Effect of gait protocols and postoperative shoes on off-loading of forefoot in preoperative patients for forefoot disorders

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ABSTRACT

Objectives: The purpose of this study was to clarify the effect of gait protocols and postoperative shoes on forefoot load in preoperative patients for forefoot disorders and compare footwear comfort between different types of postoperative shoes.

Methods: Fourteen subjects scheduled to undergo forefoot surgeries were recruited. The maximum force under the forefoot region was measured during 10 m straight walking in two gait patterns with six different shoe types. Visual analogue scale (VAS) scores for footwear comfort, subjective lower thigh pain, and electrical activities of lower thigh muscles were also evaluated.

Results: The body weight-normalized maximum force under the forefoot region significantly decreased in step-to-gait compared to normal gait regardless of the shoe types used. Under the same gait condition, no significant difference was observed in the forefoot off-loading effect between the different shoe types used. Significantly worse VAS scores, significantly higher tibialis anterior muscle activities, and complaints of lower thigh pain were demonstrated in the gait with the reverse camber shoe.

Conclusions: Gait protocol of step-to-gait had more forefoot off-loading effect than postoperative shoes. The forefoot off-loading effect did not differ among the postoperative shoes, suggesting that postoperative shoes can be selected with an emphasis on footwear comfort.

KEYWORDS: Footwear comfort; forefoot load; forefoot surgery; gait protocols; postoperative shoes

Introduction

Forefoot disorders such as rheumatoid foot, hallux valgus, and lesser toe deformities sometimes require operative treatments including soft tissue procedures, osteotomies, or both [1]. Postoperatively, a certain period of complete or partial reduction of forefoot load is usually required to protect the surgical site and prevent postoperative complications including pain, swelling, wound dehiscence, loss of fixation, malunion, and nonunion [2].

Conventional postoperative treatments for off-loading the forefoot region include gait instructions and postoperative shoes designed for forefoot load relief. A step-to-gait pattern, in which the foot remains flat during the stance phase and a large push-off is not required, is commonly instructed for off-loading of the forefoot [3]. With respect to postoperative shoes, various ideas have been adopted, including rocker sole, cushioning sole, and reverse-wedged heel [4–10]. Although previous pedobarographic analysis studies have demonstrated the forefoot off-loading effect of gait patterns and postoperative shoes [3–5, 10–14], most of these studies have discussed these interventions separately. Moreover, most of the previous studies on forefoot off-loading effect using pedobarographic analysis have been performed in healthy or nonsurgical subjects, not reflecting the situation in real operative patients who require these interventions postoperatively.

Footwear comfort has been reported as an important factor in choosing postoperative shoes because discomfort with the shoes could lead to poor compliance [8, 15]. Forefoot off-loading shoes are reportedly associated with discomfort, especially in a reverse camber shoe, which is a popular forefoot off-loading shoes [6, 8–10]. Discomfort of forefoot off-loading shoes has been evaluated subjectively in some studies using the visual analogue scale (VAS) [10, 13, 16] or lower thigh pain [7, 9] and objectively in other studies using the electrical muscle activity of the lower thigh [17, 18]. However, there are limited studies on the discomfort of the postoperative shoes with both subjective and objective measures in patients with forefoot disorders.
The primary purpose of this study was to clarify the effect of gait protocols and postoperative shoes on forefoot load in preoperative patients for forefoot disorders including the patients with rheumatoid arthritis. Additionally, we compared the foot wear comfort between different types of postoperative shoes using both subjective and objective measures, including the VAS score for footwear comfort, a questionnaire for lower thigh pain, and electrical muscle activity of the lower thigh.

