Research Article

The Relationship Between Knee Moments and Function with Western Ontario and McMaster Universities in Moderate Knee Osteoarthritis

Samaneh Gholami[1], Giti Torkaman[1*], Fariba Bahrami[2], Noushin Bayat[3]

1. Department of Physical Therapy, Faculty of Medical Sciences, Tarbiat Modares University, Tehran, Iran.
2. Human Motor Control and Computational Neuroscience laboratory, School of Electrical and Computer Engineering, University of Tehran, Tehran, Iran.
3. Department of Rheumatology, Exercise Physiology Research Center, Lifestyle Institute, Baqiyatallah University of Medical Sciences, Tehran, Iran.

Use your device to scan and read the article online

Citation: Gholami S, Torkaman G, Bahrami F, Bayat N. The Relationship Between Knee Moments and Function with Western Ontario and McMaster Universities in Moderate Knee Osteoarthritis. Journal of Modern Rehabilitation. 2023; 17(3):306-318. https://doi.org/10.18502/jmr.v17i3.13072

https://doi.org/10.18502/jmr.v17i3.13072

Article info:
Received: 25 Dec 2021
Accepted: 29 Jan 2022
Available Online: 01 Jul 2023

ABSTRACT

Introduction: The knee is the most affected weight-bearing joint by osteoarthritis. The kinetics parameters are correlated with the progression of knee osteoarthritis (KOA). This study was done to investigate the relationship between kinetics parameters and functional tests with Western Ontario and McMaster Universities osteoarthritis index (WOMAC) scores in people with moderate KOA.

Materials and Methods: Twenty- three participants with moderate KOA participated in this study. Gait analysis involved the measurement of the external peak knee adduction moment (PKAM), peak knee flexion moment (PKFM), knee adduction moment impulse (KAM impulse), and knee flexion moment impulse (KFM impulse) during level walking. Functional tests included timed up and go (TUG) and figure of eight walkings (FO8W) tests. Pearson's correlation coefficient was used to investigate the correlation between kinetics parameters and functional test scores with WOMAC total scores and sub-scores.

Results: There was a significant inverse correlation between the first PKAM and WOMAC total score and pain sub-score (r=-0.43 P=0.03 and r=-0.6 P=0.002, respectively). Also, there was a significant inverse correlation between the second PKAM and pain sub-score (r=-0.46 P=0.02). There was no significant correlation between functional tests and WOMAC scores.

Conclusion: The low score of the WOMAC in the moderate KOA should not be attributed to the low level of joint knee moments.

Keywords:

Knee osteoarthritis; Kinetics; Pain; Physical activity

*** 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*

1. Introduction

Knee osteoarthritis (KOA) is the most common form of arthritis [1]. In 2020, the prevalence of KOA in the world was 22.9%, and in Asia 19.2% [2]. The greater prevalence of this disease in the medial tibiofemoral joint is due to the greater force on the medial cartilage [3, 4] associated with greater knee adduction moment [4, 5]. Knee adduction moment (KAM) is a good predictor of medial-lateral load distribution [6] and is highly related to a knee contact force [7]. From the mechanical point of view, during functional activities, such as walking and climbing stairs, the knee joint's medial compartment bears greater force than the lateral compartment [8]. Greater peak knee adduction moment (PKAM) is related to the presence [9], severity [10], and progression of knee osteoarthritis [11], and pain [12]. Pain is the most common complaint in people with KOA [13]. Pain, stiffness, and difficulty in knee movement are the most common signs of KOA that reduce the patient's ability and quality of life [14]. Although less frequently used, the KAM impulse may be important because it indicates cumulative loading of the medial tibiofemoral joint during the stance phase of gait [15]. PKAM represents the force at one point in the stance phase and does not consider the total time that force applies to the knee joint, which can be influenced by gait speed [16]. KAM impulse takes into account both time and magnitude of force; thus, it provides more complete information about the detailed loading status [16] and is more sensitive compared to PKAM in the diagnosis of different severities of KOA based on Kellgren Lawrence (KL) grade or alignment [16]. The KL global rating system detects the severity of KOA based on the presence of osteophytes, joint space narrowing, and subchondral sclerosis and then grades the severity from 0 to 4 [17, 18]. Also, the increase in the knee flexion moment (KFM) has been suggested to significantly contribute to greater knee contact force despite the reduction in KAM [19, 20]. Higher peak knee flexion moment (PKFM) during gait has been previously demonstrated in people with KOA than OA-free individuals [21-23]. It has been reported that greater KFM is associated with faster progression of KOA [24]. Furthermore, the KFM impulse takes into account the area below the KFM-time curve, and it seems to be more related to KOA than KFM [25-27].

The Western Ontario and McMaster Universities osteoarthritis index (WOMAC) questionnaire is a patient-based subjective instrument that is the most commonly used clinical instrument for assessing people with KOA [28]. WOMAC questionnaire has been used to evaluate the effectiveness of surgical procedures [29, 30], therapeutic devices [31-33], biofeedback [34] and physical therapy [35] in a randomized control trial [36]. Various validation studies of the WOMAC questionnaire have made this a valuable instrument for assessing therapeutic methods [28]. Shull et al. reported that after a six-week gait retraining, the first PKAM significantly decreased immediately after training and 1-month follow-up, with improvement in WOMAC pain and WOMAC function sub-score at both time points [37]. Hunt et al. reported that after four months of gait retraining, the second PKAM decreased significantly in the intervention group and the first PKAM increased in the control group, but WOMAC pain and WOMAC function sub-score as a long-term effect improved in both groups [38]. Cheung et al. evaluated the effect of gait retraining on pain, function, and joint stiffness six weeks and six months after training in people with early KOA [39]. They showed an improvement in total WOMAC score, pain, and function sub-scores with a significant reduction in the first PKAM six weeks and six months after gait retraining [39]. Falahatgar et al. reported that PKAM did not change the following orthosis, but WOMAC pain and WOMAC function sub-score improved [40]. Erhart et al. stated that after using six months of variable stiffness shoes, no relationship was seen between the first PKAM and WOMAC pain and WOMAC function score [41]. Also, they showed a significant relationship between KAM impulse and WOMAC pain and function sub-scores [41]. It seems that there is a controversy about the direction of changes in PKAM and WOMAC questionnaire scores in different studies [42, 43].

Measuring adduction and flexion moments require a motion analysis system that is very expensive that is not available in all hospitals and health centers. Thus, if there is a significant relationship between adductor and flexor moment parameters with WOMAC score, it will be helpful to attribute the changes in knee joint loading to clinical assessment. It can be important to study this relationship in estimating the loading status and the effectiveness of empowerment methods in reducing knee joint loading. No study has examined the correlation between KFM impulse and WOMAC questionnaire score in people with moderate KOA.

As a functional test, timed up and go (TUG) and figure of eight walk (FO8W) tests have been used for the assessment of OA patients and appear to be useful and responsive outcome measures to guide clinical care and evaluate mobility difficulty [44-47]. The correlation between these functional tests and the WOMAC questionnaire is important because they are frequently used together or alone to evaluate and follow up with people with KOA in clinical practice [48-51]. Several studies have reported changes in TUG as a functional test and the score of the WOMAC questionnaire as a subjective test after training [48-50]. Recently, a significant and weak correlation has been demonstrated between the functional domain WOMAC and TUG in people with moderate to severe KOA [52].

