

Relationship Between Positive Clinical Outcomes of Foot Orthotic Treatment and Changes in Rearfoot Kinematics

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Background: Previous two-dimensional kinematic studies that assessed the effect of foot orthoses on rearfoot motion have yielded mixed results regarding whether control of rearfoot motion is related to symptom relief.

Methods: We sought to determine the effect of foot orthoses on rearfoot motion and to correlate these changes with the degree of symptom improvement in 22 individuals with excessive rearfoot pronation (17 women and 5 men; mean $\pm$ SD age, 44.3 $\pm$ 16.7 years; mean $\pm$ SD weight, 74.9 $\pm$ 15.9 kg). Two-dimensional motion-analysis software was used to assess frontal plane rearfoot motion with and without foot orthoses. The mean $\pm$ SD Foot Posture Index of the left foot was 8.83 $\pm$ 3.54 and of the right foot was 9.22 $\pm$ 3.64). The pain and function subscales of the Foot Health Status Questionnaire were then used to determine the degree of symptom relief associated with the orthoses at baseline and 4 weeks later.

Results: Orthoses had a small but statistically significant effect on rearfoot motion, although no significant correlations were found between differences in rearfoot motion with and without foot orthoses and the improvements demonstrated in the Foot Health Status Questionnaire subscales of pain and function.

Conclusions: The effect of orthoses on frontal plane rearfoot motion is considered small and probably insufficient to account for the extent of symptom reduction found in this study. Other parameters of orthotic function, such as kinetic and neuromechanical variables, should be further investigated. (J Am Podiatr Med Assoc 97(3): 207-212, 2007)

Foot orthoses are a mechanical modality frequently prescribed by clinicians for the conservative care of lower-limb pathologic conditions. Functional foot orthoses are generally fabricated from rigid thermoplastic materials, such as polypropylene, to achieve motion control of the foot. Functional devices usually are fabricated using the neutral casting technique and are designed to limit excessive pronation of the subtalar joint, which has been suggested to be responsible for numerous lower-extremity injuries.¹ Root et al² suggest that foot orthoses in the treatment of excessive pronation aim to invert the subtalar joint to its neutral position throughout the stance phase of gait. This is defined as the position of the subtalar joint when it is neither pronated nor supinated. Through orthotic intervention the foot is assumed to be realigned in relation to the supporting surface, which

reestablishes the propulsive sequence by enabling the foot to function as a rigid lever-like structure.³

Theoretically, by maintaining the foot in an inverted position, a functional foot orthosis increases the supination moment on the medial aspect of the transverse plane position of the subtalar joint axis.⁴ This vertically oriented force exerted by the orthosis on the foot is termed the *orthosis reaction force*. The orthosis reaction force is suggested to oppose the pronatory ground reaction forces acting lateral to the subtalar joint axis.⁵ By aligning the foot in the presumably advantageous “neutral” or “inverted” position, functional foot orthoses have been suggested to alter tissue stress and ultimately achieve symptom reduction.²

The positive clinical effects of functional foot orthoses have been reported in various outcome studies.⁶⁻⁸ Despite the limitations of most of the study designs used to evaluate the clinical effectiveness of foot orthoses, it can be concluded that treatment with foot orthoses generally results in relief of pain. Numerous studies have used two-dimensional (2-D) op-

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tical systems to assess the effect of foot orthoses on frontal plane rearfoot kinematics, with mixed results. Some studies^{9, 10} suggest that orthoses significantly alter rearfoot kinematics, whereas other studies^{11, 12} suggest that orthoses do not significantly alter rearfoot motion. The results of three-dimensional (3-D) studies are also mixed, with some studies^{13, 14} postulating that orthoses have a significant effect on rearfoot motion and others^{15, 16} suggesting the contrary.

Despite the mixed outcomes of kinematic studies, it is clear that orthotic treatment alleviates symptoms associated with lower-limb pathologic conditions. To our knowledge, however, no study to date has determined whether a correlation exists between the reduction in symptoms associated with orthotic treatment and the orthotic effect on frontal plane rearfoot motion. Therefore, this study was undertaken to measure frontal plane changes in rearfoot position with and without orthoses and correlate these changes with the clinical outcomes of orthotic treatment. We hypothesized that there is no correlation between rearfoot-position changes and positive clinical outcomes.

