Research Report

Effects of Three Different Posting Methods on Controlling Abnormal Subtalar Pronation

Background and Purpose. *The purpose of this study was to determine the effects of different orthotic posting methods on controlling abnormal foot pronation during ambulation.* ***Subjects.*** *Twenty-two individuals with forefoot varus deformities of at least 8 degrees (13 women, aged 21–40 years, and 9 men, aged 20–50 years) participated in the study. The female subjects had an average height and weight of 162.6 cm (64 in) and 55.3 kg (122 lb), and the male subjects had an average height and weight of 175.3 cm (69 in) and 80.7 kg (178 lb).* ***Methods.*** *The subjects were examined with a computerized video motion analysis system. A control trial consisted of walking at 4.0 km/h in running shoes. Experimental trials included walking at 4.0 km/h in running shoes with unposted orthotic shells and with orthotic shells posted in the forefoot, the rear foot, and both forefoot and rear foot.* ***Results.*** *Maximal calf-to-calcaneus and calcaneus-to-vertical angles were decreased more by orthoses posted in both the forefoot and the rear foot than by orthoses posted only in the forefoot. No difference in maximal calf-to-calcaneus and calcaneus-to-vertical angles were found with combined forefoot and rear-foot posting compared with posting in the rear foot alone. The maximal calf-to-calcaneus angle was decreased by orthoses posted in any of the three methods and by the orthotic shell alone when compared with shoes alone. The maximal calcaneus-to-vertical angle was decreased by orthoses posted in any of the three methods, but not by the orthotic shell alone when compared with shoes alone.* ***Conclusion and Discussion.*** *Clinicians should consider combined posting or rear-foot posting alone when maximal control of rear-foot frontal-plane pronation is desired, though forefoot posting alone and the orthotic shell also provide control of rear-foot frontal-plane pronation. [Johanson MA, Donatelli R, Wooden MJ, et al. Effects of three different posting methods on controlling abnormal subtalar pronation. Phys Ther. 1994;74:149–161.]*

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Key Words: *Foot pronation, Orthotic devices.*

Normal pronation of the foot provides mechanisms for shock absorption and adaptation to uneven terrain early in the stance phase of gait.[1] Abnormal foot pronation during the gait cycle can be defined either as excessive pronation or as some pronation during a phase of the gait cycle in which supination is normal. Excessive pronation is difficult to precisely define because the magnitude of normal foot pronation in a large sample of asymptomatic subjects has never been described.

One frequent cause of abnormal foot pronation is excessive forefoot varus. *Forefoot varus* is defined as a deformity in the frontal plane such that the forefoot is in a position of inversion in relation to the rear foot when the subtalar joint is in the neutral position.[2,3] A forefoot varus results in an abnormal gait pattern when abnormal compensatory subtalar joint pronation appears, thereby allowing the medial metatarsal heads to contact the weight-bearing surface. The medial metatarsal heads are allowed to contact the weight-bearing surface by excessive calcaneal eversion, talar adduction, and talar plantar flexion, which are the three components of subtalar joint pronation when the foot is bearing weight.

Deciding whether to use a post with an orthosis for a forefoot varus deformity typically depends on subtalar joint range of motion (ROM), the neutral position of the subtalar joint, and degree of forefoot varus. A post is a wedge on the medial or lateral aspect of an orthotic device designed to control motion.[4] Posts may be applied in the forefoot or the rear foot, or both. A forefoot post is believed to normalize the position of the forefoot relative to the rear foot and to the supporting surface,[5] and a rear-foot post is believed to control eversion of the calcaneus.[3,6,7] Forefoot posts are thought to decrease the need for compensatory pronation at the subtalar joint due to forefoot varus deformities by bringing the weight-bearing surface closer to the medial metatarsal heads.[4,5,8] Rear-foot posts are thought to position the subtalar joint closer to an ideal neutral position at heel-strike and control calcaneal eversion directly after heel-strike.[3,6,7]

Treating abnormal foot pronation associated with excessive forefoot varus angles often includes prescribing a foot orthosis to control the pronation. Are such orthoses effective? Retrospective studies[6,9] have shown that the use of foot orthoses to control abnormal pronation reduces pain and increases function. The literature generally supports the use of orthoses to reduce abnormal foot pronation in gait, as measured by the calf-to-calcaneus or the calcaneus-to-vertical angle. Novick and Kelley[8] found that ambulation with orthoses posted in both the forefoot and the rear foot decreased calf-to-calcaneus and calcaneus-to-vertical angles, as shown by computer analysis of video recordings, compared with ambulation in shoes alone. Sims[7] measured calf-to-calcaneus angles during ambulation with an electric goniometer in a group of subjects with abnormal foot pronation. He reported decreased calf-to-calcaneus angles for subjects wearing orthoses posted in both the forefoot and the rear foot as compared with subjects ambulating with shoes alone.

