Research Article

Association of Flat Feet with Knee Moments and Western Ontario and McMaster Universities Arthritis Index in Knee Osteoarthritis

Maryam Sohrabi[1], Giti Torkaman[1*], Fariba Bahrami[2]

1. Department of Physical Therapy, Faculty of Medical Sciences, Tarbiat Modares University, Tehran, Iran.
2. Human Motor Control and Computational Neuroscience Lab, School of Electrical and Computer Engineering, College of Engineering, University of Tehran, Tehran, Iran.

Use your device to scan and read the article online

Citation Sohrabi M, Torkaman G, Bahrami F. Association of Flat Feet with Knee Moments and Western Ontario and McMaster Universities Arthritis Index in Knee Osteoarthritis. Journal of Modern Rehabilitation. 2024; 18(4):461-470. http://dx.doi.org/10.18502/jmr.v18i4.16915

doi http://dx.doi.org/10.18502/jmr.v18i4.16915

Article info:
Received: 19 Nov 2023
Accepted: 17 Jan 2024
Available Online: 01 Oct 2024

ABSTRACT

Introduction: Flat feet are prevalent among individuals with medial compartment knee osteoarthritis (KOA), showing a correlation with elevated knee pain and cartilage degeneration. This study investigates the relationship between calcaneal eversion angle (CEA) and medial longitudinal arch angle (MLAA) with knee kinetics and pain.

Materials and Methods: This analytical observational study included 30 volunteers with moderate KOA. The Vicon motion analysis system and two synchronized force plates were employed to capture level walking and the static standing position to measure CEA and MLAA. The study assessed the first and second peaks of the knee adduction moment, knee adduction moment impulse, peak knee flexion moment, and the peak knee flexion angle at heel strike (PKFA-HS). The Western Ontario and McMaster Universities arthritis index (WOMAC) pain and physical function were evaluated.

Results: A significant positive correlation was found between CEA and the knee pain sub-score (Pearson correlation [PC]=0.446, P=0.011) and WOMAC total score (PC=0.363, P=0.049). Additionally, a significant negative correlation was observed between CEA and peak knee flexion moment/PKFA-HS (PC=-0.418, P=0.022, and PC=-0.479, P=0.001, respectively). The results also indicated a negative significant correlation between MLAA and WOMAC pain sub-score (PC=-0.389, P=0.034).

Conclusion: Increased CEA and decreased MLAA are associated with elevated WOMAC pain sub-score and decreased PKFA-HS in individuals with moderate KOA. Addressing flat feet should be considered in KOA management to enhance pain relief and functional outcomes.

Keywords:

Knee joint; Osteoarthritis; Flat feet; Pain

*** Corresponding Author:**
Giti Torkaman, Professor.
Address: *Department of Physical Therapy, Faculty of Medical Sciences, Tarbiat Modares University, Tehran, Iran.*
Tel: *+98 (21) 82884509*
E-mail: *torkamg@modares.ac.ir*

Introduction

Knee osteoarthritis (KOA) stands as the most prevalent type of arthritis, emerging as a leading cause of knee pain and disability [1]. This condition significantly impacts the quality of life, affecting daily activities, and leading to increased pain, diminished muscle mass, proprioception deficits, and altered gait mechanics [2]. While studies have traditionally concentrated on local knee alignment [3, 4], recent attention underscores the crucial role of foot status in KOA [5-7]. Biomechanically linked within a closed kinetic chain during walking, the foot, and the knee's interplay influences knee loading, subsequently impacting knee kinetics and kinematics [8-10]. Notably, individuals with KOA often exhibit a more pronated foot type compared to age-matched controls [7, 11, 12]. Recent investigations have linked flat feet in KOA individuals with heightened pain and disability [13-15]. Gross et al. highlighted the association of flat feet with increased knee pain and medial cartilage damage in the elderly [15], while Guler et al. demonstrated that coexisting foot deformities, including flat feet, escalate disability levels in women with KOA [14]. Recognizing the biomechanical changes linked to increased pain in KOA individuals with flat feet is pivotal for designing effective treatment plans. The knee adduction moment (KAM) and angular impulse (KAAI) are robust predictors of KOA presence [16], severity [5, 17, 18], and progression rate [19]. Medial compartment KOA individuals typically exhibit higher peak knee adduction moments (PKAMs). KAAI, assessing loading throughout the stance phase, surpasses PKAM in sensitivity for estimating knee load [20]. Recent findings associate the peak knee flexion moment (PKFM) with tibial cartilage changes in medial compartment KOA individuals, with a higher baseline PKFM correlating to greater cartilage thickness loss [21]. PKFM is also sensitive to pain, reducing in individuals experiencing pain [6]; therefore, evaluating these factors in KOA individuals with flat feet is crucial for treatment planning. Limited studies exist, with biomechanical knee changes noted in healthy subjects with flat feet [22, 23]. However, in KOA individuals, only KAM-related parameters have been explored [24]. No studies have compared pain levels and biomechanical parameters in symptomatic KOA individuals with and without flat feet, potentially revealing compensatory strategies. Kimberly Byrnes found that children with flat feet exhibit less KAM than those with normal feet, with no significant relationship between flat foot components and KAM [23]. Hirotaka reported bilateral, but not unilateral, flat feet significantly associated with worse knee pain after adjustments for possible confounders [13]. As changes in foot position in healthy individuals post-fatigue impact knee moments [25, 26], the relationship between flat feet and KAM and PKFM should be concurrently explored in KOA individuals. Precise equipment is required for moment assessment, typically unavailable in clinics. However, the McMaster University Osteoarthritis Index (WOMAC), a disease-specific tool, proves practical for assessing physical function, pain, and stiffness in KOA individuals. In this study, we also investigate the impact of flat feet on WOMAC scores. Two components are measured to determine flat feet, including calcaneal eversion angle (CEA) and medial longitudinal arch angle (MLAA). Understanding these relationships aids in developing prevention and treatment strategies by correcting structural foot deformities. Accordingly, this study explores the relationship between flat foot subcomponents (CEA and MLAA) and knee kinetics, kinematics (first peak of KAM, P1KAM, second peak of KAM [P2KAM], KAAI, PKFM, peak knee flexion angle in heel strike [PKFA-HS]), and WOMAC scores in KOA individuals. The primary hypothesis posits that higher CEA and lower MLAA correlate with PKAMs, KAAI, PKFM KFAI, and PKFA-HS in KOA individuals, aligning with the observed association of flat feet with increased pain and knee cartilage damage. The secondary hypothesis suggests an association between increased pain sub-score and the total score of WOMAC with elevated CEA and reduced MLAA. The study's findings may significantly contribute to the development of effective treatment plans for modifying flat foot subcomponents in KOA individuals.