Subjects and Methods

Participants

Twenty-two subjects (17 women and 5 men) participated in the study (mean $\pm$ SD age, 44.3 ± 16.7 years; mean $\pm$ SD weight, 74.9 ± 15.9 kg). All of the patients required an orthotic device for treatment of a lower-limb condition that was assumed to be associated with excessive rearfoot pronation. The Foot Posture Index was used to determine subject foot type; the mean $\pm$ SD Foot Posture Index of the left foot was 8.83 ± 3.54 and of the right foot was 9.22 ± 3.64 , which indicates that all of the subjects had a relatively pronated foot type.¹⁷ Eighteen subjects were prescribed custom foot orthoses, and the other four subjects were prescribed prefabricated foot orthoses. Subjects were excluded from the study if they previously had undergone orthotic treatment or had a biomechanically induced pathologic condition not attributed to excessive rearfoot pronation (eg, rheumatoid arthritis). All of the subjects signed an informed consent form approved by the Faculty of Health, Human Ethics Committee, La Trobe University Ethics Committee.

2-D Kinematic Data

SiliconCOACH Professional motion-analysis software (50 Pal/60 NTSC Hz) (siliconCOACH Ltd, Dunedin, New Zealand) was used to obtain 2-D kinematic data during subject analysis. Although, to our knowledge,

no studies to date have used the siliconCOACH Professional program to assess rearfoot motion, numerous studies have used similar 2-D motion-analysis systems. Mueller and Norton¹⁸ used the FootTrak System (Quadrant Components Inc, Fremont, California) and reported high intraclass correlation coefficient (ICC) values for time to maximum pronation (0.95–0.99) and maximum pronation velocity (0.88–0.96). They concluded that this system was highly reliable (>0.95) when the mean of three repeated measures of a single gait cycle was used. Similar to siliconCOACH Professional, the FootTrak motion-analysis system consists of a 60-Hz camera that relays digitized information *via* a video processor to a host computer.¹²

To assess the sensitivity and reliability of measurements of movement through the rearfoot complex with the siliconCOACH program, 11 subjects were digitally recorded relaxing from the neutral calcaneal stance position to the resting calcaneal stance position. To assess sensitivity, the distance from a reference point marked on the left shoe to the lateral malleolus was analyzed initially with the subject in the neutral calcaneal stance position and then in the resting calcaneal stance position. Two measures were performed on the same digital footage of each subject 1 week apart to determine whether the results were reliable.

Clinical Outcomes

The Foot Health Status Questionnaire was used to assess the clinical outcomes of treatment with foot orthoses for lower-limb conditions attributed to rearfoot pronation. The Foot Health Status Questionnaire demonstrated a high degree of construct validity and test–retest reliability during a second-order factor analysis of its four subscales: foot pain, foot function, footwear, and general foot health.¹⁹ The Foot Health Status Questionnaire has been used in a variety of studies to further establish construct validity. Landorf et al²⁰ showed that the Foot Health Status Questionnaire is an effective clinical tool for measuring pain and functional disability levels in patients with plantar fasciitis, and Rome et al⁷ used the Foot Health Status Questionnaire in a study that evaluated the clinical effectiveness of accommodative and functional foot orthoses in the treatment of plantar heel pain.

Experimental Protocol

A digital camera (model DCR-HC26; Sony, Tokyo, Japan) was used to record the gait cycle of each subject from the posterior aspect of a treadmill, which captured motion in the frontal plane. The subjects

were assessed under two experimental conditions: with orthoses and without orthoses. All of the subjects were provided a flat-soled pair of canvas shoes with a vertical line as a reference point marked on the middle posterior aspect of the left sole. The treadmill speed was set at 3.2 km/h, and subjects were given 5 min to acclimatize. During both conditions, subjects were digitally recorded for approximately 14 steps; participants were instructed to have the middle of the leading foot land adjacent to a reference point marked on the treadmill base to maintain a constant distance between the camera and each subject.

SiliconCOACH Professional motion-analysis software was used to assess the kinematic effects of orthoses. The change in rearfoot position was assessed by measuring the distance between the reference point marked on the left shoe and the lateral and medial malleoli in the frontal plane. The simplified conceptual foot model derived from Inman and Mann²¹ suggests that as the subtalar joint pronates, the medial malleolus becomes more prominent in the frontal plane medially. Alternatively, as the subtalar joint supinates, the lateral malleolus becomes more prominent laterally. Therefore, frontal plane motion of the calcaneus was assessed by measuring the discrete distances from the most prominent aspects of the lateral and medial malleoli to the reference line marked on the footwear.