A search of the literature revealed a dearth of published studies on the effects of the different components of posting on control of abnormal foot pronation during gait. Some authors[10,11] suggest that rear-foot posting alone is sufficient to control subtalar pronation, thereby controlling forefoot pronation as well. Some authors[5,12,13] recommend forefoot posts alone. Still other authors[6–8,14] advocate varus posting in both the rear foot and the forefoot. Despite the assertions of various authors advocating one method of posting over another, no study has really critically assessed a particular method of posting. Many reports of studies involving orthoses do not even describe the methods of posting.[9,15–17]

The purpose of our study was to compare the effects of controlling abnormal foot pronation in subjects with forefoot varus deformities by the use of semirigid orthoses that included both rear-foot and forefoot varus posting and by the use of orthoses that used rear-foot or forefoot posting alone. Previous studies[6,8,15,16] have shown that orthotic devices significantly reduce pronation, but have not specifically studied the effects of forefoot posts, rear-foot posts, or combined posts. We surmised that in individuals with forefoot varus deformities, orthoses posted in the forefoot and the rear foot would both reduce the need for compensatory subtalar pronation and control calcaneal eversion. We further surmised that these orthoses would control pronation more than would orthoses posted in the forefoot or the rear foot alone. Our hypothesis was that semirigid orthoses posted in both the forefoot and the rear foot would decrease maximal pronation, total pronation, maximal eversion, and total eversion to a greater extent than would orthoses posted in the rear foot or forefoot alone.

Method

Subjects

Twenty-two men and women with forefoot varus deformities volunteered to be subjects. The subjects' ages ranged from 21 to 50 years, with a mean of 30.5 years and a standard deviation of 8 years. Thirteen subjects were women, aged 21 to 40 years, with an average height of 162.6 cm (64 in) (range=157.5–174.0 cm [62-68.5 in]) and an average weight of 55.3 kg (122 lb) (range=47.9–64.4 kg [106-142 lb]). The other 9 subjects were men, aged 20 to 50 years, with an average height of 175.3 cm (69 in) (range=167.6–190.5 cm [66-75 in]) and an average weight of 80.7 kg (178 lb) (range=56.7–106.6 kg [125-235 lb]). Subjects were recruited from two physical therapy education programs and from a private physical therapy

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This study was approved by the Institutional Review Board at Georgia State University and was completed in partial fulfillment of the requirements for Ms Johanson's Master of Science Degree in Orthopaedic Physical Therapy at Georgia State University.

This study was partially supported by equipment grants from Motion Analysis Corp, Orthofeet Inc, and NIKE Inc.

This article was submitted August 11, 1992, and was accepted August 18, 1993.

practice in the metropolitan Atlanta, Ga, region. Requirements for inclusion in this study consisted of pain-free ambulation for at least 1 month prior to testing; no previous history of surgery or major bony or neurological pathology of the lower extremities; no leg-length discrepancy greater than 1 cm; and normal ROM in the hips, knees, and first metatarsophalangeal joints. At least 8 degrees of forefoot varus needed to be present bilaterally. Additional criteria for subject acceptance included 8 degrees of eversion and 15 degrees of inversion at the subtalar joint, 5 degrees of ankle dorsiflexion with the knee extended, and 30 degrees of plantar flexion. Each prospective subject signed an informed consent statement prior to participating in the study.

Measurements

All static measurements of subtalar joint (ROM) and forefoot varus were taken by one investigator with the subject in a prone position. Subtalar joint eversion and inversion were determined with the subject positioned prone and the lower half of the calf off the edge of the plinth. Sliding calipers were used to identify midpoints on the calf and calcaneus, and lines were drawn along the midlines on the posterior third of the calf and on the calcaneus. Ranges of eversion and inversion were measured by a method described by Smith-Oricchio and Harris.[18] The axis of a standard goniometer was placed between the malleoli in the frontal plane. The stationary arm of the goniometer was placed over the line on the posterior calf, and the movable arm was placed over the line on the posterior calcaneus. The calcaneus was passively everted and inverted to obtain subtalar joint (ROM) measurements. Although Smith-Oricchio and Harris[18] and Elveru et al[19] reported poor interrater reliability, with intraclass correlation coefficients (ICCs) below .50 for calcaneal inversion and below .35 for calcaneal eversion, Elveru et al reported intrarater reliability ICCs of .74 for calcaneal inversion and .75 for calcaneal eversion.

Forefoot varus or valgus was measured with the subtalar joint in the neutral position. The neutral position of the subtalar joint was determined by palpating the talus while inverting and everting the foot until bony congruity was palpated, as described by Smith et al.[16] The midshaft of the fifth metatarsal was supported with the thumb and first two fingers with slight distraction and dorsiflexion forces. Forefoot position was measured with one arm of a goniometer parallel to the metatarsal heads and the other arm perpendicular to the line bisecting the calcaneus. The mean of three measurements to the nearest whole degree was used. Intrarater reliability for this measurement was assessed using the ICC (3, 1).[20] The ICCs were .88 for the left side and .84 for the right side, slightly higher than the ICC value of .77 reported by Elveru et al,[19] who used a similar measurement method. We chose to exclude those subjects with less than 8 degrees of forefoot varus because in a previous study of both feet of 120 asymptomatic subjects,[21] 86.6% of the feet exhibited forefoot varus angles and the average varus angle was 7.82 degrees.

Two markers with 2-cm diameters were placed on the skin over the calcaneus. The top edge of the proximal marker was placed 2 cm above the posterior aspect of the calcaneus, just distal to the insertion of the Achilles tendon. The second marker was placed 3.5 cm below the proximal marker, measured center to center. Two markers were also placed on the calf, measuring center to center. The more distal marker was placed 8 cm above the proximal calcaneal marker, and the second marker was placed 8 cm above the distal calf marker. The markers defined two lines that were used to describe angles. The width of the foot, measured from the medial aspect of the first metatarsal head to the lateral aspect of the fifth metatarsal head, was used in calculating how high a forefoot post needed to be to support a given forefoot varus angle (Fig. 1). A process checklist was followed on each subject, and one investigator observed the primary investigator during the measurement of every fifth subject to ensure consistency of the procedures.