Materials and Methods

This analytical observational study was conducted in the laboratory of the Physical Therapy Department at Tarbiat Modares University.

Study participants

A total of 62 volunteers with moderate KOA were recruited through community advertisements from November 1, 2019, to February 29, 2020. Sample size calculation, based on the peak (KAMs) from Heiden et al. [2] using G*Power software, version 3.1, indicated that a minimum of 22 participants were required for 80% power and α=0.05. To account for potential subject dropouts, a total of 30 participants were considered sufficient. The inclusion criteria comprised confirmation of grade 2 or 3 unilateral or bilateral KOA (with mild involvement on the opposite side) based on the Kellgren Lawrence scale

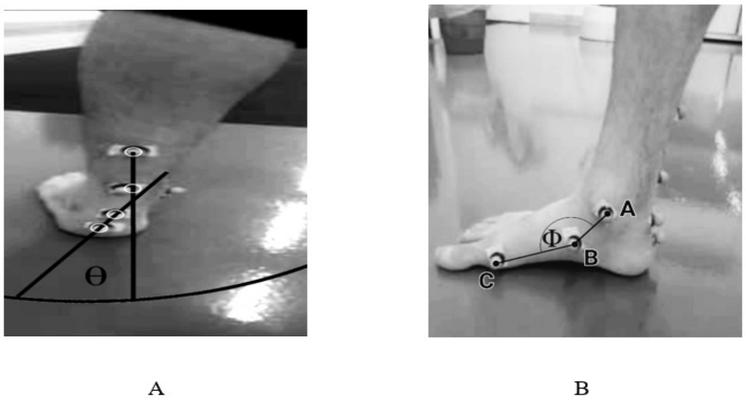

Figure 1. A) Calcaneal eversion angle, B) Medial longitudinal arch angle

JMR

via standard anterior/posterior knee joint X-ray, age between 45 and 65, body mass index between 25 and 30 (kg/m²), and the ability to walk on an even surface without aids. Meanwhile, the exclusion criteria included a history of intra-articular injection within the past six months, participation in a strengthening program within the past three months, a history of neurological, vestibular, visual, or musculoskeletal diseases, lower limb joint damage affecting balance, osteoporosis, and any abnormality in the lower limb alignment (screened individually). Foot status was assessed using a 3D motion capture system, measuring the CEA and medial longitudinal arch angle (MLLA). Based on these measurements, 15 individuals with KOA and flat feet and 15 with KOA and normal feet were identified. Eligible participants were fully informed about the study's method and objectives, and they signed a consent form.

Study procedure

For the assessment of MLAA and CEA during level walking, a 3D Vicon motion capture system (Vicon, Oxford, UK) equipped with eight cameras (Vero, 2.2 MP, UK) was utilized. The motion capture system was synchronized with two force plates (9286B; Kistler Co., Winterthur, Switzerland). To accurately capture level-walking and determine MLAA and CEA, sixteen retro-reflective markers based on the standard Plug-In-Gait lower body setup were employed, supplemented by six additional markers.

Evaluation of the foot posture

CEA, representing the frontal plane component of subtalar joint pronation, is commonly employed as an indicator of pronation [27-29]. We adopted a validated method to assess MLAA and CEA for the determination of flat feet [30]. CEA, defined as the acute angle between the distal midline of the leg and the midline of the calcaneus (Figure 1A), was calculated. MLAA was determined as the angle between a line connecting the most medial aspect of the medial malleolus and the navicular tubercle, and a line connecting the most medial aspect of the navicular tubercle and the first metatarsal head (Figure 1B). Six additional markers were strategically placed to aid in the calculation of MLAA and CEA (Figure 1A and 1B).

