Medializing the Center of Pressure to Offload the Knee and Decelerate Osteoarthritis: Fact or Fiction

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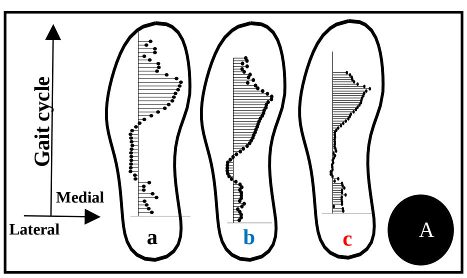
INTRODUCTION: Gait modification, a well-accepted non-surgical strategy for management of knee osteoarthritis, attempts to decelerate osteoarthritis progression by offloading the knee joint. To achieve this, modified gait patterns which reduce the knee adduction moment (KAM), a validated surrogate of load distribution across medial and lateral knee compartment, are frequently attempted. Medializing foot center of pressure (COP) is one example of gait modification which attempts to reduce KAM by altering the location of the COP under the foot during stance[1]. This gait strategy rapidly triggered technological investments to implement it, ranging from flexible shoes[2] to auditory feedback training[1]. However, recent evidence has found that although KAM is higher in patients with knee OA, KAM reduction does not necessarily guarantee a reduction in knee compressive loads and hence may not decelerate cartilage degeneration[3]. Consequently, medializing the COP may reduce KAM but whether it effectively reduce tissue stress at tibial cartilage warrants further research. Additionally, it is not clear whether the strong association between KAM and COP displacement, reported during a laboratory-based level walking, remain as such during various daily-life activities outside of the lab and within the community. Collectively, these factors cast doubt on the effectiveness of medializing COP to decelerate disease progression. Taking advantage of in-shoe pressure insoles, we aimed to investigate the association between COP and stress distribution within the proximal tibial cartilage for a variety of different daily-life activities within a community setting

METHODS: This prospective, observational study included 10 consenting patients with mild to moderate knee osteoarthritis. Participants wore standard running shoes while bilateral insoleswere replaced with pressure sensing insoles (OpenGO, Moticon GmbH; Munich, Germany). Each insole consisted of 13 capacitive sensors which measure the plantar pressure distribution during stance. Subjects were ask to conduct five different activity trials at their self-selected pace including (1) level-ground walking, (2) treadmill running, (3) stair ascending/descending and (4) ramp ascending/descending and (5) obstacle crossing. The insole was retrieved after a maximum of 4 hours (2.0±0.83 hours). COP was quantified in terms of its medial-lateral displacement relative to foot longitudinal line connecting the heel center to 2nd toe. Simultaneous with COP measurement, gait kinematics and kinetics were collected using an 8-camera motion capture system (Motion Analysis Corporation, Santa Rosa, CA) and force-plate (Bertec Corporation, Columbus, OH). Thirty-two reflective markers were placed bilaterally on the lower limbs using a modified Cleveland Clinic marker set and were tracked at 1000 Hz. Knee joint forces (axial, medial–lateral and anterior–posterior), moments (internal–external and flexion–extension, and abduction–adduction) and flexion-extension angle were then obtained from a multi-body dynamic analysis. Knee joint forces and sagittal movement were used as load and boundary conditions for finite element (FE) analysis of the knee joint. Geometry of one knee joint was captured from a volunteer individual (healthy, male, 45 years old, BMI=25 kg/m^2) using magnetic resonance imaging, which was then modified (GEOMAGIC software, Raindrop Inc., USA) to create a 3D model of knee joint in ABAQUS software (Dassault Systems Simulia Corp., Providence, USA). Deformable FE model, consisted of tibial and femoral bone and cartilages (Young's modulus = 10 MPa, Poisson's ratio = 0.45), menisci (Young's modulus = 59 MPa and Poisson's ratio=0.49) and ligaments were solved quasi-statically for a single stance. Femoral and tibial bones were modeled as rigid body for computational efficacy.