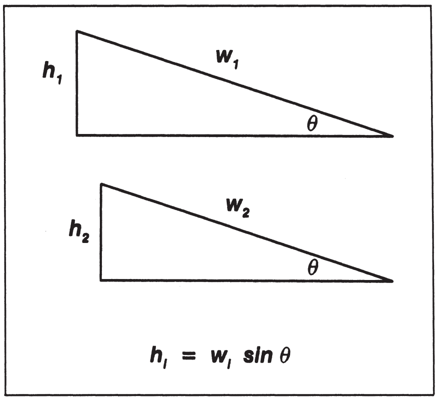

Figure 1. *Trigonometric basis used to calculate height of forefoot posting needed to support the forefoot varus angle. (θ=forefoot varus angle; w=width of foot; h=height of post.) (Note that if $w_1>w_2$, then $h_1>h_2$. That is, the height of the post depended partly on the measured width of the foot.*

Measurement Instrumentation

A FootTrak* two-dimensional motion analysis system determined calf-to-calcaneus and calcaneus-to-vertical angles (Fig. 2) during gait on a treadmill. Gait timing information from pressure-sensitive footswitches and angular movement information from filming the reflective markers were available for computer analysis. The FootTrak system was self-calibrated to one vertical and one horizontal line before each testing session. Reliability of the FootTrak system during barefoot ambulation was studied by Mueller and Norton,[22] who reported ICCs on single repeated measures of 1.00 for maximal calf-to-calcaneus angle (CCA$_{max}$) and .86 for total calf-to-calcaneus angle range of motion (CCA ROM).

Limitations of the FootTrak motion analysis system include the necessity

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*Motion Analysis Corp, 3650 N Laughlin Rd, Santa Rosa, CA 95403.

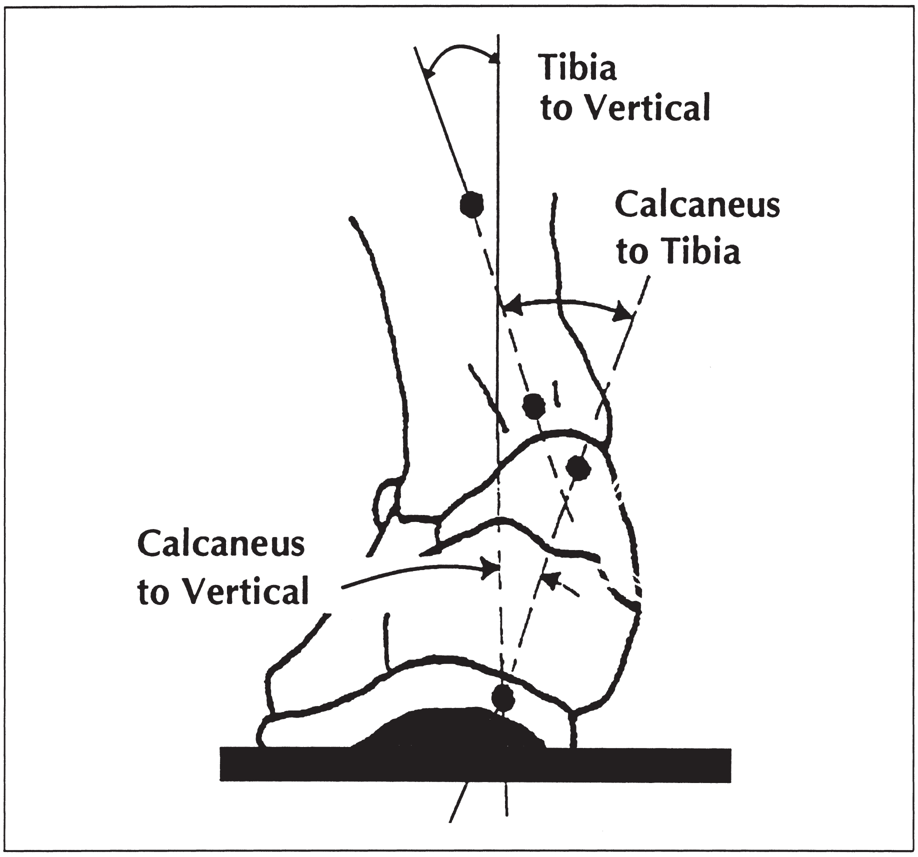

Figure 2. *Calf-to-calcaneus and calcaneus-to-vertical angles recorded by the FootTrak system.*

of analyzing treadmill ambulation versus overground ambulation and the inability to assess normal treadmill ambulation in individuals with crossover gait patterns. Most importantly, the use of a single camera to measure three-dimensional movements is subject to error that cannot be measured. Movements of the tibia and calcaneus in the sagittal and transverse planes cannot be differentiated from movements of these bones in the frontal plane. We therefore cannot be certain that our findings were due to frontal-plane movements of the subtalar joint.

Precision and Accuracy of Instrumentation

In a pilot study to test precision and accuracy of the FootTrak system, we drew two known angles on a clipboard. We placed reflective markers on the lines defining the angles. One angle measured 24 degrees, with the inferior line 16 degrees from the vertical to simulate significantly pronated calf-to-calcaneus and calcaneus-to-vertical angles. The other angle measured 5 degrees and 8 degrees, respectively, and simulated supinated angles. The results of 100 static observations with the clipboard perpendicular to the camera showed the FootTrak system had a standard deviation of 0.6 degrees from the known angle. The highest standard deviation for any group of 10 observations was 0.94 degrees, and the lowest standard deviation was 0.00 degrees.

