Effects of Rearfoot-Controlling Orthotic Treatment on Dorsiflexion of the Hallux in Feet with Abnormal Subtalar Pronation

A Preliminary Report

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The aim of this study was to determine whether the treatment of abnormal subtalar pronation restores functional (as opposed to structural) limited dorsiflexion of the first metatarsophalangeal joint (functional hallux limitus). We studied 16 feet of eight individuals with abnormal subtalar pronation. Orthoses were made for all of the feet, and hallux dorsiflexion was measured during weightbearing. Each patient was unshod without the orthosis, unshod with the orthosis fitted on the same day, and unshod with the orthosis fitted approximately 5 months later. The results suggest that in functional hallux limitus caused by abnormal subtalar pronation, hallux dorsiflexion will gradually be restored by the use of foot orthoses to control the abnormal subtalar pronation. (J Am Podiatr Med Assoc 96(4): 283-289, 2006)

The biomechanics and pathomechanics of the first metatarsophalangeal joint have been a focus of attention for many years. The greater importance of first metatarsophalangeal joint movement in the sagittal plane lies in the movement of dorsiflexion.[1] Without it, propulsion cannot be attained under optimal conditions. The normal range of motion of the first metatarsophalangeal joint has been proposed by many authors. It is known that a minimum of 60° to 65° of hallux dorsiflexion is required for normal propulsion.[2-11] Restriction of this mobility results in pathology. Such limitation can be permanent or can occur only when the foot is bearing weight. The latter is an alteration that Dananberg[12] termed "functional hallux limitus."

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The movement of plantarflexion of the first ray is necessary for the hallux to dorsiflex completely over the head of the first metatarsal. Phillips et al[13] stated that the first 20° of hallux dorsiflexion does not require plantarflexion of the first ray and that from then on, for each 3° of hallux dorsiflexion there is 1° of plantarflexion of the first ray. According to Banks and McGlamry,[14] hallux dorsiflexion without plantarflexion of the first ray is 25° to 30°, an opinion shared by Grady et al.[5] However, Hetherington et al[6] report that a mean hallux extension of approximately 34° is achieved without metatarsal plantarflexion, and Roukis et al[15] report 22.7°. Root et al[2] suggested that approximately 10° of plantarflexion of the first metatarsal during the propulsion phase of gait is required for complete extension of the hallux. This means that without adequate plantarflexion of the first metatarsal during propulsion, the proximal phalanx of the hallux would not be able to completely articulate with the dorsal surface of the head of the first metatarsal.[9, 14]

Various factors may negatively affect normal plantarflexion of the first ray and thus may reduce the range of dorsiflexion of the hallux.[1, 16] One such factor is the inability of the peroneus longus to stabilize the first metatarsal on the ground. Abnormal subtalar pronation and peroneus longus inefficiency have been associated previously.[2, 17] The present study tested the effect on the first metatarsophalangeal joint of controlling excessive subtalar pronation for approximately 5 months in young subjects.

Materials and Methods

Twenty individuals who visually appeared to be the type of subject we were seeking were recruited voluntarily into this study. Each subject had to satisfy the following criteria: no limitation of the metatarsophalangeal joint in a nonweightbearing position, the posterior bisection of the calcaneus with the subject in the resting calcaneal stance position formed an angle with the ground greater than 5° of eversion, subtalar eversion was more than one-third of the total range of movement of this joint, and no history of pathology of the first metatarsophalangeal joint or of trauma or surgery affecting it. After the selection tests, eight subjects (two men and six women) aged 20 to 32 years (mean age, 23.6 years) were chosen for the study. Given that the variable to be studied was dorsiflexion of the hallux, we considered all 16 feet in the study sample. All of the individuals in the sample gave their written informed consent before study participation. The study was approved by the governing body of the Podiatry Clinic of the University of Seville before data collection.

