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Effect of foot progression angle and lateral wedge insole on a reduction in knee adduction moment

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Running Title: Effects of foot angle and wedge.

Abstract

This study evaluated the effect of foot progression angle on the reduction in knee adduction moment caused by a lateral wedged insole during walking. Twenty healthy young volunteers walked 10 m at their comfortable velocity wearing lateral wedged insole or control flat insole in three foot progression angle conditions: natural, toe-out, and toe-in. A 3-dimensional rigid link model was used to calculate the external knee adduction moment, the moment arm of ground reaction force to knee joint center, and the reduction ratio of knee adduction moment and moment arm. The result indicated that toe-out condition and lateral wedged insole decreased the knee adduction moment in the whole stance phase. The reduction ratio of the knee adduction moment and the moment arm exhibited a close relationship. Lateral wedged insoles decreased the knee adduction moment in various foot progression angle conditions due to decrease of the moment arm of the ground reaction force. Moreover, the knee adduction moment during toe-out gait with lateral wedged insole was the smallest due to the synergistic effect of the lateral wedged insole and foot progression angle. Lateral wedged insoles may be a valid intervention for patients with knee osteoarthritis regardless of the foot progression angle.

Keywords: lateral wedge insole, foot progression angle, knee adduction moment, ankle valgus moment, moment arm

Word Count: 3571

Introduction

Knee osteoarthritis (OA) is one of the most common musculoskeletal disorders causing knee pain and disability in the elderly population.[1] Mechanical stress on the knee joint has been shown to play a key role in the development and progression of the disease.[2] A previous study examined the joint reaction force during gait using strain gages in an artificial joint. That study reported that the joint reaction force was 215% of the body weight at early stance phase and 266% at late stance phase and that the shared force of the medial compartment was 70%.[3] Thus, the knee medial compartment is most commonly affected in knee OA patients.[4]

Patients with medial knee OA frequently have increased external knee adduction moment compared to healthy older adults due to varus alignment of a lower limb, which extends the moment arm of the ground reaction force to the knee joint center.[5,6] Increased knee adduction moment is related to lateral thrust, which is observed as a rapid lateral displacement of the knee in the frontal plane,[7] pain, and progression of OA.[8] Knee adduction moment is typically used as an indicator for medial compartment loading.[5,6,9] Therefore, a logical intervention for patients with medial knee OA is to reduce the knee adduction moment during gait.

Lateral wedged insoles and knee braces have been utilized as conservative interventions to treat patients with medial knee OA in the earlier stages. Lateral wedged insoles are a reliable and inexpensive treatment option that has high compliance because of its ease of wear.[10] Lateral wedged insoles shift the center of pressure (COP) laterally and bring the ground reaction force vector closer to the center of the knee joint thereby decreasing the knee adduction moment.[11] In patients with knee OA, lateral wedged insole have been shown to reduce the peak knee adduction moment by approximately 4–12% on average.[12-15]

Inconsistent data have been obtained from randomized control trials for lateral wedged insole.[10,16] Thus, different recommendations have been made for knee OA.[17,18] This discrepancy may result from various patient responses to the lateral wedged insole due to patient characteristics, including the degree of deformity, physical function, and gait pattern. Therefore, to obtain the expected effect, it is important to prescribe an appropriate lateral wedged insole that is consistent with a given patient's characteristics. Several studies have demonstrated that patients with knee OA modify their gait pattern as a strategy to alter the load on the knee joint, decrease pain, and prevent further progression of OA.[19] These compensations include a reduction in walking speed,[20-22] medio-lateral trunk sway,[23-25] medialization of the knees,[26] and altered foot progression angle.[27-35] Increasing the toe-out angle will theoretically shift the COP laterally in late stance, thereby reducing the moment arm of the ground reaction force and subsequently decreasing the knee adduction moment.[31-33] In contrast, toe-in gait reduces the knee adduction moment at early stance but increases the knee adduction moment at late stance.[36]

Because patients with knee OA walk with various foot progression angle conditions, it is very important to prescribe an appropriate lateral wedged insole to properly understand the effect of the foot progression angle on the reduction in knee adduction moment caused by a lateral wedged insole. Previous studies evaluating the effect of lateral wedged insole on the knee adduction moment analyzed a gait with natural foot progression angle; however, few studies have evaluated the relationship between foot progression angle and the effect of the lateral wedged insole. The purpose of this study was to evaluate foot progression angle and the effect of lateral wedged insole on knee adduction moment during walking. We hypothesized that lateral wedged insole and a toe-out foot progression angle would have a synergistic effect, and reduce the moment arm from the ground reaction force to the knee joint center. In turn, a toe-out gait with a lateral wedged insole would show the greatest reduction in the knee adduction moment. On the other hand, a lateral shift of the COP induced by a lateral wedged insole would increase the ankle valgus moment.[37] Because the kinematic effect of the lateral wedged insole is transmitted through the ankle joint, the use of a lateral wedge requires attention to the ankle load.[38] Hence, we also examined the effect of the foot progression angle and lateral wedge insole on ankle valgus moment.