Ten observations were also collected for each of the following 12 static conditions: with the clipboard tilted 10 and 20 degrees toward the camera, corresponding to dorsiflexion; with the clipboard not tilted from vertical and tilted 10, 20, 30, 40, and 50 degrees away from the camera, corresponding to plantar flexion; and with the clipboard rotated clockwise and counterclockwise in the vertical plane to 10- and 20-degree positions, corresponding to lateral (external) and medial (internal) rotations of the lower extremity. Means and standard deviations of differences between the known angles and the angles determined by the FootTrak system were calculated.

The FootTrak system was accurate to within 2 degrees, with standard deviations of 0.3 to 1.2 degrees when the clipboard was tilted no more than 10 degrees toward the camera, 40 degrees away from the camera, or rotated no more than 10 degrees clockwise or counterclockwise. Such asymmetrical results can be attributed to the position of the camera, which was mounted higher than the subtalar joint and tilted slightly downward. Maximum pronation occurs by approximately 25% of the stance phase of gait.[1,23] The expected position of the calf and the posterior calcaneus in the sagittal plane with respect to the view of the camera at the point of maximum pronation was likely to occur when the FootTrak system demonstrated the greatest accuracy.

Materials

Orthofeet Biothotics[†] were used to construct orthotic shells. We define an *orthotic shell* as any type of a shoe insert to which posting material may be applied. The materials consisted of prefabricated shells injected with water in the plantar arch area. The water reacted with polyurethane, which subsequently expanded. The unit remained malleable for a few minutes and could thus conform to a given arch. Posting material consisted of beveled ethyl vinyl acetate with manufacturer durometer A readings in the 50 to 60 range.

[†] Orthofeet Inc, 319 Knickerbocker Ave, Hillsdale, NJ 07642.

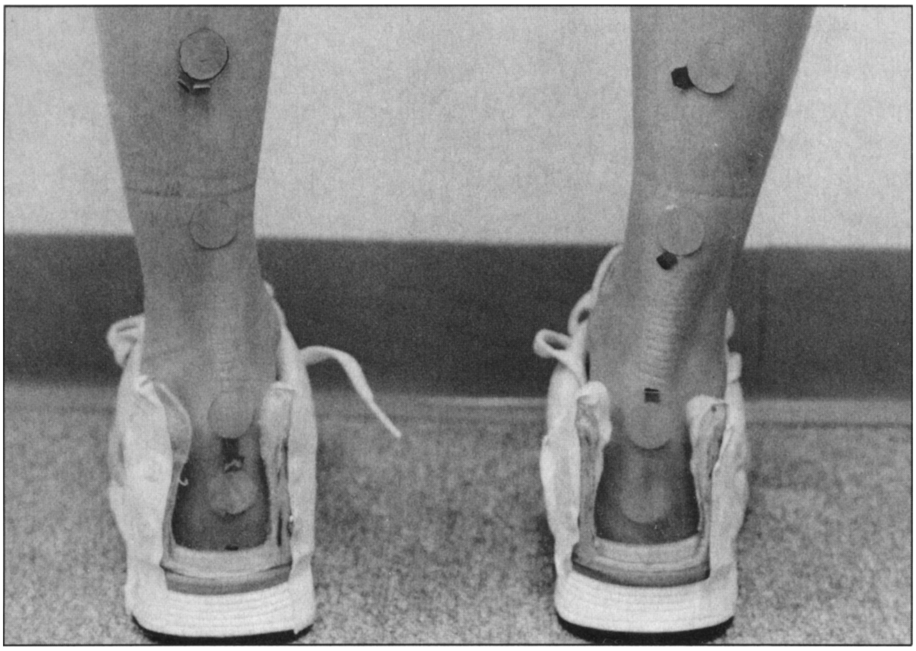

Figure 3. *Subject in running shoes with translucent heel counters and reflective markers in place.*

New NIKE Aircraft running shoes[‡] were worn by all subjects for all trials. In each shoe, a 5-cm portion of the Achilles pad and heel counter was excised down to the heel stabilizer to provide a window. This portion of the shoe was covered on the outside with 1-mm-thick translucent urethane film attached with four rivets (Fig. 3). Although this attachment may have affected the stability of the shoe, the investigators and subjects observed the shoes to be reasonably stable, and the urethane material allowed direct observation of the skin over the calcaneus.

The shell of the orthosis was shaped by having the patient ambulate with the shell for 3 minutes after water was injected into the plantar arch. The shell was marked to ensure consistent placement of posts.

Posting Method

Forefoot and rear-foot posts, made from the ethyl vinyl acetate material, were affixed to the orthotic shells according to the following formulas:

> Forefoot post height in millimeters=30% of sine of forefoot varus angle multiplied by the width of the foot
>
> Rear-foot post height in millimeters=80% of the height of the forefoot post

The formula for height of the forefoot post took the width of the foot into account, because the height of posting under the first metatarsal would have to have varied slightly among feet of differing widths to correct a given angle of forefoot varus to the same extent. A limitation of the usual method of determining height of the forefoot post based solely on the forefoot varus angle is that a wider foot receives relatively less posting under the first metatarsal head. We chose 30% of the forefoot angle because pilot data indicated to us that this percentage would provide an approximate 50% correction of the measured forefoot varus angle in millimeters under the first metatarsal head. Ideally, we would use a post that provided a 50% correction in degrees of the measured forefoot varus angle. However, it is difficult to sand posting material such that each subject has a smoothly beveled post that ends exactly at the lateral edge of the shell.