Understanding the association between measures of knee joint moments as a surrogate for joint loading and clinical outcomes in people with KOA will help guide future research to optimize treatment and identify people with KOA most likely to gain clinical benefit with intervention. As far as we know, no study has ever examined the relationship between kinetics, functional objective, and subjective tests in a cross-sectional study in people with moderate KOA.

This study was done to evaluate the correlation between kinetics parameters (PKAM, KAM impulse, PKFM, and KFM impulse) during level walking and using functional tests and the WOMAC questionnaire in people with moderate KOA. We hypothesized that there would be a positive correlation between the first PKAM, second PKAM, and PKFM with WOMAC score. Another hypothesis was a positive correlation between the KAM impulse and KFM impulse with the WOMAC score. Finally, we hypothesized that there would be a positive correlation between functional test scores (TUG and FO8W) and WOMAC scores in people with moderate KOA.

2. Materials and Methods

Study design

This cross-sectional study was conducted at the motion analysis laboratory of the physical therapy department at Tarbiat Modares University, Tehran, Iran. The sample size was predicted based on Hall et al.'s research, according to the Mean±SD of the PKAM, with a 95% confidence interval and 80% of the power in subjects with KOA [53].

Participants

Twenty-three patients with moderate KOA were recruited through Tarbiat Modares University Health Center and the Rheumatology Department of Baqiyatallah University of Medical Sciences. Inclusion criteria were confirmation of grade 2 and 3 unilateral KOA based on the Kellgren Lawrence scale [54] by a rheumatologist via standard anterior/posterior knee X-ray, the age of 45-65 years, body mass index (BMI) of 25-35, and the ability to walk on an even surface without any aids.

Exclusion criteria were a history of intra-articular injection within the past six months, participation in strengthening or musculoskeletal exercise programs within the past three months, neurological, vestibular, and musculoskeletal diseases, lower limb joint damage, affecting balance, and osteoporosis. The study's aim and method were entirely explained to all eligible participants and then, they signed the consent form. All volunteer patients participated in all assessments and there was no drop-out.

Data collection

All assessments were performed from 9 AM to 11 AM. by an expert physiotherapist. In the motion analysis lab, after familiarizing the participants with the laboratory environment and how to evaluate the parameters, anthropometric information was recorded. Then, they were asked to complete the WOMAC Persian questionnaire, a valid and reliable clinical tool for reporting KOA [28]. An expert physiotherapist guided them if needed. A Vicon motion analysis system (Vicon, Oxford, UK) captured walking using eight cameras (Vero, 2.2 MP, UK). The motion analysis system was synchronized with a force plate (9286B; Kistler Co., Winterthur, Switzerland). The frequency of the camera recording was 120 Hz.

A standard Plug-in-Gait lower body marker set was used, containing 16 retro-reflective markers (Figure 1). The markers adhered bilaterally on the second metatarsal head, calcanei, malleoli, tibia, femur, femoral epicondyle, and anterior and posterior superior iliac spines [55]. After a static calibration trial, the participants were asked to walk at a comfortable preferred speed along the 5.3 m laboratory walkway. Three successful walking trials on the walkway were recorded. Using the ground reaction force, we determined the first (at the first half of the stance phase) and second (at the second half of the stance phase) peaks of KAM, KAM, PKFM, and KFM impulse as a normalized value to body weight. For doing TUG, we used a chair with arms, and the participants were instructed as follows: "Go, stand up, walk comfortably and safely three meters, walk around, come back, and sit back on the chair." The timing was started on the word "go" and ended when the participants returned to the chair" [56]. For performing FO8W, participants were instructed to stand mid-way between two cones that were placed five feet apart, facing outward from the plane of the cones, and walked at their comfort speed in a counter-clockwise direction in a figure of eight paths around the cones. Timing started when participants took the first step and stopped until both of their feet returned to the starting position. The time was recorded by a stopwatch [56]. An average of three recorded trials was used for data analysis.

Data processing

Motion data were low-pass filtered with a Butterworth filter (fourth order, cut-off frequency 5 Hz). KAM was calculated as the ground reaction force moment about the knee joint center [57]. The knee adduction moment was reported in the tibial reference frame with the mediolateral (y) axis parallel to the knee rotation axis. The first and second KAM peaks were identified as the maximum moment during 0–50% (early stance) and 51–100% (late stance) of the stance, respectively [58] (Figure 2 A). PKFM was described as the highest moment during the stance phase [6] (Figure 2 A). KAM impulse was calculated as the area under the curve of the KAM and reflected both the magnitude and duration of the KAM waveform [6] (Figure 2 B). KFM impulse was calculated as the integral of knee flexion moment (Nm/kg) concerning time (milliseconds) when sagittal plane knee moment was positive for each walking trial [59] (Figure 2 C). We used a custom-written MATLAB TM software, version 2018 to calculate kinetics parameters (MathWorks Inc, Natick, MA).

Statistical analysis

The Shapiro-Wilk test was applied to assess the normal distribution of data. Based on normal distribution, we used Pearson's correlation coefficient to investigate the correlation between kinetics parameters (PKAM, KAM impulse, PKFM, and KFM impulse) and scores of functional tests (TUG and FO8W) with WOMAC total score and sub-scores. Statistical significance was set at $P \leq 0.05$. SPSS software, version 25 (IBM NY, USA) was used for statistical analysis.

3. Results

Characteristics data and explanatory gait for 23 participants are shown in Table 1. For participants with moderate KOA, the first PKAM was significantly and inversely related to the total WOMAC and pain sub-score, respectively (r=-0.43 P=0.03 and r=-0.6 P=0.002, respectively) (Figure 3 A , B, respectively). There was no significant relationship between the first PKAM, function, and stiffness sub-scores (P>0.05). The second PKAM was significantly and inversely related to the pain sub-score (r=-0.46 P=0.02) (Figure 3 C). No significant relationship was seen between the second PKAM and the total score of WOMAC, sub-scores of function, and stiffness (P>0.05). The relationship between the KAM impulse and the WOMAC score was insignificant (P>0.05). There was no significant relationship between PKFM and KFM impulse with WOMAC score (P>0.05). The results showed no significant relationship between TUG and FO8W scores with the WOMAC score (P>0.05) (Table 2).

