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Rear foot kinematics when wearing lateral wedge insoles and foot alignment influence the effect of knee adduction moment for medial knee osteoarthritis

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ABSTRACT

Lateral wedge insoles (LWIs) are prescribed for patients with medial knee osteoarthritis to reduce the external knee adduction moment (KAM). However, the biomechanical effects of LWIs are limited in some patients. The purpose of this study was to investigate whether the biomechanical effects of LWIs depend on individual foot alignment and to examine the relationship between change in KAM and changes in foot and ankle biomechanics when wearing LWIs. Twenty-one patients participated in this study. They were categorized into normal or abnormal foot groups based on the foot posture index (FPI). All patients were requested to perform a normal gait under barefoot and LWI conditions. A three-dimensional motion analysis system was used to record 1st and 2nd KAM, knee adduction angular impulse (KAAI), center of pressure displacement, and knee-ground reaction force lever arm. Furthermore, the foot and ankle frontal plane kinematic parameters were evaluated. The 1st KAM was significantly reduced under the LWI condition compared to that under the barefoot condition in the normal foot group. In contrast, there was no significant difference in 1st KAM between both conditions in the abnormal foot group. Decreased rear foot eversion strongly correlated with reduction in the 1st KAM in the normal foot group. These findings suggested that it is helpful to assess individual foot alignment to ensure adequate insole treatment for patients with medial knee osteoarthritis and that decreased rear foot eversion during the early stance phase is significantly involved in the reduction of 1st KAM when wearing LWIs with normal feet.

1. Introduction

Knee osteoarthritis (OA) is one of the most common musculoskeletal disorders in older people and is associated with pain and functional impairment. Although symptom relief is one of the major aims of treatment, simultaneous conservative treatment aimed at reducing knee load during walking has been proposed as a viable option to slow the disease progression in patients with medial knee OA [1]. Knee joint loading, as estimated by surrogate measures such as the external knee adduction moment (KAM), has been implicated in the structural progression of medial knee OA [2,3].

Lateral wedge insoles (LWIs) are a frequently recommended treatment option in guidelines for the clinical management of medial knee OA [4]. LWIs have been shown to reduce KAM in patients with early to mild medial knee OA [1]. However, individual KAM response to LWIs is remarkably variable, with up to 30% of treated patients demonstrating no change or increase in KAM [5–7]. This lack of a consistent response to LWIs suggests that certain subgroups of people with medial knee OA are more responsive to LWIs. Therefore, it is important to identify which patient characteristics potentially mediate a positive response to LWIs.

Such characteristics include foot alignment and kinematics. The majority of past research on the biomechanical effects of LWIs has been conducted on subjects with mixed foot types. We previously demonstrated in healthy individuals that variations in foot alignment have different effects on change in peak KAM when wearing LWIs, in particular, an individual with a normal foot is more likely to respond positively to LWIs [8]. It is typically recommended that assessments of

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patients with knee OA should include foot alignment evaluations because these patients reportedly exhibit a more pronated foot type than unaffected controls [9,10]. In addition, a recent study has shown that different foot alignments are associated with differences in foot movement during gait [11]. Taken together, these findings suggest that foot alignment potentially impacts variations in the biomechanical effects of LWIs in patients with medial knee OA. With respect to foot kinematics, Chapman et al. [12] demonstrated that individuals with a greater everted ankle/subtalar complex (i.e., the foot being modelled as a rigid and single segment) under control conditions were more likely to have a decrease in peak KAM with the LWI. However, which joint (e.g., the ankle or subtalar) has a positive and significant effect on change in KAM when wearing LWIs remains unknown. In general, the rear foot angle was calculated as the heel segment relative to the shank segment [13]. Butler et al. [14] reported that eversion excursion at the rear foot was significantly increased in the LWI condition compared with control condition. However, they did not investigate whether increased rear foot eversion correlates to reduction in KAM.