Methods

Subjects

Twenty healthy young volunteers (age, 23.1 ± 3.5 years; height, 1.72 ± 0.07 m; mass, 64.9 ± 12.6 kg) without orthopedics or neurological disorders participated in this study. This study was approved by the Clinical Review Board of the Faculty of Medicine at Kagoshima University. Each participant read and signed an informed consent form approved by the Clinical Review Board.

Study Protocol

The subjects walked 10 m at a comfortable velocity wearing lateral wedged insole or control flat insole in three different foot progression angle: natural, toe-in, and toe-out. The subjects were asked to walk naturally and to walk as instructed with either a toe-in or toe-out progression angle. A positive value indicated the toe-out progression angle in this study. A previous study reported that patients without knee OA progression rotated the toe outward 22.5° during gait.[31] Another study reported that a -2.1° toe-in gait reduced the knee adduction moment during the early stance phase in OA patients.[39] Hence, in this study, the foot progression angle was set to 22.5° in the toe-out condition and -2.5° in the toe-in condition. Prior to taking measurements, the subjects practiced the gaits for each condition using visual feedback provided by markings on the floor. During the measurement session, the subjects were instructed (i.e., toe-in or toe-out) without visual feedback.

Instrumentation

Three-dimensional gait analysis was conducted with a 7-camera optoelectronic motion analysis system (VICON MX3, Oxford Metrics, Oxford, UK) combined with two force plates (OR6-7 and BP400600, AMTI Inc., MA, USA). The sampling frequencies of the infrared camera and the force plate were 100 Hz and 1000 Hz, respectively. Reflective markers were placed on the leg along both sides of the anterior superior iliac spine, the center between both sides of the posterior superior iliac spine, the lateral aspect of the thigh, the lateral epicondyle, the medial epicondyle, the lateral aspect of shank, the lateral malleolus, the medial malleolus, first and fifth heads of the metatarsal bone and heel. The hip joint center was determined using methods described by Davis *et al*.[40] The center of the knee and the ankle joint was determined to be the midpoint of two markers placed medially and laterally on each joint. The thigh segment was defined by the hip joint center and the bilateral epicondyles of the femur, the shank segment by the knee joint center and bilateral malleoli, and the foot by the first and fifth heads of the metatarsal bone and the heel marker (Fig 1). The foot longitudinal axis was defined as the line from the heel marker to the midpoint between the first and fifth heads of the metatarsal bone.[41]

Wedge condition

Full-length lateral wedged insole and control flat insole were made of high-density ethylene vinyl acetate (Kyowa Shokai, Kobe, Japan) with a modulus of repulsion elasticity of 20%. The thickness of the control flat insole was 5 mm. The lateral wedged insole was laterally inclined 7° along the full-length of the hindfoot to forefoot, according to a previous study.[42] Penny *et al*.[43] investigated inclination angles of 5° to 7° for lateral wedged insole used in interventions for knee OA patients. Previous studies found that using a 5° lateral wedged insole during walking does not have a consistent effect on the knee adduction moment.[43,44] Therefore, we used a 7° lateral wedged insole in this study. The insoles were adjusted to the subject's feet and fixed to the subjects' soles bilaterally with double-faced tape according to a previous study to avoid the effects of shoe shape.[41]

Data analysis

Step length and gait velocity were calculated using a heel marker. Joint moment was derived using the inverse dynamics approach with BodyBuilder 3.6.2 (Oxford Metrics, Oxford, UK). The relative location of the COP to the knee joint center, but not to the longitudinal axis of the foot, is important in analyzing the effect of displacement of the COP on the moment arm of the ground reaction force to the knee joint center. Therefore, the location of the COP was calculated as the distance from the projected antero-posterior axis of the shank to the floor and a positive value represented a lateral location. A 3-dimensional rigid link model, which consists of the pelvis, thigh, shank, and foot, was used to calculate the external knee adduction moment and ankle valgus moment. The moment arm of the ground reaction force to the knee joint center was calculated as the perpendicular distance from the vector of the ground reaction force in the plane consisting of the longitudinal and mediolateral axes in the shank coordinate system. The joint moment, ground reaction force, location of the COP and the moment arm were smoothed by a third-order Butterworth low-pass filter at 6 Hz after inverse dynamics.[46] The ground reaction was calculated as the relative force in the coordinate system of the shank. The ground reaction force and joint moment were normalized to each subject's body mass. Kinematic and kinetic data were normalized to percentage of the stance phase. Previous studies reported that external knee adduction moment had a two-peak pattern during the stance phase.[12,47] Therefore, we analyzed the maximal value during the early (0–50%) stances as the first peak and the late (50–100%) stances as the second peak (Fig 2A). The ground reaction force, moment arm, and location of the COP were calculated during the early and late stances, similar to the peak of the knee adduction moment. The reduction ratios of the knee adduction moment and the moment arm were calculated as the ratio of the changes produced by lateral wedged insole to the value in control flat insole for each foot progression angle condition. Also we estimated the ankle maximum valgus moment during early stance and maximum varus moment during late stance to examine the load of ankle joint (Fig 2B). Averages were obtained from five trials for each walking condition.[15,42] The results are shown as the mean ± standard deviation. Data processing was performed using Scilab 5.4.