Only the left foot of each subject was assessed with the system, which was initially calibrated by setting a scale between two constant points in the captured image. For each recorded segment, the first and seventh steps of the left foot are ignored. The foot is then paused one frame before forefoot contact, and a vertical line is superimposed over the reference line on the shoe. Vertical lines are then drawn at the most prominent aspects of the medial and lateral malleoli. A magnifying tool assists in the accurate positioning of these lines. The discrete distances between the medial malleolus and the reference point and between the lateral malleolus and the reference point can be measured (Fig. 1). The same process is repeated with the foot paused one frame before heel-off. Of the five sets of results for each of the forefoot contact and heel-off frames (taken from five consecutive steps), the lowest and highest scores are eliminated, with the mean of the remaining three sets of results for forefoot contact and heel-off used for analysis. The process is conducted initially for the no-orthoses condition and then is repeated for the with-orthoses condition.

To assess the clinical outcomes of orthotic treatment, the baseline was established by means of the Foot Health Status Questionnaire that was initially completed by the patient during orthotic device dis-

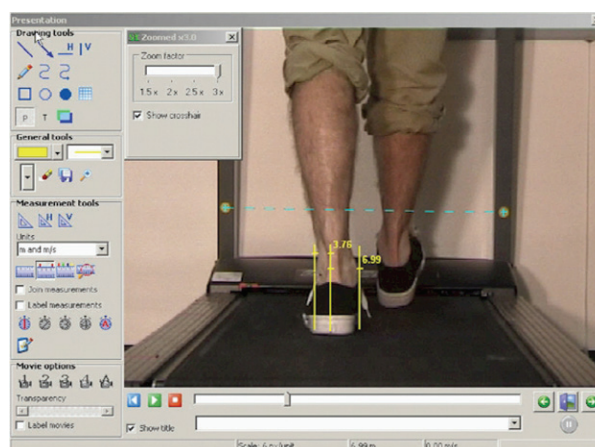


Figure 1. Measurement of the discrete distances between the medial malleolus and the reference point and between the lateral malleolus and the reference point.

tribution. The patient was provided 10 min of privacy in a consulting room to complete the form to prevent any bias on the part of the researcher. The process was then repeated during the patient's orthotic review, scheduled approximately 4 weeks after baseline.

Statistical Analysis

To determine the sensitivity and reliability of the siliconCOACH Professional program, correlations and a paired *t* test were conducted on the results obtained from a pilot study. Paired *t* tests were used to compare siliconCOACH measurements with and without the use of orthoses and to compare changes in Foot Health Status Questionnaire scores from baseline to follow-up. A Pearson product moment correlation was used to determine whether a relationship existed between changes in rearfoot motion and clinical outcomes of orthotic treatment.

Results

Sensitivity and Reliability of siliconCOACH Measurements

To determine siliconCOACH sensitivity in detecting frontal plane rearfoot motion, the pilot study of 11 subjects (4 men and 7 women; mean $\pm$ SD age, 22.0 $\pm$ 2.5 years) analyzed participants relaxing from the neutral calcaneal stance position to the resting calcaneal stance position. The mean $\pm$ SD distance from a reference point marked on the left shoe to the lateral malleolus during the neutral calcaneal stance posi-

tion was 4.09 ± 0.82 cm and during the resting calcaneal stance position was 3.28 ± 0.76 cm. A paired *t* test of the neutral and resting calcaneal stance positions revealed a mean $\pm$ SD difference of 0.82 ± 0.19 cm ($P < .001$). These results indicate that the siliconCOACH motion-analysis program is sensitive enough to determine motion changes that occur through the rearfoot complex.

The reliability of the siliconCOACH data was assessed by correlating two sets of results from the analysis of the same digital footage taken a week apart. The type (2,1) ICCs²² were 0.99 (95% confidence interval [CI], 0.96–0.99) for the neutral calcaneal stance position and 0.98 (95% CI, 0.92–0.99) for the resting calcaneal stance position, which indicates the reliability of the repeated measures of the distance from a reference point marked on the shoe to the lateral malleolus of 11 subjects relaxing from the neutral calcaneal stance position to the resting calcaneal stance position.