4. Discussion

This study was done to determine the relationship between WOMAC scores, kinetics parameters, and functional test scores. We found a significant inverse correlation between the first PKAM and WOMAC total score and pain sub-score. In addition, there was a significant

Figure 1. The setting of the Plug-in-Gait lower body containing 16 retro-reflective markers

JMR

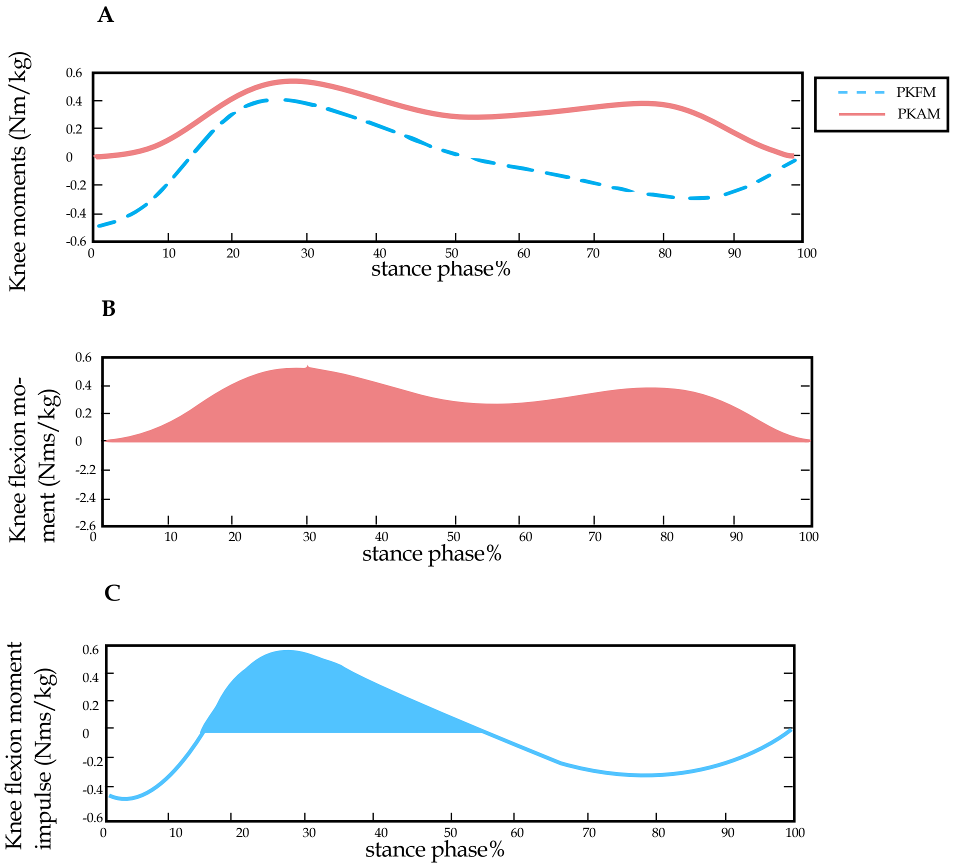


Figure 2. A) The first and second peak knee adduction moments and peak flexion moment, B) The knee adduction moment impulse in the stance phase, C) The knee flexion moment impulse in the stance phase.

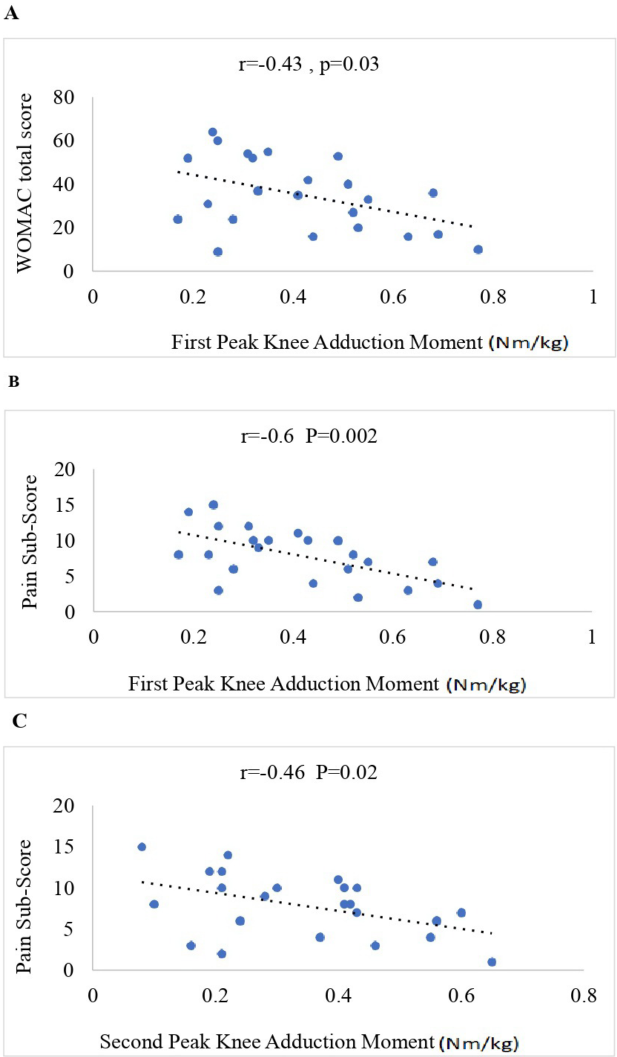
PKAM: The peak knee adduction moment.

inverse correlation between the second PKAM and WOMAC pain sub-score.

KOA is not a fatal disease, but it causes a major impact on the physical and social activity and quality of life of people with KOA. In KOA, the radiological finding is rarely correlated with functional impairment [60, 61], and we hypothesized that WOMAC score can cause a positive relationship with PKAM in people with moderate KOA. Contrary to the first hypothesis, there was an inverse correlation between the first PKAM and WOMAC total scores and between the first and second PKAM and pain sub-score.

Degenerative joint damage develops gradually, and people with KOA use adaptive and compensatory strategies to reduce pain; thus, the PKAM may not be consistent with the score of the subjective assessment of the WOMAC questionnaire. Although increased PKAM is correlated with structural progression of KOA [15, 24, 62], concurrent improvement has been reported in clinical outcomes with increased [38, 63, 64] rather than decreased [37, 39] first PKAM after exercise. Sometimes, clinical outcomes are improved with no change in movement parameters [40]. Also, reducing function leads to sedentariness that can trigger depression and negatively impact pain. Thus, it is possible that using this questionnaire allows people with KOA to overestimate their symptoms to speed up surgical management and receive secondary gains [65].

