CHAPTER **42**

FOREFOOT TO REARFOOT RELATIONSHIP - WHAT DOES IT REALLY MEAN?

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Introduction

Abnormal pronation of the rearfoot during gait has been attributed to one or more structural malaligments of the forefoot.[1-4] Excess pronation is thought to occur secondary to compensation of the subtalar and midtarsal joints.[1-4] Two of the most commonly implicated forefoot malalignments include forefoot varus and forefoot valgus.

In forefoot varus, the axis joining the metatarsal heads is inverted relative to the calcaneus when the subtalar joint is in neutral position.[3,6-7] As a result, the first metatarsal is elevated relative to the lesser metatarsals (Figure 1). There is debate, however, as to whether forefoot varus is a positional deformity or a functional deformity, sometimes referred to as forefoot supinatus.[8] Regardless of the cause, if the forefoot varus is relatively rigid, then compensation in the form of pronation will occur during stance phase of gait at the subtalar joint to allow full contact of the metatarsal heads on the ground.[2,3,9,10] Numerous implications have been reported to include postural fatigue, plantar fasciitis/heel spur syndrome, tendonitis and shin splints, and other lower extremity mechanical pain conditions.[3,10-13]

In forefoot valgus, the heads of the metatarsals are everted relative to the calcaneus when the subtalar joint is in neutral position.[1-3,7] The lesser metatarsals are therefore elevated relative to the first metatarsal (Figure 1). The compensation typically seen at the subtalar joint includes limited subtalar pronation or even subtalar supination.[2,3] This compensation is thought to continue during locomotion resulting in less than normal pronation during the stance phase of gait. Forefoot valgus has been attributed to lateral ankle instability and chronic ankle sprains, sesamoiditis, plantar fasciitis, anterior tarsal tunnel syndrome, iliotibial band syndrome, and leg and thigh pain.[3,7,14-17]

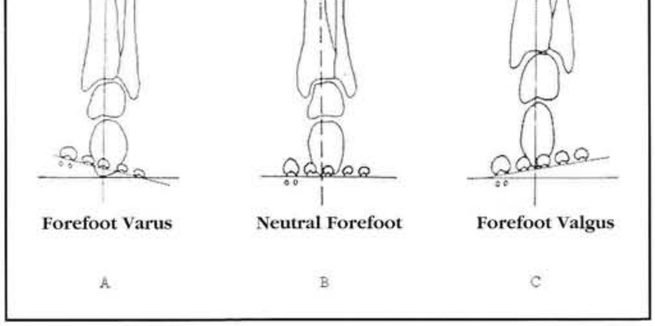

Figure 1. Drawing showing the frontal plane forefoot deformities of varus (A), neutral (B), and valgus (C).

Authors have investigated the reliability of assessing individuals for the presence of forefoot deformities. Astrom and Arvidson assessed 20 healthy individuals by two different clinicians for the magnitude of forefoot alignment using a goniometer. There was poor intra-rator reliability.[17] In 2002, Gheluwe and associates had similar results of poor intra-rater reliability in their study.[18] Somers, in his study, compared visual analysis versus goniometric analysis. He found that visual estimation was more reliable than goniometric measurement.[19]

There is limited research on the influence of forefoot varus and forefoot valgus alignments on rearfoot kinematics. In 1999, Donatelli et al, studied 74 professional baseball players and looked at the relationship between static foot posture and dynamic two-dimensional rearfoot motion during walking.[20] They found that there was a statistically significant association between a forefoot varus deformity and excessive pronation during the stance phase of gait. Despite this association, the results of their study were not entirely conclusive. Although those individuals with forefoot varus showed increased rearfoot pronation, the reverse effect was not seen with forefoot valgus. Such a finding would certainly be predicted based upon the published literature on this subject.

The purpose of this study was to determine whether forefoot frontal plane deformities produce a predictable gait pattern of the rearfoot during stance phase. Information from this study would determine whether or not forefoot alignment produces predictable patterns of hindfoot motion during gait and therefore useful in making clinical decisions regarding treatment. This study was in collaboration with Dr. Mark Cornwall at the Gait Research Laboratory of Northern Arizona University.