The gait parameters (foot progression angle, velocity, and step length), kinematic data (joint moment and ground reaction force), location of the COP, and the moment arm were analyzed by two-way repeated measures ANOVA (type of insole vs. foot progression angle) to confirm the effects of the lateral wedged insole and foot progression angle on knee adduction moment. If an interaction was present, the effect of the wedge was tested by a paired *t* test, and the effect of the foot progression angle was tested by one-way repeated measures ANOVA. Schaffer's test was employed as a post hoc test. Meanwhile, the η^2 and Cohen’s d were calculated to estimate the effect size in ANOVA and *t* test, respectively. The relationship between the reduction ratios of the knee adduction moment and the moment arm was analyzed by Pearson correlation coefficient and Spearman's rank correlation coefficient after data were tested for normality by Shapiro-Wilk Test. The level of significance was set at $P < 0.05$. Effect size was classified into small ($\eta^2 = 0.01$, $d = 0.20$, $r = 0.10$), medium ($\eta^2 = 0.06$, $d = 0.50$, $r = 0.30$), and large ($\eta^2 > 0.14$, $d > 0.80$, $r > 0.50$), according to previous studies.[47,48] All statistical analyses were performed with the R (2.8.1) statistics software.

Results

The observed foot progression angles were close to the instructed angle (Table 1). Use of an insole significantly affected the foot progression angle; however, the differences between the control flat insole and lateral wedged insole were less than 2°. Therefore, the differences in the foot progression angle due to the insole condition had little influence in this study. The foot progression angle significantly affected velocity when walking with a control flat insole, and the velocity for the natural condition was the fastest out of all walking conditions. The insole type and foot progression angle did not have any effects on the step length.

The toe-out condition significantly decreased the knee adduction moment during the whole stance phase ($P < .001$), while the toe-in condition decreased the knee adduction moment during the early stance phase ($P = .003$) and increased the knee adduction moment during the late stance phase ($P = .034$) when compared with the natural condition (Fig 3A, Table 2). Lateral wedged insoles decreased the knee adduction moment across walking conditions during the whole stance phase ($P < .001$). The knee adduction moment for the toe-out condition with lateral wedged insole during the late stance phase was the lowest of all the waking conditions. The effect size on the knee adduction moment was larger in the wedge (medium) during the early stance phase, and in the foot progression angle during the late stance phase (large).

In contrast to the knee adduction moment results, the toe-out condition increased the ankle varus moment during the late stance ($P < .001$) and the toe-in condition decreased both valgus and varus moment ($P = .014$, $P < .001$; Fig 3B). Lateral wedged insoles increased the ankle valgus moment during early stance ($P < .001$) and decreased the ankle varus moment ($P = .008$) during the late stance across walking conditions.

With respect to the vertical ground reaction force, the first peak decreased in the toe-in condition, and the first and second peaks decreased during the toe-out condition compared with the natural condition (Table 3). Other than this decrease, the type of insole had no effect on the vertical ground reaction force. The toe-out condition decreased the medial ground reaction force during the whole stance phase when compared with the natural condition. The toe-in condition significantly decreased during the early stance phase and increased the medial ground reaction force in the late stance phase. Lateral wedged insoles increased the medial force during across walking conditions.

Compared to the natural condition, the toe-out condition shifted the COP medially during the early stance phase and shifted the COP laterally during the late stance phase (Table 4). The toe-in and toe-out conditions had opposite effects on the shift of the COP. Lateral wedge insoles shifted the COP laterally for all foot positions during the whole stance phase and across foot positions. The toe-out condition decreased the moment arm during the whole stance phase, and the toe-in condition increased the moment arm during the late stance phase. Lateral wedged insoles significantly decreased the moment arm across walking conditions during the whole stance phase. The effect size on the moment arm was larger in the wedge (large) during the early stance phase, and in the foot progression angle during the late stance phase (large).