Materials and methods

Subjects

The subjects were patients older than 18 years and scheduled to undergo reconstructive surgeries of the forefoot due to their symptomatic forefoot pain at the University of Tokyo Hospital from August 2018 to February 2019. Subjects who needed assistance in walking were excluded. Fourteen subjects consented to participate in the study, of which background information is summarized in Table 1. Of these, six subjects

### Table 1. Patients’ backgrounds.

<table>
<thead>
<tr>
<th>No.</th>
<th>Age (year)</th>
<th>Weight (kg)</th>
<th>Pathology</th>
<th>Forefoot surgery</th>
<th>Foot deformities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Non-RA</td>
<td>First MTPj arthrodesi</td>
<td>Hallux, Lesser toes, Midfoot, Hindfoot</td>
</tr>
<tr>
<td>1</td>
<td>80</td>
<td>48</td>
<td>Non-RA</td>
<td>Scarf + Akin osteotomy second and third distal metatarsal osteotomy</td>
<td>Hallux valgus, Third hammer toe, Flat foot, Pes cavus</td>
</tr>
<tr>
<td>2</td>
<td>59</td>
<td>55</td>
<td>Non-RA</td>
<td>Scarf + Akin osteotomy</td>
<td>Hallux valgus, Second and third hammer toe, Pes cavus</td>
</tr>
<tr>
<td>3</td>
<td>62</td>
<td>48</td>
<td>Non-RA</td>
<td>Scarf + Akin osteotomy</td>
<td>Hallux valgus, Lisfranc joint destruction, Pes cavus</td>
</tr>
<tr>
<td>4</td>
<td>62</td>
<td>55</td>
<td>Non-RA</td>
<td>Plantar plate repair for second MTPj</td>
<td>Hallux valgus, Second and third MTPj dislocation, Pes cavus</td>
</tr>
<tr>
<td>5</td>
<td>71</td>
<td>49</td>
<td>RA</td>
<td>Joint-preserving arthroplasty for all toes</td>
<td>Hallux valgus, Second and third MTPj dislocation, Pes cavus</td>
</tr>
<tr>
<td>6</td>
<td>74</td>
<td>54</td>
<td>Non-RA</td>
<td>Scarf + Akin osteotomy second plantar plate repair</td>
<td>Hallux valgus, Second and third MTPj dislocation, Pes cavus</td>
</tr>
<tr>
<td>7</td>
<td>76</td>
<td>50</td>
<td>Non-RA</td>
<td>First MTPj arthrodesi second-fourth distal metatarsal osteotomy</td>
<td>Hallux valgus, Second and third MTPj dislocation, Pes cavus</td>
</tr>
<tr>
<td>8</td>
<td>74</td>
<td>40</td>
<td>Non-RA</td>
<td>Scarf + Akin second distal metatarsal osteotomy</td>
<td>Hallux valgus, Second and third MTPj dislocation, Pes cavus</td>
</tr>
<tr>
<td>9</td>
<td>50</td>
<td>53</td>
<td>RA</td>
<td>Joint-preserving arthroplasty for all toes</td>
<td>Hallux valgus, Second and third MTPj dislocation, Pes cavus</td>
</tr>
<tr>
<td>10</td>
<td>60</td>
<td>54</td>
<td>Non-RA</td>
<td>Scarf + Akin osteotomy second and third distal metatarsal osteotomy</td>
<td>Hallux valgus, Second and third MTPj dislocation, Pes cavus</td>
</tr>
<tr>
<td>11</td>
<td>71</td>
<td>49</td>
<td>RA</td>
<td>Joint-preserving arthroplasty for all toes</td>
<td>Hallux valgus, Second and third MTPj dislocation, Pes cavus</td>
</tr>
<tr>
<td>12</td>
<td>75</td>
<td>42</td>
<td>RA</td>
<td>Joint-preserving arthroplasty for all toes</td>
<td>Hallux valgus, Second and third MTPj dislocation, Pes cavus</td>
</tr>
<tr>
<td>13</td>
<td>75</td>
<td>48</td>
<td>RA</td>
<td>Joint-preserving arthroplasty for all toes</td>
<td>Hallux valgus, Second and third MTPj dislocation, Pes cavus</td>
</tr>
<tr>
<td>14</td>
<td>71</td>
<td>50</td>
<td>RA</td>
<td>Joint-preserving arthroplasty for all toes</td>
<td>Hallux valgus, Second and third MTPj dislocation, Pes cavus</td>
</tr>
</tbody>
</table>

