Many different types of foot orthoses are used to treat biomechanical dysfunction of the foot. Little evidence is available to guide clinicians in the selection of foot orthoses. The aim of this project was to determine whether resistance of the foot to supination or the Foot Posture Index could predict the static stance response to different types of prefabricated foot orthoses. The Foot Posture Index score was determined and resistance to supination was measured in 18 subjects (36 feet). Changes in the frontal plane calcaneal angle and navicular height were then measured as the subjects stood on six different types of foot orthoses. All orthoses resulted in an increase in navicular height, but only three orthoses changed the calcaneal angle in the frontal plane. Resistance to supination did not predict the response to the different types of orthoses, but the Foot Posture Index score was associated with changes from using some of the orthoses. (J Am Podiatr Med Assoc 93(6): 492-498, 2003)
function,11, 12 and no research has shown which parame-
ters measured in the biomechanical evaluation can predict a response to foot orthoses. The challenge now is to find clinical measures that are reliable, that predict a response to the use of a foot orthosis, and that can be related to patient outcomes.

Because static clinical measurements of lower-extremity alignment are generally unreliable,10 Redmond et al13, 14 developed the Foot Posture Index (FPI). This index gives each foot a composite score based on eight weightbearing observations (talar head palpation, supralateral and infralateral malleolar curvature, Helbing’s sign, calcaneal position, prominence of the talonavicular region, congruence of the lateral border of the foot, and the position of the forefoot on the rearfoot) to represent the posture of the foot. Each observation is scored from –2 to +2, depending on its magnitude. A negative score represents a supinated foot and a positive score represents a pronated foot. A total overall score of –1 to 4 is assumed to indicate a relatively normal foot, 5 to 9 a mildly pronated foot, and 10 or greater a highly pronated foot (maximum score, 16). The FPI has been shown to be a reliable tool for assessing foot posture.13-15 However, it is not known whether this index can assist with the prescription of foot orthoses.

Using a specially constructed device to measure resistance to supination, Payne et al16 showed that the amount of force needed to supinate the foot is related to the nonweightbearing position of the subtalar joint axis. Measuring the resistance of the foot to a supinatory moment has potential as a clinical indicator to predict the response of a foot to an orthosis because it may reflect the amount of force needed by the orthosis to change the alignment in a pronated foot. Noakes and Payne15 also showed that the manual technique of determining resistance to supination described by Kirby and Green17 and Kirby18 is reliable for those experienced with its use.

The FPI and resistance of the foot to supination have potential use in foot orthotic prescription decision making. The aim of this preliminary project was to determine whether supination resistance or the FPI score could predict the static stance response to different types of prefabricated foot orthoses.

**Materials and Methods**

Subjects for this study were participants in a previous study15 originally recruited from the undergraduate student population at La Trobe University, Melbourne, Australia. Approval was given by the Faculty of Health Sciences Human Ethics Committee at La Trobe University.

Resistance of the foot to supination was measured using a mechanical device that was described and used on the same group of subjects in the previous study (Fig. 1).15 This device consisted of a nonstretchable woven fabric that was fixed to the base of a platform lateral to the foot in the region of the calcaneocuboid joint. The fabric passed medially under the foot just proximal to the talonavicular joint and was attached to a Mecmesin force gauge (Mecmesin Ltd, West Sussex, England) via a pulley system. The pulley system was used to apply force of a magnitude just great enough to overcome the inertia needed to invert the calcaneus as the investigator observed a bisection that was placed on the posterior aspect of the calcaneus. This method of measuring supination resistance has been shown to be reliable, with an intraclass correlation coefficient (ICC) for testing on two separate days of 0.95 (95% confidence interval, 0.88–0.98).16 The mean of the ten trials from the previous study15 was used.

The posture of each subject’s feet was determined from the previous study15 using the FPI. In that study, the FPI score was determined by four clinicians on two separate days, with the mean of the eight measurements used for analysis in the present study.

Six different orthotic conditions were used as interventions in this study: a 6° inverted heel wedge made from firm ethyl vinyl acetate, a firm “arch cookie,” a firm Prothotic (The Orthotic Laboratory, Mel-
bourne, Australia), a medium-density Formthotic (Foot Science International, Christchurch, New Zealand), an Orthopro (Peninsula Podiatric Laboratory, Melbourne), and a Vasyli (Vasyli International, Brisbane, Australia) (Fig. 2). These orthoses were chosen to be representative of the different types of prefabricated orthoses currently on the market.