To avoid overcrowding within the shoe and to ensure tolerance by the subject, no forefoot post was allowed to exceed 7 mm and no rear-foot post was allowed to exceed 6 mm. The forefoot post was applied just behind the first metatarsophalangeal joint line and extended to the fourth metatarsal with a beveled contour. The rear-foot post was applied to the medial aspect of the inferior surface of the calcaneus and extended half the width of the heel with a beveled contour. Ideally, the height of the rear-foot post should have been determined by the standing calcaneal angle, because we were intending to place the subtalar joint closer to an ideal neutral position. Due to a lack of normative data on standing calcaneal position, unlike the situation for forefoot position, the rear-foot post height in this study was simply 80% of the height of the forefoot post. In our experience, higher rear-foot posts are not tolerated as well as higher forefoot posts due to pistoning of the heel and subjective reports of instability in a supinatory direction.

Gait Analysis

Each subject walked under five different conditions, imposed in random order. Each subject performed a control trial, which consisted of ambulation with the insoles of the shoes in place, and four experimental trials in which the subject ambulated with (1) unposted orthotic shells, (2) orthotic shells with forefoot posts, (3) orthotic shells with rear-foot posts, and (4) orthotic shells with both forefoot and rear-foot posts. The insole of the shoe was removed for all four experimental conditions and replaced with the orthosis to allow the shoes to fit. Two pressure-sensitive footswitches were taped to the sole of each shoe, one under the first metatarsal head and

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[‡] NIKE Inc, 9000 SW Nimbus Dr, Beaverton, OR 97005.

the other beneath the calcaneus. A standard treadmill that measured speed differences of tenths of a kilometer per hour was used for all subjects. Prior to filming, the subjects were allowed as much time as needed until they were comfortable with ambulating on the treadmill.

The position of the camera (47 cm behind the end of the treadmill, 45 cm above the floor, and tilted downward 10°) was rechecked each testing day. In each trial, data were collected during six cycles of ambulation at 4.0 km/h beginning with left heel-strike. The trial was accepted only if all data from at least three of the six cycles from each foot were recorded by the computer. Cycles contaminated by reflections from sources other than the reflective markers were deleted. This was judged to have happened when recorded data from one cycle deviated from any other cycle by 20 degrees or more. The subject was allowed 1 to 2 minutes of ambulation between trials to feel comfortable with the orthosis and shoe. Four variables were measured: CCA_{max}, CCA ROM, maximal calcaneus-to-vertical angle (CVA_{max}), and total calcaneus-to-vertical range of motion (CVA ROM). Maximal calf-to-calcaneus angle was the greatest value of the calf-to-calcaneus angle in the direction of pronation recorded during the stance phase and measured maximal pronation in the frontal plane. Calf-to-calcaneus angle range of motion was degrees of change of the calf-to-calcaneus angle in the direction of pronation between heel-strike and CCA_{max} and measured total pronation in the frontal plane. Maximal calcaneus-to-vertical angle and CVA ROM were analogous quantities with respect to the calcaneus-to-vertical angle.

To test reliability of the experimental procedures, after the five trials were completed on the first 10 subjects, markers and pen marks were completely removed, preparatory procedures were repeated, and the control trial was retested. The last 12 subjects repeated the control trial using the initial markers applied, to differentiate reliability of measurements obtained with the FootTrak system from the reliability of reflective marker placements reproduced by the investigator.

Data Analysis

Independent *t* tests were used to determine whether the group of 10 subjects who repeated the preparation procedures as well as the control trial and the group of 12 subjects who repeated the control trial without repeating the preparation procedures were significantly different. Intraclass correlation coefficients were used to assess reliability of the control trial ICC [3, 1].[24]

A priori contrasts (*t* tests) were used to specifically examine group mean differences in CCA_{max}, CCA ROM, CVA_{max}, and CVA ROM of the combined forefoot and rear-foot posted condition compared with the forefoot-only and rear-foot-only posted conditions to test our hypothesis. A two-way analysis of variance (ANOVA) for repeated measures tested differences among all group means; Newman-Keuls *post hoc* tests were used to test for differences between all pairs of means if the overall F test was statistically significant. Because side of the body is a potential variable, we included side of body in the ANOVA tests and collapsed the data when there was no significant main effect for side. A confidence level of .05 was selected for all statistical tests.

Results

The *t* tests showed significantly decreased CCA_{max} and CVA_{max} when the orthoses were posted in both the forefoot and the rear foot than when posted in the forefoot alone (Tab. 1). No significant differences in CCA_{max} or CVA_{max} were found when posting in both the forefoot and rear foot compared with rearfoot posting alone. No differences were found among posting methods for CCA ROM or CVA ROM.

Analyses of variance demonstrated statistically significant differences among groups due to condition (Tab. 2). No differences could be attributed to side of the body. *Post hoc* testing (Tab. 3) revealed significantly decreased CCA_{max} with all types of posting, and even with the unposted shell, than with the control condition. The CVA_{max} also significantly decreased from the control value with all three types of posting, but not with the unposted shell.