To measure MLAA, three markers were positioned on the medial malleolus, navicular landmark, and the innermost center point of the first metatarsophalangeal joint. Four markers were placed in the midline direction of the calcaneus bone and the midline direction of the distal leg for CEA [28, 31, 32]. For CEA determination, the subject assumed a prone position and retro-reflective markers were centered on each of the four bisection points of the bilateral distal legs [31].

MLAA was calculated using three retro-reflective markers on the medial aspect of the medial malleolus, the navicular tubercle, and the first metatarsal head. The angles were computed by capturing a 20-s static standing position at a frequency of 120 Hz. A foot was classified as flat if CEA was equal to or greater than 12°, and MLAA was less than 131° [32]. If CEA was between 3° and 12°, and MLAA was between 131° and 150°, it was categorized as a normal foot posture [32].

Level-walking motion capture

For the level-walking assessment, motion capture was executed employing the 3D Vicon motion capture system synchronized with two force plates. The cameras had a sampling frequency of 120 Hz, while the force plates operated at a frequency of 1200 Hz. The standard Plug-In-Gait lower body markers were strategically

Figure 2. Marker setting on lower limbs according to plug-in gait model [33]

JMR

placed bilaterally on the second metatarsal head, calcanei, malleoli, tibia, femur, femoral epicondyle, and anterior and posterior superior iliac spines (Figure 2) [33].

Before the walking trials, a static calibration trial was conducted to ensure accurate motion capture. The participants then walked barefoot at a self-selected comfortable pace on a 5.3-m walkway. To maintain data quality, three successful walking trials were recorded for each participant. A trial was deemed acceptable if each foot landed on the center of a force plate, and each marker was consistently visible to at least three cameras throughout the entire walking trial.

The participants walked barefoot at their preferred speed, and three gait trials capturing successful heel strike to toe-off on the force platforms were saved for analysis. The initial processing of all kinetic and kinematic data, preceding feature extraction, was performed using Nexus software, version 6.2.1.

The assessment of pain, stiffness, and physical function was carried out using the validated Persian version of the WOMAC questionnaire, administered as a self-assessment [34]. This questionnaire comprises 24 questions categorized into three domains as follows: Pain (5 questions), stiffness (2 questions), and physical function (17 questions). Higher scores indicate a higher intensity of the related symptom.

Data processing

Motion and force data underwent low-pass filtering using a Butterworth filter (fourth order, cut-off frequency 5 Hz) through a custom script developed in MATLABTM R2018B (the MathWorks Inc, Natick, MA). The KAM and KFM were computed as the ground reaction force moment about the knee joint center.

The KAM was reported in the tibial reference frame, with the mediolateral (y) axis parallel to the knee rotation axis. The first and second peaks of KAM (P1KAM and P2KAM) were identified as the maximum moment during 0%–50% (early stance) and 51%–100% (late stance) of the stance phase, respectively. The PKFM was reported with the anterior-posterior (X) axis in the tibial reference frame. The peak time of the first and second KAM and KFM was determined as a percentage of the stance phase.

The PKAMs, KAAI, as the integral time of frontal knee moment), and PKFM were normalized to body weight. Additionally, the PKFA-HS during the stance phase was measured.

Statistical analysis

Statistical analyses were conducted using SPSS software, version 22.0, with a significance level set at less than 0.05. The Pearson correlation coefficient was employed to explore potential relationships among the variables, including P1KAM, P2KAM, KAAI, PKFM, PKFA-HS, and WOMAC score, with CEA and MLAA. The correlation coefficients (PC) between 0.10 and 0.39 were considered weak, 0.40 to 0.69 as moderate, 0.70 to 0.89 as strong, and greater than 0.90 to 1.00 as very strong [11].

Table 1. Participant characteristics in the groups

Characteristics	Mean±SD		P
	OANF (n=15)	OAFF (n=15)	
Age (y)	54.93±4.76	54.20±5.60)	0.805
Sex (Female/Male), No.	9/6	9/6	1.000
Height (m)	1.65±8.59	1.62±7.20	0.612
Weight (kg)	76.93±10.13	79.40±11.05	0.911
Body mass index (kg/m²)	27.25±2.41	28.25±2.17	0.167
Walking speed (m/s)	0.70±0.17	0.71±0.11	0.123
CEA	4.79±1.80	14.17±2.03 [a]	<0.001
MLAA	140.83±3.71	127.22±3.29 [b]	<0.054
WOMAC (total score)	39.20±5.38	42.07±6.33	0.030
Pain sub-score	7.66±2.16	10.86±3.07	0.030

JMR

Abbreviations: CEA: Calcaneal eversion angle; MLAA: Medial longitudinal arch angle; OANF: Osteoarthritis, and normal feet; OAFF: Osteoarthritis, and flat feet.