Foot Health Status Questionnaire and Rearfoot-Motion Outcomes

The results of the Foot Health Status Questionnaire indicate that the use of orthoses results in significant improvement in the pain and function subscale scores (Fig. 2). The results of the siliconCOACH measurements indicate that orthotic treatment had a small but significant effect (4%–8%) on rearfoot motion (Fig. 3).

There were generally no significant correlations between differences in rearfoot motion with and without

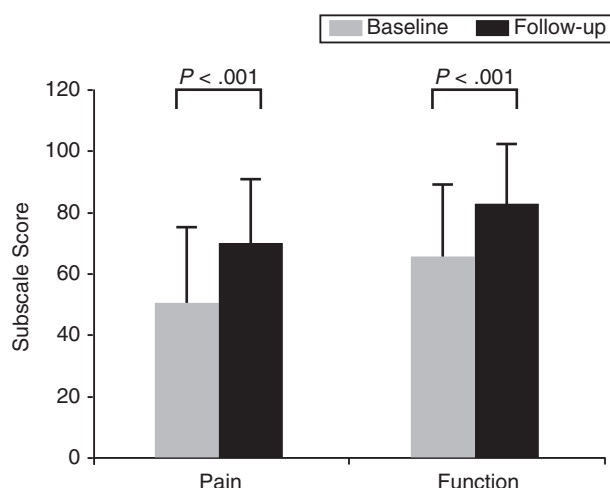


Figure 2. Foot Health Status Questionnaire pain and function subscale scores at baseline and follow-up. Error bars represent SD.

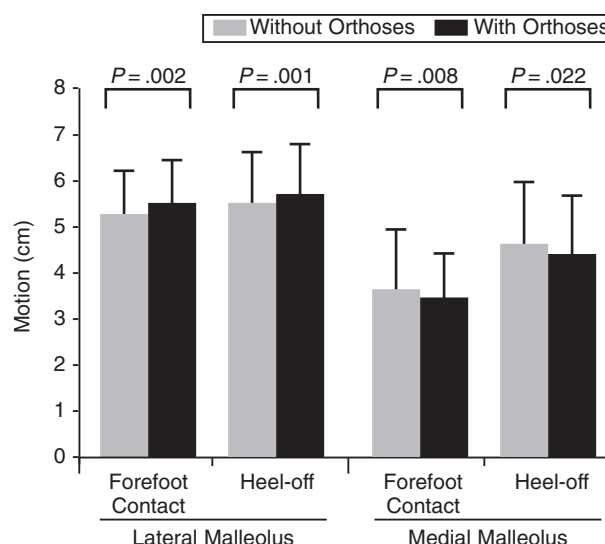


Figure 3. SiliconCOACH motion-analysis software results. Error bars represent SD.

foot orthoses and changes in the Foot Health Status Questionnaire subscales of pain and function (Table 1). The only significant correlation was the difference in distance between the reference point and the lateral malleolus with and without foot orthoses at forefoot contact and the change in the function subscale. The correlation was negative, which indicates that the greater the distance between the lateral malleolus and the reference point (more supinated), the less improvement in the function subscale, opposite to what was initially hypothesized. Therefore, the null hypothesis is accepted, stating that no correlation exists between rearfoot-motion changes resulting from foot orthoses and positive clinical orthotic outcomes.

Discussion

The purpose of this study was to determine whether a correlation exists between rearfoot-motion changes caused by foot orthoses and positive clinical outcomes. The siliconCOACH results demonstrated that the orthoses significantly reduced rearfoot eversion; however, the effect size was very small. The mean percent change between the no-orthoses and with-orthoses conditions ranged from 4% to 8%. Similar orthotic effects on rearfoot motion have been reported in a variety of studies^{9, 10, 23} that assessed 2-D frontal plane rearfoot kinematics. Numerous 3-D studies^{13, 14} that assessed temporal events during gait with orthotic treatment have also concluded that orthoses significantly affect rearfoot kinematics. Contrary to the findings of this study and those previously described,

Table 1. Correlations Between Differences in Rearfoot Motion With and Without Foot Orthoses and Changes in the Foot Health Status Questionnaire Subscales of Pain and Function

	Change in Pain Subscale		Change in Function Subscale	
	<i>r</i>	<i>P</i> Value	<i>r</i>	<i>P</i> Value
At forefoot contact				
Reference point to medial malleolus	−0.09	.68	0.21	.38
Reference point to lateral malleolus	−0.32	.14	−0.51	.01
At heel-off				
Reference point to medial malleolus	0.37	.08	0.29	.18
Reference point to lateral malleolus	−0.07	.75	−0.22	.31

other studies^{15, 16} have suggested that foot orthoses have an insignificant effect on rearfoot kinematics.