Abbreviations: non-RA; patients without rheumatoid arthritis; RA, rheumatoid arthritis; MTPj, metatarsophalangeal.
had rheumatoid forefoot deformities, six had hallux valgus with or without lesser toe deformities, one had hallux varus, and one had plantar plate injury of the lesser toe. There was 1 man and 13 women with a mean age of $68.6 \pm 8.5$ years and a mean body mass index of $20.9 \pm 2.0$ kg/m$^2$. Ethical approval was granted by the Ethics Committee at the University of Tokyo (approval number 2018017NI). All subjects were provided verbal and written explanations about the study, and then, they signed the consent form.

**Gait protocols**

The subjects were instructed to walk in the normal gait and step-to-gait patterns (Figure 1). The step-to gait began with a step using the surgical side, followed by a step using the healthy side. The subjects were instructed to shorten the step on their healthy side so that the step ends next to and not beyond their surgical side. Gait was continued with a step by the surgical side [11].

**Shoes**

A total of six different types of shoes, including baseline shoes, four types of specially designed postoperative shoes with additive cushioning soles, and reverse camber shoe (Ortho Wedge Shoe®, DARCO Co, Ltd, Huntington, USA), which is a popular forefoot off-loading shoe [6, 9], were tested (Figure 2). For each shoe, three sizes of small, medium, and large were prepared, and the shoe closest to the size of the subject’s foot was selected.

Footwear with a flat sole of ethylene vinyl acetate (EVA) of 10 mm thickness (Tento-Yobo Shoes®, Taketora Co, Ltd, Kanagawa, Japan) was adopted as a baseline shoe. Specially designed postoperative shoes were made based on the baseline shoes by adding the cushioning soles. The original sole of the baseline shoe was sanded off, and a cushioning mid-hindfoot sole pad made of EVA with 20 mm thickness was attached. The forefoot cushioning sole pad had two types of materials including vinyl sponge as a flexible material or EVA as a rigid material and two types of different shapes, rocker shape with a $20^\circ$ rocker angle or flat shape with a $5^\circ$ rocker angle. Therefore, we prepared four types of shoes with an additive forefoot cushioning sole: flexible material with rocker shape (flexible-rocker shoe), flexible material with flat shape (flexible-flat shoe), rigid material with rocker shape (rigid-rocker shoe), and rigid material with flat shape (rigid-flat shoe). The sole of the reverse camber shoe is made of thermoplastic rubber, which is a more rigid material than EVA and has a $15^\circ$ heel wedge shape.

**Measurements**

The F-Scan2 pedobarography system with 960 force-sensing resistors (25 mm$^2$ cells) (Nitta Co, Ltd, Tokyo, Japan) was used to collect in-shoe foot pressure data [19]. The pressure-sensing insole was trimmed to fit the shape of the subject’s foot and was inserted into the shoes.

The BiosignalsPlux surface electromyography system (PLUX Co, Ltd, Lisbon, Portugal) was used to collect electrical muscle activity of the lower thigh. Tibialis anterior and gastrocnemius medialis muscle were selected as measurement muscles because imbalance associated with wearing forefoot off-loading shoe affected the muscle activity around the ankle joint in healthy subjects [17]. The skin was prepared for surface electromyography by cleansing with isopropyl alcohol to minimize skin impedance. Wireless surface electromyography electrodes were placed at the center of the muscle belly of the tibialis anterior and gastrocnemius medialis with two bipolar electrodes parallel to the muscle fiber orientation with an interelectrode distance of 20 mm [20].

