# The response of the foot to prefabricated orthoses of different arch heights

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## ABSTRACT

A number of different design parameters are used in foot orthoses, one of which is the height of the arch. The aim of this study was to investigate the response of the foot to prefabricated foot orthoses of different arch heights. Sixteen subjects stood in static stance on six different pairs of foot orthoses and changes in navicular height and frontal plane calcaneal angle were measured. All devices resulted in statistically significant changes in the frontal plane calcaneal angle and height of the navicular. The changes to the calcaneal angle were correlated to the amount of force needed to supinate the foot. The changes in navicular height were correlated to the posture of the foot. Further work is needed to determine if these changes are related to dynamic changes and clinical outcomes.

## INTRODUCTION

Foot orthoses are widely used to treat lower limb biomechanical dysfunction. A number of decisions have to be made as to which of a multitude of variables need to be considered in the prescription of foot orthoses for this purpose. However, very little evidence is available to guide clinicians in this decision making process. This is further complicated by the kinematic response to foot orthoses being considered as subject specific, in that no two individuals will respond to the same foot orthotic.[1,2,3] The subject specific variables that determine a kinematic response to foot orthoses have not, as yet, been empirically determined. Investigating the link between subject specific variables and the different variables that can be incorporated into foot orthoses is complex due to the large numbers of both and the different individual preferences of clinicians. One such variable in the use of foot orthoses is the height of the medial longitudinal arch of the device. It has not been previously reported how subjects respond to the same type of foot orthoses manufactured with different arch heights. The aim of this project was to determine the static stance response of the foot to prefabricated foot orthoses available in different arch heights.

## METHODS

Subjects were recruited from the undergraduate student population and staff at La Trobe University. Informed consent was obtained from each participant and the project was approved by the Faculty of Health Science's Human Ethics Committee. Subjects were recruited who did not have any structural or functional problem of the lower limb that prevented them from weightbearing on different types of foot orthoses.

Six prefabricated foot orthoses from the one manufacturer[Δ] were used so consistency was achieved in the shape of the foot orthoses with the exception of the differing arch heights. Three different plastic (rigid) metatarsal head length devices with rearfoot posts with an identical shape and profile, but with a different arch height (Control Tech Flex[Δ] 4, 6 and 8 degrees), two soft full-length devices, each with a different arch height (Control Tech Soft[Δ] 4 and 6 degrees) and a soft metatarsal head length device that is cut down to fit in dress shoes (Slim Tech Soft[Δ]) (Figures 1 and 2).

**Figure 1: The three rigid pre-fabricated foot orthoses with different arch heights used in the study (Control Tech Flex, Interpod Ltd).**

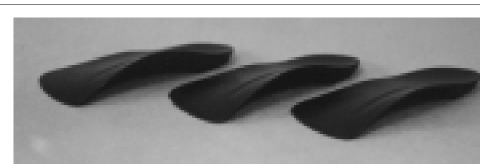

**Figure 2: The two different types of soft prefabricated foot orthoses used in the study (Control Tech Soft and Slim Tech Soft, Interpod Ltd).**

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Figure 3: The cut down canvas shoes used in the study so that changes in frontal plane calcaneal angle and navicular height could be measured.

Figure 4: The use of the digital inclinometer to measures changes in the frontal plane calcaneal position with the use of the different foot orthoses.

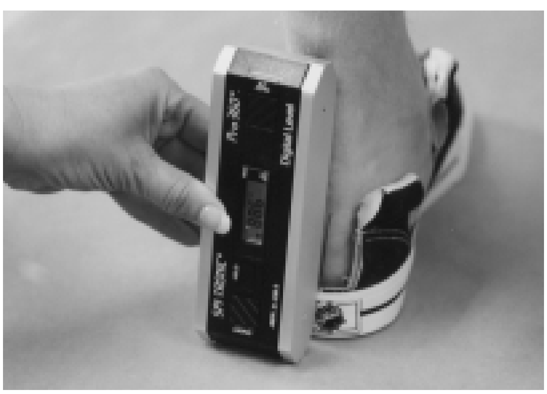

Figure 5: The use of the digital callipers to measure changes in the height of the navicular with the use of the different foot orthoses.