As mentioned above, there was a significant inverse correlation between the first and second PKAM and WOMAC pain sub-score. The KAM may be associated with pain, but this correlation is debatable. The pain experience of people with KOA is multifactorial [66]. Our study's lack of positive correlation is perhaps because knee joint pain is not the only result of mechanical loading conditions. Other factors should be considered, such as muscle weakness, neuromuscular control [67], proprioception, and coordination [33]. Therefore, it seems that only having a kinetic point of view of decision-making concerning this correlation is not complete. Jain et al. reported that the WOMAC questionnaire



JMR

Figure 3. Scatter plots show the correlation between: A) The first peak knee adduction moment and the WOMAC total score, B) The first peak knee adduction moment and pain sub-score, C) The second peak knee adduction moment and pain sub-score.

has superior sensitivity in reduced pain, increased range of motion, and reduced disability [68]. Furthermore, Amin et al. showed that people with higher KAM were more likely to develop chronic pain within 3-4 years [69]. Increased medial compartment loading during weight-bearing activities, such as walking may lead to pain due to intraosseous pressure, ischemia, and effusion [70]. Local mechanical stress at the knee joint is a risk factor for the development of incidental knee pain [71]. Nevertheless, studies exploring the correlation between KAM and pain intensity reported inconsistent findings [53, 72, 73]. In support of our result, Weidenhielm et al. did not find a relationship between KAM and pain and function by a modified British Orthopedic Association knee function chart [74]. Hall et al. demonstrated a relationship between PKAM and pain based on WOMAC and visual analog score (VAS) and function in people with mild and moderate KOA based on KL (grades 2 and 3) [53]. Henriksen et al. reported a negative correlation between PKAM and pain intensity based on VAS in less severe KOA (KL≤2) and no relationship in more severe KOA (KL>2) [73]. Furthermore, other studies have demonstrated that pain intensity assessed with the pain sub-score of the WOMAC questionnaire was also not correlated with the magnitude of KAM in people with KOA [75, 76]. Previous longitudinal studies have found an inverse correlation between a reduction in pain with non-steroidal anti-inflammatories and increase in the PKAM in people with KOA [77, 78]. An inverse correlation between VAS pain intensity and KAM was reported in previous studies in participants with mild KOA [73, 79]. Contrary to our finding, Thrope et al. reported a positive correlation between KAM and WOMAC pain sub-score in mild KOA (KL grade 2) [12].

Table 1. Participant's characteristics and value of the kinetics parameters

Variables		Mean±SD/No. (%)
Age (y)		54.17±7.26
Height (m)		1.61±0.07
Mass (kg)		76.87±8.76
BMI (kg/m^2)		29.70±3.24
Gender	Female	19(82.6)
	Male	4(17.39)
1st PKAM (Nm/kg)		0.41±0.17
2nd PKAM (Nm/kg)		0.34±0.15
KAM impulse (Nm/kg)		0.12±0.07
PKFM (Nm/kg)		0.18±0.28
KAM impulse (Nm/kg)		0.02±0.02

JMR

Abbreviations: PKAM: The peak knee adduction moment, KAM impulse: The knee adduction moment impulse, PKFM: The peak knee flexion moment; KFM impulse: The knee flexion moment impulse, SD: Standard deviation.

Kim et al. showed a strong significant relationship between single-limb stance KAM and the pain, function, and total WOMAC scores in people with symptomatic radiographic knee OA [65]. A negative correlation between KAM and pain may indicate that people with KOA adopt a compensatory gait pattern to decrease knee joint loading [10] and pain in the affected knee [65]. This inverse correlation could be an avoidance mechanism in response to pain-provoking stimuli [73]. Also, pain is a protective strategy that leads to a self-selected reduction in KAM during walking [21, 77]. Generally, the presence of conflicting results on the correlation between KAM and clinical symptoms, such as pain and disability is that the WOMAC questionnaire evaluates individuals' perception of mobility [80]. For example, the function domain of WOMAC assesses the subjective perception of the people in their daily life ability; it seems that this domain is not considered the sole evaluation device for improvement and worsening of functional capacity to evaluate the efficiency of a given treatment [52]. Furthermore, this questionnaire is affected by motivation and provides less information about participants' perception of their environment [81-83]. It should be noted that the questionnaire presents some limitations that are associated with several factors, including mood, motivation, fatigue, health, memory fluctuation, specific knowledge, and familiarity with test items [52]. Although it is difficult to interpret the relationship in this cross-sectional study, the results contain a clinical point that the low score of the WOMAC questionnaire in KOA people should not be attributed to the low level of joint contact forces.

There was no significant correlation between KAM impulse and WOMAC pain. Hall et al. reported no significant correlation between KAM impulse and WOMAC pain and pain intensity based on the numerical ration scale (NRS) in people with mild KOA (KL 2) and a significant positive correlation between KAM impulse and NRS pain and WOMAC pain in people with moderate KOA (KL 3) and a significant inverse correlation between KAM impulse and WOMAC pain in people with severe KOA (KL 4) [53]. Henriksen et al. also reported a positive correlation between pain intensity based on VAS and KAM impulse in severe KOA (KL>2) [73]. Kito et al. reported a positive correlation between KAM impulse and pain, stiffness, function, and disability sub-score and total score based on a Japanese knee osteoarthritis measure (JKOM) [84]. The discrepancies between our results and other studies may be due to the fact that the relationship between KAM impulse and WOMAC score is dependent on KOA severity, and we only assessed grades 2 and 3 according to the KL criteria.

We found no significant correlation between KFM parameters and WOMAC score. Huang et al. reported a significant positive correlation between KFM and pain intensity based on VAS. They showed no relationship between KFM and pain intensity based on a knee injury and

Table 2. The correlation of WOMAC sub-scores and knee moments

WOMAC Score Kinetics Parameters	Total Score	Pain Sub-score	Function Sub-score	Stiffness Sub-score
1st PKAM (Nm/kg)	r=-0.43* P=0.03	r=-0.6* P=0.002	r=-0.15 P=0.48	r=-0.38 P=0.07
2nd PKAM (Nm/kg)	r=-0.36 P=0.08	r=-0.46* P=0.02	r=-0.15 P=0.48	r=0.33 P=0.12
KAM impulse (Nms/kg)	r=-0.32 P=0.13	r=-0.36 P=0.09	r=-0.11 P=0.61	r=-0.3 P=0.15
PKFM (Nm/kg)	r=-0.14 P=0.51	r=-0.09 P=0.67	r=-0.03 P=0.88	r=-0.16 P=0.46
KFM impulse (Nms/kg)	r=-0.08 P=0.7	r=-0.002 P=0.99	r=0.05 P=0.82	r=-0.12 P=0.58
TUG (s)	r=0.3 P=0.15	r=0.26 P=0.22	r=0.18 P=0.4	r=-0.3 P=0.15
FO8W (s)	r=0.27 P=0.2	r=0.18 P=0.39	r=0.03 P=0.87	r=0.3 P=0.15

JMR

Abbreviations: PKAM: The peak knee adduction moment; KAM impulse: The knee adduction moment impulse; PKFM: The peak knee flexion moment; KFM impulse: The knee flexion moment impulse; TUG: The timed up and go test; FO8W: The figure of eight walking test.

*Statistical significance (P≤0.05).

osteoarthritis outcome score (KOOS) [85]. O'Connell et al. reported limited information about the positive association between knee pain based on the WOMAC questionnaire and KFM [79]. A possible explanation for the discrepancy between these studies could be that the WOMAC questionnaire is a multidimensional tool emphasizing disease progression and joint function, and the WOMAC subscale measures pain intensity on a Likert-type scale during several activities, including level walking [80]. However, no study has been conducted on the relationship between KFM impulse and WOMAC score.

We found no correlation between the WOMAC score and TUG and FO8W scores. One reason for the lack of correlation between these functional tests and WOMAC is probably related to the time-dependent measurement feature of the performance-based tests and inadequate inquiry of the functions in the self-evaluation questionnaire [86]. TUG and FO8W represent lower limb function and measure enough time for standing up and walking. We expected the increase in pain sub-score and WOMAC total score to be associated with an increase in the duration of activity of these functional tests, but this correlation was not obtained. This relationship may be dependent on the severity of KOA. It is suggested that this relationship be investigated using a larger sample size and different severities of KOA.

