First metatarsophalangeal joint dorsiflexion is necessary to stabilize the foot during the propulsive phase of gait, from heel lift of the supporting foot to heel strike of the opposite foot. Such dorsiflexion facilitates the passage of the center of mass over and beyond the foot safely and efficiently owing to the simultaneous activation of stabilizing autosupport mechanisms in the foot, while creating a rigid lever to increase the efficiency of the propulsive forces acting on it. Restriction of first metatarsophalangeal joint dorsiflexion is believed to result in abnormal foot function and, thus, pathology.

To reduce pathology, orthoses can be used to modify the structure or function of the foot and lower limb. Many researchers have investigated the value of foot orthoses as a treatment modality. However, the results of these studies tend to be mixed, with some outcomes supporting and others negating the effectiveness of orthotic use. These confounding results may be due at least partly to lack of both a common method and scientific rigor.

Orthotic devices are commonly used to stabilize the rearfoot or alter the orientation of joints, especially the subtalar joint, since excessive pronation at this joint is commonly associated with foot pathology. The Root functional orthosis, the Blake inverted orthosis, and the medial heel skive technique have been developed to address such problems. These techniques effectively create a wedge to support the rearfoot on the side that is prone to overrotation, stabilizing it against any undesired rotational motion about the axis in a more functionally desirable position.

Fuller suggested that varus heel wedges supinate the subtalar joint, leading to a reduction in force on the first metatarsal and plantar aponeurosis, thereby allowing the first ray to dorsiflex. Increased dorsiflexion of the first ray tends to reduce the dorsiflexion capability of the first metatarsophalangeal joint. However, when the effects of a 6° wedge, in a variety of positions and combinations, were investigated, the results indicated that there was no statistically significant change in the tension of the plantar aponeurosis among the rearfoot varus, rearfoot valgus, and no wedge conditions. However, this study used a static assessment of a sample of nine cadaveric limbs and thus may not be representative of dynamic in vivo function.

The Effect of 5-Degree Valgus and Varus Rearfoot Wedging on Peak Hallux Dorsiflexion During Gait

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The dynamic effects of 5° varus and valgus rearfoot wedging on peak hallux dorsiflexion were investigated in 30 asymptomatic subjects (5 males and 25 females). Statistically significant reductions in peak hallux dorsiflexion were found with rearfoot varus wedging and rearfoot valgus wedging. Furthermore, the reduction in peak hallux dorsiflexion occurring with rearfoot varus wedging was statistically significant compared with that associated with rearfoot valgus wedging. These findings have implications for the orthotic management of a variety of lower-limb pathologies. (J Am Podiatr Med Assoc 94(6): 558-564, 2004)

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Kilmartin et al. conducted a preliminary study of the effects of modified Root orthoses on the range of first metatarsophalangeal joint dorsiflexion during gait. To address the potential displacement of skin markings relative to the structures to be measured, the authors inserted acupuncture needles to act as markers during a videotaped gait analysis. The results showed a decrease in dorsiflexion in shod feet ($P \leq .001$), with no significant difference found when orthoses were worn ($P \geq .05$). However, an enhanced potential for type II statistical error was acknowledged in a relatively small sample of five subjects.

Harradine and Bevan conducted an in vivo study of the effects of valgus rearfoot wedging on maximal dorsiflexion of the first metatarsophalangeal joint ($N = 44$). Varying degrees of valgus rearfoot wedging were incorporated into an insole, and the maximal first metatarsophalangeal joint dorsiflexion was measured in static stance using a digital goniometer. The results indicated that with the wedging present, first metatarsophalangeal joint dorsiflexion was reduced (Table 1). Although all variations in rearfoot wedging angulation resulted in a decrease in first metatarsophalangeal joint dorsiflexion, the most significant reduction in motion occurred with a 5° rearfoot wedge ($P \leq .05$). The study was conducted with the foot static and involved skin markings that may have become displaced. Thus results obtained may not be applicable to dynamic foot function during gait.

More recently, Hogan and Kidd investigated the effectiveness of casted orthoses and of orthoses produced after the matching of a pedograph output with a preexistent laboratory cast to limit first metatarsophalangeal joint dorsiflexion in order to reduce symptoms in 30 patients with hallux limitus. Neither type of orthosis was found to affect first metatarsophalangeal joint dorsiflexion; this may have been due, at least in part, to a static assessment mode.