Range of motion was measured in the ankle joint, the subtalar joint, and the first and fifth rays as described by Root et al.[18] Range of motion of the first metatarsophalangeal joint was explored in a nonweightbearing position using a manual goniometer, making the mid-axis of each arm coincide with the longitudinal axis of the proximal phalanx and the longitudinal axis of the first metatarsal on the medial part of the foot, respectively. These lines were always determined by the same examiner (P.V.M.) by means of observation. The starting position consisted of the great toe and ankle in a relaxed hanging position, with the knee and hip extended.

After this measurement, each individual was placed on a pedoscope (a system that visualizes the footprint using a mirror and a fluorescent light), and a mold of the foot was made in phenolic foam.[19] To correct the excessive subtalar pronation, the examiner held the distal one-third of the individual's leg and applied external rotational force until the mirror showed incipient loss of the print of the first ray, that is, that the first metatarsal had begun to lift and lose contact with the glass of the pedoscope. At that moment, the examiner stopped applying external rotational force to the leg. This maneuver was repeated several times because the external rotation applied to the foot in contact with the glass would be approximately the same as that applied when introducing the foot into the phenolic foam (the external rotation of the leg produces abduction and dorsiflexion of the talus, causing supination of the subtalar joint and correcting the excessive pronation). The positive mold obtained was used to make 3-mm-thick polypropylene foot orthoses to fit from the heel to just behind the metatarsal heads.

After the foot orthoses were prepared, videotape recordings were made similar to those described by Hetherington et al[16] in 1990. Before the recording, four points were estimated and marked on the medial part of each foot: the center of the base of the first metatarsal, the center of the head of the first metatarsal, the center of the base of the proximal phalanx of the hallux, and the center of the head of the proximal phalanx of the hallux (Fig. 1). The same examiner (P.V.M.) made all of the marks for both recording sessions. Each subject walked in a straight line and with an angle of gait as parallel as possible to the line of progression, with the medial side of the foot toward the camera and the foot between two marks on the floor corresponding to the camera's field of recording. The camera lens was situated 8 cm above the

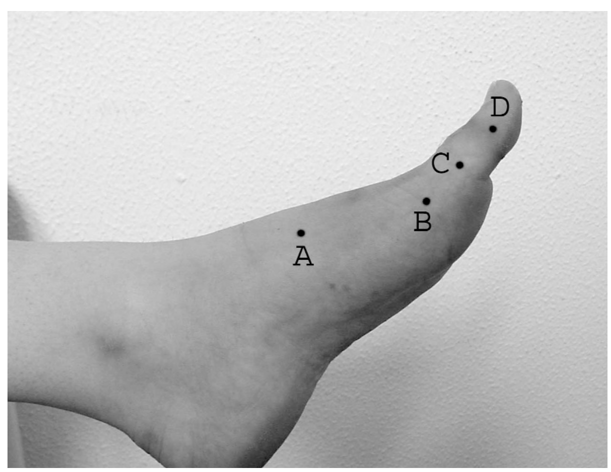

Figure 1. Marks made on the medial part of each foot: the center of the base of the first metatarsal (A), the center of the head of the first metatarsal (B), the center of the base of the proximal phalanx of the hallux (C), and the center of the head of the proximal phalanx of the hallux (D).

floor and 42 cm from the area where the subject had to place the foot; the field of recording at this distance was 44 cm. The camera was fitted with an image sensor (AV Tech B/N C307, Tapei, Taiwan) and recorded at 25 frames per second.

Each foot was recorded twice: once unshod without the orthosis (video 1) and once unshod with the orthosis (video 2). The orthosis was held on the unshod foot using a self-adhesive elastic cloth bandage to bind the most proximal part of the orthosis to the ankle and foot up to approximately the first cuneiform, leaving visible the markings at the first metatarsal and proximal phalanx (Fig. 2). The tension of the bandage around the foot was sufficient to hold the orthosis firmly on the foot without restricting the motion of the ankle or of the subtalar joint.

