between correcting knee joint loading through physical therapy or orthopedic correction.

REFERENCES:
1. Lenhart et al., Ann Biomed Eng, 43(11): 2675-85, 2015
2. Van Dijck et al., Comp Meth Biomech Biomed Engin.,21(9):568-78, 2018
3. De Roeck et al., Front. Bioeng Biotechnol.,9:696360, 2021
4. Van Rossom et al., Knee, 26(4):813-823, 2019
5. Kumar et al., Osteoarthritis Cartilage, 21(2):298-305, 2013

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IMAGES AND TABLES:

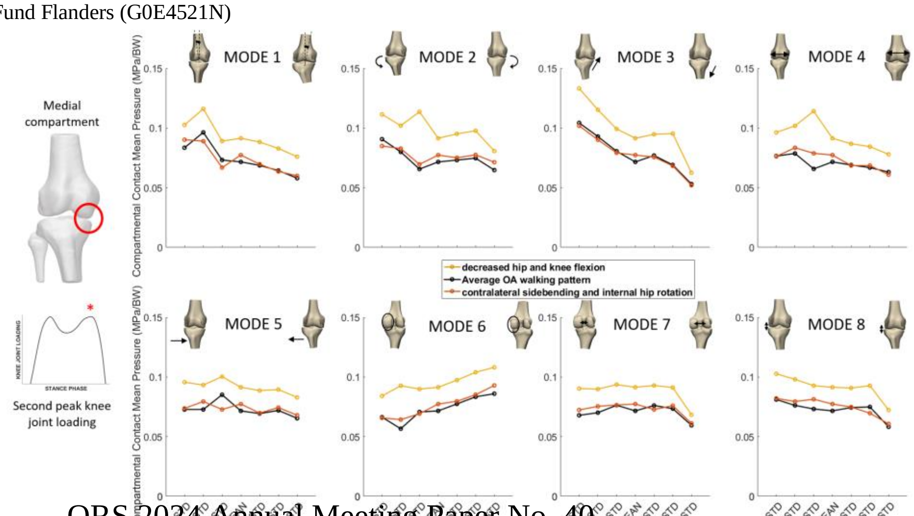


Fig. 1:
*Medial compartment mean contact pressure (MPa/BW) during the second peak of knee joint loading for first 8 modes of SSM (MEAN +/- 1,2,3 STD) and 2 walking patterns (component 1 (yellow) and 5 (orange)).*