Notes: [a] shows significantly higher than OANF and [b] shows significantly lower than OANF.

Results

Anthropometric characteristics for all 30 subjects based on foot condition are summarized in Table 1. The analysis revealed no statistically significant differences between the groups concerning height (P=0.612), weight (P=0.911), body mass index (P=0.167), and age (P=0.805).

The CEA in the group with osteoarthritis and flat feet (OAFF) was significantly higher than in the group with osteoarthritis and normal feet (OANF) (P<0.001). Additionally, in the OAFF group, the MLAA was significantly lower compared to the OANF group (P<0.054). Furthermore, the OAFF group exhibited a significantly higher pain sub-score and total WOMAC score compared to the OANF group (P=0.030).

There was a moderate and statistically significant correlation between the CEA and WOMAC pain sub-score (PC=0.446, P=0.01), accompanied by a weak positive correlation with WOMAC total score (PC=0.363, P=0.04). Additionally, a significant negative correlation was identified between CEA and PKFM as well as PKFA-HS (PC=-0.418, P=0.02 and PC=-0.479, P=0.001, respectively) (Figure 3). No significant correlation was observed in the other parameters (Table 2).

A significant correlation was observed between MLAA and WOMAC pain sub-score (PC=-0.389, P=0.034)

Table 2. Correlation coefficient between CEA, MLLA, and knee parameters

Variables	KOA (n=30)						
	P1KAM	P2KAM	KAAI	PKFM	PKFA-HS	WOMAC Total Score	Pain Sub-Score
CEA	PC=0.13 P=0.941	PC=0.126 P=0.506	PC=0.172 P=0.364	PC=-0.418 P=0.022	PC=-0.479 P=0.001	PC=0.363 P=0.049	PC=0.446 P=0.011
MLAA	PC=-0.185 P=0.327	PC=0.257 P=0.171	PC=-0.67 P=0.726	PC=0.294 P=0.115	PC=0.171 P=0.076	PC=-0.162 P=0.129	PC=-0.389 P=0.034

Abbreviations: CEA: Calcaneal eversion angle; MLLA: Medial longitudinal arch angle; PC: Pearson correlation.