Before each recording, the subject walked freely for a while in the area set aside for the study. When the examiner judged that the manner was as relaxed as possible, recording was begun without the subject's awareness to avoid variations in gait at that moment. The recording was long enough to capture the medial face of each foot three times. Each recording was then digitized using a biomechanical dynamic analysis system (Podomovie PODOBIT PRO, Meditrónica Sistemas, Cádiz, Spain) software and was visualized using a personal computer to obtain the frame in which the first metatarsophalangeal joint was in the position of maximum extension for each step recorded for each foot. Three investigators had to agree about that frame. This frame was then imported into a program enabling straight lines to be made by joining the marks drawn on the foot so that the two marks of the first metatarsal would give an approximation of its longitudinal axis, and similarly for the proximal phalanx (Fig. 3). This procedure was performed three times for each unshod foot without the orthosis and another three times for each unshod foot with the orthosis. The frames were then printed, and the angle formed by the two lines was measured on the paper: this was the angle of maximum dorsiflexion of the hallux in each step recorded. The mean of the three measurements for each unshod foot without the orthosis was compared with that of the three measurements for each unshod foot with the orthosis. The subjects were instructed to use the orthoses every day until the next recording, which in principle would be approximately 6 months later. Compliance with these instructions was encouraged by reminding the subjects monthly of their participation in the study. No diaries were kept of the amount of time that the orthoses were worn because of the difficulty this task implied. Subjects would have had to record the amount of time they were sitting, standing, and walking because we think those different positions can also affect the results of orthotic treatment.

These later recordings were made on the same feet. The marks were drawn on each foot by the same examiner who had made them on the previous occa-

Figure 2. A self-adhesive elastic cloth bandage was used to hold the orthosis on the unshod foot. The orthosis was placed in its correct position on the foot and was fixed by surrounding the ankle and rearfoot with the bandage. The marks remain visible on the medial part of the foot.

Figure 3. The angle measured in each frame in which the first metatarsophalangeal joint was at maximum extension during that particular step. The angle was obtained after joining the two marks drawn on the proximal phalanx and after joining the two marks drawn on the first metatarsal.

sion. The orthoses were affixed to the unshod foot in the same manner as for the earlier recording, and the procedure was exactly the same as in the first session except that this time no recording was made of the unshod foot without the orthosis—only the unshod foot with the orthosis was recorded (video 3). As in the first session, three steps were recorded for each foot, and the mean of the three measurements was compared with the mean of the three measurements made 5 months earlier on the unshod foot without the orthosis.

In the statistical analysis, besides the descriptive statistics to calculate the mean of the three measurements of each foot in each situation, the *t*-test was applied to relate the data obtained in video 1 to those obtained in video 2 and to relate those obtained in video 1 to those obtained in video 3. This test was used to check the statistical significance of the difference between the means.

Results

Mean dorsiflexion of the first metatarsophalangeal joint in open kinetic chain was 78.12° (range, 65°–85°), and mean plantarflexion was 47.18° (range, 35°–65°). Maximum dorsiflexion values in the propulsive phase of gait for the unshod foot without and with the orthosis are given in Table 1. Mean metatarsophalangeal joint dorsiflexion in the propulsive phase of gait was 49.95° without the orthosis and 51.70° with the orthosis. These values are from videos 1 and 2, respectively. The difference between mean metatarsophalangeal joint dorsiflexion in video 1 and that in video 2 was very small and was not statistically significant ($P = .36$). This value changes when we compare mean dorsiflexion in video 1 with that in video 3. Mean metatarsophalangeal joint dorsiflexion after 5 months of orthotic treatment was 58.43° (Table 2). The difference between this value and that obtained from video 1 was 8.48°, which is statistically significant ($P = .004$) (Fig. 4).