Canvas shoes were cut down so that the foot orthoses could be placed in the shoes and subjects could be measured standing on the different foot orthoses (Figure 3). The posterior and medial aspects of the shoes were cut out so that changes in navicular height and frontal plane calcaneal angle could be measured. The resting calcaneal stance angle was measured using a digital inclinometer (Spi-Tronic™) with no orthoses and with each of the orthoses (Figure 4). The navicular height was measured using digital callipers (Mitutoyo™) with no orthoses and with each of the orthoses (Figure 5). The skin lines for the measurements were placed by one experienced clinician and changes were independently measured by two experienced clinicians. The mean of the two clinicians was used for the analysis.

To determine foot structure and type, the Foot Posture Index (FPI)[4,5,6] was used. As many of the measurements of the foot and lower limb have been shown to have some degree of unreliability associated with them[7] the FPI uses 8 observations of the foot and assigns a score of –2 (supinated) to +2 (pronated) to each observation depending on the position of the foot. These weightbearing observations include palpation of the head of the talus for congruence of the talonavicular joint, comparison of the curves above and below the lateral malleoli, bowing of the achilles tendon (Helbing's sign), frontal plane position of the calcaneus (inverted/everted), bulging in the region of the talonavicular joint, height and congruence of the medial longitudinal arch, congruence of the lateral border of the foot, and abduction/adduction of the forefoot on the rearfoot. A composite score of –1 to +4 is considered to represent a relatively normal foot posture. A score from +5 to +9 is considered mildly pronated and a score above +10 is considered highly pronated (maximum score is +16). A score of –2 to –6 is considered supinated and below –6, highly supinated (lowest score is –16). Two experienced clinicians independently determined the FPI, with the mean of the two being used for analysis.

The composite FPI score was correlated to changes in frontal plane angle and navicular height with the six different devices. In addition 3 of the 8 items that make up the FPI (calcaneal inverted/everted, bulging in the region of the talonavicular joint and congruence of the medial longitudinal arch) were also used to correlate to changes with the foot orthoses. These three were chosen as they are assumed to represent positions of the foot in the frontal plane (calcaneal inversion/eversion), sagittal plane (medial longitudinal

Figure 6: The supination resistance device used to measure the amount of force needed to supinate the rearfoot.

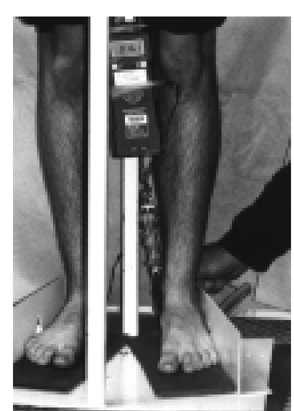

**Table 1: Changes in the static stance frontal plane calcaneal angle from no orthoses condition and the different orthoses.**

| | Mean (+/-SD) change from no orthoses (degree) | Range | *p* for difference to no orthoses condition |
|---|---|---|---|
| Soft (medium arch height) | 2.17 (+/-1.78) | 0.20-7.55 | *p*<0.0001 |
| Soft (high arch height) | 2.19 (+/-1.73) | 0.25-8.30 | *p*<0.0001 |
| Rigid (low arch height) | 1.99 (+/-1.76) | 0.05-6.45 | *p*<0.0001 |
| Rigid (moderate arch height) | 2.67 (+/-1.63) | 0.65-7.25 | *p*<0.0001 |
| Rigid (high arch height) | 3.05 (+/-2.01) | 0.35-9.55 | *p*<0.0001 |
| Slim (low arch height) | 2.45 (+/-1.89) | 0.10-9.20 | *p*<0.0001 |

**Table 2: Static stance navicular height in the no orthoses condition and the different orthoses.**

| | Height (+/-SD) of navicular (mm) | Range | *p* for difference to no orthoses condition |
|---|---|---|---|
| No orthoses | 50.61 (+/-7.53) | 35.35-70.02 | |
| Soft (medium arch height) | 60.01 (+/-6.37) | 47.73-78.20 | *p*<0.0001 |
| Soft (high arch height) | 61.63 (+/-6.65) | 47.04-79.65 | *p*<0.0001 |
| Rigid (low arch height) | 54.86 (+/-7.16) | 41.24-75.72 | *p*<0.0001 |
| Rigid (moderate arch height) | 56.42 (+/-6.67) | 43.52-76.03 | *p*<0.0001 |
| Rigid (high arch height) | 57.17 (+/-6.70) | 44.77-76.57 | *p*<0.0001 |
| Slim (low arch height) | 55.46 (+/-6.36) | 42.21-74.16 | *p*<0.0001 |

arch height) and transverse plane (bulging in talonavicular region).

