Research Article

Knee and ankle biomechanics with lateral wedges with and without a custom arch support in those with medial knee osteoarthritis and flat feet[†]

Running Head: Lateral Wedges for Knee Osteoarthritis

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Abstract

This study compared immediate changes in knee and ankle/subtalar biomechanics with lateral wedge orthotics with and without custom arch support in people with knee osteoarthritis and flat feet. 26 participants with radiographic evidence of medial knee osteoarthritis (22 females; age 64.0 years (SD 8.0 years), BMI 27.2 kg/m^2 (4.2)) and flat feet (median foot posture index = +5) underwent three-dimensional gait analysis for three conditions: control (no orthotic), lateral wedge, and lateral wedge plus arch support. Condition order was randomized. Outcomes included frontal plane knee and ankle/subtalar biomechanics, and comfort. Compared to the control, lateral wedge and lateral wedge with arch support reduced the knee adduction moment impulse by 8% and 6%, respectively ($p<0.05$). However, the lateral wedge resulted in a more everted foot position (4.3 degrees) than lateral wedge plus arch support (3.2 degrees) ($p<0.05$). In contrast, lateral wedge plus arch support reduced foot frontal plane excursion compared to other conditions ($p<0.05$). Participants self-reported significantly more immediate comfort with lateral wedge plus arch support compared to the control, whereas there was no difference in self-reported comfort between lateral wedge and control. No immediate changes in knee pain were observed in any condition.

Keywords: knee, osteoarthritis, gait, orthotics

Clinical Significance: Rather than prescribing lateral wedges to all patients with knee osteoarthritis, those who have medial knee osteoarthritis and flat feet may prefer to use the combined orthotic to reduce loads across the knee to minimize the risk of foot and ankle symptoms as a consequence of orthotic treatment.

Introduction

Knee osteoarthritis (OA) is the cause of significant economic burden and has a negative impact on quality of life[1]. The pain, stiffness, muscle strength deficits, and joint instability resulting from knee OA make it the leading cause of difficulty with activities of daily living in people over the age of 65 years[2]. Unfortunately, there is no cure for knee OA. Total knee arthroplasty (TKA) is reserved for those with severe knee OA, and there is a demand for conservative treatments to delay or prevent the need for TKA. It is recognized that knee OA is a mechanically induced disease[3], and that interventions must address the underlying mechanical disorder in order to result in long-term benefit[4]. Given that gait biomechanics have been associated with knee OA progression[5-9], there has been much focus on addressing modifiable gait biomechanical factors with conservative interventions.

The external knee adduction moment (KAM) is one gait biomechanical variable that has consistently been associated with knee OA progression[5-9] and is a commonly reported gait outcome measure in studies in the knee OA population. The KAM is an accepted indirect measure of tibiofemoral compartment load distribution, with higher values indicating larger loads in the medial tibiofemoral compartment[10]. Given that the majority of knee OA occurs in the medial tibiofemoral compartment, identification of treatments that can effectively redistribute loads away from the medial compartment during movement (i.e. reduce the KAM) represent an important research and clinical objective.

Lateral wedges are one example of a conservative intervention that targets the KAM. Studies have shown that a lateral wedge of at least five degrees produces reductions in the KAM ranging, on average, from 4-12%[11-18], due to lateralization of the centre of pressure and resultant reductions in the ground reaction force lever arm at the knee[16]. However, there is wide variability in the response to lateral wedges that has been observed in those with knee OA. For example, Hinman et al found a mean reduction in peak KAM of 6% in a cohort of 73 participants with medial compartment knee OA, however variability in individual responses ranged from decreases of nearly 25% to increases of over 20% [16]. A potential reason for this variability in results could be the foot posture/type of participants (e.g. a pes planus flat foot versus a pes cavus high arch foot). Since lateral wedges act directly at the foot and ankle complex, ankle and subtalar biomechanics are likely to play a role in mediating the effect of lateral wedges further up the lower limb chain at the knee joint. Since eversion of the ankle and subtalar joints occurs with lateral wedge use[19], and it is believed that foot posture and subtalar joint mechanics are related[20], differences in foot posture amongst individuals in a sample may account for the variability seen in biomechanical changes with the same lateral wedge treatment. Previous studies to date have all included heterogeneous samples of people with varying foot posture, which may have masked or washed out the effects of lateral wedge treatment on knee biomechanics. Accordingly, examination of the effects of orthotic use on a sample of people with knee OA and similar foot postures will provide useful information needed to better prescribe orthotic use in this population.