5. Conclusion

Our cross-sectional study showed an inverse correlation between the first and second PKAM and WOMAC pain sub-score and the first PKAM with a total WOMAC score. This result indicates a compensatory mechanism to decrease mechanical loads at greater pain intensity. Also, we did not find a significant correlation between PKFM, KFM impulse, KAM impulse, TUG, and FO8W scores with the WOMAC score. Although it is difficult to interpret the relationship in this cross-sectional study, the results contain a clinical point that the low score on the WOMAC questionnaire in the KOA people should not be attributed to the low level of joint contact forces. Thus, it is better to use these tests together as a complementary tool in studies on people with KOA. Furthermore, future investigations using large sample sizes and different severity of KOA are recommended.

Limitation

We could not determine the cause-and-effect relationship between the WOMAC questionnaire and the kinetics and functional tests as a cross-sectional study. Our exploratory study is hypothetical rather than definitive. Future studies may yield different findings. Future longitudinal studies are needed to determine the pathomechanics factors underlying the symptoms of knee OA. Mild and severe KOA not included in the study limited the results to be available only to people with grade 2 and 3 KL radiography. It is suggested that this correlation should be investigated in a larger sample at different KOA intensities.

Ethical Considerations

Compliance with ethical guidelines

The research project was ethically approved by Tarbiat Modares University (Code: IR.MODARES.REC.1398.004).

Funding

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

Authors' contributions

Conceptualization and supervision: Giti Torkaman; Methodology, investigation, writing original draft, review & editing: All authors; Data collection: Samaneh Gholami; Data analysis: Samaneh Gholami, Giti Torkaman and Fariba Bahrami; Funding acquisition and resources: Giti Torkaman.

Conflict of interest

The authors declared no conflict of interest.

Acknowledgments

This study was supported by the Faculty of Medical Sciences, Tarbiat Modares University, Tehran, Iran. We gratefully acknowledge all participants who participated in this study.

References

[1] Felson DT. The epidemiology of knee osteoarthritis: Results from the Framingham Osteoarthritis Study. Seminars in Arthritis and Rheumatism; 1990; 20(3 Suppl 1):42-50. [PMID]

[2] Cui A, Li H, Wang D, Zhong J, Chen Y, Lu H. Global, regional prevalence, incidence and risk factors of knee osteoarthritis in population-based studies. EClinicalMedicine. 2020; 29-30:100587. [DOI:10.1016/j.eclinm.2020.100587] [PMID] [PMCID]

[3] Andriacchi TP. Dynamics of knee malalignment. The Orthopedic Clinics of North America. 1994; 25(3):395-403. [DOI:10.1016/S0030-5898(20)31924-6] [PMID]

[4] Schipplein OD, Andriacchi TP. Interaction between active and passive knee stabilizers during level walking. Journal of Orthopaedic Research. 1991; 9(1):113-9. [DOI:10.1002/jor.1100090114] [PMID]

[5] Crenshaw SJ, Pollo FE, Calton EF. Effects of lateral-wedged insoles on kinetics at the knee. Clinical Orthopaedics and Related Research®. 2000; 375:185-92. [DOI:10.1097/00003086-200006000-00022] [PMID]

[6] Gerbrands TA, Pisters MF, Vanwanseele B. Individual selection of gait retraining strategies is essential to optimally reduce medial knee load during gait. Clinical Biomechanics. 2014; 29(7):828-34. [DOI:10.1016/j.clinbiomech.2014.05.005] [PMID]

[7] Zhao D, Banks SA, Mitchell KH, D'Lima DD, Colwell CW Jr, Fregly BJ. Correlation between the knee adduction torque and medial contact force for a variety of gait patterns. Journal of Orthopaedic Research. 2007; 25(6):789-97. [DOI:10.1002/jor.20379] [PMID]

[8] Johnson F, Leitl S, Waugh W. The distribution of load across the knee. A comparison of static and dynamic measurements. The Journal of Bone and Joint Surgery British volume. 1980; 62(3):346-9. [DOI:10.1302/0301-620X.62B3.7410467] [PMID]

[9] 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(7):573-9. [DOI:10.1053/joca.2002.0797] [PMID]

[10] Mündermann 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 & Rheumatism: Official Journal of the American College of Rheumatology. 2004; 50(4):1172-8. [DOI:10.1002/art.20132] [PMID]

[11] Hatfield GL, Cochrane CK, Takacs J, Krowchuk NM, Chang R, Hinman RS, et al. Knee and ankle biomechanics with lateral wedges with and without a custom arch support in those with medial knee osteoarthritis and flat feet. Journal of Orthopaedic Research. 2016; 34(9):1597-605. [DOI:10.1002/jor.23174] [PMID]

[12] Thorp LE, Sumner DR, Wimmer MA, Block JA. Relationship between pain and medial knee joint loading in mild radiographic knee osteoarthritis. Arthritis Care & Research. 2007; 57(7):1254-60. [DOI:10.1002/art.22991] [PMID]

[13] Hunter DJ, McDougall JJ, Keefe FJ. The symptoms of osteoarthritis and the genesis of pain. Rheumatic Disease Clinics of North America. 2008; 34(3):623-43. [DOI:10.1016/j.rdc.2008.05.004] [PMID] [PMCID]

[14] Neogi T, Felson D, Niu J, Nevitt M, Lewis CE, Aliabadi P, et al. Association between radiographic features of knee osteoarthritis and pain: Results from two cohort studies. BMJ. 2009; 339:b2844. [DOI:10.1136/bmj.b2844] [PMID] [PMCID]

[15] Thorp LE, Sumner DR, Block JA, Moisio KC, Shott S, Wimmer MA. Knee joint loading differs in individuals with mild compared with moderate medial knee osteoarthritis. Arthritis & Rheumatism: Official Journal of the American College of Rheumatology. 2006; 54(12):3842-9. [DOI:10.1002/art.22247] [PMID]

[16] 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] [PMID]

[17] Zeni JA, Rudolph K, Higginson JS. Alterations in quadriceps and hamstrings coordination in persons with medial compartment knee osteoarthritis. Journal of Electromyography and Kinesiology. 2010; 20(1):148-54. [DOI:10.1016/j.jelekin.2008.12.003] [PMID] [PMCID]

[18] Olsson S, Akbarian E, Lind A, Razavian AS, Gordon M. Automating classification of osteoarthritis according to Kellgren-Lawrence in the knee using deep learning in an unfiltered adult population. BMC Musculoskeletal Disorders. 2021; 22(1):844. [DOI:10.1186/s12891-021-04722-7] [PMID] [PMCID]

[19] Walter JP, D'Lima DD, Colwell CW Jr, Fregly BJ. Decreased knee adduction moment does not guarantee decreased medial contact force during gait. Journal of Orthopaedic Research. 2010; 28(10):1348-54. [DOI:10.1002/jor.21142] [PMID] [PMCID]