To determine the amount of force needed to supinate the rearfoot, a previously described mechanical supination resistance device[8,9,10] was used (Figure 6). This device consisted of a non-stretchable woven fabric that was fixed to the base of a platform lateral to the foot in the region of the calcaneocuboid joint. It passed under the foot medial to the talonavicular joint, then proximally to be attached to a pulley system and a Mecmesin® force gauge that measured the force in Newtons. The pulley system was used to apply a force to just overcome the inertia needed to invert the calcaneus, as the investigator observed a bisection that was placed on the posterior aspect of the calcaneus. Ten trials were collected from each foot of the subjects with the mean used for the analysis. The device has been previously reported to be reliable.[9]

Repeated measures ANOVA was used to determine the differences in frontal plane calcaneal angle and navicular height from the barefoot condition and the use of the six difference devices. Bonferroni post hoc testing was used to determine where the difference occurred. Pearson's correlation coefficient was used to determine the association of the FPI and supination resistance to the changes in the frontal plane position of the calcaneus and the height of the navicular for each of the orthoses. Intraclass correlation coefficients (type 2,1) were used to determine the intra-rater reliability of the two clinicians in determining the FPI and measuring the changes in the frontal plane calcaneal angle and the height of the navicular.

## RESULTS

A total of four males and twelve females (32 feet) were recruited for this study. The mean age was 24.2 (+/-6.6) yrs and the mean weight was 65.3 (+/-12.2) kgs. The mean Foot Posture Index was 6.03 (+/-3.7) (range: -1.00 to 11.50) and the mean supination resistance was 173.2 (+/-64.6) N (range 78.72-358.47).

The intraclass correlation coefficients for reliability of the two clinicians for the FPI was 0.96 (95% CI: 0.92-0.98), for the frontal plane calcaneal angle measurements it was 0.83 (95% CI: 0.78-0.88) and for the navicular height measurements it was 0.92 (95% CI: 0.90-0.94).

The mean changes in the frontal plane calcaneal angle and the changes in navicular height with the six orthoses are reported in Tables 1 and 2. Repeated measures ANOVA for the difference between change in calcaneal angle and changes in the navicular height with no orthoses and the orthoses was significant ($p<0.0001$). Post hoc testing showed that all orthoses had a significantly different change from the no orthoses condition.

The correlations between supination resistance and FPI with the changes in frontal plane calcaneal angle and navicular height for the six different orthoses are reported in Table three. The main finding here was the moderate negative correlation between supination resistance and change in frontal plane angle of the calcaneus with five of the six different devices (first column in Table 3). There was a similar moderate negative correlation between supination resistance and the change in navicular height for the soft orthoses, but not the

**Table 3: Correlation between supination resistance and Foot Posture Index and changes in the calcaneal angle and navicular height for each of the six prefabricated devices.**

| | Supination resistance and change in calcaneal angle | Supination resistance and change on navicular height | Foot Posture Index and change in calcaneal angle | Foot Posture Index and change in navicular height |
|---|---|---|---|---|
| Soft (medium arch height) | -0.47 (*p*=0.006)* | -0.46 (*p*=0.008)* | 0.09 (*p*=.61) | 0.43 (*p*=0.014)* |
| Soft (high arch height) | -0.53 (*p*=0.002)* | -0.45 (*p*=0.009)* | 0.21 (*p*=0.26) | 0.38 (*p*=0.03)* |
| Rigid (low arch height) | -0.39 (*p*=0.03)* | -0.289 (*p*=0.11) | 0.01 (*p*=0.95) | 0.17 (*p*=0.35) |
| Rigid (moderate arch height) | -0.37 (*p*=0.04)* | -0.32 (*p*=0.74) | 0.17 (*p*=0.35) | 0.34 (*p*=0.08) |
| Rigid (high arch height) | -0.32 (*p*=0.08) | -0.37 (*p*=0.35) | 0.035 (*p*=0.85) | 0.31 (*p*=0.08) |
| Slim (low arch height) | -0.40 (*p*=0.02)* | -0.41 (*p*=0.02)* | 0.19 (*p*=0.31) | 0.42 (*p*=0.02)* |

