Gait Analysis after Shoe Lifts in Adults with Unilateral Developmental Dysplasia of the Hip

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Received 7 Aug 2005; Accepted 20 Sep 2005

Abstract

Shoe lifts are able to correct the leg-length discrepancies (LLDs) and relieve limp gaits of patients with unilateral developmental dysplasia of the hip (DDH). Four unilateral DDH patients were treated for leg-length equalization using shoe lifts. We evaluated gait parameters and the performance of the shoe lifts. The results showed that shoe lifts not only improved pelvic levelness, but also reduced supinatory forces within the shorter limb and pronatory forces within the longer limb. However, shoe lifts added vertical ground-reaction force (GRF) on the affected side which may cause increases of joint stress of the lower limbs. To diminish the reaction force, the heels and outsoles should be made of materials with proper shock-absorbing capabilities and as little mass as possible. Moreover, the forefoot rocker in the shoe lifts provided easier and smoother motion during the process of propelling the body forward, however, the rocker also reduced the support force for the contraction of the gastrocnemius and soleus muscles, and thus diminished the propelled force.

Keywords: Developmental dysplasia of the hip, Shoe lifts, Gait analysis, Ground reaction force

Introduction

Adult patients with unilateral developmental dysplasia of the hip (DDH) have leg-length discrepancies (LLDs). LLDs have been related to postural anomalies during standing and walking with a characteristic limp that causes more energy expenditure and asymmetrical gait [1-5]. The long-term effects of LLDs are low-back pain and arthritis of the hip on both limbs [2-5,6-8].

Lia et al. [9] reported that patients with Crowe Type-4 DDH showed significant clinical improvements after total hip arthroplasty (THA) with concomitant leg-length equalization in unilateral patients. The outcomes of the surgeries showed that the patients not only experienced reduced pain, but also had significantly improved ability to walk efficiently and comfortably. However, THA is not appropriate for the young or adult DDH patients without severe arthritis on the hip. Lengthening of the shorter limb requires long and complicated processes [10]. To correct LLDs to a reasonable range and relieve the amount of complications, shoe lifts on the lower limbs have become acceptable and necessary for the unilateral DDH patients [11]. Shoe lifts improve the patients’ ability to walk efficiently and comfortably which have been widely observed in clinical application, but a comprehensive gait analysis of unilateral DDH patients after wearing shoe lifts is still lacking. The objectives of this study were to investigate gait parameters with the use of shoe lifts for adult patients with unilateral DDH and to determine the performance of shoe lifts.

Subjects and Methods

Four unilateral DDH patients (one male and three female) who had LLD participated in this study. Two patients had legs shorter on the left side and two patients had legs shorter on the right (Table 1). Their ages ranged from 22 to 38 years (mean, 31 years), body weight ranged from 47 to 59 kg (mean, 50.8 kg), and body height ranged from 151 to 170 cm (mean, 159 cm). LLDs, measured as the difference between the highest point of the iliac crest and the lateral malleolus without force added to achieve pelvic levelness, ranged from 55 to 75 mm (mean, 64 mm). Among the four patients, two patients had used shoe lifts since childhood, while the others had never used shoe lifts.

The shoe lifts in this study were designed to fit each patient such that the patients wore the footwear on the lower limb to correct the LLD within 20 mm. The shoe lifts were composed of Ethylvinyl Acetate foaming (EVA; type C hardness: 70-80, density: 0.19-0.23 g/cm3) and rubber (type C hardness: 65-68, density: 1-1.2 g/cm3) outsoles (Figure 1). The outsole was designed from forefoot to heel and could not be
Table 1. Subject characteristics

<table>
<thead>
<tr>
<th>No.</th>
<th>Age</th>
<th>Sex</th>
<th>LLD (mm)</th>
<th>Affected side</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>38</td>
<td>M</td>
<td>75</td>
<td>L</td>
<td>170</td>
<td>59</td>
</tr>
<tr>
<td>2</td>
<td>22</td>
<td>F</td>
<td>70</td>
<td>R</td>
<td>151</td>
<td>49</td>
</tr>
<tr>
<td>3</td>
<td>38</td>
<td>F</td>
<td>55</td>
<td>R</td>
<td>156</td>
<td>48</td>
</tr>
<tr>
<td>4</td>
<td>26</td>
<td>F</td>
<td>55</td>
<td>L</td>
<td>159</td>
<td>47</td>
</tr>
</tbody>
</table>

Figure 1. The composition of outsole and the design of forefoot rocker

Figure 2. The subject is wearing the footwear and 15 light-reflecting markers are set according to the Helen-Hays method [12].

bent during walking. To provide an easier and smoother motion during the process of propelling the body forward, the shoe lifts were furnished a rocker at the forefoot.