The results of many studies of the effects of foot orthoses on first metatarsophalangeal joint function either are conflicting or remain relatively inconclusive owing to the method used. There have been no previous dynamic studies, to our knowledge, of the effects of rearfoot valgus and varus wedging on first metatarsophalangeal joint dorsiflexion. The aim of this study was to assess the effects of 5° varus and valgus rearfoot wedging applied to a simple (non-casted) insole on peak first metatarsophalangeal joint dorsiflexion during gait.

### Materials and Methods

#### Subjects

Thirty subjects (25 females and 5 males; mean age, 28.5 years [range, 11 to 43 years]) were selected to take part in the study using convenience sampling. No medical or health problems were reported. All participants’ feet and lower limbs were asymptomatic. All subjects provided written consent.

#### Footwear Standardization and Modification

Ten pairs of shoes, popularly termed “Chinese slippers,” were obtained in the greatest range of sizes available (European sizes 36 to 44). Each shoe was manufactured with a hard plastic sole of 5-mm thickness, a heel of 8-mm thickness, and a cotton upper. To obtain the range of sizes required for the study, it was necessary to use two different styles of shoe: one style fastened with a strap and buckle (European sizes 36 to 41) and the other was a slip-on style (European sizes 42 to 44) (Fig. 1). An area of the upper corresponding to the hallux and first metatarsophalangeal joint region was cut away so that the hallux

<table>
<thead>
<tr>
<th>Valgus Rearfoot Wedging (°)</th>
<th>First Metatarsophalangeal Joint Dorsiflexion (°)</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
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<tr>
<td>0</td>
<td>85.91</td>
<td>15.35</td>
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<td>54–112</td>
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<td>36–90</td>
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<tr>
<td>8</td>
<td>51.66</td>
<td>11.53</td>
<td></td>
<td>33–78</td>
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Figure 1. Footwear used with the first ray cut out to accommodate the O’Brien goniometer.
could freely extend and the goniometer could be secured to the proximal phalanx.

**Insoles and Wedging**

Given the findings of Harradine and Bevan,\(^\text{18}\) 5° ethylene vinyl acetate wedging was selected for use in this study. By sandwiching the wedge between two layers of regenerated leatherboard of 2-mm thickness, the insoles could be reversed in the shoe, allowing the rearfoot wedge to be positioned in either a varus or a valgus attitude (Figs. 2 and 3).

**Measurement of Peak First Metatarsophalangeal Joint Dorsiflexion**

An O'Brien goniometer was used to obtain peak dorsiflexion angle measurements at the first metatarsophalangeal joint (Fig. 4). The device consists of two hinged units (one of which incorporated housing for a pen unit), a pen unit, fixation devices, and adhesive labels with a printed degree scale. The range of motion at the first metatarsophalangeal joint is measured by the Law of Cosines\(^\text{21}\) based on angular calculation from the known lengths of the sides of a triangle. The triangle in this case is formed by the attachments to the proximal phalanx and the metatarsal, which remain a constant length, and the first metatarsophalangeal joint range of motion creates a varying measurement (Fig. 5). This variation in distance is recorded using the pen marks on the measurement scale. Because the scale is correlated to the angular changes within the triangle and then scaled in degrees using calculations according to the Law of Cosines,\(^\text{21}\) the peak range of motion represented by the point on the scale reached by the longest pen marking can be read as the degree of angulation. A pilot study was undertaken to ensure reliability of the O'Brien goniometer and to verify its appropriateness for the task in the modified, standardized footwear. Consistent readings were obtained during the pilot study, and the device was deemed appropriate for the purpose.

The foot for first attachment of the goniometer and the order in which the experimental conditions were applied were randomly selected by flipping coins. Each participant was asked to stand, to take a small step forward, and then to remain with feet

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**Figure 2.** Lateral view of the insole. The shape of the insole allows the same insole to be used in both valgus and varus wedging positions.

**Figure 3.** Posterior view of the insole illustrating the position and angulation of the wedging.

**Figure 4.** The O'Brien goniometer and footwear *in situ*.

**Figure 5.** Demonstration of the principle of the Law of Cosines as applied to the use of the O'Brien goniometer on the first metatarsophalangeal joint.
apart. The hallux was dorsiflexed several times while the joint was palpated, and the motion was observed to locate the joint margin. The skin over the proximal articular line of the proximal phalanx was marked with a line using a skin-marking pen. The distal section of the unit was then applied using the fixation device provided. The label had been previously applied to the proximal component of the goniometer according to the manufacturer’s instructions. The fixation device was attached to the proximal portion of the goniometer unit before it was placed onto the distal portion. The uncapped tip of the pen situated in the distal portion was lined up with the zero line on the label, and the proximal portion was then affixed to the foot while maintaining the zero position of the pen (Fig. 4).