In support of studies that have implemented the Foot Health Status Questionnaire to assess orthotic outcomes, the results of this study indicated a significant improvement in foot pain and foot function subscale scores. The mean $\pm$ SD changes from baseline to follow-up for the pain and function subscales were 21.02 ± 20.67 points and 20.38 ± 22.55 points, respectively. Landorf et al²⁰ and Rome et al⁷ displayed similar outcomes when they implemented the Foot Health Status Questionnaire to evaluate the clinical effectiveness of foot orthoses in the treatment of plantar heel pain. The studies revealed a significant improvement in the foot pain and foot function domains.

Traditionally, functional foot orthoses have been generally prescribed by clinicians in accordance with the theory proposed by Root et al.² Placing the foot in the presumably advantageous “neutral” or “inverted” position has been suggested to be the underlying principle of orthotic function in achieving symptom reduction. Although foot orthoses significantly altered rearfoot motion in this study, the degree of change was minimal. The findings were considered negligible and insufficient to account for the extent of positive orthotic outcomes. Stacoff et al²⁴ suggest that the effect of foot orthoses on rearfoot motion is insignificant and inconsistent between subjects. On finding negligible differences in rearfoot motion with orthotic intervention, Nawoczenski et al²⁵ suggest that the benefits of orthotic treatment may result from changes in tibial rotation rather than frontal plane rearfoot motion.

Orthoses seem to achieve relief of symptoms, but the underlying mechanism of orthotic function may be different from that proposed by Root et al.² An alternative model for the way foot orthoses reduce symptoms has been proposed by Nigg.²⁶ It is suggested that foot orthoses alter muscle function *via* a signal input (impact forces), thereby enabling the lower limbs to follow their assumed preferred movement

pattern. Because foot orthoses support the body’s preferred pathways, muscle activity is minimized. The kinetic parameters of orthotic function may also play a contributing role in the extent of positive clinical outcomes. Williams et al¹⁶ found a significant difference in rearfoot kinetics with the use of foot orthoses. A reduction was noted in rearfoot inversion moment and negative work, which suggests that foot orthoses provided greater vertical force to the mid-foot and decreased the force generation needed by muscles to control eversion. Stackhouse et al¹⁵ also discovered that orthoses had a greater effect on frontal plane kinetics (forces) than on kinematics (motion). It was suggested that the kinetic variables of orthotic function should be considered when evaluating the efficacy of orthotic intervention.

This study had several limitations. First, it has been suggested that 2-D motion analysis of the rearfoot does not accurately reflect subtalar joint motion, which is triplanar in nature.²⁷ Second, the occlusive nature of shoes makes accurate bisection of the calcaneus difficult, although Smith et al²³ found that shoe and heel movements showed similar angular excursion. Third, the significant orthotic effect may have been attributable to the wedge design of some orthoses; therefore, it would have been more appropriate to assess the effect of a single orthotic design. Finally, the relatively small sample size limited the study’s generalizability; the results are applicable only to patients displaying symptoms as a result of excessive rearfoot pronation, with only the short-term effects of orthotic treatment depicted in this study.

Conclusion

This study found that orthoses had a small but significant effect on rearfoot motion; however, no relationship existed between these minimal changes in rearfoot motion and improvements in the Foot Health Status Questionnaire pain and function subscale

scores. The findings suggest that clinicians are currently prescribing foot orthoses in accordance with theories that have questionable validity. Additional well-controlled clinical trials that are methodologically consistent must be conducted to determine the clinical efficacy of orthotic treatment. As the medical world progresses toward evidence-based practice, a scientific validation for orthotic function is required. It is essential to investigate other mechanical and neuromechanical parameters of orthotic function.

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Conflict of Interest: None reported.

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