Fifteen light-reflecting markers were attached to each subject according to the Helen-Hays method [12]. These anatomical landmarks are as follows: the anterior superior iliac spine (ASIS), the greater trochanter, the mid-thigh, the knee joint line, the mid-shank, the lateral malleolus, and between the second and third metatarsal heads bilaterally and 10 cm above the sacrum at the midline (Figure 2). Each subject walked at his or her selected speed on an 11 m long and 2.1 m wide walkway equipped with a motion analysis system (ExpertVision, Motion Analysis Corporation, Santa Rosa, CA) containing six cameras and three force plates (Type 9281B, Kistler Instrument, Winterthur, Switzerland). A photocell trigger was placed 3 m away from the first force plate to synchronize the signals from the cameras and the force plates.

Data from four walking trials were collected for each subject while with and without shoe lifts. In the group of without shoe lifts, the shoes worn in affected and unaffected sides were the same.

Kinematics and kinetics data of both limbs were measured during each trial. Ortho Track software (Motion Analysis Corporation, Santa Rosa, CA) was used during the computation of gait parameters. The gait parameters included: walking velocity, cadence, step and stride lengths and single and total support times. The vertical ground-reaction forces (GRF) were normalized to each patient’s body weight. The ratio of the affected side versus the unaffected side (a/u ratio) was used as an index of bilateral symmetry for some of the gait parameters. Paired t-tests were applied for statistical analysis of differences between with and without shoe lifts. A p value <0.01 was considered as statistically significant.

Results

Temporo-spatial parameters

Temporo-spatial parameters are shown in Table 2. The walking velocity, cadence and stride length on the affected side with shoe lifts were larger than those without shoe lifts, but their differences were not significant. The a/u ratio for single and total supports had the same effects, but the ratios in the step length, single and total supports were also not significantly different.

Angular changes

The pelvis obliquity on the frontal plane of the healthy subjects showed a sinusoid curve with the stance-side down and the swing-side up [9]. In the trials without shoe lifts, the
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Figure 3. Pelvic obliquity on the frontal plane, a 22-year-old woman with and without a shoe lift on the right side. The gray area is the mean standard deviation of the healthy subjects [9].

Figure 4. More flexion of the knee joints in the unaffected sides as without shoe lifts on the affected side (a 38-year-old man).

Figure 5. More pronation of ankle joints throughout the gait cycle in the unaffected sides as without shoe lifts on affected sides (a 38-year-old man).

Subjects without shoe lifts had more flexion of the knee joints on the unaffected side than those with shoe lifts (Figure 4). Subjects without shoe lifts had more pronation of their ankle joints throughout the gait cycles on the unaffected sides (Figure 5).

Ground-reaction force (GRF)

The GRF curve of the healthy subjects had two peaks during the stance phase, where the first peak occurred before midstance and the other occurred after midstance. The GRF curves of the unilateral DDH patients on the affected sides lacked an obvious peak after midstance. The first peak for those with shoe lifts increased markedly; the peak value of shoe lifts was 2.5 times higher than for those without shoe lifts (Figure 6). A shift of the GRF to the lateral side occurred during the stance phase on the side without shoe lifts (Figure 7).

Discussion

In this study, we designed the shoe lifts with different thicknesses on the outsoles to fit each unilateral DDH patient. The primary reason for this design was to ensure that each patient had the LLD corrected to within 20 mm. These would cause difficulty in comparison between patients, but we used this design to allow for comparisons of gait parameters with and without the use of shoe lifts and to investigate the shoe lift design.