A bisection was placed on the posterior aspect of the calcaneus, and a mark was placed on the most medial aspect of the navicular of each foot. Each subject stood in single-limb stance on each device as well as barefoot (no intervention). This position was used to simulate midstance. Subjects held on to a frame to aid balance and ensure that there was no movement or muscle activity of the lower limb. The height of the mark on the navicular was measured using digital calipers in each condition (Fig. 3), and the angle of the calcaneal bisection was measured in each condition using an angle finder (Fig. 4). Because both measurements used in this study have previously been shown to have some level of clinical unreliability,19, 20 two clinicians carried out the measurements. Each clinician was masked to the findings of the other, and the mean of the measurements was used for analysis.

The data were analyzed using ICCs for the intertester reliability of the two clinicians carrying out the measurements. Repeated-measures analysis of variance (ANOVA) tested for changes in the navicular and calcaneal positions. The Pearson product moment correlation was used to assess the relationship between the changes in the two measured parameters and the resistance to supination and the FPI score.

Results

Ten female and eight male subjects (36 feet) were recruited (mean ± SD age, 21.9 ± 6.3 years; weight, 76.3 ± 15.7 kg; and height, 174.1 ± 10.2 cm). The mean ± SD mechanical supination resistance was 122.1 ± 33.9 N, and the mean ± SD FPI score was 7.3 ± 2.7.

Changes in navicular resting height with use of the different orthoses and ICCs for the reliability of the two clinicians are reported in Table 1. For the repeated-measures ANOVA, the assumption of sphericity was breached, so the Greenhouse-Geisser adjustment was used, showing that there was a difference between the barefoot condition and the different orthotic conditions (P < .0001). Results of Bonferroni post hoc pairwise comparisons showed that the differences occurred between the barefoot condition and all of the different orthotic conditions (P < .0001).

Changes in frontal plane calcaneal position with the different orthoses and ICCs for the reliability of the two clinicians are reported in Table 2. The repeated-measures ANOVA showed that there was a difference between the barefoot condition and the different orthotic conditions (P < .0001). Results of Bonferroni post hoc pairwise comparisons showed that the differences were between the barefoot condition and the wedge, the Prothotic, and the Orthopro (P < .0001 for all). There were no differences between the barefoot condition and the Formthotic (P = .988), the arch cookie (P = .988), and the Vasyli (P = .958).

The Pearson product moment correlation between the response to the different orthotic conditions for changes in calcaneal position found significant correlations between the FPI score and the Prothotic only (r = 0.334; P = .044). No correlations were found between supination resistance and the response to the different orthoses. Only the FPI score was associated with changes in the navicular height for the Prothotic (r = 0.48; P = .003), the Formthotic (r = 0.39; P = .027), the Orthopro (r = 0.36; P = .029), and the Vasyli (r = 0.33; P = .047).

Figure 2. Posterior (A) and superior (B) views of the different orthoses used in this study, from left to right: arch cookie, heel wedge, Orthopro, Formthotic, Prothotic, and Vasyli.
Discussion

The results of this preliminary study show that there are differences in the static stance response of subjects to different types of prefabricated foot orthoses. Measurements of calcaneal position and navicular height have previously been shown to be unreliable. To improve the reliability of these measurements, the mean of two measurements performed independently by two clinicians was used for analysis in this study. Previous studies reporting the reliability of these measurements involved clinicians who re-marked

<table>
<thead>
<tr>
<th>Orthosis</th>
<th>Change in Navicular Height (mm)</th>
<th>ICC (95% CI)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Range</td>
</tr>
<tr>
<td>Wedge</td>
<td>5.76 ± 2.25</td>
<td>–1.55–9.89</td>
</tr>
<tr>
<td>Arch cookie</td>
<td>1.32 ± 2.69</td>
<td>–4.89–7.02</td>
</tr>
<tr>
<td>Formthotic</td>
<td>5.11 ± 1.66</td>
<td>0.02–8.16</td>
</tr>
<tr>
<td>Prothotic</td>
<td>7.69 ± 2.52</td>
<td>1.30–13.99</td>
</tr>
<tr>
<td>Orthopro</td>
<td>6.33 ± 2.74</td>
<td>–1.10–12.33</td>
</tr>
<tr>
<td>Vasyli</td>
<td>4.44 ± 2.60</td>
<td>–2.80–10.47</td>
</tr>
</tbody>
</table>

Abbreviations: ICC, intraclass correlation coefficient; CI, confidence interval.
Note: Positive values indicate an increase in height.
*Intratester reliability of the two clinicians taking the measurements.