JMR

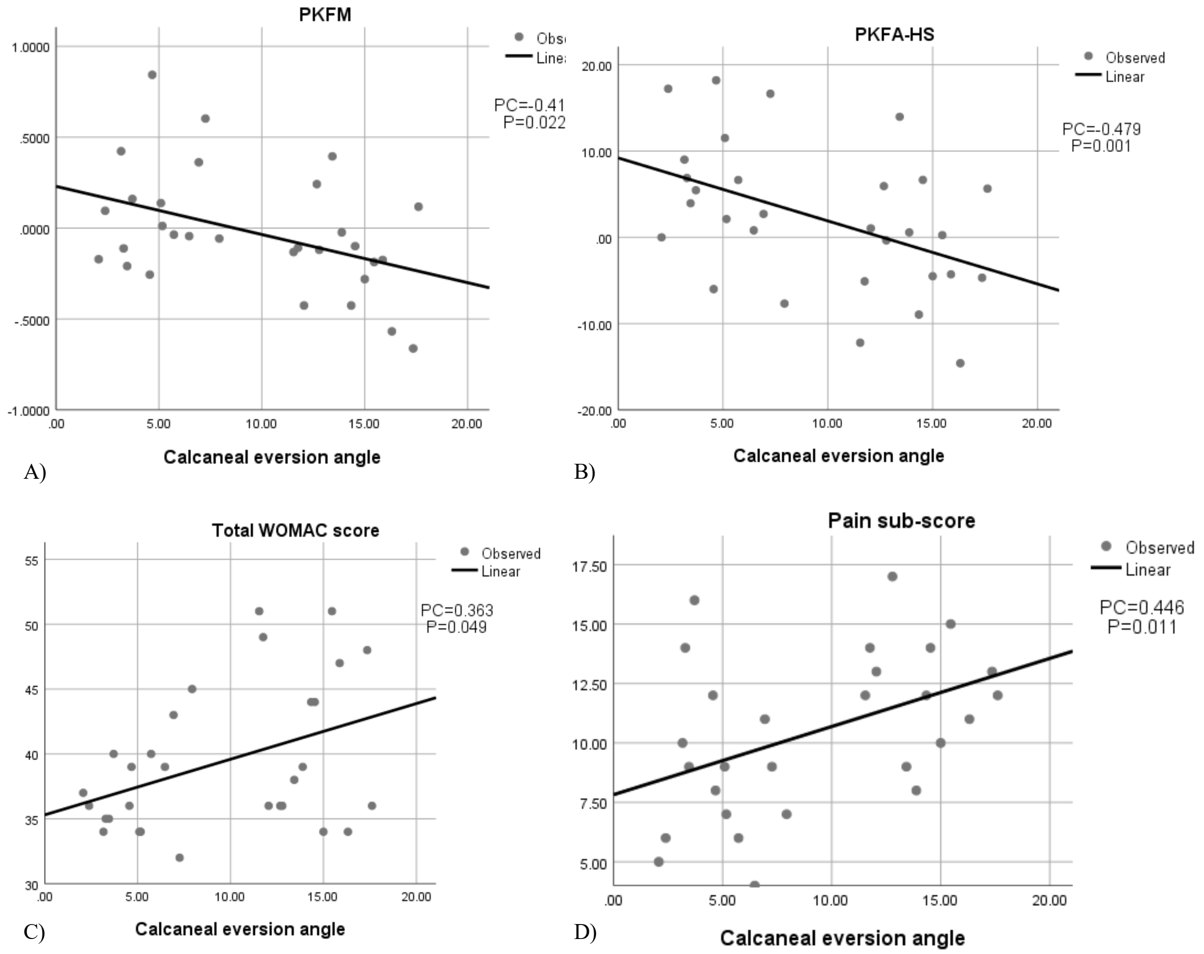

Figure 3. Correlation between calcaneal eversion angle and A) PKFM, B) PKFA-HS, C) Total WOMAC score, D) Pain sub-score

Abbreviations: PKFM: Peak knee flexion moment; PKFA-HS: Peak knee flexion angle at heel strike; WOMAC: Western Ontario and McMaster Universities arthritis index.

(Figure 4). However, no significant correlation was identified between MLAA and the knee moments (Table 2).

Discussion

This study investigated the relationship between the flat feet subcomponents, including CEA and MLLA, with the knee kinetic, kinematic, and pain sub-score and total score of WOMAC in people with moderate KOA. Symptomatic KOA has been identified as the most potent contributor to walking difficulty [35]. KOA is a crucial feature of aborted biomechanics [4, 35]. However, the foot plays an even more immediate role in absorbing the mechanical stresses of ground contact and modifying the postural alignment and mobility at the knee joint and throughout the lower extremity [36]. Little is known about the consequences of abnormal foot morphology (flat foot) for the knee biomechanics and symptoms. The available evidence suggests the existence of biomechanical links between the foot and tibia [8, 9], so alterations in foot posture in a pronated direction in people with KOA may result from a compensatory response to the knee. The current study revealed that the increase in the CEA and decrease in the MLLA were significantly associated with worse OA-related knee pain. Regression analysis showed similar relationships of CEA with total WOMAC score, thereby indicating a robust adverse effect of flat feet on the knee. These results are consistent with Hirotaka and Hiroshi [13] and Gross et al. [15], which showed that a flat foot is associated with increased pain and disability. In terms of the association between the knee kinetics, kinematics, and subcomponents of the flat feet, contrary to our hypothesis, no significant associations were found between CEA/MLAA PKAMs and KAAI. However, there were significant associations between the CEA with the PKFA-HS. Our study's lack of correlation between the KAM and the CEA/MLAA can refute the hypothesis that flatfeet in these people