The time between the initial recordings and the final recording varied depending on the individual because it was impossible to convene all of the subjects together to conclude the study. The mean time between initial and final recordings was approximately 5 months (145.75 days; range, 115–174 days). This time was originally meant to be 6 months for all of the subjects, but we did not allow for the timing of follow-up. The first recordings were made in December 2002, so that the final measurements at 6 months would be taken in June. However, because it begins to get hot in April in this region of Spain and women tend to prefer wearing open shoes in hot weather, the foot orthoses could not be fitted in the shoes of the female participants at the 6-month measurement. Although we stressed that the subjects should bear the use of closed shoes and orthoses as long as possible, we could not achieve the 6 months' duration in all of the subjects (mostly women), and the time was shortened.

Table 1. Maximum Dorsiflexion of the First Metatarsophalangeal Joint During the Propulsive Period of Gait for Unshod Feet Without and With the Orthosis Obtained the Same Day

		Dorsiflexion (°)		
Subject No.	Foot	Without Orthosis	With Orthosis	Difference[a]
1	Right	54	66.50	12.50
	Left	47.33	55	7.67
2	Right	62.83	57.16	–5.67
	Left	69	59	–10
3	Right	58.33	57.83	–0.50
	Left	74.33	73	–1.33
4	Right	44.33	36.83	–7.50
	Left	34.16	51.33	17.17
5	Right	47.66	54	6.34
	Left	49.33	56	6.67
6	Right	41.50	47.5	6
	Left	40.33	40	–0.33
7	Right	44.50	45	0.50
	Left	53.33	53.50	0.17
8	Right	36.33	39.33	3
	Left	42	35.33	–6.67
Total, mean		49.95	51.70	1.75[b]

[a]Negative values indicate that with the orthosis, metatarsophalangeal joint dorsiflexion decreased; and positive values, that dorsiflexion increased.
[b]$P = .36$.

Discussion

This study tested the effect on the first metatarsophalangeal joint of controlling the excessive subtalar pronation that can result in inefficiency of the peroneus longus, causing instability of the first ray and limiting dorsiflexion of the hallux. As described by Hicks,[20] falling of the medial longitudinal arch of the foot causes hallux flexion due to the tension of the plantar fascia inserted into the base of the proximal phalanx. Theoretically, if the abnormal subtalar pronation is controlled and flattening of the internal longitudinal arch is impeded, the flexion produced by tension of the plantar fascia will be reduced. However, according to the results of the study, and in contrast to the expectations of the authors, such an effect was not achieved immediately, as the difference between

Table 2. Dorsiflexion of the First Metatarsophalangeal Joint During the Propulsive Period of Gait for Unshod Feet Without and With the Orthosis Recorded After a Mean of Approximately 5 Months

Subject No.	Foot	Dorsiflexion (°) Without Orthosis	With Orthosis After a Time	Difference[a]	Time Between the Two Recordings (days)
1	Right	54	69	15	115
	Left	47.33	58	10.67	
2	Right	62.83	66	3.17	156
	Left	69	59	−10	
3	Right	58.33	54	−4.33	125
	Left	74.33	63	−11.33	
4	Right	44.33	58.33	14	167
	Left	34.16	57.66	23.50	
5	Right	47.66	57.66	10	130
	Left	49.33	60.33	11	
6	Right	41.50	54.16	12.66	174
	Left	40.33	60	19.67	
7	Right	44.50	61.16	16.66	174
	Left	53.33	59.66	6.36	
8	Right	36.33	45	8.67	125
	Left	42	52	10	
Total, mean		49.95	58.43	8.48[b]	145.75

[a]Negative values indicate that with the orthosis, metatarsophalangeal joint dorsiflexion decreased; and positive values, that dorsiflexion increased.
[b]$P = .004$.