The reduction ratios of the knee adduction moment ranged from 8.8% to 17.7%. The reduction ratios of the moment arm ranged from 8.7% to 15.3% (Table 5). The reduction ratios for both the knee adduction moment and the moment arm were the largest in the toe-out condition. Those reduction ratios showed a significant relationship. The correlation coefficients ranged from 0.57 to 0.87 (Table 5), and these effect sizes were large.

Discussion

We evaluated the effects of foot progression angle and lateral wedged insole on the knee adduction moment and ankle valgus moment during walking. We also evaluated the relationship between the reduction ratio of the knee adduction moment and the moment arm. In summary, these results were generally consistent with our hypothesis. Our study results indicated that the toe-out condition and lateral wedged insole decreased the knee adduction moment during the whole stance phase. For the toe-out condition with the lateral wedged insole, the knee adduction moment had the smallest value, due to the synergistic effect of the lateral wedged insole and the foot progression angle. The close relationship between the reduction ratio of the knee adduction moment and the moment arm indicated that the lateral wedged insole and the foot progression angle changed the relative position between the knee joint center and the ground reaction force, which resulted in decreased knee adduction moment.

The toe-out foot progression angle decreased the knee adduction moment during the whole stance phase, but the toe-in foot progression angle decreased the knee adduction moment during the early stance phase and increased the knee adduction moment during the late stance phase compared with the natural foot progression angle condition. In the early stance phase, the toe-out foot progression angle shifted the COP medially relative to the antero-posterior axis of the shank compared with that of the natural foot progression angle condition. This change in relative location of the COP to the shank in the toe-out foot progression angle condition depends on a lateral shift of the knee joint center due to an outside turn of the talocrural joint. However, external rotation of the shank in the horizontal plane during the toe-out gait decreased the distance from the ground reaction force to the knee joint center compared to the natural foot progression angle condition. A reduction in the medial ground reaction force and moment arm resulted in a decrease in the knee adduction moment. Meanwhile, during the late stance phase, the toe-out foot progression angle condition shifted the COP outside and reduced the knee adduction moment.[31-33,36] Internal rotation of the tibia caused by the toe-in foot progression angle condition shifted the center of the knee joint close to the ground reaction force vector, and thus decreased the moment arm and the knee adduction moment during the early stance phase.[36] In contrast, the toe-in foot progression angle condition shifted the COP medially, resulting in an increase in the knee adduction moment during the late stance phase.[28]

Walking with a lateral wedged insole and a natural foot progression angle gait resulted in a reduction of approximately 12-13% in the knee adduction moment, which was similar to the results of a previously published study.[12-15] Lateral wedged insoles also decreased the knee adduction moment in the toe-in and toe-out conditions, especially in the toe-out condition. The reduction ratio of the knee adduction moment had a significant correlation with the reduction ratio of the moment arm.[11] In this study, lateral wedged insole increased the medial ground reaction force for all walking conditions, which would increase the knee adduction moment. However, the lateral shift of the COP and resulting reduction in moment arm had a larger effect on the knee adduction moment than that of the increase in the medial ground reaction force. Thus, the lateral wedged insole decreased the knee adduction moment in all of the foot progression angle conditions, in the whole stance phase. This result indicated that lateral wedged insole may be a valid intervention for patients with knee OA regardless of the foot progression angle and that the toe-out foot progression angle condition and lateral wedged insole had a synergistic effect on the knee adduction moment during walking. Meanwhile, the results of the effect size of insole and foot progression angle on knee adduction moment and moment arm indicated that the lateral wedged insole was effective during the early stance phase, and conversely, the toe-out condition was effective during the late stance phase. The lateral wedged insole and toe-out condition could therefore be effective in a complementary manner.

In contrast to the results concerning the knee joint, lateral wedged insole increased the ankle valgus moment during the early stance phase, similar to the result of previous study.[37] The lateral shift of the COP increased the moment arm of the ground reaction force to the axis of the postero-anterior ankle, which resulted in an increase of the ankle valgus moment. The increased valgus moment may cause chronic ankle instability.[6] Clinicians should consider the load on the ankle joint when examining the utilization of a lateral wedge for patients to prevent the progression of knee OA.

There were limitations to our study. The difference in gait velocity among gait conditions may have an effect on the knee adduction moment. Furthermore, we examined the effects of the lateral wedged insole for three different foot progression angle conditions in healthy young subjects. Patients with knee OA with malalignment and instability of the knee joint may have a different response to wearing a lateral wedged insole. A second limitation is that the load on the medial knee component was estimated by the knee adduction moment in this study. A previous study reported that the peak knee adduction moment did not reflect peak joint reaction force of the medial compartment of tibia.[49] Furthermore, this study did not contain the analysis of influence of a footwear on the knee adduction moment. Therefore, further studies involving the joint reaction forces of the medial component and influence of footwear in OA patients are needed to clarify the effects of lateral wedged insole in various foot progression angle conditions.