Independent *t* tests showed no difference between the group of 10 subjects who repeated both the preparation procedures and the control trial and the group of 12 subjects who repeated the control trial without repeating the preparation procedures for any of the dependent variables on either side. Intraclass correlation coefficients for all dependent variables are shown in Table 4.

Discussion

Combined posting decreased CCA_{max} and CVA_{max} significantly more than did forefoot posting alone, but not more than rear-foot posting alone. These results support contentions by some authors[10,11,16] that rear-foot posting by itself effectively controls subtalar joint pronation. Rear-foot posting would be expected to reduce subtalar joint pronation between heel-strike and heel-off, when maximal pronation normally occurs. A rear-foot post has a more direct effect than a forefoot post on subtalar joint motion in the frontal plane before heel-off.

Limitations in measuring the different components of pronation during gait when using a two-dimensional motion analysis system may also have played a part in distinguishing between the effects of rear-foot versus forefoot posting. Pronation at the subtalar joint during weight bearing consists of concurrent motions of calcaneal eversion, talar adduction, and talar plantar flexion.[3] The calf-to-calcaneus and calcaneus-to-vertical angles as measured in this study primarily reflected only certain aspects of pronation, namely changes at the rear foot in the frontal plane. Calcaneal eversion may thus have been responsible for a great deal of the pronation recorded.

Table 1. *A priori Contrasts of Combined Forefoot/Rear-Foot Posting (FR) Versus Forefoot Posting (F) and Rear-Foot Posting (R) on CCA$_{max}$,[a] CCA ROM,[b] CVA$_{max}$,[c] and CVA ROM[d]*

Condition	Measure	*df*	SS	MS	*t*	*P*
FR and R	CCA$_{max}$					
	$\bar{X}$	1	3.54	3.54	4.71	.1552[e]
	Error	21	34.15	1.63		
FR and F	CCA$_{max}$					
	$\bar{X}$	1	12.29	12.29	69.06	.0089[f]
	Error	21	31.07	1.48		
FR and R	CCA ROM					
	$\bar{X}$	1	0.25	0.25	0.02	.7238[e]
	Error	21	40.56	1.93		
FR and F	CCA ROM					
	$\bar{X}$	1	0.10	0.10	0.00	.8539[e]
	Error	21	61.38	2.92		
FR and R	CVA$_{max}$					
	$\bar{X}$	1	4.89	4.89	3.20	.1953[e]
	Error	21	57.43	2.73		
FR and F	CVA$_{max}$					
	$\bar{X}$	1	21.88	21.88	225.90	.0009[f]
	Error	21	30.58	1.46		
FR and R	CVA ROM					
	$\bar{X}$	1	0.55	0.55	0.11	.5683[e]
	Error	21	34.31	1.63		
FR and F	CVA ROM					
	$\bar{X}$	1	4.00	4.00	1.19	.3075[e]
	Error	21	76.61	3.65		

[a] CCA$_{max}$=maximal calf-to-calcaneus angle in pronation.

[b] CCA ROM=degrees of pronation between heel-strike and CCA$_{max}$.

[c] CVA$_{max}$=maximal calcaneus-to-vertical angle in eversion.

[d] CVA ROM=degrees of eversion between heel-strike and CVA$_{max}$.

[e] Not significant at P=.05.

[f] Significant at P=.05.

Pronation in gait, however, includes movement in the sagittal and transverse planes at the subtalar joint as well as movements in the frontal, sagittal, and transverse planes at the midtarsal joint.

Frontal-plane motion, or eversion, is the primary movement at the midtarsal joint during pronation.[25] If the forefoot varus post exerted most of its influence on pronation in the frontal plane at the midfoot, the extent to which this may have been detected using a two-dimensional rear view of gait, as in this study, is limited. The effects of forefoot posting on rear-foot pronation may have been greater at push-off than at the point of CCA$_{max}$ or CVA$_{max}$. Thus, the significant differences between double posting and forefoot posting may not necessarily have been due to actual differences in control of pronation. This question warrants further study.

The CCA ROM and CVA ROM did not change significantly with different posting methods. A change to less pronation and eversion in the calf-to-calcaneus and calcaneus-to-vertical angles at heel-strike combined with decreases of CCA$_{max}$ and CVA$_{max}$ may explain why no actual change in total degrees of pronation and eversion occurred.

Post hoc testing of all conditions showed that all posting methods and the unposted orthotic shell were effective in decreasing CCA$_{max}$, when compared with the use of running shoes alone during ambulation. Even without posts, the orthotic shell in the shoe decreased CCA$_{max}$ compared with the shoe alone, so the effect of just the orthotic shell is important to consider when evaluating pronatory control provided by orthoses. Although the orthotic shell by itself decreased CCA$_{max}$, it did not have a similar effect on CVA$_{max}$. Calcaneus-to-vertical angles can be helpful to include in studies of frontal-plane rear-foot pronation because movements of the tibia and the calcaneus can be differentiated. However, the calcaneus-to-vertical angle may be subject to more error than the calf-to-calcaneus angle with changes in frontal-plane position of the lower extremity, so the calf-to-calcaneus angle may more accurately measure rear-foot frontal-plane pronation.

Overall, the results suggest that combined posting or rear-foot posting provides the best control of rear-foot pronation in the frontal plane. When sufficient eversion is not available to compensate for a forefoot varus deformity, we believe rear-foot posting should be used with caution to avoid inversion sprains by pushing a subtalar joint with limited eversion into more inversion. The use of a forefoot post for reduction of rear-foot pronation in the frontal plane is less effective than either a rear-foot post or combined posts. As mentioned, it is possible that a forefoot post has a greater effect on aspects of pronation not measured in this study.