<table>
<thead>
<tr>
<th>Orthosis</th>
<th>Change in Frontal Plane Calcaneal Angle (°)</th>
<th>ICC (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Range</td>
</tr>
<tr>
<td>Wedge</td>
<td>2.82 ± 2.05</td>
<td>–2.50–8.00</td>
</tr>
<tr>
<td>Arch cookie</td>
<td>0.44 ± 2.19</td>
<td>–6.00–5.50</td>
</tr>
<tr>
<td>Prothotic</td>
<td>2.66 ± 1.78</td>
<td>–0.75–6.75</td>
</tr>
<tr>
<td>Formthotic</td>
<td>0.47 ± 1.79</td>
<td>–2.50–5.00</td>
</tr>
<tr>
<td>Orthopro</td>
<td>1.87 ± 2.18</td>
<td>–2.25–8.50</td>
</tr>
<tr>
<td>Vasyli</td>
<td>0.54 ± 1.57</td>
<td>–3.00–4.00</td>
</tr>
</tbody>
</table>

Abbreviations: ICC, intraclass correlation coefficient; CI, confidence interval.
Note: Positive values indicate a more inverted position.
*Intratester reliability of the two clinicians taking the measurements.
under the medial side of the calcaneus. The two devices on the left had greater height compared to the orthoses on the right with a statistically significant change in frontal plane calcaneal position, and the two devices on the right produced significant changes in this angle. These orthoses have design features that put greater force on the medial side of the assumed position of the subtalar joint axis and therefore apply greater moment to invert the rearfoot (Fig. 5). These features are designed to apply greater force on the medial side of the calcaneus than on the longitudinal arch area. Both the heel wedge and the Prothotic are very inverted in the rearfoot, applying this force at a higher magnitude than the other types of orthoses. The Orthopro is modeled on a device with a medial heel skive and a 2° inverted rearfoot post, which is specifically designed to provide greater force medial to the axis of the subtalar joint. The Formthotic, Vasyli, and arch cookie orthoses do not seem to be designed to apply greater force medial to the subtalar joint axis or have a sufficient lever arm to the axis, which would account for the lack of change in the frontal plane position of the calcaneus found in the present study. These orthoses seem to be designed to apply force to the more distal aspects of the foot, where they do not necessarily have an effect on inverting the rearfoot about the subtalar joint axis. Several prefabricated orthoses on the market are promoted as inverting the calcaneus by showing before and after photographs of a foot with and without the device; however, the data presented here show that the response to the orthosis is subject-specific and inconsistent.

All of the orthoses used in the present study were associated with a significant change in navicular height compared with the barefoot static stance position. The change in the height of the navicular could be related to three effects of the orthoses: supination of the rearfoot, elevation of the medial longitudinal arch, or elevation of the foot. The thickness of the device alone could have been responsible for the change in navicular height. It is difficult to extrapolate the clinical significance of the changes in navicular height found here because of the orthoses' elevation of the entire foot or heel.

Two other studies used a similar method, but they did not conduct any analyses of the reliability of the data they reported. Valmassy and Terrafranca found a mean inversion change of approximately 3° in the frontal plane position of the calcaneus using triplane wedges. Jay et al found a mean inversion change of 6° in the frontal plane position of the calcaneus using a “dynamic stabilizing innersole system.” Both of these studies found a greater change in the angles than is reported here, which could be accounted for by the lower body weight of the children involved in those studies compared with that of the adults involved in the present study. Payne et al previously showed that body weight is correlated to supination resistance, so it is more difficult to invert the calcaneus in individuals with greater body weight. Taken together, the results of these two studies and the present study demonstrate the changes in the frontal plane calcaneal angle that can occur with foot orthoses treatment; however, this is based on the assumption that this is a therapeutic goal of the orthoses. The function of foot orthoses is more complicated than this, and the motion of the rearfoot complex is more complicated than the simple measurement of the single parameter of frontal plane calcaneal position.