A room was selected to enable participants to walk 11 m in a straight line without obstruction. Subjects were requested to walk, stop, and remain facing in their direction of travel to prevent the possibility of a false reading due to hallucal dorsiflexion when turning around. The peak dorsiflexion reading, ie, the point on the scale reached by the longest line on the goniometer, was recorded. The goniometer alignment was reset to zero, and the procedure was repeated until all experimental conditions and data capture were completed. The goniometer was attached to the opposite foot and the procedure was repeated so that peak first metatarsophalangeal joint dorsiflexion readings were obtained for both feet for the three conditions: no wedging, 5° rearfoot valgus wedging, and 5° rearfoot varus wedging.

Statistical Analysis

A paired t-test was used to ascertain whether the data for both feet could be combined to form a single database, and further paired t-tests were used to examine whether statistically significant differences existed among dorsiflexion values with no wedging and with varus and valgus wedging.

Results

All analyses were carried out using SPSS for Microsoft Windows, Version 10.1 (SPSS Science, Chicago, Illinois). The distribution of the measurements of peak first metatarsophalangeal joint dorsiflexion of the right and left feet under the different experimental conditions is shown in Figure 6.

Data were examined for statistically significant differences between the right and left feet to reveal whether pooling of data from the right and left feet was appropriate. Paired t-tests used to test data for the right and left feet for each experimental condition showed no significant difference; therefore, these data were combined to form a single database. This larger sample size increases the statistical power and improves the reliability of the inferences drawn. The combined data are presented in Figure 7.

Table 2 gives the results of paired t-tests for each of the three experimental conditions. Paired t-tests to compare the differences between the participants’ first metatarsophalangeal joint peak dorsiflexion with no wedging versus valgus wedging in the shoe ($t_{59} = 10.411; P < .05$, two-tailed) and with no wedging versus varus wedging in the shoe ($t_{59} = 11.488; P < .05$, two-tailed) were both statistically significant. A paired t-test of the differences between participants’ first metatarsophalangeal joint peak dorsiflexion with valgus versus varus wedging in the shoe was also statistically significant ($t_{59} = 6.193; P < .05$, two-tailed).

Discussion

Valgus Wedging and Peak First Metatarsophalangeal Joint Dorsiflexion

Valgus wedging was found to significantly reduce peak first metatarsophalangeal joint dorsiflexion in
the sample by a mean of almost 6° ($P = .001$). Although this outcome agrees with the work of Harraudine and Bevan,\(^1\) it is interesting that a mean value of 47.03° obtained here in dynamic assessment with no wedging present was 55% of the measurement resulting from the static assessment carried out by these authors. In addition, the mean peak first metatarsophalangeal joint dorsiflexion value we derived with no wedging present was similar to that found in other dynamic studies\(^2,\)\(^1\)\(^7\) where shoes were worn. This finding tends to reinforce the desirability of dynamic measurement in the assessment of foot function and, arguably, to validate the findings of our study, despite a relatively small sample size. Furthermore, because the peak dorsiflexion values found with no wedging present in this study corroborate those found by other researchers, it may be that differences in the mean values obtained for 5° valgus wedging between our study and that of Harradine and Bevan\(^1\) are due to differing methods of assessment.

Although the valgus rearfoot wedging statistically significantly reduced peak first metatarsophalangeal joint function, the precise mechanism by which this occurred is not clear. It may be that the rearfoot wedging produces an alteration of subtalar joint and midtarsal joint rotational alignment, thereby affecting first-ray function, resulting in reduced peak first metatarsophalangeal joint dorsiflexion. If, as Kirby\(^2\)\(^2,\)\(^2\) suggests, valgus wedging reduces supinatory moments and increases pronatory moments around the subtalar joint axis, then, theoretically, this may also result in medial deviation of the subtalar joint axis of motion. Because the subtalar and midtarsal joints are interdependent, the midtarsal joint may "unlock" (by pronating about an obliquely oriented axis), reducing the stability of the forefoot, and permit the first ray to dorsiflex, reducing the ability of the first metatarsophalangeal joint to dorsiflex.\(^5\) The stability of the foot may be further reduced because the valgus wedging may place additional strain on the plantar aponeurosis, preventing the proximal phalanx from dorsiflexing on the head of the first metatarsal, thus inhibiting the activation of the windlass mechanism.\(^3\)