People with knee OA exhibit a flat foot posture more commonly than healthy controls[21] , and flat feet have been associated with more frequent knee pain and cartilage damage in people with knee OA[22]. With regards to orthotics use clinically, individuals with flat feet are unlikely to receive lateral wedges in isolation, since this would encourage eversion of a foot already exhibiting large amounts of eversion. Instead, they would likely receive an arch support orthotic to address the flat feet, regardless of the presence or absence of knee OA. However, the biomechanical effect of arch support on the medial side may be in direct opposition to the effects of a lateral wedge, and medial arch supports in isolation are not effective in reducing the KAM[23]. Given that foot pain is common in people with knee OA[24], it is important to consider the biomechanics and symptoms of the feet when using orthotics designed to address knee loading.

While it may seem counterintuitive to treat knee OA with orthotics that provide medial and lateral support simultaneously (i.e. arch support and lateral wedges), there is preliminary evidence that this combined orthotic design may improve biomechanical outcomes at the knee. Two studies on healthy participants have found that the combination of a lateral wedge with medial arch support produced greater reductions in the KAM compared to flat insoles during walking[25; 26]. Further, Jones et al found that a lateral wedge and a wedge with a standard amount of medial arch support provided similar KAM reductions in 70 people with medial tibiofemoral knee OA[27]. While these results are promising, it is unknown whether they are generalizable to individuals with flat feet and knee OA. If the results could be replicated in this patient population, it would provide important information that could be used to better guide the conservative management of certain subgroups of people with knee OA. Thus, the purpose of this study was to test the immediate biomechanical effects of a combined custom-made arch support plus lateral wedge in people with medial compartment knee OA and flat feet compared to a lateral wedge alone. It was hypothesized that the lateral wedge and lateral wedge with arch support would provide similar reductions in KAM magnitudes, while the lateral wedge alone would promote more eversion during walking.

Methods

Participants

Participants with knee pain were recruited from the community via advertisements in local print media as part of a larger study assessing medium-term clinical changes with the use of orthotics. Data presented in the current paper were collected from the initial baseline testing session before commencing the orthotics intervention. Participants were included in the study if they had symptomatic unilateral or bilateral radiographically-diagnosed medial tibiofemoral compartment OA (Kellgren and Lawrence[28] score ≥ 2), and flat feet, defined as a foot posture index score that was +4 or greater, including positive scores (denoting planus posture) in at least four of the six measures[29]. Two independent researchers graded standing, semi-flexed posteroanterior knee radiographs using the Kellgren and Lawrence rating scale to determine radiographic severity. In the case of those with bilateral knee OA, the knee with the higher self-reported pain rating was deemed to be the study limb, provided that limb had a foot posture index score of +4 or greater. Exclusion criteria relevant to this study included: i) low pain score on a numerical rating scale of pain (average knee pain on walking ≤ 3 out of 10 over previous week), ii) knee surgery or intra-articular corticosteroid injection within the previous 6 months, iii) current or recent (within 4 weeks) oral corticosteroid use, iv) any muscular, joint, or neurological condition affecting lower limb function, v) ankle/foot pathology or pain that precluded the use of orthotics, vi) use of foot orthotics within the past 6 months, vii) use of footwear unable to accommodate an orthotic, and viii) inability to walk without a gait aid. All participants signed a consent form approved by the Institutional Research Ethics Board.

Orthotics

Upon meeting all eligibility criteria for the study, participants underwent a pedorthic assessment conducted by a Canadian Certified Pedorthist. This included creating a three-dimensional volumetric cast of each participant's foot in a subtalar joint neutral position to determine the amount of individualized arch support across the foot. For both types of orthotics, polypropylene sheets of 3-4 mm thickness were vacuum formed or milled directly to produce a sulcus length orthotic. The lateral wedge consisted of a 5-degree ethyl-vinyl-acetone (EVA) (Shore A hardness of 55) lateral posting incorporated into the length of the shell. For the lateral wedge plus arch support orthotic, the same lateral wedge was used in combination with a custom arch support shape and heel cup determined by the volumetric cast. Both orthotics (Figure 1) were finished with the same neoprene cover, sized according to shoe size, for improved comfort and patient compliance. Orthotics were made for both feet, even in those with unilateral knee OA. Approximately one week following the initial pedorthic assessment, participants had a follow-up appointment with the pedorthist to ensure that the newly-created orthotics fit appropriately in the participant's casual or sports footwear. Adjustments were made if necessary. Both pairs of orthotics were then sent directly to the gait testing laboratory for participant gait testing.

Gait Analysis

A three-dimensional gait analysis was conducted to examine the immediate biomechanical effects of each type of orthotic. There were three conditions: i) lateral wedge plus arch support orthotic, ii) lateral wedge alone, and iii) control (no orthotic). A control shoe, a sandal with straps to allow the placement of retro-reflective markers on various aspects of the forefoot and rearfoot to measure ankle/subtalar complex motion during gait, was used for each testing condition. For the two orthotic testing conditions, orthotics were inserted in the control shoes bilaterally without removing the retro-reflective markers. The control condition was always performed first, but the order of the two orthotic conditions was randomized for each individual. Data were processed by an individual unaware of testing order.