The mean decrease in the calf-to-calcaneus angle for the combined posting trial compared with the control trial was 2.3 degrees. Previous studies of subjects running with semi-

Table 2. *Results of Two-Way Analysis of Variance for Repeated Measures for Each Dependent Variable*

Measure[a]	*df*	SS	MS	*F*	*P*
CCA$_{max}$					
Condition	4	128.47	32.12	10.83	.0010[b]
Error	84	249.13	2.96		
Side	1	26.12	26.12	0.37	.5515[c]
Error	21	1496.81	71.28		
C×S	4	12.66	3.16	1.56	.1937[c]
Error	84	170.86	2.03		
CCA ROM					
Condition	4	24.23	6.06	1.50	.2084[c]
Error	84	338.38	4.03		
Side	1	9.73	9.73	0.36	.5571[c]
Error	21	573.92	27.33		
C×S	4	18.92	4.73	1.50	.2105[c]
Error	84	265.51	3.16		
CVA$_{max}$					
Condition	4	112.91	28.23	7.71	.0010[b]
Error	84	307.37	3.66		
Side	1	109.94	109.94	2.25	.1481[c]
Error	21	1013.94	48.76		
C×S	4	10.70	2.67	1.11	.3585[c]
Error	84	202.93	2.41		
CVA ROM					
Condition	4	17.50	4.37	1.03	.3981[c]
Error	84	357.75	4.26		
Side	1	43.09	43.09	2.22	.1515[c]
Error	21	408.55	19.45		
C×S	4	21.66	5.41	1.58	.1874[c]
Error	84	288.08	3.43		

[a] CCA$_{max}$=maximal calf-to-calcaneus angle in pronation; CCA ROM=degrees of pronation between heel-strike and CCA$_{max}$; CVA$_{max}$=maximal calcaneus-to-vertical angle in eversion; CVA ROM=degrees of eversion between heel-strike and CVA$_{max}$; C×S=interaction of condition and side.

[b] Significant at P=.05.

[c] Not significant at P=.05.

rigid orthoses in shoes compared with subjects running with shoes alone[16,26] demonstrated significant decreases in maximal pronation equal to or less than the decreases observed in our study, but greater differences were reported by two previous studies of the effects of foot orthoses on pronation during ambulation. Differences in methodology may account for these discrepancies.

Novick and Kelley[8] found a 4.25-degree mean decrease in maximal and total pronation in subjects ambulating in shoes with orthoses when compared with the same subjects ambulating in shoes alone. Although the authors did not specify the amount of posting or the posting location they used, they did state the orthoses were rigid. This rigidity may explain the greater degree of control of pronation that they achieved. Sims[7] also reported a decrease in maximal pronation of 4 degrees when subjects with forefoot varus deformities ambulated in shoes with orthoses compared with shoes alone. The average forefoot varus angle of 7.5 degrees in Sims' study, however, was substantially less than the average forefoot varus angle in our study. Additionally, the amount of posting used was described as the amount needed to fully correct the forefoot and rear-foot deformities, which we expect would be a much greater amount of posting relative to the size of the forefoot varus angle than we used and potentially accounts for the greater degree of control of pronation that Sims reported. Is a 2.3-degree decrease in subtalar pronation in the frontal plane clinically significant? In our experience, patients with objective clinical findings similar to those of the subjects in this study and with pain complaints we felt were related to abnormal pronation for whom we fabricated semirigid orthoses (using posting principles similar to those described in this report) have responded quite favorably in terms of pain control. However, we believe our success with these patients cannot entirely be attributed to a mere 2.3-degree reduction in subtalar frontal plane pronation. We believe the combined effect of control of subtalar pronation in the transverse and sagittal planes as well as the frontal plane, control of midtarsal pronation in all three cardinal planes, and control of tibial medial rotation may have produced the results we observed.

This study supports previous studies[7,8] that demonstrated decreased CCA$_{max}$ and CVA$_{max}$ during ambulation with orthoses in shoes when compared with ambulation in shoes alone. In our study, however, we further attempted to differentiate which components of an orthosis actually contribute to the decrease in abnormal foot pronation. Based on the results of this study, each of the posting methods and even an unposted shell appear to reduce rear-foot frontal-plane pronation during ambulation from the amount seen in running shoes alone. The orthotic shells used in this study were thicker medially than laterally

Table 3. *Effect of Type of Posting on CCA_{max}[a] and CVA_{max}[b]*

					Pair-Wise P[c]				
Measure	**Condition**	$\bar{X}$	**SD**	**Range**	**Fr**	**R**	**F**	**S**	**NO**
CCA_{max} (°)	FR	7.25	2.91	−6.20–16.33		NS	NS	NS	<.01
	R	7.65	2.76	−0.20–16.20			NS	NS	<.01
	F	8.00	2.93	−1.60–17.17				NS	<.05
	S	8.22	3.07	1.00–17.00					<.05
	NO	9.50	2.82	1.50–17.00					
CVA_{max} (°)	FR	−1.35	2.84	−12.20–7.67		NS	NS	NS	<.01
	R	−0.88	3.29	−8.00–7.80			NS	NS	<.05
	S	−0.44	3.25	−8.75–11.60				NS	NS
	F	−0.36	3.03	−8.80–8.17					<.05
	NO	0.80	3.01	−6.17–7.33					

[a] CCA_{max}=maximal calf-to-calcaneus angle in pronation.