Based on the above, the primary purpose of this study was to evaluate whether the immediate biomechanical effects of LWIs depend on individual foot alignment in patients with medial knee OA. A secondary purpose was to evaluate the relationships between change in KAM and changes in rear foot and ankle frontal plane kinematics when wearing LWIs. It was hypothesized that in patients with normal foot alignment, KAM would significantly decrease with LWI use compared to the no-LWI condition, and that rear foot kinematic changes would correlate more with reductions in KAM.

2. Methods

2.1. Patients

In total, 21 individuals aged between 60 and 80 years with medial knee OA as diagnosed by an expert orthopedic surgeon were recruited for this study. Patients were included if they reported knee pain on most days of the previous month and had tenderness in combination with osteoarthritic signs according to the Kellgren/Lawrence (K/L) classification of Grade 1 or higher located over the medial tibiofemoral compartment of the knee. Patients were excluded if they had any musculoskeletal disorders other than knee OA, if they were unable to walk without assistance, or if they were diagnosed with any neurological disorders that limited their function. In patients with bilateral knee OA, the more symptomatic side was evaluated. Furthermore, the Western Ontario and McMaster Universities (WOMAC) Osteoarthritis Index were used to assess knee pain, stiffness, and impairment in physical function [15].

Based on clinical static foot posture measurements, patients were classified into two groups, a normal foot group and an abnormal foot group. The foot posture measurements were conducted on the foot of the symptomatic side using the foot posture index (FPI) [16]. Our previous study demonstrated good intra-rater reliability for this measurement [intraclass correlation coefficient (ICC) 1,1 = 0.87] [8]. According to previous studies [8,11,17], all feet were categorized into three groups as follows: normal foot (total score between +2 and +7), pronated foot (total score ≥ + 8), and supinated foot (total score ≤ + 1). In this study, the normal foot group consisted of normal feet and the abnormal foot group consisted of pronated and supinated feet. The participant demographic characteristics are presented in Table 1. All participants provided informed consent and the study was approved by the Institutional Ethics Committee.

2.2. Procedures

This was a within-subject design study in which every participant was tested under two conditions: barefoot and wearing the LWI on a bare foot (LWI). The LWIs were made of high-intensity silicon rubber (Nakamura Brace, Ohda, Japan), which results in an approximate 5.3 ° inclination. The same products are widely used in Japan and have previously been reported [18,19]. Participants were first asked to stand and then walk at their typical comfortable walking speed across a 10 m gait laboratory walkway. Measurements were performed during five successful trials for each condition. Prior to actual measurement, several practice trials were performed to ensure that the participants walked naturally. The barefoot condition was performed first, followed by the LWI condition. In order to adapt the LWIs, sufficient time was allotted before the LWI condition measurement. In the LWI condition, participants walked across the walkway within a mean ± 5% of their walking speed under barefoot conditions. A pair of photoelectric timers (TM-02; Tamagawa Shop, Hiroshima, Japan) was used to monitor walking speed.

Table 1
Participant characteristics in each foot subgroup, as determined by FPI.

	Normal (n = 10)	Abnormal (n = 11)
Age [years][a]	68.9 ± 6.3	73.3 ± 3.7
Height [m][a]	1.55 ± 0.08	1.52 ± 0.06
Body mass [kg][a]	58.6 ± 6.7	54.6 ± 6.0
BMI [kg/m^2][a]	24.3 ± 2.2	23.6 ± 2.5
FPI (range)	3.9 (2 to 7)	2.6 (−2 to 1, 8 to 10)
K/L grade		
Grade 1/2/3/4 (n)	5/3/1/1	4/2/3/2
WOMAC score [a]	9.2 ± 8.1	10.2 ± 11.6

BMI: body mass index; FPI: foot posture index.
[a] Values are expressed as mean ± standard deviation.

