ORIGINAl ARTICLE

Effects of Laterally Wedged Insoles on Knee and Subtalar Joint Moments

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Objective: To assess the biomechanic effects of wearing a lateral wedge on the knee joint varus moment during gait in elders with and without knee osteoarthritides (OA).

Design: Crossover design whereby subjects walked under 2 different insole conditions: a 0° control wedge and a 6° lateral wedge.

Setting: A gait laboratory with 3-dimensional motion analysis and force platform equipment.

Participants: Thirteen healthy subjects and 13 knee patients with OA.

Interventions: Not applicable.

Main Outcome Measures: Frontal plane angles and moments at the knee and subtalar joints, ground reaction forces, and center of pressure. Moments were derived by using a 3-dimensional inverse dynamics model of the lower extremity.

Results: The 6° lateral wedge significantly reduced knee joint varus moment and increased subtalar joint valgus moment in both groups when compared with no wedge. All patients had a greater knee joint varus moment with a similar subtalar joint valgus moment compared with the people without OA. There were diverse, sometimes reversed effects with the insole among the patients.

Conclusions: The 6° lateral wedge did not consistently reduce the knee joint varus moment in patients with knee OA. The biomechanic indications and limitations of laterally wedged insoles should be confirmed by a larger study.

Key Words: Biomechanics; Gait; Rehabilitation; Shoes.

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THE EFFECT OF WEARING a laterally wedged insole to reduce symptoms in osteoarthritic patients with a varus deformity of the knee was first reported in 1987. Since then, kinematic and kinetic analyses of this condition have mainly focused on a static standing position. Yasuda and Sasaki and Wolfe and Brueckmann reported that wearing a laterally wedged insole reduced the load in the medial compartment of the knee, which was effective for the treatment of knee pain in patients with osteoarthritides (OA). Since the early 1990s, the evidence relating to the clinical efficacy of wearing a laterally wedged insole as a treatment for patients with OA has also been reported in dynamic conditions, but these studies did not answer the question of what mechanisms reduced symptoms in OA patients. The effect of wearing a laterally wedged insole has not been sufficiently studied.

Recently, Crenshaw and Kerrigan and colleagues reported that wearing a laterally wedged insole reduced the knee joint varus moment, suggesting an effective mechanism for knee pain reduction in patients with OA. However, Maly et al found that wearing a laterally wedged insole did not significantly reduce the knee joint varus moment during gait. These studies suggested that the beneficial effects of wearing a laterally wedged insole were not consistent for OA patients, and hence we were interested in the biomechanic details that affected the knee joint varus moment during gait with a laterally wedged insole.

Keating et al suggested that the knee joint varus moment during gait with a laterally wedged insole was associated with the subtalar joint valgus angle. Our previous study found that healthy young adults wearing a laterally wedged insole had changes in knee joint varus moment and subtalar joint valgus moment during gait via the more laterally shifted location of the center of pressure (COP). Our current study focused on how the knee joint varus moment in patients with OA was associated with the angle and moment at the subtalar joint during gait while wearing a laterally wedged insole. In particular, our objective was to assess frontal plane kinematic and kinetic effects of wearing a 6° wedged insole on the knee joint moments. We hypothesized that the same knee joint varus moment reduction obtained with a 6° laterally wedged insole during gait in healthy elders would also be present in age-matched patients with OA.

METHODS

Participants

After informed consent was obtained, 26 elderly women (13 healthy elders, 13 osteoarthritic patients with a varus deformity of the knee) participated in the experiments. There were no statistically significant differences in age, height, and weight (table 1). OA patients were recruited through public advertisements in local community programs about knee OA in the area around the National Rehabilitation Center. The inclusion criteria for OA patients were: 50 years of age or older, knee pain for at least 6 months, and bilateral knee OA with a definite osteophyte indicated by radiograph. In addition to these inclusion criteria, the subjects must have met one of the following conditions: morning (initial) stiffness for less than 30 minutes, or crepitus on active motion of the knee (ie, with weight-bearing, eg, squatting). Patients with OA were excluded if they were currently using a wedged insole or other custom orthotics in their shoes; had had surgery on the lower extremities; or had had significant weight loss (≥ 10%) in the past 6 months.

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ity; had concurrent clinically active arthritis of the hip, ankle, hindfoot, or midfoot; had unilateral knee symptoms; or were unable to walk without a cane or walker. Healthy, age-matched elders were also recruited through public advertisements among the local community-dwelling elders.

