GAIT ANALYSIS WITH ANKLE ARTHRODESIS SHOES DURING LEVEL WALKING AND STAIR CLIMBING

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INTRODUCTION
Arthrodesis of the ankle is an established operation. The lack of normal ankle movement after ankle arthrodesis reduced the ability of the patients to walk smoothly on the arthrodesis foot. It would have a more profound effect in negotiating stairs, because large ranges of dorsiflexion and plantarflexion are required to accomplish this activity. Although gait characteristics have been reported for this population during level walking [1-3], little information is available regarding the compensations required for stair ambulation. In addition, only a limited number of scientific studies on the biomechanics of normal stair climbing are available in the literature [4-10]. We hypothesize that the special-design shoes will benefit these patients. To examine the effect of the ankle arthrodesis shoe, an understanding of the in-shoe plantar pressures and kinematics of the foot with the ankle arthrodesis shoe during stair climbing is necessary. Therefore, this study aims to investigate the gait parameters and in-shoe plantar pressures during level walking, stair climbing and stair descending with the help of healthy volunteers so that the effect of the modified shoe for the foot with ankle arthrodesis could be assessed.

METHODS
Ankle arthrodesis shoe:
It is suggested that patients wear the regular flat-bottom sport shoe with fitting of a SACH heel and a metatarsal rocker. At the same time, equalizing lift is needed on the normal side to balance the SACH heel and metatarsal rocker on the involved side. The rocker centered at 60% of the foot length from the heel and extended in each direction from this point with a continuous curve. The material thickness was 1 cm under the heel and 1 cm under the rocker. To allow a reasonably natural strike, the heel portion was filled with a soft wedge.

Equipment & Experimental protocol:
Eleven normal subjects (4 male, 7 female) participated in this study. The mean age of these subjects was 36.2±8.7 years, mean weight was 62.1±8.1 kg, and mean height was 167.8±4.3 cm. These subjects had no history of lower extremity disorders or pathological conditions. A six-camera Expert Vision™ motion analysis system (Motion Analysis Corporation, Santa Rosa, CA) and Pedar insole pressure measurement system (Novel, Germany) were simultaneously used to capture motion trajectories and collect foot pressure, respectively, for each subject wearing the ankle arthrodesis shoes or traditional shoes during level walking, stair climbing and stair descending. A set of 10 markers was placed on the body of each subject, lateral tibial condyle, medial tibial condyle, lateral malleolus, medial malleolus, cluster of markers over the lateral calcaneous and cluster of markers over the middle of the first metatarsal bone [1-3]. To place the cluster of markers directly on dorsal surface of the foot inside a shoe, small circular incisions with 1 cm diameter on the lateral heel counters and the vamp of shoes were cut. Data were collected when the subjects walked wearing a normal or modified shoe during
ascending and descending stairs without the rail and level walking.

**Data reduction and analysis:**
The 3-D coordinates of the markers and a three-segment model of the foot and ankle [1-3] were used to calculate the Eulerian angles of the hindfoot and forefoot joint during level walking, stair climbing and stair descending in a whole gait cycle. Each footprint was divided into 4 regions, toe, forefoot, hindfoot and heel regions, to enable analysis of the pressures in relation to the anatomical structures with respect to force, area, pressure and the velocity of the center of pressure. Descriptive and inferential statistics were obtained where appropriate. A significance level of $p < 0.05$ was used for comparisons.

**RESULTS & DISCUSSION**

**Kinematics**
There was an angular deviation in dorsiflexion/plantarflexion of forefoot among three walking activities (Table 1). The average range of motion of the forefoot joint in sagittal plane while wearing modified shoes was 18.4 (SD, 6.3), 11.1 (SD, 2.7), and 17.0 (SD, 6.3) degrees for activities of level walking, ascending stairs and descending stairs, respectively. While wearing traditional shoes, they were 30.1 (SD, 4.6), 21.9 (SD, 5.0), and 28.9 (SD, 9.0) degrees respectively. The range of motion of the forefoot was significantly different among three different walking activities. The statistical analysis using pair $t$-test showed that the average forefoot joint excursion in sagittal plane while wearing traditional shoes was significantly greater than that while wearing modified shoes during level walking, ascending stairs and descending stairs ($p<0.01$). The ratio of peak plantarflexion to the motion arc of the forefoot at push off was 0.62, 0.80 and 0.75 for activities of level walking, ascending stairs and descending stairs, respectively. The results showed that the rocker under metatarsal area made a major contribution to the variation in peak plantarflexion angle of the forefoot, and had a minor effect on the variation in the peak dorsiflexion angle of the forefoot.