Subjects were instructed about test conditions consisting of two different gait patterns and six different shoe types and then practiced each test condition. In the reverse camber shoe, only step-to gait was performed because normal gait was accompanied with the risk of falling [4]. The healthy side wore the same shoes as the surgical side in all trials.
After getting familiar with each test condition, subjects were asked to perform a 10 m straight walking once at self-selected gait velocity in each test condition, and the order of the test conditions was fixed, as shown in Table 1. A 1 min break was set up between each trial. During each test condition, data collection from the pedobarography and surface electromyography were synchronized by activating these two systems simultaneously before starting the measurements. Pedobarography was performed under all test conditions, and surface electromyography was performed under test conditions with a baseline shoe, a reverse camber shoe, and a flexible-rocker shoe (Table 2).

Each subject scored the comfort of each shoe during step-to gait after each test by using VAS. The subjects were also asked about the presence or the absence of lower thigh pain in each test condition.

Data processing

**Pedobarography**

Regions of interest were divided automatically using the system software into four areas including toes, distal one third, central one third, and proximal one third of the footprint. The forefoot region was defined as the sum of the distal one third and toes in the present study. The maximum force under the forefoot region was selected as a pedobarographic variable to evaluate the forefoot load. The mean maximum force under the forefoot region of the surgical side was calculated from every step while walking straight 10 m in each test condition. The body weight-normalized maximum force was obtained by dividing the maximum force under the forefoot region (N) by the body weight (kg) and used for analysis.

**Surface electromyography**

Recorded signals of the electrical activities of the tibialis anterior and gastrocnemius medialis muscles were smoothed using the root mean square (window: 100 ms). The average of the integral value of the root mean square was calculated from every step while walking straight 10 m in each test condition using electromyography analysis add-on software (PLUX Co, Ltd, Lisbon, Portugal) and expressed as relative values, with the value in normal gait with a baseline shoe of 100%.

**VAS score**

The VAS score was evaluated on a vertical line on a 10 cm VAS. The outmost left (0 cm) was labelled very uncomfortable, and the outmost right (10 cm) was labelled very comfortable. The mean VAS score for each shoe was calculated.

**Statistical analysis**

A power analysis was performed to determine the minimum number of subjects needed for this study. In the pilot trials performed using the 15 healthy subjects prior to the present study, the maximum force under the forefoot during normal gait was significantly different between the baseline shoe and the flexible rocker shoe (15.7 ± 3.3 N/kg vs 10.2 ± 3.2 N/kg, p < 0.01). Based on the results of pilot trials, a minimum of

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### Table 2. Protocol of test conditions.

<table>
<thead>
<tr>
<th>Gait patterns</th>
<th>Baseline shoe</th>
<th>Flexible rocker</th>
<th>Flexible flat</th>
<th>Rigid rocker</th>
<th>Rigid flat</th>
<th>Reverse camber shoe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal gait</td>
<td>1, a</td>
<td>4, a</td>
<td>6, b</td>
<td>8, b</td>
<td>10, b</td>
<td>–</td>
</tr>
<tr>
<td>Step-to gait</td>
<td>2, a</td>
<td>5, a</td>
<td>7, b</td>
<td>9, b</td>
<td>11, b</td>
<td>3, a</td>
</tr>
</tbody>
</table>

The numbers in the table demonstrate the order of the test conditions. The letters in the table demonstrate the measurements performed in each test condition: (a) pedobarography and surface electromyography and (b) pedobarography.

### Table 3. Body weight-normalized maximum force under the forefoot by dynamic pedobarography (mean ± standard deviation, N/kg).