### Varus Wedging and Peak First Metatarsophalangeal Joint Dorsiflexion

Similarly, a highly significant statistical difference was found when the effects of varus wedging were compared with no wedging in the shoes ($P = .001$); therefore, it is concluded that varus wedging also results in a reduction in peak first metatarsophalangeal joint dorsiflexion. In this case, a mean reduction of almost 8° was evident with varus wedging present, 2° more than occurred with valgus wedging.

Possible reasons for this finding are not evident in the literature. Previous research\(^1\)\(^6\) has indicated that...
tension in the plantar aponeurosis remains unaffected by wedging, although this may not be the case in vivo. Although conjecture about the reasons for this decrease in first metatarsophalangeal joint dorsiflexion is necessarily speculative, it is possible that the supinatory moment acting around the subtalar joint axis is increased by varus wedging. This increase would effectively supinate the subtalar joint, causing lateral deviation of its axis. Such lateral deviation could lock the midtarsal joint prematurely and prolong lateral forefoot loading for a sufficient length of time to necessitate low-gear propulsion, as it is too late or too difficult to accomplish medial forefoot loading and toe-off. The amount of first metatarsophalangeal joint dorsiflexion could be reduced, as sufficient first metatarsophalangeal joint dorsiflexion to gain clearance only would be required.

A further explanation could be that dorsiflexion did occur but that it was not apparent in the measurement owing to an adjustment of the equipment after insertion of the insole. The wedge measured 8.55 mm at its deepest part. Because of adaptability of the medial longitudinal arch, it is possible that the angle of inclination of the first ray was altered to bring the first metatarsophalangeal joint to the ground. If this was the case, the proximal phalanx could be displaced dorsally, resulting in a lower range of motion being recorded than is actually achieved (Fig. 8). Indeed, the valgus and varus rearfoot wedges are effectively heel lifts. It is possible that the heel-lifting effects of the varus and valgus wedging used in this study are the main reason for the decrease in peak hallux dorsiflexion. In other words, simply lifting the heel will decrease the necessary number of degrees of hallux dorsiflexion during propulsion because a heel lift will position the hallux during standing in a relatively dorsiflexed position compared with a barefoot standing condition. These theories require further investigation.

### Valgus versus Varus Wedging

Again, a statistically significant difference was found between peak first metatarsophalangeal joint dorsiflexion measurements with valgus wedging versus varus wedging ($P = .001$). As stated previously, varus wedging reduced mean peak first metatarsophalangeal joint dorsiflexion by an additional 2°. Until the mechanisms contributing to this reduction can be identified, it seems pointless to speculate on the significance of this result. However, the implications of this particular finding for the clinical management of first metatarsophalangeal joint pathology are of some interest to podiatric physicians, as varus wedging, with resultant supination of the subtalar joint, seems to offer greater potential for reducing painful first metatarsophalangeal joint symptoms than valgus wedging.

The limitations of a relatively small sample size cannot be overlooked, and it is recognized that, consequently, these results may lack external validity. However, these results confirm previous findings with respect to the dynamic measurement of peak first metatarsophalangeal joint dorsiflexion. Future
studies may consider the effects of rearfoot valgus and varus wedging on stride length and mean first metatarsophalangeal joint dorsiflexion (the O'Brien goniometer is capable of recording only peak measurements). If, as the results of this study indicate, wedging affects the dorsiflexion capabilities of the first metatarsophalangeal joint, then the propulsive capabilities of the foot and the stride length may be decreased accordingly.

Conclusion

This study sought to provide further information about foot function and the management of foot pathology by evaluating the effects of $5^\circ$ valgus and $5^\circ$ varus rearfoot wedging on peak dorsiflexion at the first metatarsophalangeal joint. Within the limitations of the study, the results suggest that both forms of wedging had a statistically significant effect on peak first metatarsophalangeal joint dorsiflexion, with reductions occurring with both types of wedging. Furthermore, a statistically significant difference was found when the effects of valgus and varus wedging were compared, with first metatarsophalangeal joint dorsiflexion more significantly reduced with varus wedging in place. These results may have implications for the clinical management of disorders of the first metatarsophalangeal joint, such as hallux limitus.

References