Immediate Coronal Plane Kinetic Effects of Novel Lateral-offset Sole Shoes and Lateral-wedge Insole Shoes in Healthy Individuals

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abstract

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To investigate kinetic differences in the coronal plane between healthy individuals wearing shoes with lateral-offset soles and shoes with lateral-wedge insoles while walking, hip abduction, knee adduction, and ankle abduction moments were estimated using a 3-dimensional motion analysis system under 3 different conditions: wearing conventional shoes (control), wearing lateral-offset sole shoes (condition A), and wearing lateral-wedge insole shoes (condition B). Forty-eight healthy individuals (24 men and 24 women) were tested. Condition A resulted in a significantly reduced peak knee adduction moment compared with the control (condition A = 0.316 Nm/kg; control = 0.380 Nm/kg; P = .006). The peak knee adduction moment of condition B was also lower than that of the control (condition B = 0.299 Nm/kg; P = .002); however, the peak knee adduction moment was not significantly different between conditions A and B (P = .386). Condition B resulted in an increased mean ankle abduction moment in the stance phase compared with the control and condition A (control = 0.007 Nm/kg; condition A = 0.013 Nm/kg; condition B = 0.023 Nm/kg) (control vs condition A, P = .051; control vs condition B, P < .001; condition A vs condition B, P = .002). The hip abduction moments were not significantly different between the control and condition A, control and condition B, or conditions A and B. Wearing lateral-offset sole shoes reduces the peak knee adduction moment and exerts less influence on ankle moment than does wearing lateral-wedge insole shoes. Neither lateral-offset sole shoes nor lateral-wedge insole shoes induce kinetic changes in the coronal plane of the hip.

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Knee osteoarthritis affects an estimated 20% to 40% of individuals older than 65 years.1,2 Medial compartment knee osteoarthritis is 10 times more common than lateral compartment knee osteoarthritis. This discrepancy is the result of greater load on the medial compartment cartilage of the knee joint.3-5 Influenced primarily by the knee adduction moment, the peak knee adduction moment during gait is related to severity, progression, and degree of pain in medial compartment knee joint osteoarthritis.4,6 For this reason, many studies of load-altering interventions to reduce peak knee adduction moment during gait for the treatment of medial compartment knee osteoarthritis have been performed.7,9

One of these mechanical interventions is the use of lateral-wedge insole shoes. Previous studies have indicated that wearing such shoes reduces the peak knee adduction moment; however, such shoes also induce excessive ankle valgus alignment, with associated increases in ankle abduction moment, and may cause ankle and subtalar joint problems.10-12 These altered mechanical alignments may also create changes in hip moment. The current authors hypothesized that shoes with soles that are laterally offset in the coronal plane would not only reduce the peak knee adduction moment, but also minimize increases of the ankle and hip abduction moments. Such laterally offset, trapezoid-soled shoes may ameliorate the progression and reduce the degree of pain associated with medial compartment knee osteoarthritis while inducing fewer ankle and hip joint problems than lateral-wedge insole shoes.

The purposes of this study were to compare the kinetic effects of wearing lateral-offset sole shoes and lateral-wedge insole shoes in the coronal plane among healthy individuals during walking and to determine which type of shoe better reduces peak knee adduction moment without also inducing excessive ankle and hip abduction moments. The first hypothesis was that both lateral-offset sole shoes and lateral-wedge insole shoes would reduce peak knee adduction moment during walking compared with conventional shoes. The second hypothesis was that both lateral-offset sole shoes and lateral-wedge insole shoes would increase ankle abduction moment during walking compared with conventional shoes but that the amount of increase would be less when wearing lateral-offset sole shoes than when wearing lateral-wedge insole shoes. The third hypothesis was that the hip abduction moment would also be affected by shoe type but that the amount of increase in hip abduction moment would be less when wearing lateral-offset sole shoes than when wearing lateral-wedge insole shoes. The first hypothesis was that both lateral-offset sole shoes and lateral-wedge insole shoes would reduce peak knee adduction moment; however, such shoes reduce peak knee adduction moment during walking compared with conventional shoes. The second hypothesis was that both lateral-offset sole shoes and lateral-wedge insole shoes would increase ankle abduction moment during walking compared with conventional shoes but that the amount of increase would be less when wearing lateral-offset sole shoes than when wearing lateral-wedge insole shoes. The third hypothesis was that the hip abduction moment would also be affected by shoe type but that the amount of increase in hip abduction moment would be less when wearing lateral-offset sole shoes than when wearing lateral-wedge insole shoes.