**Radiologic Assessment**

The anteroposterior radiographs of both entire legs were acquired with subjects standing barefoot and with knees in full extension. If a subject had a flexion contracture of the knee joint, the radiographic beam was projected along the joint space. Based on these weight-bearing radiographs, the femorotibial angles of the less affected legs in healthy elders (all right legs) and the more affected legs in OA patients (6 right legs, 7 left legs) were calculated as the static alignment of the lower extremity. The femorotibial angle was defined as the lateral angle between the femoral shaft and the tibial shaft. The radiographic alignment was measured by a trained investigator.

**Data Acquisition System**

Three-dimensional gait analyses were conducted with a motion analysis system (Vicon 512 System) operating at 60Hz with 12 infrared cameras and 8 force platforms (9281C) operating at 60Hz. Force platforms were situated at the midpoint of a 7m walkway. Before data collection, each infrared camera was calibrated, and it was confirmed that the average spatial resolution was less than 2mm over a measured volume of 2.4x0.8x1.0m. Infrared cameras were used to measure the 3-dimensional positions of infrared reflecting markers that were attached to each subject’s skin over bony landmarks (see Experimental Protocol below). The position of each marker was calculated by a dynamic linear transformation method in a fixed laboratory coordinate system. The vertical and mediolateral (ML) components of the ground reaction force and the location of the COP during the stance phase of gait were also obtained by using the force platforms.

**Laterally Wedged Insoles**

Two different laterally wedged insoles were tested: a control wedge with a 0° lateral angle (N) and a wedge with a 6° lateral angle (W). The control wedge was placed under the entire foot and had an even thickness from medial to lateral as well as from hindfoot to forefoot. The lateral wedges ran along the full length of the insole from the hindfoot to the forefoot. They had a coefficient of elasticity of 100 to 300kg/mm² and were made of ethylene vinyl acetate (EVA 8200). Insoles were supplied in several sizes to accommodate the differences in subjects’ foot size. We needed to attach the infrared reflecting markers to each subject’s skin over the bony landmarks of the feet. For this reason, the insoles were attached to subjects’ bare feet (around the hindfoot, midtarsal, second, or big toe) by using adhesive tapes after ethanol swab.

### Table 1: Anthropometric Data of the Subjects

<table>
<thead>
<tr>
<th>Data</th>
<th>Healthy Elders (n=13)</th>
<th>OA Patients (n=13)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (cm)</td>
<td>150.0 ± 6.0</td>
<td>153.7 ± 6.0</td>
<td>.183</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>54.1 ± 7.2</td>
<td>57.3 ± 10.3</td>
<td>.376</td>
</tr>
<tr>
<td>Femorotibial angle (deg)</td>
<td>172.9 ± 3.7</td>
<td>177.5 ± 3.9</td>
<td>.007</td>
</tr>
</tbody>
</table>

NOTE. Values are mean ± standard deviation. Boldface denotes significance.

### Experimental Protocol

Before the trials, reflective markers (diameter, 20mm) were placed over bony landmarks to minimize skin movement—the greater trochanter, lateral and medial femoral condyles, anterolateral and anteromedial tibial condyles, lateral and medial malleoli, lateral and medial calcaneal tubercles, head of talus, and 1st and 5th metatarsal heads—to define the thigh, shank, and foot segments. After the markers were attached, subjects were instructed to stand barefoot for 5 seconds to establish the relationship among the markers for the subject’s initial anatomic position. In this barefoot standing trial, they were instructed to stand with knees as fully extended as possible, the ankles at 0° dorsiflexion, and a comfortable degree of toeing-out.

For the walking trials, insoles were attached to the subjects’ feet and they were asked to walk at a walking speed of 95 steps/min, indicated by a metronome, to match the cadence of the patients with OA. This threshold speed corresponded to the self-selected walking speed of the OA patients (95 ±4 steps/min). The insoles with the N and W wedges were randomly assigned to subjects and no attempt was made to control stride length, stride width, or foot progression angle during gait.

### Data Analysis

A 3-segment rigid link model was used to describe the motion of the lower extremity in the frontal plane (fig 1). We used local reference systems to obtain the angles and moments at the knee and subtalar joints with respect to the actual rotation axes of the joints. The rotation of the knee joint was defined as the rotation of the tibial condyle relative to the femoral condyle. The rotation of the subtalar joint was defined as the rotation of the calcaneus relative to the lateral-medial malleoli. The axis of rotation of the knee joint was midway between the markers on the lateral and medial femoral condyles and the anterolateral and anteromedial tibial condyles. The axis of rotation of the subtalar joint was defined by using the markers on the lateral calcaneal tubercle and head of the talus. The moments acting about each joint were calculated using an inverse dynamics algorithm and expressed as external forces, moments, and ground reaction forces.