The primary aim of this study was to determine whether the posture of the foot or the amount of force needed to supinate the foot could be used to predict the response of the foot to different foot orthoses. This was not demonstrated. It was considered that if a large amount of force was needed to supinate a foot, then the foot would respond only to orthoses that are assumed to provide a large amount of force, such as the heel wedge, the Prothotic, and the Orthopro. It was also considered that if a foot needed only a small amount of force to supinate it, then the foot would respond to all types of foot orthoses, including those that are assumed to provide...
low and high force. The subjects in this study had a wide range of resistance to supination, with an SD of 33.9 about the mean of 122.1 N. As there was no significant response of subjects to the orthoses that are assumed to provide less supinatory force about the subtalar joint axis (ie, the arch cookie, the Formthotic, and the Vasyli), it was not possible to demonstrate any statistical correlation between the response to the device and resistance to supination.

The FPI score had a weak but statistically significant positive association with changes in the frontal plane calcaneal angle and use of the Prothotic. There was also a weak but statistically significant positive association with changes in the navicular position and use of the Prothotic, Formthotic, Orthopro, and Vasyli orthoses. This finding is not unexpected because the higher the FPI score (the more the foot is considered pronated), the greater the chance for improvement in the posture of the foot from the use of different foot orthoses.

Although the mean responses were significant for three of the orthoses and insignificant for three, the range of the mean changes for all devices showed a wide range of subject-specific responses. With each device, there was at least one subject who pronated more (Table 2). This could be an artifact of measurement, but the measurements were taken by two clinicians to reduce that possibility, and the reliability between them was very high. The reason for this finding is not entirely clear, as there is no literature exploring possible explanations, to our knowledge. Other possible determinants of these subject-specific responses to foot orthoses are not clear. Kinematic studies that have examined the effects of foot orthoses on rearfoot motion usually report only the mean and SD of changes and not the range, so it is not possible to judge whether a similar phenomenon was observed in kinematic studies. However, two kinematic studies have reported the means and SDs that showed a small group improvement in rearfoot angle, but they also reported the range about the mean. In each study, one or more subjects everted more or had an increase in internal rotation of the tibia with the use of foot orthoses, despite the overall mean group effect being one of increased calcaneal inversion and external rotation of the tibia. Although the findings of at least one subject in each orthotic condition everting more while standing in static stance are not unique, they have not been addressed in the literature before and are an important avenue for further research given the subject-specific response to the use of foot orthoses.

This study has several limitations, and the results must be interpreted in this context. The response to the different foot orthoses was measured in single-limb static stance, which is considered the position of the foot at midstance; however, the position is static and may not be representative of dynamic function. In single-limb stance, twice as much weight is borne on the foot, and the center of mass is positioned more laterally than in double-limb stance. These biomechanical differences may further limit the results of this study. During dynamic function, foot orthoses may do more than just change the posture of the foot. This study does not take into account any kinematic changes, such as the rate of foot pronation or the role that the orthoses may play in establishing the windlass mechanism of the foot. The orthoses used in this study were commercially made, prefabricated orthoses and so did not account for the specific individual causes of any excessive pronation of the foot. In clinical practice, prefabricated orthoses can be modified (eg, by the addition of varus wedges) or selected to match the desired plantar contour of the foot to make them more specific to the individual. These issues were not taken into account in this study. This study may not adequately reflect the range of orthoses available internationally, as the orthoses used in this study are commonly used in Australia but are not all available internationally. However, the orthoses used were chosen to reflect the diversity of the prefabricated orthoses available. A further limitation is that all of the subjects were young, healthy, asymptomatic adults and may not necessarily reflect the extremes that may be seen in a pathologic population. However, an FPI score greater than 5 is considered mildly pronated, so the mean of 7.3 ± 2.7 suggests that a wide range of foot types were included in the study population.

**Conclusion**

Despite these limitations, the present study implies that if the therapeutic goal is to alter the posture of the foot by inverting the rearfoot, only three of the orthoses were capable of doing this. These three orthoses had a more wedge-like inverted feature in the rearfoot. If the goal is to increase the height of the medial longitudinal arch, then most of the orthoses can do this. However, this latter finding may have been an artifact of the study design caused by the elevation of the entire foot or heel by the device. The function of the foot and its response to foot orthoses is complicated, and the change of the posture of the foot measured in this study may not necessarily be related to a change in clinical outcomes. Further work is needed to identify subject-specific characteristics that are responsible for individual responses to
foot orthoses and the use of the measurement of dynamic variables to demonstrate the response.

References