[20] Manal K, Buchanan TS. An electromyogram-driven musculoskeletal model of the knee to predict in vivo joint contact forces during normal and novel gait patterns. Journal of Biomechanical Engineering. 2013; 135(2):021014. [DOI:10.1115/1.4023457] [PMID] [PMCID]

[21] 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] [PMID]

[22] Gök H, Ergin S, Yavuzer G. Kinetic and kinematic characteristics of gait in patients with medial knee arthrosis. Acta Orthopaedica Scandinavica. 2002; 73(6):647-52. [DOI:10.3109/17453670209178029] [PMID]

[23] Al-Zahrani KS, Bakheit AM. A study of the gait characteristics of patients with chronic osteoarthritis of the knee. Disability and Rehabilitation. 2002; 24(5):275-80. [DOI:10.1080/09638280110087098] [PMID]

[24] Chehab EF, Favre J, Erhart-Hledik JC, Andriacchi TP. Baseline knee adduction and flexion moments during walking are both associated with 5 year cartilage changes in patients with medial knee osteoarthritis. Osteoarthritis and Cartilage. 2014; 22(11):1833-9. [DOI:10.1016/j.joca.2014.08.009] [PMID] [PMCID]

[25] Creaby MW, Wang Y, Bennell KL, Hinman RS, Metcalf BR, Bowles KA, et al. Dynamic knee loading is related to cartilage defects and tibial plateau bone area in medial knee osteoarthritis. Osteoarthritis and Cartilage. 2010; 18(11):1380-5. [DOI:10.1016/j.joca.2010.08.013] [PMID]

[26] Bennell KL, Creaby MW, Wrigley TV, Bowles KA, Hinman RS, Cicuttini F, et al. Bone marrow lesions are related to dynamic knee loading in medial knee osteoarthritis. Annals of The Rheumatic Diseases. 2010; 69(6):1151-4. [DOI:10.1136/ard.2009.118182] [PMID]

[27] Maly MR, Robbins SM, Stratford PW, Birmingham TB, Callaghan JP. Cumulative knee adductor load distinguishes between healthy and osteoarthritic knees-a proof of principle study. Gait & Posture. 2013; 37(3):397-401. [DOI:10.1016/j.gaitpost.2012.08.013] [PMID]

[28] Ebrahimzadeh MH, Makhmalbaf H, Birjandinejad A, Keshtan FG, Hoseini HA, Mazloumi SM. The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) in persian speaking patients with knee osteoarthritis. Archives of Bone and Joint Surgery. 2014; 2(1):57-62. [PMID]

[29] Katz JN, Brophy RH, Chaisson CE, de Chaves L, Cole BJ, Dahm DL, et al. Surgery versus physical therapy for a meniscal tear and osteoarthritis. New England Journal of Medicine. 2013; 368(18):1675-84. [DOI:10.1056/NEJMoa1301408] [PMID] [PMCID]

[30] Strange S, Whitehouse MR, Beswick AD, Board T, Burston A, Burston B, et al. One-stage or two-stage revision surgery for prosthetic hip joint infection-the INFORM trial: A study protocol for a randomised controlled trial. Trials. 2016; 17:90. [DOI:10.1186/s13063-016-1213-8] [PMID] [PMCID]

[31] Palmer S, Domaille M, Cramp F, Walsh N, Pollock J, Kirwan J, et al. Transcutaneous electrical nerve stimulation as an adjunct to education and exercise for knee osteoarthritis: A randomized controlled trial. Arthritis Care & Research. 2014; 66(3):387-94. [DOI:10.1002/acr.22147] [PMID]

[32] Chitkar SSA, Hakkak HRM, Saadati H, Hosseini SH, Jafari Y, Ganji R. Correction to: The effect of mobile-app-based instruction on the physical function of female patients with knee osteoarthritis: A parallel randomized controlled trial. BMC Women's Health. 2021; 21(1):349. [DOI:10.1186/s12905-021-01491-2] [PMID] [PMCID]

[33] Robert-Lachaine X, Dessery Y, Belzile ÉL, Turmel S, Corbeil P. Three-month efficacy of three knee braces in the treatment of medial knee osteoarthritis in a randomized crossover trial. Journal of Orthopaedic Research®. 2020; 38(10):2262-71. [DOI:10.1002/jor.24634] [PMID]

[34] Schuster E, Routson RL, Hinchcliff M, Benoff K, Suri P, Richburg C, et al. A novel walking cane with haptic biofeedback reduces knee adduction moment in the osteoarthritic knee. Journal of Biomechanics. 2021; 114:110150. [DOI:10.1016/j.jbiomech.2020.110150] [PMID] [PMCID]

[35] Monaghan B, Grant T, Hing W, Cusack T. Functional exercise after total hip replacement (FEATHER): A randomised control trial. BMC Musculoskeletal Disorders. 2012; 13:237. [DOI:10.1186/1471-2474-13-237] [PMID] [PMCID]

[36] Xiao Z, Li G. The effect of Wuqinxi exercises on the balance function and subjective quality of life in elderly, female knee osteoarthritis patients. American Journal of Translational Research. 2021; 13(6):6710-6. [PMID]

[37] Shull PB, Silder A, Shultz R, Dragoo JL, Besier TF, Delp SL, et al. Six-week gait retraining program reduces knee adduction moment, reduces pain, and improves function for individuals with medial compartment knee osteoarthritis. Journal of Orthopaedic Research. 2013; 31(7):1020-5. [DOI:10.1002/jor.22340] [PMID]

[38] Hunt MA, Charlton JM, Krowchuk NM, Tse CTF, Hatfield GL. Clinical and biomechanical changes following a 4-month toe-out gait modification program for people with medial knee osteoarthritis: A randomized controlled trial. Osteoarthritis and Cartilage. 2018; 26(7):903-11. [DOI:10.1016/j.joca.2018.04.010] [PMID]

[39] Cheung RTH, Ho KKW, Au IPH, An WW, Zhang JHW, Chan ZYS, et al. Immediate and short-term effects of gait retraining on the knee joint moments and symptoms in patients with early tibiofemoral joint osteoarthritis: A randomized controlled trial. Osteoarthritis and Cartilage. 2018; 26(11):1479-86. [DOI:10.1016/j.joca.2018.07.011] [PMID]

[40] Falahatgar M, Jalali M, Babaee T, Safaeepour Z, Torkaman A, Baniasad M. Comparing two orthoses for managing medial knee osteoarthritis: Lateral wedge with subtalar strap while barefoot versus lateral wedged insole fitted within sandal. Indian Journal of Orthopaedics. 2021; 56(2):319-26. [DOI:10.1007/s43465-021-00477-4] [PMID] [PMCID]

[41] Erhart-Hledik JC, Mahtani GB, Asay JL, Migliore E, Nguyen MM, Andriacchi TP, et al. Changes in knee adduction moment wearing a variable-stiffness shoe correlate with changes in pain and mechanically stimulated cartilage oligomeric matrix levels. Journal of Orthopaedic Research®. 2021; 39(3):619-27. [DOI:10.1002/jor.24770] [PMID]