2.3. Data analysis

Kinematic measurements were recorded using six infrared cameras (VICON MX; Vicon Motion Systems, Oxford, UK) at a sampling rate of 100 Hz. A total of 48 reflective markers were attached to the following landmarks on both sides of each subject: the temple, lateral end of the superior nuchal line, tragus, acromion, olecranon, ulnar styloid process, superior edge of the iliac crest, anterior superior iliac spine, posterior superior iliac spine, superior aspect of the greater trochanter, medial and lateral epicondyles of the femur, midpoint between the greater trochanter and the lateral epicondyle of the femur, medial and lateral tibial condyles, medial and lateral malleoli, midpoint between the lateral knee joint line and the lateral malleolus, posterior distal aspect of the calcaneus, posterior proximal aspect of the calcaneus, lateral calcaneus, sustentaculum tali, and the head of the first and fifth metatarsals. These markers were used to construct anatomical coordinate systems for the head, trunk, pelvis, thigh, shank, foot, and heel segments. Eight force plates (Tec Gihan, Uji, Japan) were used to measure the ground reaction force at a sampling frequency of 1000 Hz. Kinematic and kinetic data were low-pass filtered using a fourth-order Butterworth filter with cut-off frequencies of 6 Hz and 20 Hz, respectively [20,21].

Data analyses were performed using BodyBuilder software (Vicon Motion Systems, Oxford, UK). The knee adduction moment and the joint center coordinates of the knee and ankle were calculated according to a previous study [22]. An 8-link segmental model was developed to calculate the hip, knee, and ankle kinematic and kinetic data using inverse dynamics according to the techniques described by Vaughan et al. [23]. Anthropometric parameters for mass, center of mass, and moment of inertia for each segment were obtained from a report by Okada et al. [24]. The rear foot angle was calculated as the heel segment relative to the shank segment in accordance with the Oxford Foot Model marker set [13]. In addition, the heel and shank angle relative to the global coordinate system were extracted. Primary outcome variables of interest at the knee were first peak KAM (1st KAM), second peak KAM (2nd KAM), and knee adduction angular impulse (KAAI). 1st KAM was extracted during early stance (from the initial contact to 50% of stance) and 2nd KAM was extracted during late stance (from 50% of stance to the toe off). There variables were normalized to the participant's body mass (Nm/kg and Nm/kg s, respectively). Furthermore, knee-ground reaction force lever arm (KLA) and the position of the center of pressure in relation to the foot (COP offset) were both calculated at the time of the 1st KAM based on a report by Hinman et al. [6]. In this study, the COP offset was defined as the distance of the COP from the line of the foot (calcaneal tuberosity to the midpoint between the first and fifth metatarsal heads), where positive values indicate lateral offset. Finally, the variables of interest in this study were related to the frontal plane angles at the rear foot, ankle, shank, and heel, and were expressed as angular excursion from the initial contact to the point corresponding to 1 st KAM. In this study, the mean of the peaks of five trials was used. The means of five trials were used in the analysis.

2.4. Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics ver. 22.0 (IBM Japan, Tokyo, Japan), with the significance level set at less than 5%. The normality of the data distributions was assessed using the Shapiro-Wilk test. The effects of LWIs on biomechanical variables were evaluated using paired *t*-tests or Wilcoxon signed-rank test for each foot group, including normal and abnormal. In addition, relationships between the mean change in 1st KAM and the mean changes in the frontal plane angular excursion at the rear foot, ankle, shank and heel were evaluated using Pearson r-correlation coefficient or Spearman's rank correlation coefficient for each foot group.

3. Results

Fig. 1 depicts the individual percentage change in the 1st KAM in the normal and abnormal foot groups. Most participants (9/10) in the normal foot group demonstrated a reduction in the 1st KAM. In contrast, only 36% of participants (4/11) in the abnormal foot group demonstrated the reduction in 1st KAM. The remaining 64% of participants (7/11) demonstrated an increase in the 1st KAM.