*$p<0.05$

**Table 4: Correlation between arch height, calcaneal position and midfoot bulging and changes in frontal plane calcaneal angle and navicular height. Arch height, calcaneal position and midfoot bulging are components of the FPI and have a range of –2 (supinated) to +2 (pronated).**

| | Arch height (from FPI) and changes in navicular height | Calcaneal position (from FPI) and change in frontal plane calcaneal position | Midfoot bulge (from FPI) and changes in navicular height | Midfoot bulge (from FPI) and changes in calcaneal angle |
|---|---|---|---|---|
| Soft (medium arch height) | 0.44 (*p*=0.012)* | 0.11 (*p*=0.56) | 0.39 (*p*=0.027)* | 0.07 (*p*=0.70) |
| Soft (high arch height) | 0.35 (*p*=0.047)* | 0.24 (*p*=0.18) | 0.40 (*p*=0.023)* | 0.17 (*p*=0.36) |
| Rigid (low arch height) | 0.114 (*p*=0.53) | -0.002 (*p*=0.99) | 0.29 (*p*=0.09) | -0.04 (*p*=0.81) |
| Rigid (moderate arch height) | 0.27 (*p*=0.14) | 0.16 (*p*=0.38) | 0.52 (*p*=0.002)* | 0.09 (*p*=0.63) |
| Rigid (high arch height) | 0.29 (*p*=0.09) | 0.05 (*p*=0.78) | 0.42 (*p*=0.02)* | 0.01 (*p*=0.95) |
| Slim (low arch height) | 0.33 (*p*=0.07) | 0.30 (*p*=0.09) | 0.39 (*p*=0.03)* | 0.07 (*p*=0.71) |

*$p<0.05$

rigid orthoses (second column in Table 3). There were no correlations between FPI and change in the frontal plane calcaneal angle, but there were moderate positive correlations between FPI and the change in navicular height for the soft orthoses, but not the rigid orthoses (4th column, Table 3)

Three of the components that make up the FPI were also correlated with changes in navicular height and frontal plane calcaneal angle and are reported in Table 4. There were no correlations between calcaneal position and midfoot bulging in the talonavicular region and the frontal plane changes in the calcaneal angle for all of the devices (columns 2 and 4, Table 4). There was a moderate positive correlation between medial longitudinal arch height and changes in the height of the navicular for the soft orthoses, but not the rigid orthoses (column 1, Table 4). There was a positive mild to moderate correlation between bulging in the talonavicular region and changes in the arch height for all the orthoses (column 3 in Table 4).

## DISCUSSION

This study investigated the static stance change in the foot in response to the use of prefabricated foot orthoses with different arch heights from one manufacturer (Interpod Ltd, Melbourne, Australia). The use of these measurements are based on the assumption that realignment of the foot is the aim for the use of foot orthoses that are designed to alter foot function, which recent work suggests may not necessarily be the only aim of foot orthoses.[1,2] Any study of the type presented here needs measurements that are reliable. The measurements that were used in this study have previously been shown to be generally unreliable.[7,11,12,13] In our study the mark that was placed on the skin to represent navicular height and calcaneal angle was not removed for subsequent measurements when changes with the foot orthoses where measured, which would have improved reliability. The reliability of the three measurements used in this study (FPI, calcaneal angle and navicular height) had ICC's of 0.83 to 0.96, indicating that the measurements are reliable enough for the data to be used for subsequent analysis.

The results have shown that all of the devices within the Interpod range (Control Tech Flex, Control Tech Soft and Slim Tech Soft) resulted in a statistically significant change in the position of the calcaneus in the direction of inversion, as well as a significant increase in the height of the navicular. If the therapeutic aim is to change the calcaneal angle or improve arch height, these prefabricated foot orthoses can achieve this in static bipedal stance. The results presented here are comparable to the prefabricated foot orthoses reported in a previous study that resulted in statistically significant change in the frontal plane angle of the calcaneus in the direction of inversion.[3] In that study, three prefabricated foot orthoses resulted in a change in the frontal plane angle of the calcaneus and three other prefabricated foot orthoses did not. The design parameter that determined the ability of the orthoses to invert the foot was the use of medial heel. This medial heel wedging would increase the supination moment on the medial side of the subtalar joint axis.[14] The orthoses used in the study presented here have design features that do the same, which would account for the change in the calcaneal angle in the direction of inversion.