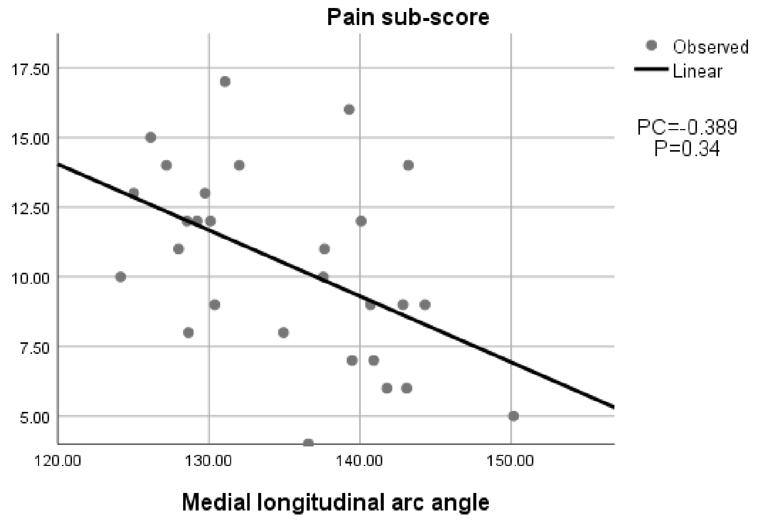

Figure 4. Correlation between medial longitudinal arch angle and pain sub-score

JMR

is a compensatory response because studies assumed increasing the CEA may be a strategy to reduce the lever arm of KAM and reduce pain. Our finding was also contrary to Levinger et al, which showed that increased rearfoot eversion in people with KOA is associated with reduced KAM during the stance phase of gait [24]. Still, the severity of pain in both groups was mild pain, and more importantly, people with KOA in Levinger's study had variable degrees of malalignment of knee varus. In contrast, in this study, similar to Hirotaka and Hiroshi's study, KOA people without visible varus were allocated to the study [13]. Also, Kimberly et al. did not show a significant association between the KAM and CEA in children with idiopathic flat feet; they stated this angle has low sensitivity to the KAM [23]. The correlations of PKFM and PKFA-HS with CEA were negative. Accordingly, pain may play an important role in creating these relationships because the previous studies showed that the KFM is sensitive to pain, and painful knee people have a reduced peak KFM [6]. In terms of the MLAA and the kinetic/kinematic and WOMAC scores, a significant negative correlation was found between the MLAA and pain WOMAC sub-score. There was no significant relationship found between this angle and KAM peaks, contrary to Kimberly et al. in children with idiopathic flat feet [23]. They suggested medial longitudinal arch height contributes to a lower KAM in healthy children during walking. Consistent with our results, Abourazzak et al. showed no significant relationship between navicular height and the prevalence of KOA [37]. Our findings do not necessarily specify the relationship between foot posture and KOA. The causal relationship between flat-foot posture and OA-related knee pain and cartilage damage is yet to be established. However, few studies have shown this association [38]. Investigating a causal relationship between flat feet and knee biomechanics and pain is necessary to clarify the potential adverse effects of flat feet. Furthermore, longitudinal studies are needed to determine whether the flat foot primarily causes biomechanical changes, pain, and cartilage damage in the knee or a compensatory response to biomechanical changes and pain in the knee. It is needed to follow children with flatfeet in the long term. Despite these limitations, our findings suggest that the assessment of foot alignment should aid in the identification of individuals who may deteriorate their knee symptoms or load-to-foot abnormalities. Thus, our results show CEA and MLAA as two flat foot components associated with the pain WOMAC sub-score, but only CEA had a significant correlation with the PKFA-HS and PKFM. Our results can be clinically significant because they show a high impact of CEA to increase pain and reduce knee joint physical function (based on pain sub-score and total score of WOMAC), so it may be advisable to consider people with KOA. Considering that flat feet can negatively impact postural balance and performance [39], without considering the flat feet status, physical therapists should not try to modify the gait pattern of people with KOA because some compensatory patterns were provided to reduce KFM and improve knee pain while walking. We suggest future studies compare KOA severity (based on the Kellgren Lawrence scale and degree of painfulness) with CEA and MLAA to determine the correlation between the flat foot and knee biomechanics. Determining the relationship between the flat foot and knee KAM/KFM, which represents the contact force of the joint, can be crucial in providing treatment methods and prescribing orthoses to reduce pain and improve the quality of life in people with KOA.

Conclusion

This study found no significant association between CEA/MLAA and the KAM. Still, there was a significant association between the CEA with the PKFA-HS and PKFM. In people with KOA, there was a significant positive correlation between pain WOMAC sub-score/total score and CEA; also, a significant negative correlation between pain WOMAC sub-score and MLAA. These results can be clinically important because they show a more potent effect of CEA on increasing pain and reducing knee joint physical function and PKFM/PKFA-HS. It is advisable to consider feet status in the people with KOA It is recommended to consider the position of the feet in people with KOA because subsequent changes in the length and strength of the muscles and disturbances in static and dynamic balance can cause increased pain and more functional impairment in people with KOA.

Study limitations

The important limitation of this study is the small sample size. In addition, our assessments were performed only on the simple level of walking, while the effect of flat feet on complex functional tasks and after fatigue may have a more significant impact on the kinetics and kinematics of the knee. Thus, there is a need for further, longitudinal, prospective studies using kinematics/kinematics analyses in larger samples to support the causality between flat feet components and KOA. Considering foot position in KOA people is crucial due to potential muscle length, strength changes, and balance disturbances, leading to heightened pain and functional impairment.

Ethical Considerations

Compliance with ethical guidelines

The study received approval from the local Institutional Research Ethics Committee of Tarbiat Modares University (IR.MODARES.REC. 1397.217).

Funding

This research did not receive any grant from funding agencies in the public, commercial, or non-profit sectors.

Authors' contributions

The authors contributed equally to preparing this article.

Conflict of interest

The authors declared no conflict of interest.

Acknowledgments

We are grateful for the support of the Faculty of Medical Sciences of Tarbiat Modares University.

References

[1] Favre J, Jolles B. Gait analysis of patients with knee osteoarthritis highlights a pathological mechanical pathway and provides a basis for therapeutic interventions. EFORT Open Review. 2016; 1(10):368-74. [DOI:10.1302/2058-5241.1.000051]

[2] Heiden TL, Lloyd DG, Ackland TR. Knee joint kinematics, kinetics and muscle co-contraction in knee osteoarthritis patient gait. Clinical Biomechanics. 2009; 24(10):833-41. [DOI:10.1016/j.clinbiomech.2009.08.005]

[3] Sharma L. The role of varus and valgus alignment in knee osteoarthritis. Arthritis and Rheumatism. 2007; 56(4):1044-7. [DOI:10.1002/art.22514] [PMID]

[4] Felson DT, Niu J, Gross KD, Englund M, Sharma L, Cooke TD, et al. Valgus malalignment is a risk factor for lateral knee osteoarthritis incidence and progression: Findings from the multicenter osteoarthritis study and the osteoarthritis initiative. Arthritis & Rheumatism. 2013; 65(2):355-62. [DOI:10.1002/art.37726]