For each condition, three-dimensional motion and ground reaction force data were collected during gait. Thirty-one retro-reflective markers (Figure 2) were affixed over specific anatomical landmarks, including unilaterally over the sacrum, and bilaterally over the anterior superior iliac spine, lateral femoral epicondyle, lateral malleolus, and second toe. Rigid plates with four markers each were placed on the lateral thighs and shanks bilaterally, and triads of markers were placed on each heel. The locations of 10 additional retro-reflective markers (bilateral placement on the greater trochanter, medial femoral epicondyle, medial malleolus, first and fifth metatarsal heads) were recorded during a static calibration trial and used to calculate joint centres and marker orientations. Motion of the markers was collected at 120 Hz using 10 high-speed motion capture cameras (Motion Analysis Corporation, Santa Rosa, CA). Ground reaction force data were collected at 1200 Hz using two force platforms (Advanced Medical Technology Inc, Watertown MA) embedded in a walkway and synchronized with the cameras. At least five trials with clean force platform strikes were obtained for each condition. Photoelectric timers, placed at known distances apart on the walkway, were used to monitor walking velocity. Self-selected walking velocity was determined for the first condition (control), and only trials within 10% of the self-selected walking velocity were acceptable for the orthotic conditions. Participants were also asked to rate knee pain (11-point numerical rating scale (NRS), "0" = "no pain" and "10" = "worst imaginable pain") and foot comfort (11-point NRS, "0" = "completely uncomfortable" and "10" = "completely comfortable") after each condition, as well as the preferred orthotic following all testing.

Visual 3D (C-Motion, Rockville, MD) was used to calculate three-dimensional ankle/subtalar and knee kinematics according to the joint coordinate system[30], and three-dimensional ankle/subtalar and knee joint kinetics were calculated using inverse dynamics. Moments are reported herein as external moments. The rearfoot segment was defined by four segment definition markers: the medial and lateral calcaneal markers (part of the heel triad), and the first and fifth metatarsal head markers. The shank segment was defined by two proximal markers (medial and lateral femoral epicondyles) and two distal markers (medial and lateral malleoli). The thigh segment was defined by the medial and lateral femoral condyles, the anterior superior iliac spine, and the hip joint centre[31]. The static position of the thigh and shank rigid plates and heel triads with respect to the segment definition markers were calculated and used to track movements during the walking trials. The origin for the rearfoot coordinate system was located at the midpoint between the two calcaneal markers (the anterior-posterior axis was oriented to the midpoint of the metatarsal markers, the medial-lateral axis was oriented from the medial to lateral calcaneal markers, and the vertical axis was orthogonal to the other two axes). The origin for the shank coordinate system was located at the midpoint between the femoral epicondyle markers (vertical axis oriented to the midpoint of the lateral and medial malleoli, anterior-posterior axis orthogonal to the plane formed by the four segment definition markers, and medial-lateral axis orthogonal to the other two axes). The origin for the thigh coordinate system was located at the hip centre (vertical axis oriented to the midpoint of the lateral and medial femoral condyles, anterior-posterior axis orthogonal to the plane formed by the four segment definition markers, and medial-lateral axis orthogonal to the other two axes). Joint angles were calculated for the distal segment relative to the proximal segment using a Cardan XYZ sequence of rotations with six degrees of freedom[30].

Gait waveforms were time-normalized to percentage of stance (heel strike to toe off) and external moments were amplitude-normalized to body mass (units of Nm/kg). The lever arm of the ground reaction force (GRF) with respect to the centre of the knee joint was calculated in Matlab (MathWorks Inc, Natick, MA) using previously published equations[32]. Gait outcome measures of interest at the knee were the peak KAM, KAM impulse (calculated as the integral of the stance phase of the non-time normalized KAM waveform[33]), and the mean frontal plane component of the lever arm of the GRF with respect to the knee joint centre during 20-80% of stance. At the ankle/subtalar joint complex, the peak ankle eversion moment, the eversion moment impulse, the ankle eversion angle (i.e. frontal plane angle) peak, and ankle frontal plane excursion (difference between frontal plane angle at initial contact and peak eversion angle) were analyzed. Statistical analysis of the outcome measures was limited to the limb with knee OA in the cases of unilateral involvement, or the limb with the greater knee pain in the case of bilateral radiographic involvement.