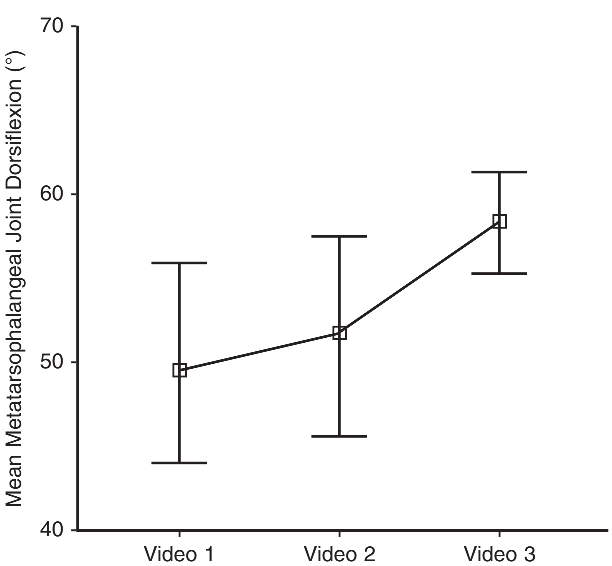

Figure 4. Change in mean metatarsophalangeal joint dorsiflexion after use of the foot orthosis for a determinate time. The error bars indicate 95% confidence intervals.

dorsiflexion of the hallux in video 1 and that in video 2 was not significant. This finding is similar to that of Kilmartin et al,[21] who, in 1991, studied the effect of foot orthoses on extension of the first metatarsophalangeal joint. They observed a significant reduction between the amount of metatarsophalangeal joint extension in unshod subjects (62°) and that in subjects wearing sneakers with the orthosis fitted inside (55°) ($P < .001$). The subjects of that study were clinically diagnosed as having excessive subtalar pronation, but they had not developed hallux rigidus. In that study, it was observed that the orthoses had no immediate positive effect on dorsiflexion of the hallux; on the contrary, their effect was negative. However, those authors did not check the effect of the orthoses after an extended period.

The lack of immediacy of the increase in metatarsophalangeal joint extension may be because the peroneus longus needs time to adapt to the new work situation imposed on it by the orthotic treatment. On controlling the excessive pronation, the peroneus longus passes from a state in which it is permitted almost no effect on the first ray to one in which the normal contraction of the muscle could stabilize the first ray against the ground reaction forces and plantarflex it. We understand that altering the working of a muscular structure to which it has long been subjected and accustomed is not achieved quickly. The muscle needs time to adapt to the new situation. Controlling excessive subtalar pronation alters the position of this joint and consequently the positions of the rest of the foot's components, including the first ray. A mechanism to compensate for abnormal subtalar pronation is, in many cases, supination of the longitudinal axis of the mediotarsal joint and dorsiflexion of the first ray. On placing the subtalar joint in a more physiologic position, the medial part of the forefoot rises. Thus, although the musculature responsible for keeping the medial part of the forefoot in contact with the ground does not react, the first ray will stay in a position of increased dorsiflexion that, at the moment of fitting the foot orthoses, probably cannot be reduced by the musculature. In such cases, at the very moment of fitting the orthosis to the foot, given the position of the first ray, the hallux will dorsiflex a few degrees less than in the unshod foot, despite the excessive subtalar pronation. We believe that this could be one explanation for the findings of Kilmartin et al.[21] However, according to the results of this work, if a determinate time is allowed to pass, the specific action of plantarflexion of the first ray, helped by the peroneus longus, could be restored so that dorsiflexion of the hallux is greater. The mean value of the recordings made after approximately 5 months' use of the orthosis is significantly higher than that of the recordings of the untreated feet.

In three of the examined feet in our study, metatarsophalangeal joint extension had not increased and had actually decreased despite use of the orthoses for 156, 125, and 125 days, respectively (Table 2). One variable that was difficult to control was compliance with wearing the orthoses by all of the subjects every day from the first recording to the last. This factor could be the cause of the decrease. It is also possible that the modification of the peroneus longus, and consequently of the first ray, had become structural so that controlling subtalar pronation was not sufficient to restore plantarflexion of the first ray under either its own capacity or that of the peroneus longus. Another possibility is that the time between the first and last recordings had not been long enough for these three feet. This possibility is questionable, however, because in such cases, it would be reasonable to expect that the joint had not gained any extension but not that it had lost it.