Conclusion

Our data suggest that a lateral wedged insole decreases the knee adduction moment in various foot progression angle conditions due to a decrease in the moment arm of the ground reaction force related to a lateral shift of the COP. The knee adduction moment was the smallest in the toe-out foot progression angle condition with a lateral wedged insole, indicating that the lateral wedged insole and toe-out foot progression angle condition had a synergistic effect. A lateral wedged insole may be a valid intervention for patients with knee OA regardless of the foot progression angle.

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Tables

Table 1 Results of the foot progression angle, velocity and step length during each gait condition. The average value for the variable and the standard deviation are given.

		Natural	Toe-out		Toe-in		P value (Effect size) Effect of insole	Effect of FPA	Effect of interaction
foot progression angle (°)									
	CFI	8.7 ± 4.3	20.5±6.3	**††	-1.7 ± 3.4	**	**.005** (.002)	< **.001** (.781)	.117 (.001)
	LWI	9.0 ± 4.0	20.8±5.9		0.2 ± 3.5				
Velocity (m/s)									
	CFI	1.27 ± 0.15	1.17 ± 0.14	**	1.19 ± 0.15	**	Natural .115 (.230) Toe-out **.012** (.292) Toe-in .582 (.091)	CFI < **.001** (.088)	**.031** (.011)
	LWI	1.24 ± 0.15	1.22 ± 0.15		1.20 ± 0.18			LWI .222 (.010)	
Step length (m)									
	CFI	0.68 ± 0.07	0.68 ± 0.07		0.67 ± 0.07		.516 (.001)	.126 (.009)	.685 (.001)
	LWI	0.69 ± 0.07	0.69 ± 0.07		0.67 ± 0.08				

Note. FPA, foot progression angle; CFI, control flat insole; LWI, lateral wedge insole.

Only the effect size of insole on velocity was estimated by Cohen's d. Bold indicates significant effect ($P < .05$).

**$P < .01$, significant difference compared to natural condition.

††$P < .01$, significant difference compared to toe-in condition.

Table 2 Results of the knee adduction and ankle valgus moment. The p value and the effect size in two-way ANOVA are given.

	P value (Effect size)		
	Effect of insole	Effect of FPA	Effect of interaction
Knee adduction moment at 1st peak	< **.001** (.063)	< **.001** (.023)	.616 (< .001)
Knee adduction moment at 2nd peak	< **.001** (.029)	< **.001** (.147)	.556 (< .001)
Ankle maximum valgus moment during early stance	< **.001** (.449)	**.001** (.054)	.103 (.004)
Ankle maximum varus moment during late stance	**.008** (.024)	< **.001** (.349)	.180 (.005)

Note. FPA, foot progression angle.

Bold indicates significant effect ($P < .05$).

Table 3 Results of the vertical and medial ground reaction force. The average value for the variable and the standard deviation are given (N/kg).

	Natural	Toe-out		Toe-in		P value (Effect size)		
						Effect of insole	Effect of FPA	Effect of interaction
Vertical force at 1st peak								
CFI	10.1 ± 1.3	9.9 ± 0.9	**†	9.7 ± 1.1	**	.514	**< .001**	.124
LWI	10.4 ± 0.9	9.8 ± 1.2		9.3 ± 1.2		(.001)	(.077)	(.017)
Vertical force at 2nd peak								
CFI	10.0 ± 0.7	9.4 ± 0.9	**††	9.9 ± 0.9		.731	**< .001**	.850
LWI	10.1 ± 0.5	9.5 ± 1.0		10.0 ± 0.5		(< .001)	(.114)	(.001)
Medial force at 1st peak								
CFI	0.91 ± 0.26	0.87 ± 0.25	*†	0.77 ± 0.25	**	**.002**	**< .001**	.607
LWI	0.98 ± 0.20	0.90 ± 0.27		0.81 ± 0.26		(.008)	(.065)	(.001)
Medial force 2nd peak								
CFI	0.63 ± 0.34	0.50 ± 0.27	**††	0.74 ± 0.30	**	**.005**	**< .001**	.209
LWI	0.71 ± 0.30	0.52 ± 0.24		0.80 ± 0.32		(.008)	(.125)	(.002)

Note. FPA, foot progression angle; CFI, control flat insole; LWI, lateral wedge insole.

Bold indicates significant effect ($P < .05$).

*$P < .05$, significant difference compared to natural condition.

**$P < .01$, significant difference compared to natural condition.

†$P < .05$, significant difference compared to toe-in condition.

††$P < .01$, significant difference compared to toe-in condition.

Table 4 Results of the location of COP and moment arm. The average value for the variable and the standard deviation are given. Bold indicates significant effect (P < 0.05).