Statistical Analysis

Statistical analyses were completed using SPSS Statistics, Version 22 (IBM Corporation, Armonk, NY) by a researcher not directly involved in the collection or processing of the data. Gait data were checked for normality prior to analysis. Biomechanical differences between the three conditions (lateral wedge plus arch support, lateral wedge, and control) were determined using a one-way repeated measures analysis of covariance (RM-ANCOVA) model for each of the 7 gait variables described above, with gait velocity as the covariate. A one-way RM-ANCOVA was also used to detect significant differences in self-reported knee pain and foot comfort. Significant main effects were further examined using post hoc pairwise comparisons with a Bonferroni correction based on the number of comparisons. Statistical significance was set at an alpha level of 0.05.

Results

Twenty-six participants (4 male, 22 female) with medial compartment knee OA participated in the study (mean age 64.0 years (SD 8.0 years), height 1.61 m (0.98), mass 70.6 kg (13.8), BMI 27.2 kg/m^2 (4.2), median foot posture index +6 (range 4-9)). Sixteen participants had a KL score of 2, and 10 participants had a KL score of 3. Baseline pain levels were 3.9 (2.3) on the 11-point NRS. There was no significant difference in walking velocity between the two orthotic conditions (mean gait velocity of 1.20 m/s for both the lateral wedge plus arch support and the lateral wedge, p=0.882), but the gait velocity for the control condition was significantly lower (1.18 m/s) than both orthotic conditions (p=0.02).

Table 1 outlines the differences in frontal plane biomechanical variables at the knee and ankle for each orthotic condition, compared to the control condition. Note that secondary analysis of data without covarying for gait speed provided similar findings. At the knee, there was a main effect of condition for the KAM peak. Both orthotic conditions resulted in a significant decrease in the KAM peak (mean difference of 0.03 Nm/kg, p<0.001, for lateral wedge, and mean difference of 0.02 Nm/kg, p=0.01, for lateral wedge plus arch support) relative to the control condition. In addition, both orthotic conditions resulted in a significant decrease in the KAM impulse (mean difference of 0.02 Nm/kg*s for lateral wedge, mean difference of 0.01 Nm/kg*s for lateral wedge plus arch support, p<0.001) relative to the control condition. However, there were no significant differences in the KAM peak or impulse between the two orthotic conditions (Figure 3). Compared to the control condition, the GRF frontal plane lever arm at the knee was significantly reduced with the use of the lateral wedge (mean difference of 1.90 mm, p<0.001), but not with the lateral wedge plus arch support (mean difference of 0.90 mm, p=0.07). There was no difference in the GRF frontal plane lever arm between orthotic conditions (p=0.06).

At the ankle/subtalar joint, the ankle eversion moment peak and impulse (Figure 3) were significantly increased for the lateral wedge relative to the control condition (mean difference of 0.03 Nm/kg for peak, mean difference of 0.01 Nm/kg*s for impulse, p<0.001) and the lateral wedge with arch support (mean difference of 0.00 Nm/kg for peak, mean difference of 0.00 Nm/kg*s for impulse, p<0.001). The frontal plane ankle excursion (Figure 4) was significantly reduced for the lateral wedge plus arch support compared to the control condition (mean difference of 0.77 degrees, p=0.02). The ankle eversion angle peak and frontal plane excursion were significantly reduced for the lateral wedge plus arch support compared to the lateral wedge condition (mean difference of 1.07 degrees for peak, mean difference of 1.15 degrees for excursion, p<0.001). There was no significant difference for the ankle eversion angle peak and frontal plane excursion between the lateral wedge and the control condition.

In terms of comfort, participants self-reported significantly greater comfort with the lateral wedge plus arch support (8.3/10) compared to the control condition (7.1/10, p=0.01). There was no significant difference in comfort between the lateral wedge (7.7/10) and control condition (p=0.17). There was no significant difference in knee pain between the three conditions (p=0.11); the control condition had a mean pain of 1.8/10, the lateral wedge condition had a mean pain of 1.6/10, and the lateral wedge plus arch support condition had a mean pain of 1.4/10. Most (n=18, 69%) participants preferred the lateral wedge with arch support over the lateral wedge. This was not due to orthotic testing order – the order of orthotic conditions was randomized, and 14 participants preferred the first orthotic, and 12 preferred the second orthotic.

Discussion

This study tested the immediate biomechanical effects of two types of orthotics (lateral wedge and lateral wedge plus arch support) for treatment of people with medial compartment knee OA and flat feet. It was hypothesized that the two orthotic conditions would provide similar KAM reductions relative to the control condition, while the lateral wedge alone would promote more ankle/subtalar eversion. These hypotheses were supported and are in agreement with previous research in people with knee OA and unreported (likely heterogeneous) foot postures[27].