Table 2 outlines the differences in biomechanical variables under the LWI and barefoot conditions in the normal and abnormal foot groups. Gait speed did not differ between the conditions. The LWI produced an immediate and significant decrease in the 1st KAM compared to the barefoot condition in the normal foot group. This change reflected a reduction in the 1st KAM from barefoot of 9.26%. In the normal foot group, the LWI resulted in a significant reduction in KLA and a significant lateral shift in the COP offset compared to the barefoot condition. In addition, at the ankle, eversion excursion significantly increased in the LWI condition compared to the barefoot condition. However, there were no significant differences in rear foot eversion, shank lateral inclination, and heel inversion excursion between the conditions. In the abnormal foot group, the ankle eversion excursion only significantly increased in the LWI compared to the barefoot condition.

Correlations between the mean change in 1st KAM and the mean changes in the frontal plane angular excursion in the normal and abnormal foot groups are reported in Table 3. Fig. 2 depicts the relationship between the mean change in the 1st KAM and the mean change in the rear foot eversion excursion. In the normal foot group, decreased rear foot eversion strongly correlated with reduction in the 1st KAM. In contrast, ankle eversion, shank lateral inclination, and heel inversion did not correlate with the 1st KAM. In the abnormal foot group, there were no correlation between the mean change in the 1st KAM and the mean changes in any frontal plane angular excursion.

4. Discussion

To our knowledge, this is the first study to analyze a clinical static evaluation of the foot and ankle and biomechanical effects of LWIs in patients with medial knee OA. We showed that the 1st KAM in the normal foot group was significantly reduced under the LWI condition compared to the barefoot condition. By contrast, in the abnormal foot group, there were no significant differences in the 1st KAM between both conditions. These results were concordant with our hypothesis. Based on the K/L grade, there was no great difference in disease severity between the foot subgroups. Furthermore, the WOMAC score was mostly the same in both groups. In comparison, all participants in both foot subgroups had decrease in peak KAM by 3.50% under the LWI condition compared to the barefoot condition. As referred to in a recent literature [25], these reductions can be considered as approximately normal. Although FPI is a static measure and only accounts for a small amount of dynamic motion, our findings have shed light on the importance of foot alignment to the effectiveness of LWI treatment for patients with medial knee OA.

This study also investigated the other biomechanical effects of wearing LWIs for each foot group. In the normal foot group, we confirmed that the LWI resulted in a significant reduction in KLA and a significant lateral shift in the COP offset compared to the barefoot condition, which is in agreement with previous studies [6,8]. In addition, the ankle exhibited a significantly increased eversion excursion with LWIs. However, there was no significance difference in the rear foot eversion excursion between the two conditions. Our results of the rear foot are not consistent with the results of previous study [14] and may be due to the study differences in the amount of LWI inclination and analysis intervals. Butler et al. [14] prescribed different inclined LWIs for each patient to reduce the greatest amount of pain. As a result, they reported that the average amount of lateral wedge was about 10°,