The ranges of motion of the hindfoot joint in sagittal and coronal planes during level walking are shown in Table 1. The results showed that the hindfoot joint excursion in sagittal and coronal planes while wearing traditional shoes was smaller than while wearing modified shoes for three walking activities, but the difference was only significant during level walking, not during stair climbing and stair descending. Compared to wearing traditional shoes, the people in this study commonly used relatively more flexion of the hindfoot, 1.33º of dorsiflexion and 3.62º of plantar flexion, to perform level walking while wearing modified shoes. The ratio of peak plantarflexion to the motion arc of the hindfoot at heel strike was 0.73 during level walking. A wedge under heel area contributed to a major extent to the variation in first plantarflexion angle of the hindfoot during level walking.

**In-shoe plantar pressure**
The modified shoes applied higher forces in the midfoot region and provided a redistribution of the load over a larger area, especially in midfoot area. The reduction in pressure caused by the modified shoe occurred in the region of the forefoot. Pressure was, however, slightly increased in the heel and midfoot regions. At the same time, these changes affected the curve of the speed of the center of pressure that became more flattened during level walking. This correspondingly helps the rocker action in lost ankle joint.

**Combined kinematics and foot pressure distribution**
We inferred that the decreased demand for push-off movement with the rocker shoe was the major cause in the pressure reduction of the forefoot in these three activities. The decreased demand for peak dorsiflexion was correlated to increased loading force and peak pressure in midfoot area during stair climbing, stair descending, and level walking. Compared with stair climbing and stair descending, the greater first plantar flexion was found during level walking, which was related to the differences between pressure distributions in heel area involved.

**CONCLUSION**
Although a lesser motion in the sagittal plane was required at the forefoot joint by the shoe modification, this is only of little help for walking after ankle arthrodesis because the rigidity is at the ankle. This modification would be more suitable after a triple arthrodesis or the fixation only of midtarsal joint. An
alteration in design, moving the rocker fulcrum backward toward the heel, is necessary for ankle arthrodesis case. Therefore, future designs of ankle arthrodesis shoe components should consider the need for providing greater dorsiflexion/plantarflexion mobility of the hindfoot by the shoes in order to facilitate stair ambulation, and reduce the real motion demand by the foot associated with this activity.

Table 1: Comparison of the average range of motion (mean ± standard deviation) at the hindfoot and forefoot in ascending, descending, and level walking

<table>
<thead>
<tr>
<th>Joint Movement</th>
<th>Level walking</th>
<th>Up stair</th>
<th>Down stair</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Modified Shoe</td>
<td>Traditional Shoe</td>
<td>Modified Shoe</td>
</tr>
<tr>
<td>Dorsiflexion / Plantarflexion</td>
<td>30.2±5.9</td>
<td>24.2±3.0</td>
<td>24.1±3.4</td>
</tr>
<tr>
<td>Inversion / Eversion</td>
<td>19.7±4.2</td>
<td>14.7±4.0</td>
<td>18.3±7.2</td>
</tr>
<tr>
<td>Internal / External rotation</td>
<td>16.9±2.7</td>
<td>15.9±4.0</td>
<td>11.6±2.7</td>
</tr>
<tr>
<td>Dorsiflexion / Plantarflexion</td>
<td>18.4±6.3</td>
<td>30.1±4.6</td>
<td>11.1±2.7</td>
</tr>
<tr>
<td>Valgus / Varus</td>
<td>14.3±6.5</td>
<td>10.5±3.5</td>
<td>9.9±3.5</td>
</tr>
<tr>
<td>Abduct / Adduct</td>
<td>19.3±4.1</td>
<td>25.5±6.7</td>
<td>16.6±5.3</td>
</tr>
</tbody>
</table>

**: p<0.01 (Pair t-test)

ACKNOWLEDGMENTS
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REFERENCES