Previous research has shown that lateral wedges result in reductions in the KAM ranging from 4-12%[11-18; 27]. In this study, the KAM peak and KAM impulse were reduced by approximately 8-9% in the lateral wedge condition. While there were no significant between-orthotic differences, mean reductions in the KAM with the use of the lateral wedge plus arch support were smaller; a 5% reduction for the KAM peak and a 6% reduction for the KAM impulse, indicating this style of orthotic may be less effective at reducing the KAM – likely due to the presence of support on the medial side. These results are consistent with those reported by Jones et al, who also looked at the immediate biomechanical response at the knee with the use of lateral wedges with and without medial arch support in healthy participants[26], and in participants with knee OA (although foot posture was not considered in these studies)[27]. Our observed significant reduction in the KAM with the use of the lateral wedge was likely due to the significant reduction in the frontal plane knee lever arm – an important determinant of change in KAM with lateral wedge use[16]. Though there was no significant difference in the frontal plane knee lever arm with the use of the lateral wedge plus arch support, there was a reduction, and these data support the mechanism of increased eversion leading to reduced knee lever arms, and subsequent smaller KAM values.

While the biomechanical results at the knee were similar between the two types of orthotics, the effects observed at the ankle/subtalar were different. The lateral wedge resulted in a greater ankle eversion angle peak compared to the lateral wedge plus arch support. There was no significant difference in the ankle eversion angle peak relative to the control condition with the lateral wedge plus arch support. These findings are similar to those reported by Jones et al who tested lateral wedges with and without off-the-shelf medial arch support in healthy participants[26]. While medial knee loading is reduced in those with increased eversion[34], the clinical implications of increased pronation with a lateral wedge alone may include aggravation of pre-existing foot/ankle symptoms, or development of foot/ankle symptoms over time. In contrast, the lateral wedge plus arch support reduced the ankle frontal plane excursion significantly compared to the control condition, indicating that it likely provided more foot support, albeit at the expense of a smaller magnitude of mean reduction in KAM parameters. Though the lateral wedge with arch support was rated as more comfortable (a finding consistent with Jones et al, who also found that healthy participants rated lateral wedges with medial arch support as more comfortable[26] and preferable, the longer-term symptomatic effects remain unknown. Specifically, knowledge of the long-term trade-off between the more immediate self-reported comfort and preference, as well as minimized ankle/subtalar eversion, and the smaller reduction in the KAM with the supported lateral wedge compared to the lateral wedge alone will provide key information needed to best inform clinical guidelines of orthotics usage in this population.

A major limitation of previous research on the use of lateral wedges has been the heterogeneity in the participant population; participants with a variety of foot postures have been included. This may potentially explain the wide variability in treatment response that has been observed[16; 19; 27]. In our study, which only included participants with flat feet, the peak KAM decreased in 23/26 participants (88%) with the use of the lateral wedge, and in 18/26 participants (69%) with the use of the lateral wedge plus arch support. Previous research in people with a variety of foot postures showed only 54% responded positively (reduced KAM) to lateral wedges and supported lateral wedges. It is possible that recruiting a homogeneous sample based on foot dynamics produced more consistent results in our study. However, despite this homogeneity, some individuals still did not experience a KAM reduction. This supports a recent commentary by Arnold advocating that lateral wedge prescription cannot be a “one size fits all” treatment approach[35]. While research into subgroup response is important in this regard as it will better focus the assessment of individuals for the purpose of treatment prescription, individual variability must still be recognized.

In his commentary, Arnold proposes that participant screening should be used to identify who is most likely to benefit from lateral wedges[35]. Chapman et al were able to predict who would respond to lateral wedge treatment by looking at ankle biomechanics[19]. They found that those with higher peak ankle eversion angles or a higher ankle eversion angle at the time of the peak KAM in the control condition were more likely to have a decrease the their KAM with the use of lateral wedges. It was hypothesized that this was due to available range of motion: those with a less everted ankle/subtalar joint complex may have restricted frontal plane range of motion which would not allow the ankle to evert sufficiently with lateral wedges to effectively reduce the KAM. While this finding appears to indicate that those with greater ankle eversion may benefit most from prescription of lateral wedges, foot posture of the participants was not considered. This conclusion may only apply to those without excessive foot pronation. However, a limitation of using ankle biomechanics during gait to identify those who would benefit most from lateral wedges is that three-dimensional gait analysis is not available to most clinicians. As a result, development of clinically-available tools that could be used to screen for those who would benefit from the use of orthotics will improve clinical outcomes.