Fig 1. The models and coordinate systems of the subtalar joint and knee joint are shown. Abbreviations: θ, angle; GRF, ground reaction force; M, moment; W, segment weight. Adapted with permission from Kakihana et al. Copyright by Am J Phys Med Rehabil.
moments. The valgus moment arm of the subtalar joint was defined as the perpendicular distance from the line of action of the ground reaction force to the subtalar joint axis in the subtalar joint coordinate system. Joint moments as well as vertical and ML ground reaction forces were normalized for body weight and reported in newton meters per kilograms.

Stance-phase data of the control group were normalized to 100% for their less affected right legs only. The stance-phase data for the patients with OA were normalized to 100% for their more affected right or left legs only. The data were considered to be valid when the markers were detected, that is, when there was no fragmentation of the marker trajectories. The mean and standard deviations were obtained from 10 trials with each insole.

**Statistical Analysis**

The average moments at the knee and subtalar joints were equivalent to the division of the area under the moment-time curve (fig 2) and its time of application, respectively. Evaluations of the average angles at the knee and subtalar joints, ML
and vertical ground reaction force, and valgus moment arm of the subtalar joint during stance phase were performed by using the same methods as for those applied for the average moments at the knee and subtalar joints. A comparison of each average parameter was performed by using a 2 (groups: healthy elders, OA patients) by 2 (conditions: insole N, insole W) analysis of variance with repeated measures on the last factor. Statistical evaluations were performed with the SPSS software program, version 11, with significance defined as $P < .05$. In addition, simple regression analysis with Pearson coefficients was used to determine correlation between the femorotibial angle and the knee joint varus moment during walking.

### RESULTS

The effects of wearing lateral wedged insoles on the knee and subtalar joint moments during stance phase were evident in each insole condition in both the healthy elders and the OA patients (fig 2, table 2). The knee joint varus moment was significantly smaller for insole W compared with insole N (a 10.4% reduction for the healthy elders, a 5.6% reduction for the OA patients; $P < .001$), whereas the subtalar joint valgus moment was significantly greater for insole W compared with insole N (a 27.7% increase for healthy elders, a 23.5% increase for OA patients; $P < .001$).

The angles at the knee and subtalar joints did not show any changes between the 2 insole conditions. In addition, no obvious differences in the insole conditions were found for the vertical ground reaction forces during the stance phase; however, the ML ground reaction forces during the stance phase for insole W were significantly greater compared with those for insole N (a 1.8% increase for healthy elders, a 3.7% increase for OA patients; $P = .035$). The most remarkable difference between the insole conditions was the shift of the COP location: the COP location was always parallel to the subtalar joint axis, but it shifted more laterally when wearing insole W (fig 3A). Consistent with this difference, the valgus moment arm of the subtalar joint for insole W was significantly greater compared with insole N (a 30.0% increase for healthy elders, a 13.0% increase for OA patients; $P < .001$) and hence produced a significantly smaller knee joint varus moment than insole N.

Figure 4 represents the change between the subtalar joint valgus moment and the knee joint varus moment from insole condition N to W of each subject. There was a reversed correlation between the subtalar joint valgus moment and the knee joint varus moment in all healthy elders (13/13) and in the majority of the OA patients (11/13). But in 2 OA patients, both the knee joint varus moment and the subtalar joint valgus moment were greater for insole W compared with insole N. In addition, the 2 subjects showed a medially shifted COP trajectory when wearing insole W, contrary to all the other OA patients (fig 3B).

The differences in femorotibial angle between the healthy elders and OA patients (172.9°±3.7° vs 177.5°±3.9°, $P = .007$) were accompanied by differences in the varus angle and moment at the knee joint. Patients with OA had greater knee joint varus moments than the healthy elders (a 24.1% increase for insole N, a 30.7% increase for insole W; $P = .005$). There was a stronger correlation between the femorotibial angle and the knee joint varus moment with insole N in the healthy elders (r = .52, $P = .070$) than in the OA patients (r = .30, $P = .325$), but this correlation was not significant for either group (fig 5).