<table>
<thead>
<tr>
<th>Gait patterns</th>
<th>Baseline shoe</th>
<th>Flexible rocker</th>
<th>Flexible flat</th>
<th>Rigid rocker</th>
<th>Rigid flat</th>
<th>Reverse camber shoe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal gait</td>
<td>8.3 ± 4.6</td>
<td>5.8 ± 3.5</td>
<td>7.0 ± 4.5</td>
<td>6.4 ± 4.5</td>
<td>6.7 ± 4.4</td>
<td>–</td>
</tr>
<tr>
<td>Step-to gait</td>
<td>2.6 ± 1.6</td>
<td>1.4 ± 0.9§</td>
<td>2.1 ± 2.2§</td>
<td>1.6 ± 1.2§</td>
<td>1.8 ± 1.4§</td>
<td>2.0 ± 1.4</td>
</tr>
</tbody>
</table>

* p < 0.05 vs. normal gait with the same shoe type.

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Figure 3. Bar graphs showing the mean visual analogue scale score for footwear comfort of each shoe during step-to gait. ** p < 0.01.

Abbreviations: B, baseline shoe; FX-Rock, flexible-rocker shoe; FX-Flat, flexible-flat shoe; RG-Rock, rigid-rocker shoe; RG-Flat, rigid-flat shoe; RCS, reverse camber shoe.
Effect of gait protocols and postoperative shoes on off-loading

12 subjects were required assuming a standard deviation of 3.0 N/kg, a power of 0.80, a difference of at least 5.5 N/kg, and an α level of 0.05. We then set a sample size of 14 in the present study.

All continuous variables were presented as mean ± standard deviation. One-way repeated measures analysis of variance followed by Tukey–Kramer multiple comparison as a post-hoc test was used for comparison of pedobarographic variables, VAS scores, and electromyography data between different gait patterns or shoes. Differences were considered statistically significant at \( p \leq 0.05 \). All statistical analyses were performed using JMP Pro version 13.2 (SAS Institute Inc., Cary, NC, USA).

Results

Pedobarography

The body weight-normalized maximum force under the forefoot is shown in Table 3. The comparison between the two gait patterns revealed that the maximum force under the forefoot significantly decreased in step-to gait compared to normal gait regardless of the shoe type used with a reduction rate of 69% in the baseline shoe, 76% in the flexible-rocker shoe, 70% in the flexible-flat shoe, 75% in the rigid-rocker shoe, and 73% in the rigid-flat shoe.

In the comparison between different shoes in terms of normal gait, the body weight-normalized maximum force under the forefoot was decreased in all types of postoperative shoes with additive cushioning soles compared to the baseline shoe, with a maximum reduction of 30% in the flexible-rocker shoe, 16% in the flexible-flat shoe, 75% in the rigid-rocker shoe, and 73% in the rigid-flat shoe.

In the comparison between different shoes in terms of normal gait, the body weight-normalized maximum force under the forefoot was decreased in all types of postoperative shoes with additive cushioning soles compared to the baseline shoe, with a maximum reduction of 30% in the flexible-rocker shoe, and a minimum reduction of 19% in the flexible-flat shoe, although the difference was not statistically significant (\( p = 0.29 \)).

VAS score, lower thigh pain

The VAS score for the footwear comfort was lowest in the reverse camber shoe (2.9 ± 0.9), followed by flexible-rocker (7.5 ± 0.6), flexible-flat (7.6 ± 0.5), rigid-rocker (7.7 ± 0.5), rigid-flat (7.9 ± 0.4), and baseline (8.1 ± 0.4) (Figure 3). The reverse camber shoe had a significantly lower VAS score than all the other shoes. No subjects complained of lower thigh pain in walks with the baseline or the postoperative shoes with additive cushioning soles; however, 4 out of 14 (29%) subjects complained of lower thigh pain at the site of the tibialis anterior compartment in a walk with the reverse camber shoe. Of the four subjects who developed lower thigh pain, three (75%) were patients with rheumatoid arthritis.