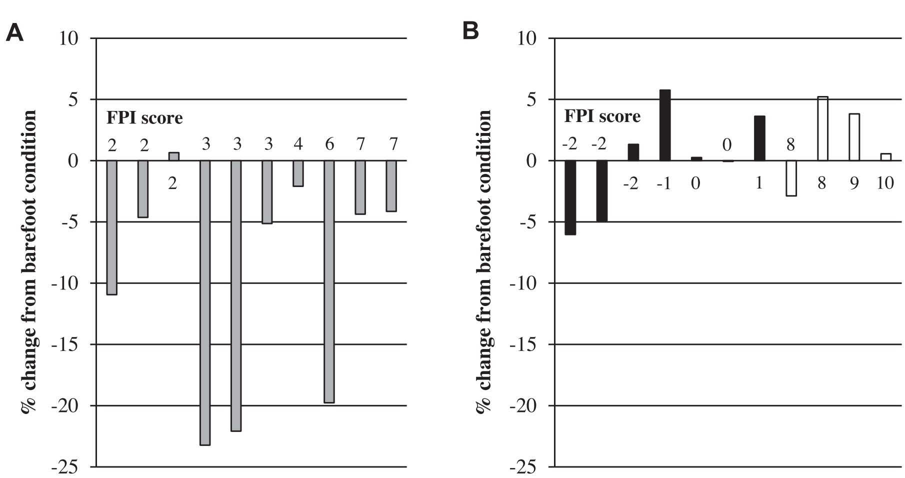

Fig. 1. Individual changes in peak KAM with LWIs reported as a percentage change from the barefoot condition: (A) normal foot group (gray column), (B) abnormal foot group (pronated foot, white column; supinated foot, black column). The respective FPI score for each of the individuals was inserted into the horizontal axis of figure.
It was calculated as the mean difference divided by the mean value with the barefoot condition, multiplied by 100.

Table 2
Biomechanical parameters under barefoot and LWI conditions in the normal and abnormal foot groups.

	Normal (n = 10)			Abnormal (n = 11)		
	Barefoot	LWI	p-value	Barefoot	LWI	p-value
Walking speed [m/s]	1.13 ± 0.25	1.12 ± 0.25	0.41	1.19 ± 0.20	1.20 ± 0.20	0.39
1 st KAM [Nm/kg]	0.54 ± 0.17	0.49 ± 0.17	< 0.05	0.57 ± 0.23	0.57 ± 0.24	0.92
2nd KAM [Nm/kg]	0.34 ± 0.12	0.33 ± 0.13	0.31	0.41 ± 0.12	0.40 ± 0.12	0.48
KAAI [Nm/kg s]	0.17 ± 0.05	0.15 ± 0.06	0.06	0.19 ± 0.06	0.19 ± 0.06	0.43
KLA [mm]	45.2 ± 11.0	40.1 ± 12.7	< 0.01	48.5 ± 16.1	47.4 ± 15.6	0.30
COP offset [mm]	8.5 ± 4.1	13.5 ± 3.6	< 0.01	7.6 ± 4.1	9.4 ± 2.9	0.23
Rear foot eversion [deg] [a]	4.0 ± 2.2	3.7 ± 2.2	0.37	5.2 ± 3.6	5.2 ± 2.4	0.64
Ankle eversion [deg] [a]	7.9 ± 3.4	9.9 ± 4.0	< 0.01	8.6 ± 2.3	11.0 ± 2.4	< 0.01
Shank lateral inclination [deg][a]	4.2 ± 2.0	4.9 ± 2.2	0.35	4.9 ± 2.7	4.8 ± 3.2	0.85
Heel inverion [deg][a]	4.8 ± 2.9	5.6 ± 3.2	0.08	5.6 ± 4.7	6.5 ± 3.1	0.06

KAM: knee adduction moment; KAAI: knee adduction angular impulse; KLA: knee-ground reaction force lever arm; COP: center of pressure; deg: degree.
[a] Values are expressed as angular excursion from the initial contact to the point corresponding to 1st KAM.

Table 3
The coefficients of correlation between the mean change in 1st KAM and mean changes in the rear foot and ankle frontal plane angular excursion for each foot group.

	Rear foot eversion	Ankle eversion	Shank lateral inclination	Heel inversion
Normal (n = 10)				
1 st KAM	0.87*	−0.28	0.26	0.20
Abnormal (n = 11)				
1 st KAM	−0.25	0.01	−0.15	0.22

* $p < 0.01$.

which was steeper than that employed by us. Furthermore, they defined analysis intervals by motion from initial contact to peak eversion during stance phase. In contrast, in the present study, in order to shed light on the effects associated with the 1st KAM, we focused on a short interval from the initial contact to the point of 1st KAM. By shortening the analysis interval, we found interesting trends for the relationship between the rear foot and ankle during the early stance phase.