As with any study, there are limitations of our study. We had a disproportionately large number of females (85%) in this study. Further, we only tested individuals with mild or moderate radiographic severity and mild knee pain. While those with severe knee OA (KL4) were not excluded, our sample did not include those with KL scores greater than 3. While we are unaware of any literature that reports differential response to lateral wedges based on sex or symptoms, the findings of this study may only be generalizable to patients with knee OA that exhibit these demographic and clinical characteristics. We limited our analysis to frontal plane angles and moments. We did this because lateral wedges aim to alter biomechanics in the frontal plane, and are not designed to alter sagittal biomechanics. It is recognized that non-frontal plane biomechanics, particularly the knee flexion moment, are important factors in the risk of knee OA progression[7; 8]. However, Jones et al have previously demonstrated that lateral wedges with and without medial arch support do not significantly affect the knee flexion moment in participants with knee OA. Though foot posture was not controlled in the Jones study, there was no difference in the knee flexion moment when participants were separated into “responders and non-responders” to lateral wedge use[27]. Additionally, the foot was modelled as a rigid body in this study. Future research could involve a foot model that would allow the interactions of the forefoot and hindfoot to be studied more accurately. Finally, a limitation of the study is that we only assessed the immediate biomechanical effects of the two orthotics. The effects may vary over longer periods of time as neuromuscular adaptation occurs. Future research could determine whether the immediate biomechanical effects observed in this study are maintained over time and whether they relate to a differential symptomatic response.

In conclusion, both a lateral wedge and a combined lateral wedge with individualized arch support significantly reduced the KAM in people with knee OA and flat feet. However the lateral wedge results in small increases in eversion angles and moments at the ankle/subtalar complex whilst the combined orthotic does not. Although these changes at the ankle are of uncertain clinical significance, our findings suggest that clinicians may prefer to use the combined orthotic to reduce loads across the knee in people with knee OA in order to minimize the risk of foot and ankle symptoms as a consequence of orthotic treatment.

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Figure Legends

Figure 1. Control sandal (A), lateral wedge (B) and lateral wedge plus arch support (C).

Figure 2. Marker set-up for the present study.

Figure 3. Frontal plane moments at the knee (A) and ankle (B) for each of the conditions (control condition in black solid, lateral wedge condition in black dashed, lateral wedge plus arch support condition in gray solid). A) Both of the orthotics resulted in a significant decrease in the knee adduction moment peak and impulse, compared to the control condition. There was no significant difference between the two orthotics. B) The ankle eversion moment peak (negative values) was significantly increased with the use of the lateral wedge compared to the control condition, and was higher with the lateral wedge than with the lateral wedge plus arch support.

Figure 4. Frontal plane angle at the ankle for each of the conditions (control condition in black solid, lateral wedge condition in black dashed, lateral wedge plus arch support condition in gray solid). Eversion is negative. There were no significant differences between the control condition and either orthotic, but the ankle eversion angle peak was significantly higher in the lateral wedge condition than the lateral wedge plus arch support condition. Frontal plane excursion was significantly reduced with the use of the lateral wedge plus arch support compared to the control condition and the lateral wedge.

Table 1: Effects of the lateral wedge plus arch support and the lateral wedge on frontal plane knee and ankle biomechanical variables, with mean differences (95% confidence intervals) compared to the control condition reported. Note, all values are adjusted for baseline gait speed.

Variable	Control	Lateral Wedge + Arch Support		Lateral Wedge	
	Mean (sd)	Mean (sd)	Mean difference (95% confidence interval)	Mean (sd)	Mean difference (95% confidence interval)
Peak KAM (Nm/kg)	0.43 (0.15)	0.40 (0.16)*	0.02 (0.00, 0.04)	0.39 (0.16)*	0.03 (0.01, 0.05)
KAM impulse (Nm/kg*s)	0.17 (0.08)	0.16 (0.09)*	0.01 (0.00, 0.02)	0.16 (0.09)*	0.02 (0.01, 0.02)
Frontal plane knee lever arm (mm)	34.20 (15.15)	33.30 (15.32)	0.90 (0.00, 2.00)	32.30 (15.44)*	1.90 (1.00, 3.00)
Peak ankle eversion£ moment (Nm/kg)	-0.12 (0.09)	-0.12 (0.09)†	-0.00 (-0.02, 0.01)	-0.15 (0.10)*	0.03 (0.02, 0.04)
Ankle eversion£ moment impulse (Nm/kg*s)	-0.04 (0.04)	-0.04 (0.04)†	0.00 (-0.01, 0.01)	-0.06 (0.05)*	0.01 (0.01, 0.02)
Ankle eversion£ angle peak (degrees)	-3.25 (3.40)	-3.24 (3.66)†	-0.01 (-1.06, 1.05)	-4.31 (3.77)	1.06 (-0.66, 2.19)
Ankle frontal plane excursion (degrees)	9.00 (2.65)	8.23 (2.56)*†	0.77 (0.16, 1.37)	9.38 (2.72)	-0.38 (-1.01, 0.25)