[42] Ferreira GE, Robinson CC, Wiebusch M, Viero CC, da Rosa LH, Silva MF. The effect of exercise therapy on knee adduction moment in individuals with knee osteoarthritis: A systematic review. Clinical Biomechanics. 2015; 30(6):521-7. [DOI:10.1016/j.clinbiomech.2015.03.028] [PMID]

[43] Tan JS, Tikoft E, O'Sullivan P, Smith A, Campbell A, Caneiro JP, et al. The relationship between changes in movement and activity limitation or pain in people with knee osteoarthritis: A systematic review. Journal of Orthopaedic & Sports Physical Therapy. 2021; 51(10):492-502. [DOI:10.2519/jospt.2021.10418] [PMID]

[44] Juhakoski R, Tenhonen S, Anttonen T, Kauppinen T, Arokoski JP. Factors affecting self-reported pain and physical function in patients with hip osteoarthritis. Archives of Physical Medicine and Rehabilitation. 2008; 89(6):1066-73. [DOI:10.1016/j.apmr.2007.10.036] [PMID]

[45] Wright AA, Cook CE, Baxter GD, Garcia J, Abbott JH. Relationship between the Western Ontario and McMaster Universities Osteoarthritis Index Physical Function Subscale and physical performance measures in patients with hip osteoarthritis. Archives of Physical Medicine and Rehabilitation. 2010; 91(10):1558-64. [DOI:10.1016/j.apmr.2010.07.016] [PMID]

[46] Cecchi F, Molino-Lova R, Di Iorio A, Conti AA, Mannoni A, Lauretani F, et al. Measures of physical performance capture the excess disability associated with hip pain or knee pain in older persons. Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences. 2009; 64(12):1316-24. [DOI:10.1093/gerona/glp125] [PMID] [PMCID]

[47] Barker KL, Batting M, Schlüssel M, Newman M. The reliability and validity of the Figure of 8 Walk test in older people with knee replacement: Does the setting have an impact? Physiotherapy. 2019; 105(1):76-83. [DOI:10.1016/j.physio.2018.07.003] [PMID]

[48] Naik RP, Rathod D, Kumar A. Effects of retro-walking underwater treadmill training on pain, functional performance & functional mobility in patients with knee osteoarthritis. International Journal of Physiotherapy and Research. 2020; 8(5):3580-5. [Link]

[49] Gohir SA, Eek F, Kelly A, Abhishek A, Valdes AM. Effectiveness of internet-based exercises aimed at treating knee osteoarthritis: The iBEAT-OA randomized clinical trial. JAMA Network Open. 2021; 4(2):e210012. [DOI:10.1001/jamanetworkopen.2021.0012] [PMID] [PMCID]

[50] Khruakhorn S, Chiwarakranon S. Effects of hydrotherapy and land-based exercise on mobility and quality of life in patients with knee osteoarthritis: A randomized control trial. Journal of Physical Therapy Science. 2021; 33(4):375-83. [DOI:10.1589/jpts.33.375] [PMID] [PMCID]

[51] Jan MH, Tang PF, Lin JJ, Tseng SC, Lin YF, Lin DH. Efficacy of a target-matching foot-stepping exercise on proprioception and function in patients with knee osteoarthritis. Journal of Orthopaedic & Sports Physical Therapy. 2008; 38(1):19-25. [DOI:10.2519/jospt.2008.2512] [PMID]

[52] Onodera CMK, Coelho-Júnior HJ, Sampaio RAC, Santos Duarte Lana JF, Teixeira LFM, Uchida MC, et al. The importance of objectively measuring functional tests in complement to self-report assessments in patients with knee osteoarthritis. Gait & Posture. 2020; 82:33-7. [DOI:10.1016/j.gaitpost.2020.08.121] [PMID]

[53] Hall M, Bennell KL, Wrigley TV, Metcalf BR, Campbell PK, Kasza J, et al. The knee adduction moment and knee osteoarthritis symptoms: Relationships according to radiographic disease severity. Osteoarthritis and Cartilage. 2017; 25(1):34-41. [DOI:10.1016/j.joca.2016.08.014] [PMID]

[54] Kellgren J, Lawrence J. Radiological assessment of osteoarthrosis. Annals of the Rheumatic Diseases. 1957; 16(4):494. [DOI:10.1136/ard.16.4.494]

[55] 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 and Rheumatism. 2008; 59(3):408-15. [DOI:10.1002/art.23326] [PMID]

[56] Wong SS, Yam MS, Ng SS. The figure-of-eight walk test: Reliability and associations with stroke-specific impairments. Disability and Rehabilitation. 2013; 35(22):1896-902. [DOI:10.3109/09638288.2013.766274] [PMID]

[57] Shull PB, Lurie KL, Cutkosky MR, Besier TF. Training multi-parameter gaits to reduce the knee adduction moment with data-driven models and haptic feedback. Journal of Biomechanics. 2011; 44(8):1605-9. [DOI:10.1016/j.jbiomech.2011.03.016] [PMID]

[58] Uhlrich SD, Silder A, Beaupre GS, Shull PB, Delp SL. Subject-specific toe-in or toe-out gait modifications reduce the larger knee adduction moment peak more than a non-personalized approach. Journal of Biomechanics. 2018; 66:103-10. [DOI:10.1016/j.jbiomech.2017.11.003] [PMID] [PMCID]

[59] Teng HL, MacLeod TD, Link TM, Majumdar S, Souza RB. Higher knee flexion moment during the second half of the stance phase of gait is associated with the progression of osteoarthritis of the patellofemoral joint on magnetic resonance imaging. Journal of Orthopaedic & Sports Physical Therapy. 2015; 45(9):656-64. [DOI:10.2519/jospt.2015.5859] [PMID] [PMCID]

[60] Barker K, Lamb SE, Toye F, Jackson S, Barrington S. Association between radiographic joint space narrowing, function, pain and muscle power in severe osteoarthritis of the knee. Clinical Rehabilitation. 2004; 18(7):793-800. [DOI:10.1191/0269215504cr754oa] [PMID]

[61] Creamer P, Lethbridge-Cejku M, Hochberg MC. Factors associated with functional impairment in symptomatic knee osteoarthritis. Rheumatology. 2000; 39(5):490-6. [DOI:10.1093/rheumatology/39.5.490] [PMID]

[62] Bennell KL, Bowles KA, Wang Y, Cicuttini F, Davies-Tuck M, Hinman RS. Higher dynamic medial knee load predicts greater cartilage loss over 12 months in medial knee osteoarthritis. Annals of The Rheumatic Diseases. 2011; 70(10):1770-4. [DOI:10.1136/ard.2010.147082] [PMID]

[63] Bennell KL, Hunt MA, Wrigley TV, Hunter DJ, McManus FJ, Hodges PW, et al. Hip strengthening reduces symptoms but not knee load in people with medial knee osteoarthritis and varus malalignment: A randomised controlled trial. Osteoarthritis and Cartilage. 2010; 18(5):621-8. [DOI:10.1016/j.joca.2010.01.010] [PMID]