In addition, we evaluated the relationship between the mean changes in biomechanical variables with LWIs for each foot group. In the normal foot group, the correlation between decreased rear foot eversion and reduction in the 1st KAM was unexpectedly strong. In contrast, ankle eversion showed no correlation with the 1st KAM. Therefore, although ankle eversion increases with LWIs, these findings indicate that this is not directly involved in the reduction of 1st KAM. Toda et al. [26] demonstrated that patients with medial knee OA on wearing LWIs with subtalar strapping had significantly decreased femorotibial and talar tilt angles on static weight bearing radiographs. They suggested that the LWI with subtalar strapping leads not only to subtalar joint valgus correction but also to correction of the femorotibial angle. On the other hand, our results indicated that there were no significant differences in shank lateral inclination and heel inversion excursion between the two conditions. Furthermore, changes in these parameters showed no correlation with 1st KAM. Therefore, these results suggest that motion of the shank or heel does not contribute singly to reduction in 1 st KAM. Although Chapman et al. [12] reported that individuals with a greater everted ankle at the instant of 1st KAM were more likely to respond positively to LWI, from the aspect of motion during the early stance phase, we consider that decreased rear foot eversion is significantly involved in the reduction of 1st KAM when wearing LWIs for medial knee OA patients with normal feet.

In the abnormal foot group, there were no correlation between the mean change in 1st KAM and the mean changes in any frontal plane angular excursion. Hinman et al. [6] reported a correlation between the peak KAM and an increase in the peak hip adduction angle during the stance phase. Additionally, another previous study revealed that healthy subjects could decrease the first peak of KAM compared with a normal gait by walking while leaning their trunks toward the stance limb [27]. In this study, 4/11 participants in the abnormal foot group demonstrated the reduction in 1st KAM. Therefore, the decrease in 1st KAM may not be due to the rear foot or ankle but may be due to another kinematic change such as a response of the hip or upper trunk.

There are limitations within the present study. First, although LWIs are usually inserted into shoes, in this study, the LWIs were directly attached to the participant's soles bilaterally with elastic strapping in order to clarify rear foot and ankle kinematics in detail. However, several studies have been conducted on barefoot walking under controlled conditions [18,19]. Second, as this study had a small sample size, and the findings need to be interpreted with caution. Third, the abnormal foot group included the pronated and supinated foot. Because the aim of this study was focused on the biomechanical efficacy of

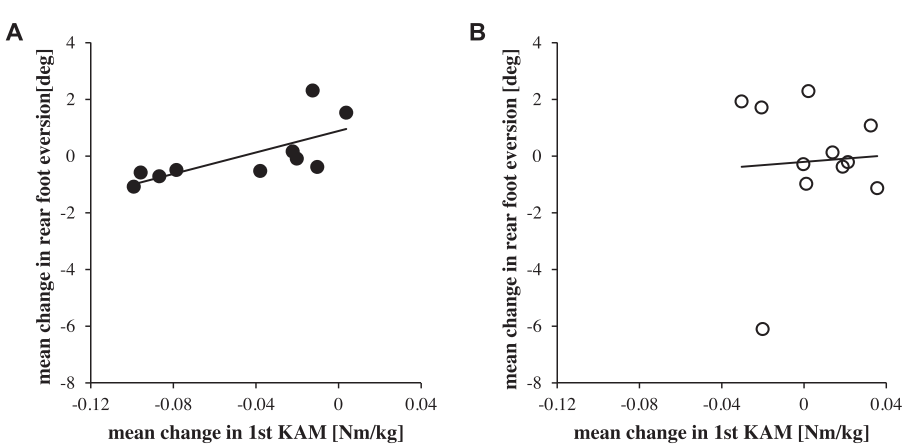

Fig. 2. Relationship between the mean change in 1st KAM and the mean change in rear foot eversion excursion for the normal foot group (A) and abnormal foot group (B). The linear regression line is shown by the solid line.

normal feet in medial knee OA patients in accordance with our previous study [8], it is unclear why the biomechanical effects were not shown in patients with pronated or supinated feet.