***** Indicates a significant difference compared to the control condition (p<0.05).
† Indicates a significant difference compared to the lateral wedge only condition (p<0.05)
£ Ankle eversion is negative and ankle inversion is positive

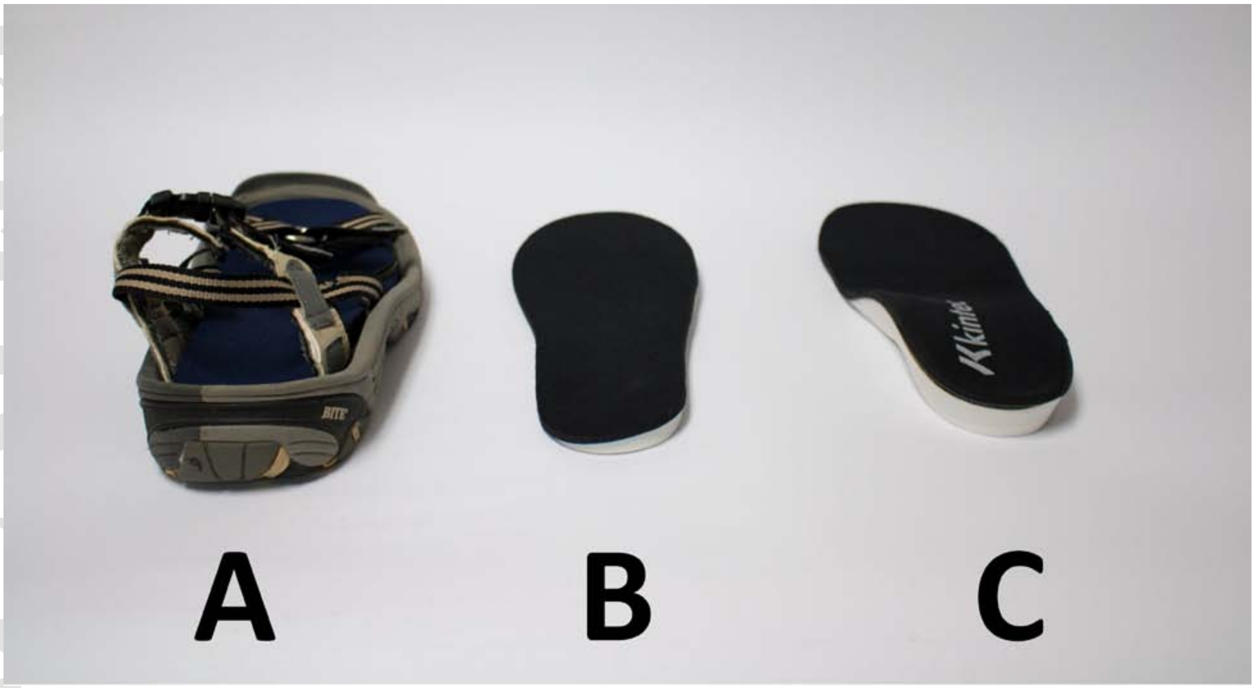

Figure 1

Figure 2