Surface electromyography

Tibialis anterior muscle activity was increased in all test conditions compared to normal gait with the baseline shoe, with a maximum gain of 39% in step-to gait with the reverse camber shoe (Figure 4(a)). Multiple comparison revealed that step-to gait with the reverse camber shoe had significantly higher activity of the tibialis anterior muscle compared to all the other test conditions. Conversely, the activity of the gastrocnemius medialis muscle was decreased in all test conditions compared to normal gait with the baseline shoe, with a maximum reduction of 45% in step-to gait with the reverse camber shoe (Figure 4(b)). Multiple comparisons revealed that step-to gait with the reverse camber shoe had significantly lower activity of the gastrocnemius medialis muscle compared to normal gait with the baseline and flexible-rocker shoes.

Discussion

This study aimed to investigate the effect of step-to-gait pattern and various postoperative shoes on forefoot load.
in real preoperative patients with forefoot disorders by pedobarographic analysis. The present study demonstrated that the effect of step-to-gait pattern for off-loading under the forefoot region was significantly large. Meanwhile, the off-loading effect produced by postoperative shoes was of no importance in the step-to-gait pattern. The comparison of footwear comfort between postoperative shoes demonstrated the worst discomfort in the reverse camber shoe that was accompanied with lower thigh pain and increased tibialis anterior muscle activity.

In the present study, step-to gait decreased maximum force under the forefoot region by 69–76% compared to the normal gait regardless of the shoe type used, which is consistent with previous studies. Two previous studies that investigated the effect of step-to gait on forefoot load in healthy young subjects with an average of 25 years demonstrated the off-loading effect of step-to gait by approximately 50% compared to normal gait [3, 11]. Another study including 20 healthy subjects with an average age of 37 years and 10 diabetic-neuropathic patients with an average age of 54 years demonstrated a significant reduction in peak pressure under the central metatarsals by 67% and 56%, respectively, in step-to gait [12]. To the best of our knowledge, the present study is the first to clarify the forefoot off-loading effect by step-to gait in elderly preoperative patients with forefoot disorders.

The use of cushioning pads in shoe inserts or soles is also one of the most often used means to reduce the impact forces during walking and running [14], and its reduction effect was reportedly less than 10–20% [21]. A recent study investigating the effect of footwear cushioning in 19 healthy basketball players who performed drop landings demonstrated that the reduction effect of landing impact by the cushioning properties was approximately 5% [22]. Although direct comparison could not be done with previous studies, the present study revealed a certain but not significant off-loading effect of 16–30% for the forefoot region in the normal gait by adding cushioning sole. The difference in the hardness of the forefoot cushioning pad between vinyl sponge and EVA and the difference in the shape of the forefoot cushioning pad between the rocker shape and flat shape did not have any significant effect on forefoot off-loading. A rocker sole is known to work for off-loading the forefoot region by restricting movement at the metatarsal phalangeal joints [23]. We consider that the effect of cushioning pad applied in the present study was greater than the difference of shape between rocker and flat or difference between material between vinyl sponge and EVA.

A reverse camber shoe or negative heel shoe is commercially available as a ready-to-wear orthotic and commonly used as a forefoot off-loading shoe [6, 9]. A reverse camber shoe works for forefoot off-loading by transferring the center of pressure posteriorly and inhibiting the proximal progression of body weight, and transferring of plantar loads to the forefoot [17]. In this study, the reverse camber shoe in step-to gait demonstrated 76% reduction of the forefoot load compared to the baseline shoe in normal gait, which is higher compared to previous studies reporting the off-loading effect under the forefoot of 34–66% in healthy subjects without any instructions about gait patterns [4, 5]. We considered that this discrepancy might be attributed to our cohort consisted of the real patients who were going to undergo forefoot surgeries or specific instructions for step-to gait. A reverse camber shoe also has an effect on altering gait patterns such as the reduction of the walking speed and stride length, which also works in off-loading of the forefoot [4]. To remove the effect of altered gait pattern, we instructed the subjects to walk in the step-to-gait pattern and compared the result with those of other postoperative shoes in the same step-to-gait pattern, showing a 23% reduction in the forefoot load compared to the baseline shoe. Therefore, our study clarified for the first time that the forefoot off-loading effect of reverse camber shoe is mainly produced by the effect of changing the gait pattern rather than the performance of the shoe itself.