[b] CVA_{max}=maximal calcaneus-to-vertical angle in eversion.

[c] FR=shell with forefoot and rear-foot post; R=shell with rear-foot post; F=shell with forefoot post; S=shell; NO=control; NS=not significant.

due to the expanding resin that filled into the contour of each subject's foot, which may account for the decrease in rear-foot frontal-plane pronation when ambulating with orthotic shells in the shoes compared with shoes alone. Combined posting and rear-foot posting alone appear to provide the greatest control, at least for rear-foot pronation in the frontal plane.

Because the forefoot can move independently on the rear foot, additional studies are needed to determine the effects of forefoot, rear-foot, and combined posting on forefoot pronation. Further research is also needed to determine the effects of different posting methods on pronation in different phases of the gait cycle and at different cadences. The findings related to CCA_{max} and CVA_{max} in this study are confined to one point during stance phase, rather than occurring throughout all phases of the gait cycle. The effect of a forefoot post on rear-foot pronation at push-off would provide valuable information, because a rear-foot post becomes ineffective as soon as the heel leaves the supporting surface. Such studies might help the clinician design orthoses for more specific problems than can be done at present, especially if one particular phase in gait can be identified as particularly associated with dysfunction or symptomatology.

Table 4. *Intraclass Correlation Coefficients for Comparison of Trial 1 and Trial 2 of the Control Condition (Shoes Only)*

Dependent Variable	**Left**	**Right**
Maximal calf-to-calcaneus angle	1.00	1.00
Total calf-to-calcaneus angle range of motion	.95	1.00
Maximal calcaneus-to-vertical angle	1.00	1.00
Total calcaneus-to-vertical angle range of motion	.94	1.00

Conclusions

The results of this study support the use of combined forefoot and rear-foot posting or rear-foot posting alone when the treatment goal is to maximally reduce rear-foot pronation. However, all types of posting and even an unposted shell decrease maximal pronation from that seen in a running shoe alone. Clinical effects may thus be achieved even when a patient cannot tolerate one of the posts, or when one of the posts is contraindicated.

Acknowledgments

We thank Jennifer A Himmelsbach of the NIKE Sport Research Laboratory for her valuable assistance with heel-counter window fabrication. We are indebted to Stephen Cole, PhD, of Research Designs Associates and Andy Bush, PhD, and Sheila Wood of Physiotherapy Associates for their expert advice on statistical testing and analysis. We also thank Professor Leonard Elbaum of Florida International University for sharing his knowledge of the FootTrak system.

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Invited Commentary

Before addressing the important clinical implications this study provides, I will comment on selected methodological issues.

Inclusion criteria required subjects in this study to have a forefoot varus deformity of at least 8 degrees. Several authors[1,2] have reported poor reliability for foot and ankle goniometric measurements. These studies, however, were conducted with testers having limited training with the measures. The reliability estimates obtained by Johanson et al, and my own experience,[3,4] indicate that with adequate training, the measures can be performed reliably. Although the measures are important for describing the study population, the clinical usefulness of the measures is questionable and will be discussed later in this commentary.

I think the authors adequately describe the limitations of using two-dimensional motion analysis to study three-dimensional rear-foot kinematics. Several questions arise, however, about the methods for obtaining rear-foot kinematic measurements. The intraclass correlation coefficient (ICC) values for two trials of each dependent variable, as reported in Table 4, seem quite high (ICC=.94–1.00). These values are higher than the ICC values reported by Mueller and Norton[5] for repeated single measures (ICC=.86–1.00), which assessed only equipment variability. The ICC values reported by Johanson et al also appear to include tester error and the normal variation expected with walking. It would have been helpful if the authors had commented on the high values they obtained and had indicated whether a mean of multiple trials was used. In addition, it would have been interesting if the calf-to-calcaneus angular velocity had been investigated. Although this measure includes more error from equipment variation than the angular position measures,[5] the measure is easily obtained from the equipment used in the study, and some researchers[6] have reported that angular velocity is an important variable in rear-foot kinematic analysis.

Johanson et al strive to answer an important clinical question: How should an orthotic device be equipped with a post to best control rear-foot pronation? In accordance with multiple references in the report, the authors suggest that orthotic posting should be performed based on goniometric measures of foot deformity, which is a common clinical practice. The results of this article, however, do not support this approach. The patients in this study had a primary forefoot deformity, but forefoot posting showed no significant improvement compared with the use of the orthotic shell alone. The results of this study indicate that the single most important component of the orthosis in controlling pronation was the shell itself. Compared with the shoe-only condition, the orthotic shell reduced pronation 1.3 degrees, whereas the forefoot post added only 0.2 degrees and the rear-foot post added only 0.6 degrees. According to the results of the statistical analysis shown in Table 3, there were no significant differences between the shell and any of the posting conditions.

From a mechanical standpoint, the semirigid orthotic shell used in this study appears to function as a traditional arch support. For the purposes of this commentary, an *arch support* may be operationally defined as an orthotic device that provides total contact to the plantar aspect of the foot, particularly under the longitudinal medial arch. Unlike the older generation of intolerable, rigid arch supports that often were rejected by patients, the arch support described in this article is semirigid and, theoretically, would allow a controlled excursion into pronation. The force