**MATERIALS AND METHODS**

**Participants**

Forty-eight healthy young participants (mean age, 23.5±2.5 years) (Table 1) were recruited using public advertisements. The number of participants required was calculated using data from a pilot study of coronal plane kinetics that included a sample of 10 healthy young Korean individuals (level of significance, 0.05; power of the test, 0.80).13 All participants provided written informed consent. The study protocol was approved by the institutional review board of Korea University Hospital.

Demographic data (ie, age, sex, history of trauma, height, weight, medications, and medical diagnoses) were acquired through interviews. To detect abnormal alignment or functional impairments of participants’ lower extremities, physical examinations were performed by a single orthopedic specialist, and radiologic assessments were performed by a single trained radiologist and another orthopedic specialist. Standing long-leg anteroposterior radiographs were obtained to assess coronal plane alignment of the lower extremities.14 The mechanical axis angle of the lower extremities has been defined as the angle between 1 line drawn from the center of the femoral head to the deepest part of the femoral notch at the knee, with a second line drawn from the midpoint of the tibial plateau to the midpoint of the inner extension of the tibiotalar joint.15 A mechanical axis angle within 3° of neutral has been accepted as normal alignment.

Participants with anatomic or functional problems (eg, musculoskeletal diseases or injuries, abnormal alignment, wearing load-altering shoes or other types of custom orthotics) of the lower extremities were excluded from the study.

**Experimental Protocol**

Three different types of shoes were tested: conventional shoes (control), lateral-offset sole shoes (condition A), and lateral-wedge insole shoes (condition B). Before testing, all participants performed walking trials at self-estimated normal

**Table 1**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean±SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>23.5±2.5</td>
</tr>
<tr>
<td>No. of men/women</td>
<td>24/24</td>
</tr>
<tr>
<td>Height, m</td>
<td>1.7±0.19</td>
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<tr>
<td>Weight, kg</td>
<td>70.5±21.5</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>23.79±4.79</td>
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<tr>
<td>Cadence, step/min</td>
<td>111.6±15.65</td>
</tr>
<tr>
<td>Speed, cm/s</td>
<td>113.78±25.28</td>
</tr>
<tr>
<td>Stride length, cm</td>
<td>125.28±19.68</td>
</tr>
<tr>
<td>Step width, cm</td>
<td>62.65±9.85</td>
</tr>
<tr>
<td>Stance phase, %</td>
<td>61.6±3.35</td>
</tr>
<tr>
<td>Swing phase, %</td>
<td>38.25±2.9</td>
</tr>
<tr>
<td>Mechanical axis angle</td>
<td>0.05</td>
</tr>
<tr>
<td>Right</td>
<td>1.86±0.55</td>
</tr>
<tr>
<td>Left</td>
<td>1.06±0.42</td>
</tr>
</tbody>
</table>

Abbreviations: BMI, body mass index; deg, degrees.
speeds wearing each of the 3 shoe types on both feet in random order. Information regarding the properties of the shoes was not given to participants to prevent attempts to alter stride length, stride width, or foot progression angle during gait. The technicians who collected data were given no information about the shoe types except for shoe names to prevent any influence on data collection. All participants were given approximately 30 minutes of rest between testing each type of shoe to minimize effects on the next test. All shoes used in this experiment were manufactured by a single vendor, were of uniform stiffness and made of the same materials, and were the correct size for each participant.

Before walking trials, reflective markers (10 mm in diameter) were placed on bony landmarks while the participants were in anatomic position with the shoes on to define the thigh, shank, and foot segments according to the Helen Hayes marker system.26 The landmarks included the anterior superior iliac spine, tip of the fifth lumbar spinous process, thigh wand (distal third point of the line from the anterior superior iliac spine to the patellar center), medial and lateral femoral epicondyles, shank wand (distal third point of the line from patellar center to the midpoint of the medial and lateral malleolus), calcaneal tuberosity (the most prominent point of the posterior surface of the heel), and second metatarsal head of both lower extremities. The markers for the calcaneal tuberosities and second metatarsal heads were placed directly over the calcaneal tuberosities, and the second metatarsal heads projected through holes of the laboratory shoe.

To establish the relationships among markers for each participant in an anatomical position with shoes on, after the markers were attached, participants were instructed to stand for 5 seconds in an erect posture on a force platform with a comfortable degree of toeing out. The relationships among the markers were reestablished for each shoe type. For the walking trials, participants were asked to proceed along a walkway at a self-estimated normal walking speed. Three practice walking trials were permitted so participants would become familiar with the testing environment. Three acceptable walking trials were obtained for each participant and for each shoe type.