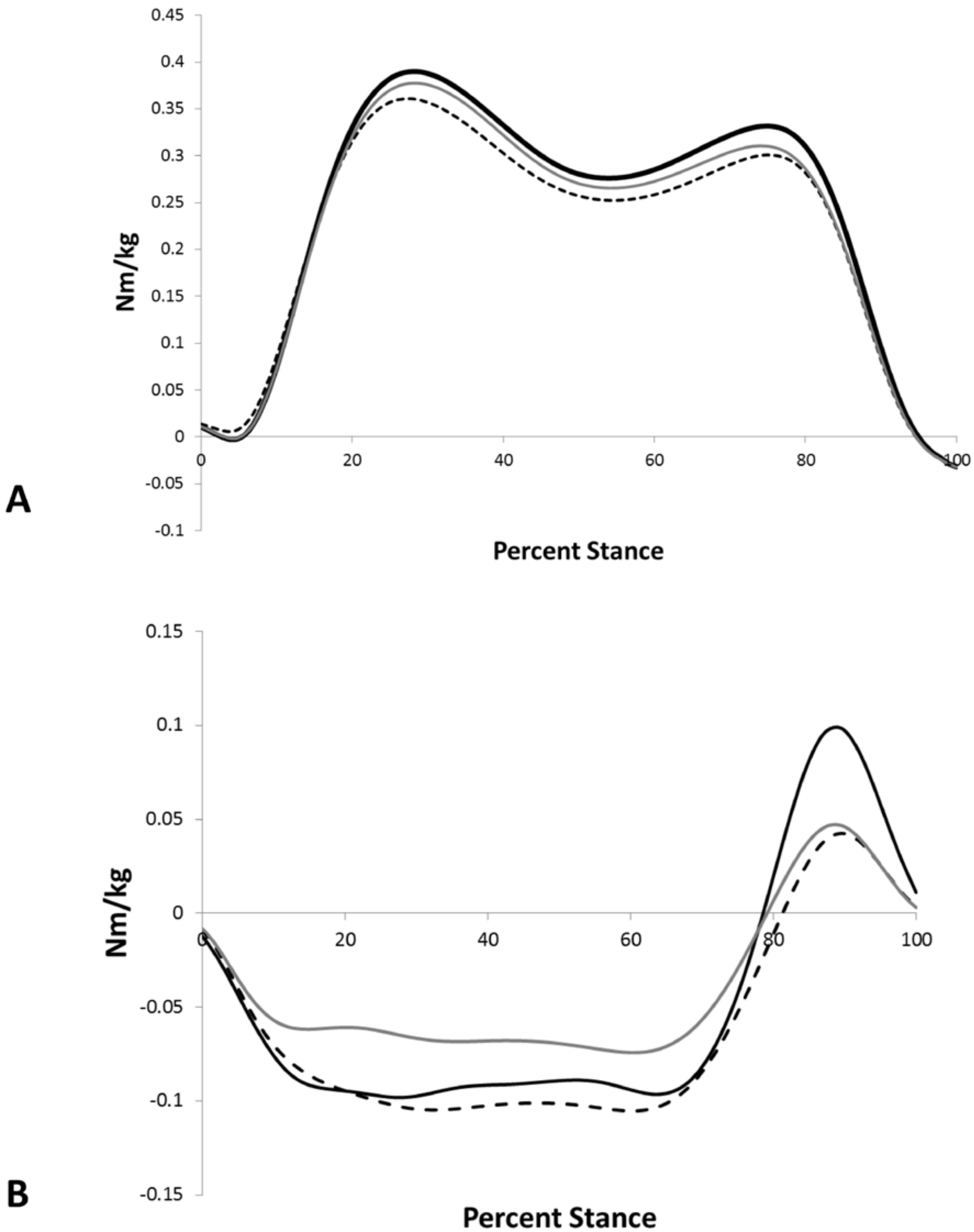
A
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
Nm/kg
0
20
40
60
80
100
Percent Stance
B
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
Nm/kg
0
20
40
60
80
100
Percent Stance

Figure 3

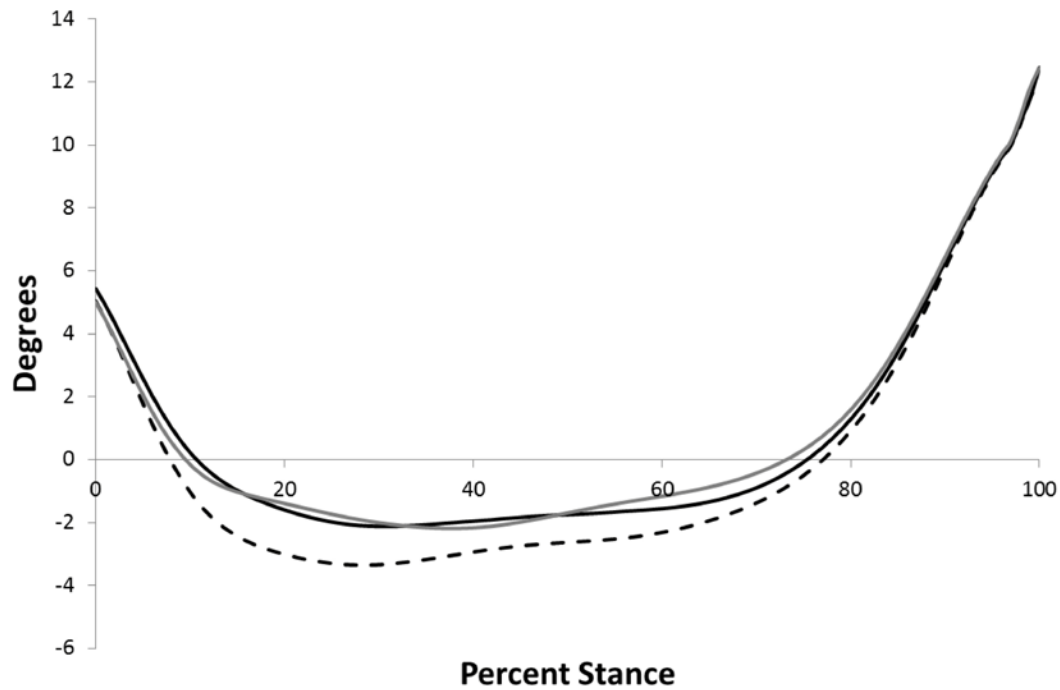

Figure 4