### DISCUSSION

Our study examined the kinematic and kinetic factors of a 6° lateral wedge insole (insole W) on the knee joint varus moment in healthy elders and in OA patients. The knee joint varus moment was significantly smaller, whereas the subtalar joint valgus moment was significantly greater with insole W compared with insole N (0° wedge) in both the healthy elders and the OA patients. With insole W, this finding correlated with a more lateral shift in the location of the COP during the stance phase. This could explain the reduced knee joint varus moment obtained with the OA patients still differed significantly compared with the healthy elders and OA patients (172.9° vs 177.5°, $P = .007$).

This study’s results support in part the hypothesis that the same reduction in the knee joint varus moment obtained with insole W in healthy elders would also be present in age-matched OA patients. Compared with insole N, insole W significantly reduced the knee joint varus moment regardless of group assignment (healthy elders or OA patients). There was a 10.4% reduction for the healthy elders and a 5.6% reduction for

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**Figure 2:** Average values between the 2 insole conditions (N: healthy elders, W: OA patients) for the knee joint varus moment (Nm/kg), subtalar joint valgus moment (Nm/kg), and ML ground reaction force (N/kg). Significant differences are noted in the table.**

**Table 2:** Stance Phase Average Values Between 0° Lateral Wedge (N) and 6° Lateral Wedge (W)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Healthy Elders (n=13)</th>
<th>OA Patients (n=13)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>W</td>
<td></td>
</tr>
<tr>
<td><strong>Moment (Nm/kg)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee joint varus</td>
<td>0.29±0.01</td>
<td>0.26±0.02</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Subtalar joint valgus</td>
<td>-0.18±0.01</td>
<td>-0.23±0.01</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Subtalar joint moment (Nm/kg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee joint varus</td>
<td>0.27±0.18</td>
<td>0.35±0.18</td>
<td>.094</td>
</tr>
<tr>
<td>Knee joint valgus</td>
<td>-6.81±1.47</td>
<td>-6.46±1.49</td>
<td>.915</td>
</tr>
<tr>
<td>Subtalar joint valgus</td>
<td>3.38±0.99</td>
<td>1.99±0.56</td>
<td>.142</td>
</tr>
<tr>
<td>Subtalar joint moment</td>
<td>-1.02±0.37</td>
<td>-1.46±0.34</td>
<td>.070</td>
</tr>
<tr>
<td>Mean</td>
<td>0.53±0.03</td>
<td>0.54±0.02</td>
<td>.035</td>
</tr>
<tr>
<td>Subtalar joint moment (Nm/kg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee joint varus</td>
<td>1.23±0.84</td>
<td>2.18±0.83</td>
<td>.049</td>
</tr>
<tr>
<td>Knee joint valgus</td>
<td>-2.68±1.09</td>
<td>-2.88±1.17</td>
<td>.915</td>
</tr>
<tr>
<td>Subtalar joint valgus</td>
<td>1.75±0.38</td>
<td>1.96±0.47</td>
<td>.142</td>
</tr>
<tr>
<td>Subtalar joint moment</td>
<td>-1.35±0.40</td>
<td>-2.14±0.71</td>
<td>.070</td>
</tr>
<tr>
<td>ML ground reaction force (N/kg)</td>
<td>7.52±0.11</td>
<td>7.49±0.10</td>
<td>.942</td>
</tr>
<tr>
<td>ML vertical</td>
<td>7.58±0.16</td>
<td>7.62±0.09</td>
<td>.777</td>
</tr>
<tr>
<td>Distance (mm)</td>
<td>20.72±1.82</td>
<td>26.80±1.52</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Subtalar joint moment arm</td>
<td>22.58±2.24</td>
<td>26.08±1.95</td>
<td>.827</td>
</tr>
</tbody>
</table>

**NOTE.** Values of columns N and W are mean ± standard error. Boldface denotes significance.

Abbreviations: 1, difference between insole conditions; 2, difference between subject groups; 3, interaction between insole conditions and subject groups.
the OA patients in the knee joint varus moment. These reductions were associated with a significant increase in the subtalar joint valgus moment, which to our knowledge have not been published elsewhere. There was a 27.7% increase for the healthy elders and a 23.5% increase for the OA patients in the subtalar joint valgus moment with insole W.