The present study showed significantly worse VAS score for footwear comfort when using the reverse camber shoe compared to the baseline shoe and the shoes with an additive cushioning sole. In accordance with the present results, it has been reported that healthy subjects with a reverse camber shoe had less comfort of the shoes compared to flat and rocker shoes [10]. A recent study also demonstrated that patients undergoing surgery of the first ray were less likely to be satisfied with a reverse camber shoe compared to a flat shoe due to the instability and difficulty in mobilization [6]. A retrospective study investigating the postoperative compliance of 64 patients who underwent forefoot surgery and were instructed to use a reverse camber shoe for at least 8 weeks demonstrated that only 39 patients (61%) complied with this instruction and others could not manage it [9].

Lower thigh pain has been reported as a side effect of the reverse camber shoe, and 16% of patients who underwent scarf osteotomy for their hallux valgus reportedly developed lower thigh pain with postoperative use of the reverse camber shoe [7]. In the present study, 29% of patients with the reverse camber shoe reported lower thigh pain, which was not reported with the use of other forefoot off-loading shoes. An experiment investigating the posture, ankle muscle activity, and postural sway in healthy subjects standing still with the use of forefoot off-loading postoperative shoes has demonstrated that the posterior shift in the center of pressure toward the behind the ankle joint axis with the use of the reverse camber shoe resulted in an increase in tibialis anterior muscle activity and a decrease in gastrocnemius muscle activity [17]. The present study confirmed that the increased activity of the tibialis anterior muscle and the decreased activity of the gastrocnemius muscle were also seen under dynamic walking conditions with the reverse camber shoe in real patients with forefoot disorders. Increased muscle activity of the tibialis anterior muscle during ankle dorsiflexion has been reported to increase intramuscular pressure in the tibialis anterior compartment [24]. Therefore, increased overload to the tibialis anterior muscle might be causally related to lower thigh pain associated with the use of the reverse camber shoe.

Some limitations of our study must be acknowledged. Firstly, the full alignment of the lower limbs was not assessed. Misalignment due to deformities in the hip, knee, or hindfoot may affect the forefoot plantar force during walking. However, the influence of other joints was considered non-significant because subjects who needed assistance in walking were excluded from this study. Secondly, this study recruited subjects with several kinds of forefoot disorders, which might give different impact on the experimental results.
However, we considered that the present study was valuable in terms of reflecting the real conditions where the postoperative shoes are used in clinical practice. Third, the patient’s compliance with the step-to-gait pattern or wearing the postoperative shoes was not evaluated in the present study because data collection was done under experimental conditions but not in daily living. Instead of not being able to investigate compliance, we investigated footwear comfort using the VAS scale because foot discomfort has been shown to be related to compliance [9]. Fourth, whether the forefoot off-loading effect was related to the clinical outcome was unclear in the present study. Further clinical studies are required to know the differences in forefoot off-loading effects shown in the present study that are clinically meaningful in terms of bone union, recurrent deformity, and other factors.

In conclusion, this study clarified for the first time the fact that gait instruction of step-to gait was more effective in off-loading the forefoot region than forefoot off-loading shoes in patients with forefoot disorders. The reverse camber shoe had negative effect on footwear comfort both subjectively and objectively. In providing gait instructions, the forefoot off-loading effect of shoes was sparse, and it would be better to select the postoperative shoes with emphasis on footwear comfort.

Conflict of interest
The authors did not receive any outside funding or grants in support of their research or in preparation of this work. Neither the authors nor a member of their immediate families received payments or other benefits or made a commitment or agreement to provide such benefits from a commercial entity.

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