5. Conclusion

Although this study had a small sample size, our results suggested that it is helpful to assess individual foot alignment to ensure adequate insole treatment for patients with medial knee OA and that decreased rear foot eversion during the early stance phase is significantly involved in the reduction of 1st KAM when wearing LWIs with normal feet. These findings may provide further insight into identifying which characteristics of patients with knee OA mediate a positive response to LWI treatment.

Conflict of interest

The authors have no conflict of interest associated with this study.

References

[1] N.D. Reeves, FL, Bowling, conservative biomechanical strategies for knee osteoarthritis, Nat. Rev. Rheumatol. 7 (2) (2011) 113–122.
[2] A.H. Chang, K.C. Moisio, J.S. Chmiel, F. Eckstein, A. Guermazi, P.V. Prasad, Y. Zhang, O. Almagor, L. Belisle, K. Hayes, L. Sharma, External knee adduction and flexion moments during gait and medial tibiofemoral disease progression in knee osteoarthritis, Osteoarthr. Cartil. 23 (7) (2015) 1099–1106.
[3] T. Miyazaki, M. Wada, H. Kawahara, M. Sato, H. Baba, S. Shimada, Dynamic load at baseline can predict radiographic disease progression in medial compartment knee osteoarthritis, Ann. Rheum. Dis. 61 (7) (2002) 617–622.
[4] W. Zhang, R.W. Moskowitz, G. Nuki, S. Abramson, R.D. Altman, N. Arden, S. Bierma-Zeinstra, K.D. Brandt, P. Croft, M. Doherty, M. Dougados, M. Hochberg, D.J. Hunter, K. Kwoh, L.S. Lohmander, P. Tugwell, OARSI recommendations for the management of hip and knee osteoarthritis, Part II: OARSI evidence-based, expert consensus guidelines, Osteoarthr. Cartil. 16 (2) (2008) 137–162.
[5] W. Kakihana, M. Akai, K. Nakazawa, K. Naito, S. Torii, Inconsistent knee varus moment reduction caused by a lateral wedge in knee osteoarthritis, Am. J. Phys. Med. Rehabil. 86 (6) (2007) 446–454.
[6] R.S. Hinman, K.A. Bowles, B.B. Metcalf, T.V. Wrigley, K.L. Bennell, Lateral wedge insoles for medial knee osteoarthritis: effects on lower limb frontal plane biomechanics, Clin. Biomech. 27 (1) (2012) 27–33.
[7] R.S. Hinman, C. Payne, B.R. Metcalf, T.V. Wrigley, K.L. Bennell, Lateral wedges in knee osteoarthritis: what are their immediate clinical and biomechanical effects and can these predict a three-month clinical outcome? Arthritis Rheum. 59 (3) (2008) 408–415.
[8] T. Sawada, K. Tokuda, K. Tanimoto, Y. Iwamoto, Y. Ogata, M. Anan, M. Takahashi, N. Kito, K. Shinkoda, Foot alignments influence the effect of knee adduction moment with lateral wedge insoles during gait, Gait Posture 49 (2016) 451–456.
[9] P. Levinger, H.B. Menz, M.R. Fotoohabadi, J.A. Feller, J.R. Bartlett, N.R. Bergman, Foot posture in people with medial compartment knee osteoarthritis, J. Foot Ankle Res. 3 (29) (2010).
[10] K. Reilly, K. Barker, D. Shamley, M. Newman, G.R. Oskrochi, S. Sandall, The role of foot and ankle assessment of patients with lower limb osteoarthritis, Physiotherapy 95 (3) (2009) 164–169.
[11] A.K. Buldt, P. Levinger, G.S. Murley, H.B. Menz, C.J. Nester, K.B. Landorf, Foot posture is associated with kinematics of the foot during gait: a comparison of normal, planus and cavus feet, Gait Posture 42 (1) (2015) 42–48.