There have been few reports on the effects of wearing a laterally wedged insole on the angle and moment at the subtalar joint. Yasuda and Sasaki\textsuperscript{2} found that, in a static standing position, the laterally wedged insole increased the valgus angle of the subtalar joint, and therefore reduced the load in the medial compartment of the knee joint. Keating et al\textsuperscript{5} suggested that during walking an increased valgus angle of the subtalar joint obtained by a laterally wedged insole might be effective for the reduction of knee pain in OA patients. In our study, the subtalar joint valgus angle did not increase significantly with the laterally wedged insole. It was assumed that the effect of wearing the laterally wedged insole on the subtalar joint angle during gait was not systematic among the subjects, in particular among OA patients. In contrast, our previous study\textsuperscript{11} and this one indicate that wearing a laterally wedged insole had the same effect on the increased subtalar joint valgus moment during gait in people with and without knee OA. We found that wearing a laterally wedged insole significantly increased the valgus moment arm of the subtalar joint, creating a lateral shift in COP location. It is assumed that this lateral shift in the location of the COP decreases the length of the knee joint moment arm resulting in a reduction of the knee joint varus moment.

This assumption was not completely met. It is generally known that wearing a laterally wedged insole reduces knee joint varus moment in the early stage of knee OA. Keating\textsuperscript{5}
showed clinically that some OA patients received less benefit from a laterally wedged insole. Two of our 13 OA patients (15.4%) who had an increased knee joint varus moment with the laterally wedged insole did not differ from the other OA patients in clinical history, physical examination, or radiologic assessment. The results of the COP location for the same 2 patients showed an increase in knee joint varus moment that differed from the other OA patients: their COP trajectory moved medially, not laterally. This biomechanic finding suggests other factors involved like biochemical changes of the articular cartilage. A close analysis of cartilage changes might help explain the nonbeneficial effect of a laterally wedged insole to those patients who do not show a reduction in knee joint varus moment. We would like to address these issues in the future. The detailed understanding of joint biomechanics during walking associated with a laterally wedged insole may further the improvement of designing appropriate wedged insoles, therefore assisting in the rehabilitation process aimed to improve gait in OA patients. In addition, physical therapy that focuses specifically on strengthening the muscles and ligaments around the knee joint may also assist in reducing maladaptive joint moments during walking.

Although the beneficial effect of reducing knee joint varus moment with a laterally wedged insole were evident in both the healthy elders and the patients with OA, the patients with OA wearing such an insole had significantly greater knee joint varus moments during gait compared with healthy elders. This finding could be interpreted as follows: the 6° lateral wedge seems to have a range of effectiveness where it successfully reduces the varus moments in OA patients. Although wearing a 6° lateral wedge reduced the varus moment significantly, it was unable to reduce it to normative levels. Kerrigan et al. showed that wearing a 10° lateral wedge further reduced the knee joint varus moment; however, it was associated with varying degrees of discomfort. Furthermore, it was assumed that the presence of knee OA was sufficient to generate differences in knee joint biomechanics during gait from age-matched, healthy elders. The dissimilarities in the femorotibial angle between the healthy elders and the OA patients were accompanied by differences in the knee varus angle and moment during stance phase.

Our study had several limitations that might reduce the generalization of our results. First, our subjects had to fix the laterally wedged insoles with adhesive and surgical tapes around their bare feet, not insert them into shoes. Second, our healthy elders had to walk at a controlled cadence that corresponded to the self-selected walking speed of the OA patients. Controlling cadence in only 1 group may have created a neuromuscular effect that we did not assess or for which we did not account. Finally, we only had a small sample of subjects with a disproportionate sex distribution. It is possible that the small sample size reduced the statistical power to detect differences in more variables, such as the subtalar joint valgus angle during gait.

CONCLUSIONS

Generally, patients with OA had significant differences in knee joint biomechanics during walking when compared with age-matched healthy elders. As compared with insole N (0° wedge), insole W (6° wedge) significantly reduced the knee joint varus moment and increased the subtalar joint valgus moment during gait. These results of insole W also correlated with a lateral shift in the location of the COP during stance phase. With respect to the 2 OA patients who had an increase in the knee joint varus moment with insole W suggests that the indication and limitations of laterally wedged insoles in general should be analyzed in more detail, possibly leading to new guidelines for the use of such wedged insoles.

References


Suppliers
b. Kistler Japan Co Ltd, 2-7-5 Shibadaimon, Minato-ku, Tokyo, Japan.
c. Kyowa Shokai, 2-4-3 Sotohama-cho, Suma-ku, Kobe, Japan.
d. SPSS, 1-1-39 Hiroo, Shibuya-ku, Tokyo, Japan.