[5] Mundermann A, Dyrby CO, Andriacchi TP. Secondary gait changes in patients with medial compartment knee osteoarthritis: Increased load at the ankle, knee, and hip during walking. Arthritis & Rheumatology. 2005; 52(9):2835-44. [DOI:10.1002/art.21262]

[6] Sharma L, Hurwitz DE, Thonar EJ, Sum JA, Lenz M. Knee adduction moment, serum hyaluronan level, and disease severity in medial tibiofemoral osteoarthritis. Arthritis & Rheumatology. 2002; 41(7):1233-40. [DOI:10.1002/1529-0131(199807)41:7<1233::AID-ART14>3.0.CO;2-L]

[7] Reilly K, Barker K, Shamley D, Newman M, Oskrochi GR, Sandall S. The role of foot and ankle assessment of patients with lower limb osteoarthritis. Physiotherapy. 2009; 95(3):164-69. [DOI:10.1016/j.physio.2009.04.003]

[8] Souza TR, Pinto RZ, Trede RG, Kirkwood RN, Fonseca ST. Temporal couplings between rearfoot-shank complex and hip joint during walking. Clinical Biomechanics. 2010; 25(7):745-8. [DOI:10.1016/j.clinbiomech.2010.04.012]

[9] Lafortune MA, Cavanagh PR, Sommer HJ 3rd, Kalenak A. Foot inversion-eversion and knee kinematics during walking. Journal of Orthopaedic Research. 1994; 12(3):412-20. [DOI:10.1002/jor.1100120314]

[10] Schwachmeyer V, Kutzner I, Bornschein J, Bender A, Bornschein J, et al. Medial and lateral foot loading and its effect on knee joint loading. Clinical Biomechanics. 2015; 30:860-6. [DOI:10.1016/j.clinbiomech.2015.06.002]

[11] Levinger P, Menz HB, Fotoohabadi MR, Feller JA, Bartlett JR, Bergman NR. Foot posture in people with medial compartment knee osteoarthritis. Journal of Foot and Ankle Research. 2010; 3(1):1-8. [DOI:10.1186/1757-1146-3-29]

[12] Reilly KA, Barker KL, Shamley D, Sandall S. Influence of foot characteristics on the site of lower limb osteoarthritis. Foot & Ankle International. 2006; 27(3):206-11.[DOI:10.1177/107110070602700310]

[13] Iijima H, Ohi H, Isho T, Aoyama T, Fukutani N, Kaneda E, et al. Association of bilateral flat feet with knee pain and disability in patients with knee osteoarthritis: A cross-sectional study. Journal of Orthopaedic Research. 2017; 35(11):2490-8. [DOI:10.1002/jor.23565]

[14] Guler H, Karazincir S, Turhanoglu AD, Sahin G, Balci A, Ozer C. Effect of coexisting foot deformity on disability in women with knee osteoarthritis. Journal of the American Podiatric Medical Association. 2009; 99(1):23-7. [DOI:10.7547/0980023]

[15] Gross KD, Felson DT, Niu J, Hunter DJ, Guermazi A, Roemer FW, et al. Association of flat feet with knee pain and cartilage damage in older adults. Arthritis Care & Research. 2011; 63(7):937-44. [DOI:10.1002/acr.20431] [PMID]

[16] Baliunas AJ, Hurwitz DE, Ryals AB, Karrar A, Case JP, Block JA, et al. Increased knee joint loads during walking are present in subjects with knee osteoarthritis. Osteoarthritis and Cartilage. 2002; 10:573-9. [DOI:10.1053/joca.2002.0797]

[17] Henriksen M, Tomas G, Aaboe J, Andriacchi TP, Bliddal H. Gait changes in patients with knee osteoarthritis are replicated by experimental knee pain. Arthritis Care & Research. 2010; 62(4):501-9. [DOI:10.1002/acr.20033]

[18] Mundermann A, Dyrby CO, Hurwitz DE, Sharma L, Andriacchi TP. Potential strategies to reduce medial compartment loading in patients with knee osteoarthritis of varying severity: Reduced walking speed. Arthritis and Rheumatism. 2004; 50(4):1172-8. [DOI:10.1002/art.20132]

[19] Henriksen M, Aaboe J, Bliddal H. Relationship between pain and dynamic knee joint loading in knee osteoarthritis varies with radiographic disease severity. A cross sectional study. The Knee. 2012; 19(4):392-8. [DOI:10.1016/j.knee.2011.07.003]

[20] Kean CO, Hinman RS, Bowles KA , Cicuttini F, Davies-Tuck M, Bennell KL. Comparison of peak knee adduction moment and knee adduction moment impulse in distinguishing between severities of knee osteoarthritis. Clinical Biomechanics. 2012; 27(5):520-3. [DOI:10.1016/j.clinbiomech.2011.12.007]

[21] Favre J, Erhart-Hledik JC, Chehab EF, Andriacchi TP. Baseline ambulatory knee kinematics are associated with changes in cartilage thickness in osteoarthritic patients over 5 years. Journal of Biomechanics. 2016; 49(9):1859-64. [DOI:10.1016/j.jbiomech.2016.04.029]