[12] G.J. Chapman, M.J. Parkes, L. Forsythe, D.T. Felson, R.K. Jones, Ankle motion influences the external knee adduction moment and may predict who will respond to lateral wedge insoles? An ancillary analysis from the SILK trial, Osteoarthr. Cartil. 23 (8) (2015) 1316–1322.
[13] J. Stebbins, M. Harrington, N. Thompson, A. Zavatsky, T. Theologis, Repeatability of a model for measuring multi-segment foot kinematics in children, Gait Posture 23 (4) (2006) 401–410.
[14] R.J. Butler, J.A. Barrios, T. Royer, I.S. Davis, Effect of laterally wedged foot orthoses on rearfoot and hip mechanics in patients with medial knee osteoarthritis, Prosthet. Orthot. Int. 33 (2) (2009) 107–116.
[15] N. Bellamy, W.W. Buchanan, C.H. Goldsmith, J. Campbell, L.W. Stitt, 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, J. Rheumatol. 15 (12) (1988) 1833–1840.
[16] A.C. Redmond, J. Crosbie, R.A. Ouvrie, Development and validation of a novel rating system for scoring standing foot posture: the Foot Posture Index, Clin. Biomech. (Bristol Avon) 21 (1) (2006) 89–98.
[17] A.C. Redmond, Y.Z. Crane, H.B. Menz, Normative values for the foot posture index, J. Foot Ankle Res. 1 (1) (2008) 6.
[18] S. Shimada, S. Kobayashi, M. Wada, K. Uchida, S. Sasaki, H. Kawahara, T. Yayama, I. Kitade, K. Kamei, M. Kubota, H. Baba, Effects of disease severity on response to lateral wedged shoe insole for medial compartment knee osteoarthritis, Arch. Phys. Med. Rehabil. 87 (11) (2006) 1436–1441.
[19] Y. Kuroyanagi, T. Nagura, H. Matsumoto, T. Otani, Y. Suda, T. Nakamura, Y. Toyama, The lateral wedged insole with subtalar strapping significantly reduces dynamic knee load in the medial compartment-gait analysis on patients with medial knee osteoarthritis, COsteoarthr. Cartil. 15 (8) (2015) 932–936.
[20] H. Tateuchi, Y. Koyama, H. Akiyama, K. Goto, K. So, Y. Kuroda, N. Ichihashi, Radiographic and clinical factors associated with one-leg standing and gait in patients with mild-to-moderate secondary hip osteoarthritis, Gait Posture 49 (2016) 207–212.
[21] T.A. Gerbrands, M.F. Pisters, P.J. Theeven, S. Verschueren, B. Vanwanseele, Lateral trunk lean and medializing the knee as gait strategies for knee osteoarthritis, Gait Posture 51 (2017) 247–253.
[22] N. Kito, K. Shinkoda, T. Yamasaki, N. Kanemura, M. Anan, N. Okanishi, J. Ozawa, H. Moriyama, Contribution of knee adduction moment impulse to pain and disability in Japanese women with medial knee osteoarthritis, Clin. Biomech. 25 (9) (2010) 914–919.
[23] C.L. Vaughan, B.L. Davis, J.C. O'Conners, Integration of anthropometry, displacements, and ground reaction forces, Dynamics of Human Gait, Third ed., Human Kinetics Champaign, 1992, pp. 15–43.
[24] H. Okada, M. Ae, N. Fujii, Y. Morioka, Body segment inertia properties of Japanese elderly, Biomechanisms 13 (1996) 125–139 (in Japanese).
[25] J.B. Arnold, Lateral wedge insoles for people with medial knee osteoarthritis: one size fits all, some or none? Osteoarthr. Cartil. 24 (2) (2016) 193–195.
[26] Y. Toda, N. Segal, A. Kato, S. Yamamoto, M. Irie, Effect of a novel insole on the subtalar joint of patients with medial compartment osteoarthritis of the knee, J. Rheumatol. 28 (12) (2001) 2010–2705.
[27] A. Mündermann, J.L. Asay, L. Mündermann, T.P. Andriacchi, Implications of increased medio-lateral trunk sway for ambulatory mechanics, J. Biomech. 41 (1) (2008) 165–170.