Several authors have reported orthotic treatment of hallux limitus.[4, 5, 9, 14, 22, 23] Shrader and Siegel[24] report a case of functional hallux limitus in a patient with rheumatoid arthritis whose range of motion in the metatarsophalangeal joint in a resting calcaneal standing position was 0°. Those authors state that after 6 weeks' use of a semirigid metatarsal-length shell with a rearfoot intrinsic varus post of 8° on the left foot and 4° on the right foot, and a 5° forefoot extrinsic varus tip post bilaterally, the metatarsophalangeal joint extension in the resting calcaneal standing position increased from 0° to 15°. Root et al[2] consider this type of treatment to be very important. They note that the control of abnormal subtalar pronation is the most effective treatment for hallux limitus caused by abnormal pronation of the foot and that it restores motion of the metatarsophalangeal joint in many cases. Dananberg et al[25] state that certain components of an orthotic device may help to increase hallux dorsiflexion in feet with hallux limitus. These authors argue that rearfoot control should be used only in cases in which true rearfoot pronation exists. All of the feet in the present study demonstrated abnormal rearfoot pronation, so the results of our study corroborate what Dananberg et al[25] and Root et al[2] postulated.

Although the measurements were made and the data were collected with the greatest precision and reproducibility permitted by the methods used, other more sophisticated systems could be used in future studies to increase the precision and reproducibility. We also recognize that the study is sustained by marks drawn directly on the skin and that there could have been movement of the skin over the bones so marked. Another limitation of this study is the poor accuracy and reproducibility of these marks and lines. No recording was made of the foot without orthoses at the later recording session. If there had not been a nonsignificant difference between the unshod and shod foot at this session, the implication would be that improvement could be maintained even when orthoses are not worn. On the contrary, if there had been a significant difference, one could infer that improvement continues only when orthoses are worn, which would mean that treatment must continue for life. We have not shown that movement is gradually restored. To demonstrate this, we would have had to conduct monthly evaluations, which is impractical but would have made this report more concise.

Another weakness of our study lies in the fact that we used the same orthotic prescription for all of the subjects to standardize the independent variable (orthotic treatment). Similar forefoot-to-rearfoot relationships were assumed for all of the subjects. Because the same cast technique was used for each participant, the possibility exists that some of the subjects who demonstrated a decrease in available first metatarsophalangeal joint motion at 5 months did so because of ill-fitting orthotic devices.

It would be of interest to gather a larger sample for further research on this topic. It is possible, especially with such small numbers, that the before and after differences obtained were due to experimental error, although marks, lines, and measurements were made by the same investigator every time. Nevertheless, we believe that this study could be reproduced without great variation from our findings.

Conclusion

Most of the 16 feet studied, which are potential candidates for structural hallux limitus, increased their range of hallux dorsiflexion by controlling the abnormal pronation with foot orthoses. Control of excessive subtalar pronation through orthotic treatment would not be sufficient to bring about an increase in motion in limited hallux dorsiflexion caused by trauma, degenerative articular disease, or a rigid and irreducible dorsiflexed first ray. Control of excessive subtalar pronation is vitally important to prevent the onset of the deformity of functional hallux limitus and to treat it if it has already begun. Treatment will also avoid the negative effect that hallux limitus can have on the whole body during gait, a finding that has already been discussed by other researchers.[12] Other types of studies will be needed to determine how much mobility can be gained in specific periods, the causes of earlier restoration in one foot than in another (or even nonrestoration), and whether the same effect is achieved with different types of orthoses. We stress the importance of recognizing this as a pilot study and as a basis for encouraging other researchers to conduct further studies.

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