The conventional shoes used in the study had rectangular soles in the axial plane and flat, thin insoles. The lateral-offset sole shoes had the same flat, thin insoles as the conventional shoes, but the soles were laterally shifted and trapzoidal in the axial plane, running the full length of the shoes with the plane of the sole perpendicular to the gravity line (Figure 1). The shifting angle (defined as the angle between the gravity line and the axis of the sole in the axial plane) of the lateral-offset soles was 10°. A shifting angle of 10° was based on a pilot study that found that the knee adduction moment was inversely proportionate to the shifting angle; however, excessive shifting angles (greater than 10°) induced subjective ankle discomfort and joint instability while standing and walking.

The lateral-wedge insole shoes used in the study had insoles similar to those of the conventional shoes, except for insole shape. The insoles of the lateral-wedge insole shoes ran the full length of the shoe and had a 5° valgus angle (defined as the angle between the ground plane and the surface of the wedged insole in the axial plane), with the lateral thickness slightly greater than the medial thickness. The wedged insole was attached to the bottom of a thin, flat insole that was the same as the insole used in the conventional shoes. The 5° wedge was also based on the pilot study.23 The 10° shifting angle of the lateral-offset sole and 5° valgus angle of the lateral-wedge insole had similar effects when reducing the knee adduction moment, and wedging greater than 5° was associated with subjective ankle discomfort and instability.16 Therefore, it was decided that the 5° wedged insole was optimal for this study.

**Data Acquisition**

Three-dimensional gait analysis was performed using a motion analysis system comprising 6 infrared cameras and 2 force platforms. Force platforms (500-Hz vertical natural frequency) were placed at the center of a 6-meter walkway to assess the vertical, coronal, and sagittal components of ground reaction force and the location...
of the center of pressure during the stance phase of gait. Infrared cameras were used to assess the 3-dimensional positions of infrared reflecting markers that were attached to each participant’s skin and shoes over bony landmarks. Each infrared camera was calibrated before data collection. Three-dimensional marker routes were captured during gait by a frame-by-frame motion-capture software program (EVaRT version 5.0; Motion Analysis Corporation, Boston, Massachusetts) at a frequency of 60 Hz. External moments at each joint center were calculated using biomechanical data analysis software (OrthoTrak; Motion Analysis Corporation) for kinetic and kinematic data.

**Results**

Results are shown in Table 2. Condition A demonstrated significantly reduced peak knee adduction moments compared with the control (condition A = 0.316 Nm/kg; control = 0.380 Nm/kg; *P* = .006). The peak knee adduction moment of condition B was also lower than that of the control (condition B = 0.299 Nm/kg; *P* = .002). However, the peak knee adduction moment was not significantly different between conditions A and B (*P* = .386) (Figure 2). Condition B demonstrated increased mean ankle abduction moment in the stance phase compared with the control and condition A (control = 0.007 Nm/kg; condition A = 0.013 Nm/kg; condition B = 0.023 Nm/kg; control vs condition A, *P* = .051; control vs condition B, *P* < .001; condition A vs condition B, *P* = .002) (Figure 3). Hip adduction moments were not significantly different between the control and condition A, the control and condition B, or conditions A and B (Figure 4).

**Discussion**

This study’s results support the first and second hypotheses, indicating that wearing lateral-offset sole shoes reduces peak knee adduction moment with less...
Influence on ankle abduction moment than wearing lateral-wedge insole shoes during normal gait. Previous studies have found that lateral-wedge insole shoes shift the center of pressure to the lateral side of the shoe, shortening the length of the knee joint moment arm and reducing the knee adduction moment during the stance phase.10,12,15,16,19-22 The results of the current study also support this action mechanism, with a similar reduction of the knee adduction moment in participants wearing lateral-wedge insole shoes.

In participants wearing lateral-offset sole shoes, the mechanism of reducing the knee adduction moment can be explained in the same way as for lateral-wedge insole shoes: the lateral-offset sole shifts the center of pressure to the lateral side of the shoe in the axial plane and reduces the knee adduction moment arm. Although both lateral-wedge insole shoes and lateral-offset sole shoes have the same mechanism of action for the reduction of the knee adduction moment, the mechanism of action for the increase of the ankle abduction moment differs between lateral-wedge insole shoes and lateral-offset sole shoes, regardless of whether foot eversion is induced. The lateral shift of the center of pressure causes an increase in the ankle abduction moment by lengthening the ankle moment arm in both lateral-wedge insole shoes and lateral-offset sole shoes.

If the slope of the wedged insole in the lateral-wedge insole shoe and the degree of offset angle of the lateral-offset sole shoe are equal, the lateral shift of the center of pressure should be equal for both shoes. However, additional foot eversion is induced in the ankle joint by lateral-wedge insole shoes because the foot naturally tries to maintain the alignment of the lower extremity to the weight-bearing axis by musculoskeletal adaptation. This additional eversion aggravates the lengthening of the ankle moment arm, which in turn causes an increase of the ankle abduction moment. However, the planes of the upper and bottom surfaces of lateral-offset soles are parallel to the ground, which does not induce additional foot eversion. Thus, the length of the moment arm and the ankle joint abduction moment are smaller than those of lateral-wedge insole shoes (Figure 5).