[64] Lim BW, Hinman RS, Wrigley TV, Sharma L, Bennell KL. Does knee malalignment mediate the effects of quadriceps strengthening on knee adduction moment, pain, and function in medial knee osteoarthritis? A randomized controlled trial. Arthritis and Rheumatism. 2008; 59(7):943-51. [DOI:10.1002/art.23823] [PMID]

[65] Kim W, Richards J, Jones RK, Hegab A. A new biomechanical model for the functional assessment of knee osteoarthritis. The Knee. 2004; 11(3):225-31. [DOI:10.1016/S0968-0160(03)00068-1] [PMID]

[66] Georgiev T, Angelov AK. Modifiable risk factors in knee osteoarthritis: Treatment implications. Rheumatology International. 2019; 39(7):1145-57. [DOI:10.1007/s00296-019-04290-z] [PMID]

[67] Tanaka R, Hirohama K, Ozawa J. Can muscle weakness and disability influence the relationship between pain catastrophizing and pain worsening in patients with knee osteoarthritis? A cross-sectional study. Brazilian Journal of Physical Therapy. 2019; 23(3):266-72. [DOI:10.1016/j.bjpt.2018.08.011] [PMID] [PMCID]

[68] Jain A, Raja R, Kumar KS. Effectiveness of short form-36 health status questionnaire versus WOMAC Arthritis Index Questionnaire on chronic knee osteoarthritis patients. Journal of Clinical & Diagnostic Research. 2021; 15(3):RC01 - 5. [DOI:10.7860/JCDR/2021/47098.14584]

[69] Amin S, Luepongsak N, McGibbon CA, LaValley MP, Krebs DE, Felson DT. Knee adduction moment and development of chronic knee pain in elders. Arthritis Care & Research. 2004; 51(3):371-6. [DOI:10.1002/art.20396] [PMID]

[70] O'Reilly SC, Jones A, Muir KR, Doherty M. Quadriceps weakness in knee osteoarthritis: The effect on pain and disability. Annals of The Rheumatic Diseases. 1998; 57(10):588-94. [DOI:10.1136/ard.57.10.588] [PMID] [PMCID]

[71] Segal NA, Anderson DD, Iyer KS, Baker J, Torner JC, Lynch JA, et al. Baseline articular contact stress levels predict incident symptomatic knee osteoarthritis development in the MOST cohort. Journal of Orthopaedic Research. 2009; 27(12):1562-8. [DOI:10.1002/jor.20936] [PMID] [PMCID]

[72] Astephen Wilson JL, Stanish WD, Hubley-Kozey CL. Asymptomatic and symptomatic individuals with the same radiographic evidence of knee osteoarthritis walk with different knee moments and muscle activity. Journal of Orthopaedic Research. 2017; 35(8):1661-70. [DOI:10.1002/jor.23465] [PMID]

[73] Henriksen M, Aaboe J, Bliddal H. The 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] [PMID]

[74] Weidenhielm L, Svensson OK, Broström LA, Mattsson E. Adduction moment of the knee compared to radiological and clinical parameters in moderate medical osteoarthrosis of the knee. Annales Chirurgiae et Gynaecologia. 1994; 83(3):236-42. [PMID]

[75] Astephen Wilson JL, Deluzio KJ, Dunbar MJ, Caldwell GE, Hubley-Kozey CL. The association between knee joint biomechanics and neuromuscular control and moderate knee osteoarthritis radiographic and pain severity. Osteoarthritis and Cartilage. 2011; 19(2):186-93. [DOI:10.1016/j.joca.2010.10.020] [PMID]

[76] Maly MR, Costigan PA, Olney SJ. Mechanical factors relate to pain in knee osteoarthritis. Clinical Biomechanics. 2008; 23(6):796-805. [DOI:10.1016/j.clinbiomech.2008.01.014] [PMID]

[77] Schnitzer TJ, Popovich JM, Andersson GB, Andriacchi TP. Effect of piroxicam on gait in patients with osteoarthritis of the knee. Arthritis & Rheumatism: Official Journal of the American College of Rheumatology. 1993; 36(9):1207-13. [DOI:10.1002/art.1780360905] [PMID]

[78] Hurwitz D, Ryals A, Block J, Sharma L, Schnitzer T, Andriacchi T. Knee pain and joint loading in subjects with osteoarthritis of the knee. Journal of Orthopaedic Research. 2000; 18(4):572-9. [DOI:10.1002/jor.1100180409] [PMID]

[79] O'Connell M, Farrokhi S, Fitzgerald GK. The role of knee joint moments and knee impairments on self-reported knee pain during gait in patients with knee osteoarthritis. Clinical Biomechanics. 2016; 31:40-6. [DOI:10.1016/j.clinbiomech.2015.10.003] [PMID]

[80] Bellamy N, Buchanan WW, Goldsmith CH, Campbell J, Stitt LW. Validation study of WOMAC: A health status instrument for measuring clinically important patient relevant outcomes to antirheumatic drug therapy in patients with osteoarthritis of the hip or knee. Journal of Rheumatology. 1988; 15(12):1833-40. [PMID]

[81] Myers AM, Holliday PJ, Harvey KA, Hutchinson KS. Functional performance measures: Are they superior to self-assessments? Journal of Gerontology. 1993; 48(5):M196-M206. [DOI:10.1093/geronj/48.5.M196] [PMID]

[82] Sager MA, Dunham NC, Schwantes A, Mecum L, Halverson K, Harlowe D. Measurement of activities of daily living in hospitalized elderly: A comparison of self-report and performance-based methods. Journal of the American Geriatrics Society. 1992; 40(5):457-62. [DOI:10.1111/j.1532-5415.1992.tb02011.x] [PMID]

[83] Hoeymans N, Wouters ER, Feskens EJ, van den Bos GA, Kromhout D. Reproducibility of performance-based and self-reported measures of functional status. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences. 1997; 52(6):M363-8. [DOI:10.1093/gerona/52A.6.M363] [PMID]

[84] Kito N, Shinkoda K, Yamasaki T, Kanemura N, Anan M, Okanishi N, et al. Contribution of knee adduction moment impulse to pain and disability in Japanese women with medial knee osteoarthritis. Clinical Biomechanics. 2010; 25(9):914-9. [DOI:10.1016/j.clinbiomech.2010.06.008] [PMID]

[85] Huang C, Chan PK, Chiu KY, Yan CH, Yeung SS, Fu SN. Exploring the relationship between pain intensity and knee moments in participants with medial knee osteoarthritis: A cross-sectional study. BMC Musculoskeletal Disorders. 2021; 22(1):685. [DOI:10.1186/s12891-018-2378-y] [PMID] [PMCID]

[86] Sabirli F, Paker N, Bugdayci D. The relationship between Knee Injury and Osteoarthritis Outcome Score (KOOS) and Timed Up and Go test in patients with symptomatic knee osteoarthritis. Rheumatology International. 2013; 33(10):2691-4. [DOI:10.1007/s00296-012-2512-3] [PMID]