	Natural	Toe-out		Toe-in		P value (Effect size) Effect of insole	Effect of FPA	Effect of interaction
Location of COP at 1st peak (mm)								
CFI	-14.1 ± 13.2	-22.0 ± 19.7	**††	1.8 ± 15.8	**	< **.025** (.213-.642)	**< .001** (.183-.275)	**.002** (.005)
LWI	-5.4 ± 13.9	-12.8 ± 18.4	**††	5.0 ± 14.6	**			
Location of COP at 2nd peak (mm)								
CFI	-0.3 ± 14.7	15.3 ± 14.3	**††	-14.2 ± 18.3	**	**< .001** (.027)	**< .001** (.388)	.374 (.001)
LWI	4.8 ± 14.7	23.6 ± 12.7		-7.9 ± 19.0				
Moment arm at 1st peak (mm)								
CFI	35.9 ± 8.7	33.4 ± 9.8	**†	34.0 ± 9.4		**< .001** (.052)	**.004** (.016)	.115 (.004)
LWI	31.0 ± 8.9	28.2 ± 8.7		31.5 ± 8.9				
Moment arm at 2nd peak (mm)								
CFI	38.5 ± 10.0	31.4 ± 8.4	**††	40.9 ± 9.9	**	**< .001** (.029)	**< .001** (.158)	.638 (< .001)
LWI	34.9 ± 10.4	27.1 ± 8.8		37.8 ± 11.8				

Note. FPA, foot progression angle; COP, center of pressure; CFI, control flat insole; LWI, lateral wedge insole.

Only the effect size of insole on the location of the COP at the first peak was estimated by Cohen's d. Bold indicates significant effect (P < .05).

**P < .01, significant difference compared to natural condition.

†P < .05, significant difference compared to toe-in condition.

††P < .01, significant difference compared to toe-in condition.

Table 5 Relation between reduction of the knee adduction moment and moment arm. The average value for the variable and the standard deviation are given.

	Natural	Toe-out	Toe-in
Reduction ratio of knee adduction moment (%)			
1st peak	12.9 ± 8.6	17.7 ± 10.7	15.3 ± 13.2
2nd peak	11.9 ± 8.0	14.9 ± 11.0	8.8 ± 12.2
Reduction ratio of moment arm (%)			
1st peak	13.4 ± 18.7	15.3 ± 10.1	7.1 ± 12.6
2nd peak	10.1 ± 9.3	14.1 ± 12.5	8.7 ± 13.6
Relation between reduction ratio of knee adduction moment and moment arm			
1st peak	0.81**	0.66**	0.57**
2nd peak	0.87**	0.83**	0.79**

**P < .01, significant correlation.

Figure Captions

Figure 1 Coordinate system of the thigh, shank, and foot. The X-axis indicates the medio-lateral axis, Y-axis indicates the antero-posterior axis, and Z-axis indicates the longitudinal axis in each segment.

Figure 2 Ensemble average of the external joint moments of the knee adduction (A) and ankle valgus (B) during walking with three foot progression angle conditions; natural (left column), toe-out (middle column), toe-in (right column). LW reduced the knee adduction moment and increased the ankle valgus moment in all walking conditions. The smallest knee adduction moment was observed during the late stance phase in the toe-out condition.

Figure 3 Knee adduction moment (A) and ankle moment (B) in each gait condition. Knee adduction moment was decreased by lateral wedged insole and foot progression angle across walking conditions in the whole stance phase. Black