Although the offset angles of lateral-offset sole shoes are greater than the wedge slopes of lateral-wedge insole shoes, the ankle abduction moment associated with the peak knee adduction moment is paradoxically greater in lateral-wedge insole shoes. This indicates that lateral-offset sole shoes may prevent additional foot eversion. Previous studies suggested that the effects associated with lateral-wedge insole shoes may cause ankle and subtalar joint problems.12,19,21,27,28 However, the lateral-offset sole shoes examined in the current study caused no excessive increases in the ankle abduction moment. This indicates that lateral-offset sole shoes are more comfortable for the ankle joint than lateral-wedge insole shoes.

The reductions of the peak knee adduction moment and mean ankle abduction moment observed in this study were slightly less than those observed in other studies.15,16,21 This may be due to the lower degree of slope of the lateral-wedge insole shoes used in the current study (5°) than in other studies (6°-10°).15,16,21 If the slope was greater than 6°, the reduction of the peak knee adduction and mean ankle abduction moment is expected to be greater in lateral-wedge insole shoes.

The study’s third hypothesis was that altered knee and ankle coronal plane moments would change the hip coronal plane moment (hip adduction moment). However, the hip adduction moment was not significantly different according to shoe type in the study because the hip ad-
ductor muscles around the hip joint compensated for the hip abduction moment caused by the lateral shifting of the center of pressure to maintain the normal posture of the leg and trunk.

The peak knee adduction moment in patients with medial compartment osteoarthritis is greater than in healthy individuals, and the risk of progression of medial compartment knee osteoarthritis increases as the peak knee adduction moment increases. Fisher et al reported that shoe design can influence loading at the knee. Although altered shoe insole angles (lateral-wedge insole) reduce the peak knee adduction moment, these immediate biomechanical effects are greater in individuals with greater peak knee adduction moments.

In a prospective study, Barrios et al reported that lateral wedging may aid in maintaining coronal plane knee mechanics prior to intervention over a 12-month time period and has long-term biomechanical effects in patients with medial knee osteoarthritis. In the current study, both the lateral-wedge insole shoes and the lateral-offset sole shoes had immediate biomechanical effects in reducing peak knee adduction moment in healthy individuals; therefore, the use of lateral-wedge insole shoes and lateral-offset sole shoes may have greater immediate effects in reducing peak knee adduction moments for patients with medial compartment knee osteoarthritis than for healthy individuals and may also have long-term biomechanical effects in reducing peak knee adduction moments. However, it could not be determined whether the lateral-wedge insole shoe and lateral-offset sole shoes would have immediate or long-term biomechanical effects for patients with medial compartment osteoarthritis because the study was performed to evaluate immediate biomechanical effects in healthy individuals.

Although many studies have shown a positive biomechanical long-term effect of the lateral wedge, a recent randomized, controlled study by Bennell et al on the 1-year clinical effects of lateral-wedge insoles reported that lateral-wedge insoles provided no symptomatic or structural benefits compared with flat insoles. This suggests that no proportional relationship exists between the biomechanical benefit and clinical outcome of the lateral wedge in patients with medial compartment osteoarthritis. However, it is possible that clinical outcome (ie, symptoms, functional activity, and cartilage degradation) is controlled by multiple factors, although the medial compartment load is the most important factor in pain severity and progression of medial compartment osteoarthritis and the pain in medial compartment osteoarthritis is not generated from the medial compartment alone but rather from other regions of the knee. Moreover, in a study on articular cartilage changes in patients with medial compartment osteoarthritis after high tibial osteotomy, which is a more powerful load-altering intervention to medial compartment osteoarthritis than lateral-wedge insoles, the cartilage of the medial compartment began to regenerate 6 months postoperatively. Therefore, a time period of 1 year was not long enough to detect disease modification in the study of Bennell et al.

CONCLUSION

The current study’s results suggest that wearing lateral-offset sole shoes can reduce the peak knee adduction moment with less influence on the ankle joint than wearing lateral-wedge insole shoes and that neither lateral-offset sole shoes nor lateral-wedge insole shoes affect the hip coronal plane moment. The current design of the lateral-offset sole shoe may represent a new and more comfortable form of mechanical intervention to reduce the knee adduction moment.

One limitation of this study was that only healthy individuals with normal knee alignments were included; thus, the findings may not be applicable to patients with knee osteoarthritis or with high adduction moments. However, the lateral-offset sole shoe may be more beneficial for such patients than the lateral-wedge insole shoe. Further studies of patients with medial compartment knee osteoarthritis are pending.

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