Supination resistance testing has been developed as a method to measure the force needed to supinate the rearfoot in static stance.[8,9,10] This study has demonstrated a moderate negative correlation between the force needed to supinate the foot (supination resistance) and the change in the frontal plane calcaneal angle for all of the six orthoses (one was not statistically significant). This means that the greater the supination resistance, the less the change in frontal plane angle of the calcaneus. As a manual version of supination resistance testing has been shown to be reliable when used by those experienced in its use[10], this finding could possibly be extrapolated to be used clinically to assist in deciding how much change is likely to happen in the static stance change to the frontal plane angle of the calcaneus with foot orthoses. There was also a moderate negative correlation between supination resistance and navicular height changes for the soft orthoses (Control Tech Soft and Slim Tech Soft). This can be interpreted as, for example, when the supination resistance was higher, there was less change in navicular height when using a softer orthoses. For the rigid orthoses (Control Tech Flex) this did not happen, which indicates that changes in navicular height with the use of rigid orthoses was not related to the force needed to supinate the foot.

The Foot Posture Index[4,5,6] was used to determine the posture of the foot without the need to use measurements that have been previously reported as being unreliable.[7,11] This study has shown that the posture of the foot, using the overall FPI score or the individual components of calcaneus inverted/everted position and midfoot bulging in the talonavicular region is not related to changes in the frontal plane calcaneal angle for any of the six orthoses. However, the overall FPI score was moderately and positively correlated to changes in navicular height for the soft orthoses and not the rigid orthoses. In other words, the higher the FPI score (the more pronated the foot is), the greater the change in navicular height for the soft orthoses. A mild positive correlation was noted for the two rigid devices with the higher arch heights, but this did not quite reach significance. For all the orthoses, bulging in the talonavicular region (as a component of the FPI) was moderately and positively correlated to changes in the navicular height; ie the greater the medial bulging, the greater the change in navicular height.

The results of this study have to be interpreted in the context of a number of limitations. All the subjects were healthy asymptomatic young adults and may not be representative of a pathological population, however the range of FPI values (-1, 'normal' to 11.58, severely pronated) and supination resistance values (78.72 to 358.47) indicate a wide range of foot types used in the study. All measurements used in this study were done in static bipedal (double limb) stance and not dynamically, so they may not necessarily represent what occurs during dynamic stance. Also, the different outcomes noted between the hard and soft orthoses may have been due to other variables, such as the softer devices have higher flanges and are wider.

## CONCLUSION

In conclusion, this study has shown that the Interpod range of prefabricated foot orthoses can result in a statistically significant change during static stance in the frontal plane position of the calcaneus in the direction of inversion and an increase in the arch height. We have also shown that the greater the force needed to supinate the foot, the less will be the change in the frontal plane calcaneal angle. Using the Foot Posture Index as a measure of how pronated the foot is, it was also shown that the posture of the foot was not related to how much the calcaneal angle can change, but it is related to how much the height of the navicular changes. Further work is needed to investigate if these static changes are related to dynamic changes and if they are related to clinical outcomes.

[Δ]Interpod Ltd, Melbourne Australia

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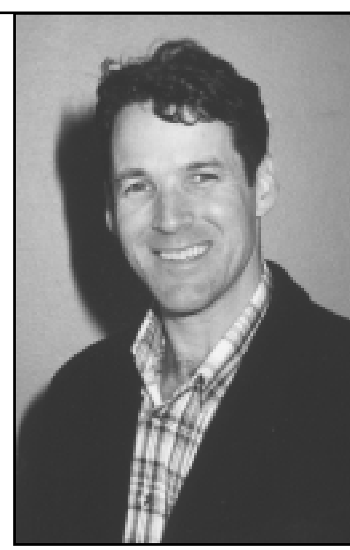

The Australasian Podiatry Council wishes to acknowledge the major contribution of Christopher Wheeler to the development of the Australasian Journal of Podiatric Medicine. Chris has recently stepped down as Scientific Editor of the Journal. In his last editorial, Chris generously acknowledges the role of the Journal's Assistant Editors, Reviewers, and other contributors; however it has been Chris, as the Scientific Editor who has provided the drive, stimulus and energy for the Journal over more than a decade.

This has been no small task for a profession with a small number of potential authors. Also in recent times "competition" from other Podiatry Journals has made the task harder.

The profession across Australia and New Zealand is greatly indebted to Chris for his dedication and commitment over that time.

Council will be recognising Chris' work as Editor at the Victorian/Tasmanian Conference in Hobart in March; also, later in the year, through a new Honour Board for Australasian Podiatry Council office bearers in the Council's Melbourne office.