Fig 1

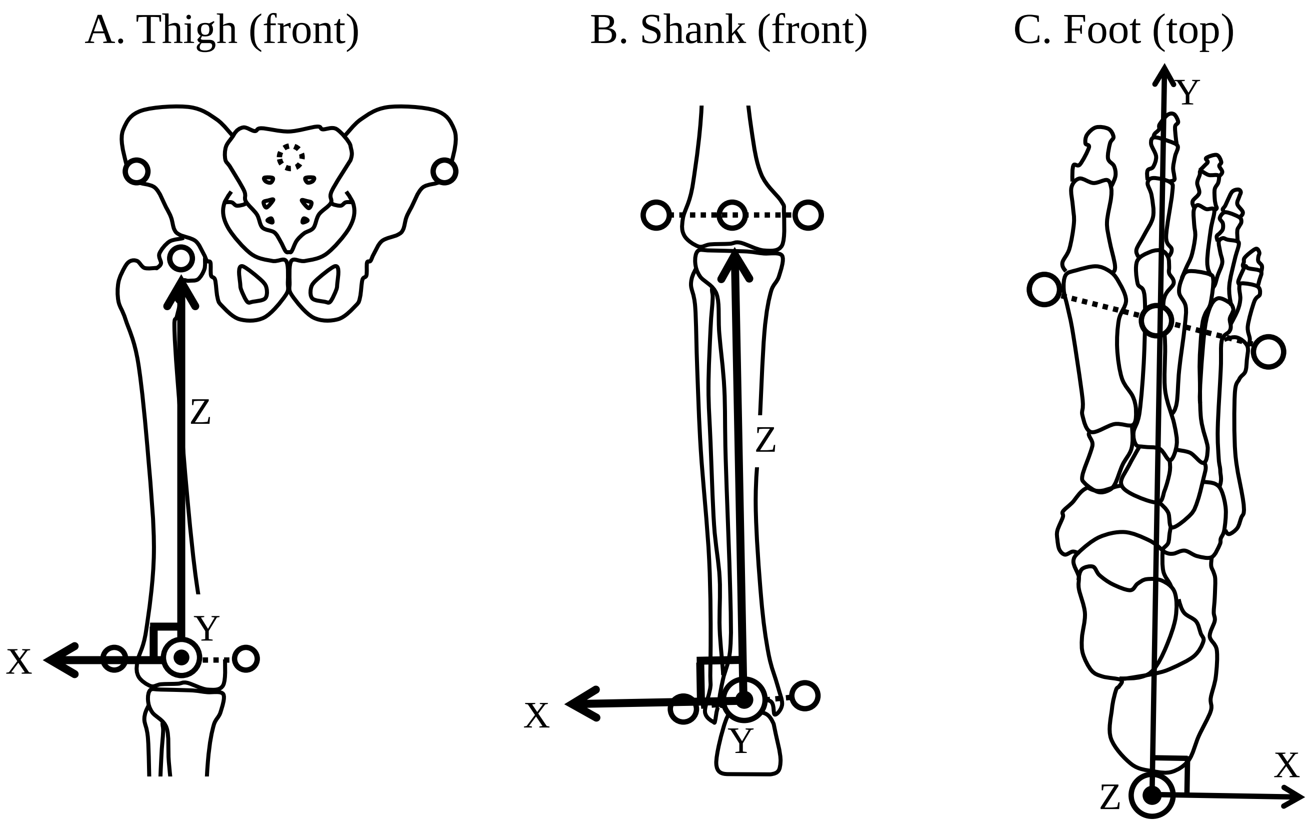
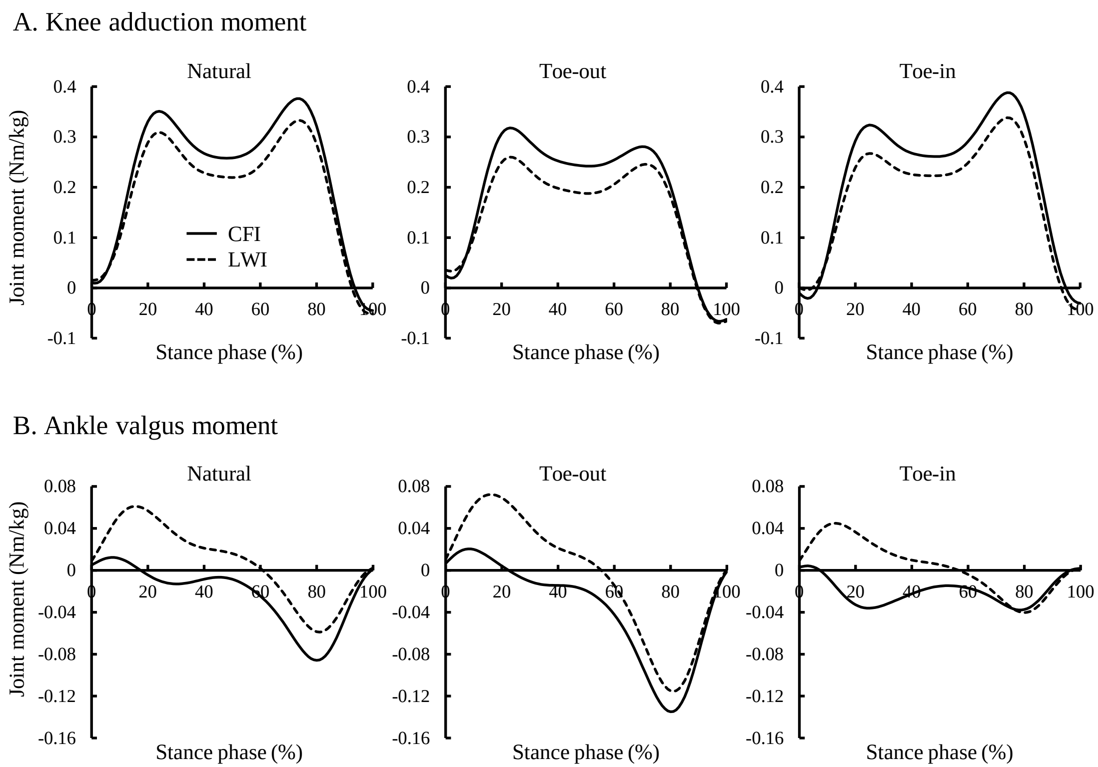
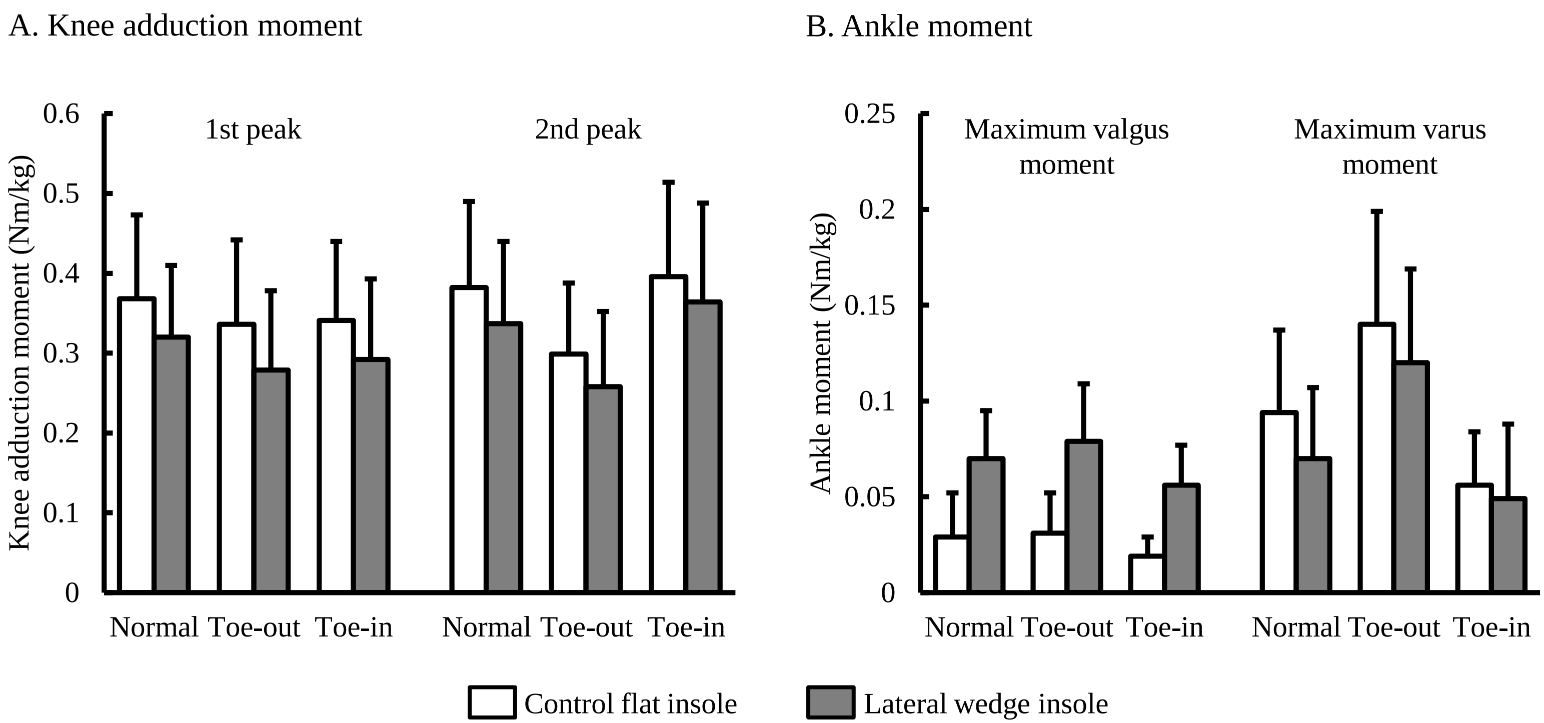


Fig 2



A. Knee adduction moment
Natural
Toe-out
Toe-in
Joint moment (Nm/kg)
0.4
0.3
0.2
0.1
0
-0.1
0
20
40
60
80
100
Stance phase (%)
CFI
LWI
B. Ankle valgus moment
Natural
Toe-out
Toe-in
Joint moment (Nm/kg)
0.08
0.04
0
-0.04
-0.08
-0.12
-0.16
Stance phase (%)

Fig 3



A. Knee adduction moment
B. Ankle moment
0.6
0.5
0.4
0.3
0.2
0.1
0
Knee adduction moment (Nm/kg)
1st peak
2nd peak
Normal
Toe-out
Toe-in
Normal
Toe-out
Toe-in
0.25
0.2
0.15
0.1
0.05
0
Ankle moment (Nm/kg)
Maximum valgus moment
Maximum varus moment
Normal
Toe-out
Toe-in
Normal
Toe-out
Toe-in
Control flat insole
Lateral wedge insole