METHODS

Thirty individuals (16 men, 14 women) between the ages of 22 and 52 years (mean ± SD 28.1 ± 7.9 years) served as subjects for this study. The subjects had a mean ± SD weight of 68.4 ± 14.6 kg and a mean ± SD height of 168.8 ± 8.6 cm. None of the subjects had a history of a congenital deformity, pain or traumatic injury to either lower extremities six months prior to the study.

Instrumentation

Frontal plane movement of the calcaneus relative to the tibia, termed hindfoot (HF) motion, was measured using the 6-D RESEARCH, (Skill Technologies Inc., Phoenix, AZ USA 85014) electromagnetic motion analysis system. This system is based upon the Fastrak tracking device (Polhemus, Cholchester, VT USA 05446) and uses an electromagnetic transmitter with up to four electromagnetic sensors. The sensors measure 2.8 X 2.3 cm in size and have a mass of 17g. The signals from each sensor are input to a digital signal processor that computes the sensor's position and orientation relative to a transmitter. Within this range, it has an accuracy of .8 mm and .15 degrees RMS.[21] Although a 76 cm radius is typically too small for recording a full walking stride, it is sufficient for analyzing the stance phase of a single limb.[22] For this study, the electromagnetic transmitter was positioned at a height of 65 cm, at the midway point of a six meter raised walk way. The walkway was raised to a height of 46 cm to avoid any possible distortion of the electromagnetic fields caused by metal reinforcement in the laboratory's concrete floor. Two electromagnetic sensors were used to collect the angular position data of the tibia and calcaneus during walking. Joint coordinate system angles for the ankle as defined by Allard et al was calculated using the two sensors.[23]

Movement about an anterior-posterior axis (Y) was defined as inversion/eversion. The axes were aligned with the global (laboratory) reference frame established by the electromagnetic transmitter. The sampling rate for each sensor was 60Hz and the resulting angles were smoothed using a 6 Hz low-pass digital Butterworth filter. Then temporal occurrences of heel strike and toe off were recorded using force-sensing switches (Interlink Electronics, Camarillo, CA USA 93012). The switches were secured to the plantar surface of each subject's right heel and hallux using adhesive tape. The signal produced by each switch was recorded and then resynchronized with the kinematic data.

Procedure

Both feet of each subject were evaluated for the presence of forefoot varus, valgus, or neutral alignment using the visual method described by Somers et al.[19] The criteria for the classification of forefoot alignment were similar to that outlined by McPoil et al.[24,25] The procedure involved evaluation the subject in a prone position by placing each foot in a subtalar neutral position. This was accomplished by palpating the medal and lateral aspects of the talar head while pronating and supinating the foot. Subtalar neutral was defined as the position where the medial and lateral aspects of the talar head are equally palpated. The examiner then visualized the forefoot-to-rearfoot relationship (Figure 2). A forefoot varus was determined if the plane of the metatarsal heads were felt to be inverted. A forefoot valgus was determined if the metatarsal heads were felt to be everted. The

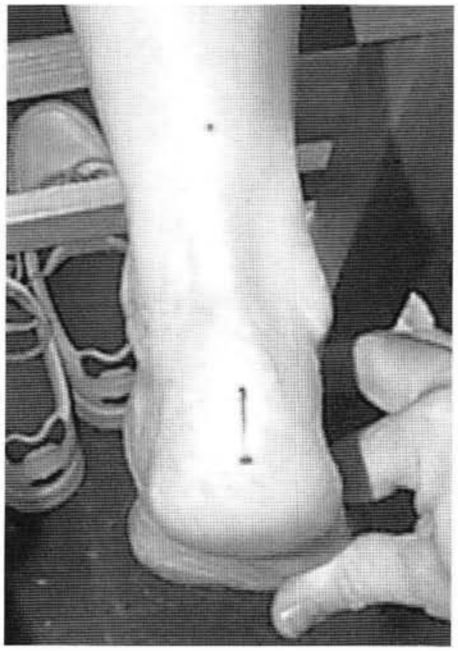

Figure 2. The position of the subjects foot when classifying frontal plane forefoot alignment.

clinician rater considered all of the feet evaluated for this study to be inflexible rather than rigid.