RESULTS: FE calculations of von Mises stress and contact area at medial (5.7-7.7 MPa, 310-370 mm^2) and lateral cartilage (2.6-4.9 MPa, 360-407 mm^2) were comparable with previous reports from cadaveric studies[4]. Figure 1 depicts translation of COP during stance, peaks of KAM and peaks of stress at medial and lateral tibial cartilage when COP is medialized across different walking trials. In general, medialization of COP seemed to increase from level walking to stair/ramp descending and obstacle crossing. On average, a 5 mm medial translation of COP toward foot longitudinal axis reduced 1st and 2nd peaks of KAM by 0.15 and 0.1 (%BW×Ht), a reduction of 12% ($p = 0.015$) and 8% ($p = 0.040$), respectively. Meanwhile, with a 5mm medial translation of COP, values of von Mises stress at the tibial cartilage increased by 8% during treadmill walking, and by 11.5% during stair/ramp descending and 12.5% during obstacle crossing. By contrast, the lateral tibial cartilage experienced corresponding reductions in peak stress by approximately 3.8%, 4.6% and 6.9%. Sub group analysis of participants showed that individuals, who medialized their COP by mainly rotating their tibial internally, experienced even higher increase in stress at their medical cartilage (9% at treadmill walking, and by 12.3% during stair/ramp descending and 13.7% during obstacle crossing). Linear regression analysis between the medial-lateral displacement of COP and peak stress values across all activity trials from all subjects demonstrate a weak-to-moderate relationship to peaks of KAM (R^2=0.25) and peaks of von Mises stress (R^2=0.12).

DISCUSSION: This study aimed to investigate the efficacy of medialized center-of-pressure to reduce load and decelerate osteoarthritis progression. Our study found a moderate correlation between COP and peaks of knee adduction moment accompanied with a weak association between COP and peaks of stress at medial and lateral cartilage. Noteworthy, medializing the COP during stance may reduce peaks of knee adduction moment but may adversely reduce contact area and hence increase contact pressure and stress on cartilage. Notable contributions of this study, compared to the existing literature include: (1) investigation of tissue-level efficacy of a newly proposed gait strategy; (2) extending the scope of investigation to daily-life activities other than walking (stair, ramp, obstacle) and (3) exploring the real-time correlation between COP displacement and changes in knee loading outside of laboratory.

SIGNIFICANCE/CLINICAL RELEVANCE: Tissue-level investigation is needed to confirm the efficacy of gait modification strategies. Tissue stress, rather than knee adduction moment, may provide a more reliable golden standard to design gait strategy.



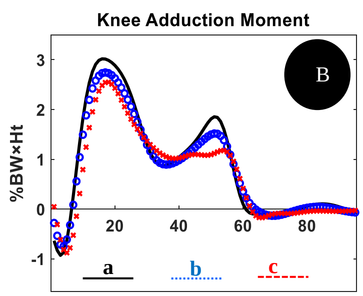
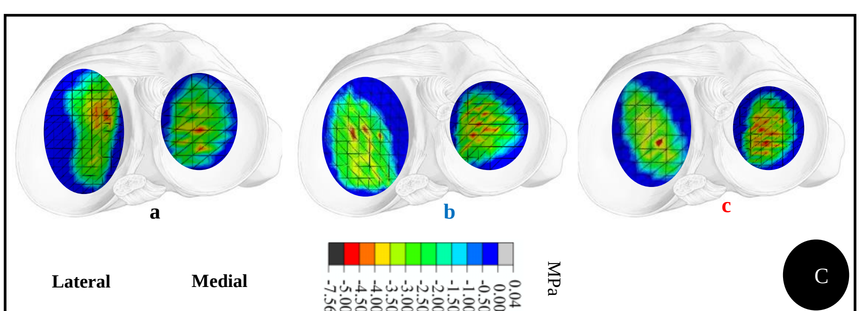


Figure 1. Comparison of COP movement (A), knee adduction moment (B) and peaks of von Mises stress at tibial cartilage (C) for a selected participant. As COP is more medialized from (a) to (c), , the peaks of knee adduction moment are decreased. Peaks of von-Mises stress however increased and decreased respectively on the medial and lateral cartilage.



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