INTRODUCTION

Wearing high heels alters walking kinematics and kinetics and can create potentially adverse effects on the musculoskeletal structures of the lower extremity. Although research is limited, higher external knee adduction moments, which are thought to contribute to larger medial tibiofemoral compartment loads [1], have been shown in shoes of moderate heel height compared to flat shoes [2, 3]. Additionally, little is known about the effects of heel height on the hip and ankle in the frontal plane. Our purpose was to determine how heel height affects frontal plane joint moments at the hip, knee, and ankle, with a specific focus on the external knee moment due to its importance for joint loading and knee osteoarthritis (OA) [1]. It was hypothesized that frontal plane net joint moments of the lower extremity increase systematically as heel height increases.

METHODS

Fifteen women (23.8 ± 4.4 yrs, 165.5 ± 7.1 cm, 60.9 ± 8.7 kg) completed two test sessions. In session 1, anthropometric measures were taken and subjects were fitted with three shoes with heel heights of 1, 5, and 9 cm. Heel height was randomly ordered and preferred walking speed was determined for each shoe condition as the average of 10 overground trials. Subjects then practiced overground walking at the experimental speed of 1.3 m·s⁻¹ for each of the three heel height conditions.

Session 2 was completed within 7 days after session 1. Fifteen reflective markers were placed on anatomical landmarks of the subject’s trunk, pelvis and right lower extremity. Subjects completed shoe conditions in the same randomly determined order as used in session 1. Ten trials for each of the three heel height conditions were completed at each subject’s preferred walking speed (± 3%). Subjects then completed 10 trials for each heel height condition at 1.3 ± 0.04 m·s⁻¹. Marker position and ground reaction force (GRF) data were collected synchronously at 200 Hz and 1000 Hz, respectively.

Net internal three-dimensional joint moments were calculated using inverse dynamics with rigid body assumptions. Because of limited musculature counteracting the external knee adduction moment [1], the frontal plane knee moment was presented as an external knee moment [2, 4], whereas the hip and ankle were expressed as internal joint moments.

A one-way, repeated measures ANOVA was used to assess the effect of heel height on frontal plane net joint moments and walking kinematics for preferred and fixed walking speed conditions.

RESULTS AND DISCUSSION

Average preferred walking speed was slower for 9 cm heels (1.28±0.15 m·s⁻¹) compared to 1 cm (1.35±0.10 m·s⁻¹) and 5 cm heels (1.35±0.15 m·s⁻¹). Overall, heel height effects on net frontal plane moments of the hip, knee, and ankle were similar for fixed and preferred walking speed conditions; peak joint moments increased as heel height increased (Table 1).

As hypothesized and consistent with previous heel height investigations [2, 3], peak external knee adduction moments early and late in the stance phase increased systematically as heel height increased for fixed speed and preferred speed conditions (Fig 1). Our results demonstrate that the direct relationship between heel height and peak external knee adduction moment can be extended beyond moderate heel heights, which has important implications on how higher heel heights affect medial loading in the knee. Because high external
knee adduction moments are believed to be an important contributor to the development of medial compartment knee OA, wearing high heels, especially higher heels, may put individuals at greater risk for developing knee OA.

As expected, net frontal plane ankle moments increased in amplitude as heel height increased. Specifically, peak ankle eversion moment was higher for the 5 and 9 cm heel heights compared to the 1 cm height for both fixed and preferred speed conditions (Table 1). Kinetic changes at the ankle with increasing heel height likely contribute to adverse loading at the knee. Lower peak external knee adduction moments have been associated with lower peak ankle eversion moments [5]. Increasing heel height contributes to an inversion-biased foot position, contributing to higher peak ankle eversion moments and higher peak external knee adduction moments. Therefore, the changes in foot and ankle orientation with higher heel heights may contribute to higher compression on the medial compartment of the knee.

Table 1. Mean (SD) frontal plane joint moments (N·m·kg⁻¹) in response to heel height at fixed and preferred walking speeds.

<table>
<thead>
<tr>
<th></th>
<th>1.3 m·s⁻¹</th>
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<th>Preferred speed</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>1 cm</td>
<td>5 cm</td>
</tr>
<tr>
<td>Peak internal hip abduction moment a</td>
<td>0.78(0.07)</td>
<td>0.79(0.08)</td>
<td>0.86(0.09)</td>
</tr>
<tr>
<td>Peak external knee adduction moment – early stance a b</td>
<td>0.46(0.11)</td>
<td>0.48(0.07)</td>
<td>0.55(0.08)</td>
</tr>
<tr>
<td>Peak external knee adduction moment – late stance a b</td>
<td>0.38(0.06)</td>
<td>0.44(0.09)</td>
<td>0.49(0.10)</td>
</tr>
<tr>
<td>Peak internal ankle eversion moment a b</td>
<td>0.14(0.08)</td>
<td>0.23(0.12)</td>
<td>0.29(0.10)</td>
</tr>
</tbody>
</table>

a = significant heel height effect (p<0.05) for fixed speed trials, b = significant heel height effect for preferred speed trials

Although the peak frontal plane hip moment slightly increased as heel height increased, only the peak hip abduction moment for the 9 cm heel height in early stance under the fixed speed condition differed significantly from other values (Table 1). A higher peak hip abduction moment during stance would attempt to produce a more varus position at the knee, contributing to medial loading within the knee. However, because differences in hip moments were small with differing heel heights, adaptations within the hip with increasing heel height likely do not contribute substantially to adverse loading at the knee.

CONCLUSIONS

Frontal plane net joint moments of the lower extremity during the stance phase of walking increase systematically as heel height increases. The observed changes likely contribute to higher compressive loading on the medial aspect of the knee, which is believed to contribute to the development of knee OA. Therefore, wearing high heels may put individuals at greater risk for the development of medial compartment knee OA.

REFERENCES