[22] Buldt AK, Levinger P, Murley GS, Menz HB, Nester CJ, Landorf KB. Foot posture and function have only minor effects on knee function during barefoot walking in healthy individuals. Clinical Biomechanics. 2015; 30(5):431-7. [DOI:10.1016/j.clinbiomech.2015.03.014]

[23] Byrnes SK, Wearing S, Böhm H, Dussa CU, Horstmann T. Effects of idiopathic flatfoot deformity on knee adduction moments during walking. Gait & Posture. 2021; 84:280-6. [DOI:10.1016/j.gaitpost.2020.12.021]

[24] Levinger P, Menz HB, Morrow AD, Bartlett JR, Feller JA, Bergman NR. Relationship between foot function and medial knee joint loading in people with medial compartment knee osteoarthritis. Journal of Foot and Ankle Research. 2013; 6(1):33. [DOI:10.1186/1757-1146-6-33]

[25] Qichang M, Yaodong G, Liangliang X, Julien SB, Justin F. Foot Pronation contributes to altered lower extremity loading after long distance running. Exercise Physiology. 2019; 10:573. [DOI:10.3389/fphys.2019.00573]

[26] Farahpour N, Sharifmoradi K, Azizi S. Effect of fatigue on knee kinematics and kinetics during walking in individuals with flat feet. Physical Therapy & Rehabilitation Journal. 2017; 7(3):141-8. [Link]

[27] Hughes LY. Biomechanical analysis of the foot and ankle for predisposition to developing stress fractures. Physical Therapy in Sport. 1985; 7(3):96-101. [DOI:10.2519/jospt.1985.7.3.96]

[28] Novick A, Kelly DL. Position and movement changes of the foot with orthotic intervention during the loading response of gait. Journal of Orthopaedic & Sports Physical Therapy. 1990; 11(7):301-12. [DOI:10.2519/jospt.1990.11.7.301]

[29] Rodgers M, Leveau BF. Effectiveness of foot orthotic devices used to modify pronation in runners. Journal of Orthopaedic & Sports Physical Therapy. 1982; 4(2):86-90. [DOI:10.2519/jospt.1982.4.2.86]

[30] Jonson SR, Gross MT. Intraexaminer reliability, interexaminer reliability, and mean values for nine lower extremity skeletal measures in healthy naval midshipmen. Journal of Orthopaedic & Sports Physical Therapy. 1997; 25(4):253-63. [DOI:10.2519/jospt.1997.25.4.253]

[31] Genova JM, Gross MT. Effect of foot orthotics on calcaneal eversion during standing and treadmill walking for subjects with abnormal pronation. Journal of Orthopaedic & Sports Physical Therapy. 2000; 30(11):664-75. [DOI:10.2519/jospt.2000.30.11.664]

[32] McCulloch MU, Brunt D, Vander Linden D. The effect of foot orthotics and gait velocity on lower limb kinematics and temporal events of stance. Journal of Orthopaedic & Sports Physical Therapy. 1993; 17(1):2-10. [DOI:10.2519/jospt.1993.17.1.2]

[33] Hinman RS, Payne C, Metcalf BR, Wrigley TV, Bennell KL. Lateral wedges in knee osteoarthritis: What are their immediate clinical and biomechanical effects and can these predict a three-month clinical outcome? Arthritis Care & Research. 2008; 59(3):408-15. [DOI:10.1002/art.23326]

[34] Nadrian H, Moghimi N, Nadrian E, Moradzadeh R, Bahmanpour K, et al. Validity and reliability of the Persian versions of WOMAC osteoarthritis index and lequesne algofunctional index. Clinical Rheumatology. 2012; 31:1097-102. [DOI:10.1007/s10067-012-1983-7]

[35] King LK, Kendzerska T, Waugh EJ, Hawker GA. Impact of osteoarthritis on difficulty walking: A population-based study. Arthritis Care & Research. 2018; 70(1):71-9. [DOI:10.1002/acr.23250]

[36] Williams DSB, David IS, Hamill J, Buchanan TS. Lower extremity kinematic and kinetic differences in runners with high and low arches. Journal of Applied Biomechanics. 2001; 17(2):153-63. [DOI:10.1123/jab.17.2.153]

[37] Abourazzak FE, Kadi N, Azzouzi H, Lazrak F, Najdi A, Nejjari C. A positive association between foot posture index and medial compartment knee osteoarthritis in Moroccan people. The Open Rheumatology Journal. 2014; 8:96-9. [DOI:10.2174/1874312901408010096] [PMID]

[38] Nester CJ, Hutchins S, Bowker P. Shank rotation: A measure of rearfoot motion during normal walking. Foot & Ankle International. 2000; 21(7):578-83. [DOI:10.1177/107110070002100709]

[39] Sedaghati P, Kazemi Pakdel F, Zarei Z. Investigating the effects of high-arch and flat foot deformities on postural control: A systematic review and meta-analysis. Journal of Modern Rehabilitation. 2023; 17(4):363-74. [DOI:10.18502/jmr.v17i4.13884]