None of the temporo-spatial parameters for patients with and without shoe lifts were significantly different. This unexpected outcome may have resulted from four major compensatory mechanisms during walking. The first compensatory mechanism was that the pelvis dropped with leaning of the ipsilateral aspect of the trunk on the shorter side. This phenomenon was observed from that the pelvis on the side without a shoe lift remained lower than the side with a shoe lift throughout the gait cycle (Figure 3). The second was that the subjects had more flexion of the knee on the longer side to equalize the functional limb lengths (Figure 4). The third was that the pronation effect of the foot on the longer side was obvious to equalize the functional limb lengths (Figure 5). The fourth was that the subject held his or her foot in equine and supination on the shorter side. This compensatory reaction resulted in a shift of the GRF to the lateral side which occurred during the stance phase on the side without a shoe lift (Figure 7). Though the temporo-spatial parameters were not significantly different in our results, they indicated that the addition of shoe lifts resulted in an equalization of the parameters.

Our results showed that an equalization of compensatory mechanisms between both feet resulted in a reduction of pelvic obliquity on the frontal plane, a 22-year-old woman with and without a shoe lift on the right side. The gray area is the mean standard deviation of the healthy subjects [9].
promatory forces within the longer limb and supinatory forces within the shorter limb. These findings are consistent with the results of D’Amoco [13] and Schuit’s [14] studies, although their subjects exhibited a structural LLDs of between 5 and 20 mm and heel lifts equalized the amount of LLD up to a maximum thickness of 12.7 mm.

In the vertical GRF curve during the stance phase, the first peak is an indication of the impact force at and immediately following heel strike as the center of gravity of the body is elevated [13]. In this study, the first peak of the GRF on the side with a shoe lift was markedly increased (Figure 6). This adverse effect may have caused increases of joint stress to the lower limb. This phenomenon may be due to the greater impulse of the heel and outsole of the footwear, which resulted from the increase of material hardness and mass. To diminish the reaction force, the heel and outsole should be made of materials with proper shock-absorbing capability and as little mass as possible.

The GRF curves lacked obvious peaks after midstance in this study (Figure 6). This phenomenon resulted from two major reasons. The first reason was the protective compensation of the DDH subjects who had dysplastic hips. The subjects had reduced push-off force for the affected limbs as adaptation to reduce the load on the joints. This protective compensation was observed in the patients with dysplasia of the hips [15]. The second was the design of shoe lifts in this study. The forefoot rocker had an unfixed point to provide easier and smoother motion during the process of propelling the body forward (Figure 1), however, they reduced the support force for the contraction of the gastrocnemius and soleus muscles and thus the GRF decreased.

The hip joints of the healthy subjects are ball-and-socket joints with cuplike acetabulums which make the femoral head rotation without translations, and articular capsule, ligaments, and muscles surrounding the joints contribute to the stability of joints [16]. However, an adult patient with DDH has dysplastic femoral head and acetabulum, and a pseudo hip joint placed above the acetabulum. This pseudo hip joint generally lacks appropriate support to fix the femoral head firmly, a piston-like sliding occurs between the femoral head and ilium during a gait cycle; the femoral head slides up during the stance phase and slide down during the swing phase. This effect resulted in the pelvis on the affected side with a shoe lift to remain lower than on the unaffected side, especially around the heel strike due to marked sliding up on the femoral head (Figure 3).

In this study, we observed unilateral DDH patients with the piston-like sliding between the femoral head and ilium during a gait cycle. This effect changed the related positions of the landmarks on the affected sides between the ASIS and others. Further studies of DDH patients while proposing a mathematical method to trace the position of the femoral head on the affected sides could be used to more accurately analyze the kinematics and kinetics parameters of the gait.

The forefoot rocker used in this study was furnished by manufacturer according to experience. The rocker is a necessary design in shoe lift to easier and smoother walking, but it could provide a propelling motion unlike a normal foot and shoe and may change the gait parameters. Hence, the effects of forefoot rocker on gait parameter and motion efficiency should be investigated in future work.

Conclusions

Shoe lifts improved the pelvic levelness and eliminated the limp on the LLDs for unilateral DDH patients and reduced pronatory forces on the longer limb and supinatory forces on the shorter limb. However, the use of shoe lifts also added vertical GRF, which may cause increased joint stress of the lower limbs. To diminish the contact forces of the shoe lifts, the materials of the heel and outsole should be made of materials with proper shock-absorbing capability and as little mass as possible. A forefoot rocker provided easier and smoother motion during the process of propelling the body forward, but it also diminished the propelling force.

Acknowledgements

This study was supported by the NSC Southern Rehabilitation Engineering Research Center. We would like to express our thanks to Professor Hsu Ar-Tyan of the Department of Physical Therapy at the National Cheng Kung University for providing valuable opinions.

References

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