Frontal plane kinematics of the rearfoot was assessed using the electromagnetic motion analysis system by attaching two electromagnetic sensors to the lower extremity being tested. The sensors were secured to the subject's skin using double-sided adhesive tape. One sensor was placed on the anterior shaft of the tibia at the mid-point between the tibial tubercle and medial malleolus. The other sensor was placed on the posterior aspect of the calcaneus, just proximal to the calcaneal fat pad. These locations were selected because of minimal soft tissue presence and therefore reduced the likely hood of sensor-bone movement during gait. The sensors were connected to a microcomputer for data collection by means of a 30-foot serial cable. The subject then sat in a chair and their feet positioned flat on a small platform so they were parallel to the line of progression and their heel centered with the long axis of the second metatarsal. A series of wedges were placed either under the medial or lateral calcaneus until the calcaneus was positioned perpendicular to the supporting surface using visual inspection. Finally, the knee was moved in either a medial or lateral direction until the tibial tubercle was directly over the second metatarsal in the frontal plane (Figure 3). While in this position, each sensor's orientation was initialized relative to the zero reference point for all future angular measurements.

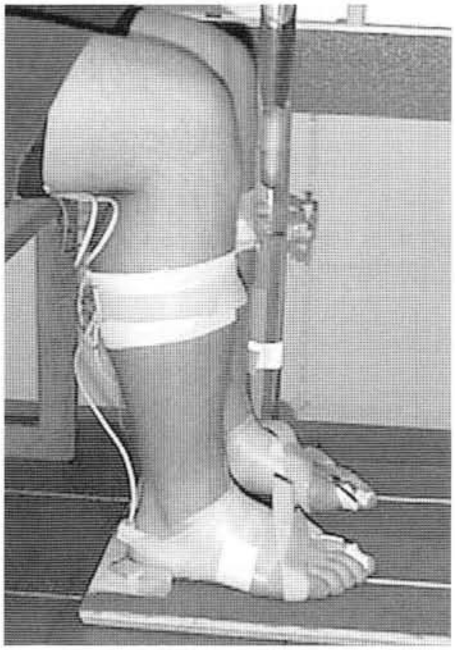
Figure 3. The zero reference position of the foot and lower leg used to define all kinematic measurements.

Following initialization of the sensors, the subject proceeded to walk along the walkway at his or her own pace. The subject's stance phase duration (SPD) for each trial was continuously monitored to ensure the consistency of their walking speed. Any trial in which the SPD deviated more than ten percent from the mean of all other trials was deleted and another trial was collected. This process was repeated until a total of at least five walking trials were recorded for each subject. Using this procedure, no more than seven walking trials were needed to obtain five consecutive trials. The electromagnetic motion analysis system used in this study and the data collection procedures outlined have previously been shown to have good between-trial reliability.[17,26] Eversion of the calcaneus relative to the tibia was then calculated and stored for later analysis.

Each trial was normalized to the person's stance phase duration and ensemble averaged with the other four trials. From the averaged motion pattern during the stance phase of gait of each extremity, the following frontal plane kinematic variables were calculated; the rearfoot angle at the instant of heel strike (HSANG), maximum eversion (MAXEVR), time to maximum hindfoot eversion (TMAXEVR), and total hindfoot eversion range of motion (TOTEVER). These variables were selected because of their representation of the magnitude and pattern of hindfoot motion during walking.

In addition to descriptive statistics, the effect of forefoot classification on frontal plane hindfoot kinematics was assessed using a series of analysis of variance tests (ANOVA).[27] An alpha level of 0.05 was used for all tests of statistical significance.

RESULTS

Twenty-two feet (36.7%) were identified by the clinician as having a forefoot valgus deformity. Twenty-nine (48.3%) of the feet were considered to have a neutral alignment, and nine (15%) feet were deemed to have forefoot varus deformity.

The pattern of HF eversion for each of the three groups of subjects, based upon their forefoot classification, can be seen in figure 4. Table 1 shows the mean values for each of the dynamic HF variables calculated for each forefoot classification. The results of the ANOVA tests showed that

TMAXEVR was significantly ($P < 0.05$) shorter for the feet classified as having a forefoot varus compared to either a neural or valgus forefoot. No other variables were found to be significantly different ($P > 0.05$) between the three groups of subjects (see Table 1).

DISCUSSION

The distribution of frontal plane forefoot deformities found in this study was similar to that reported by McPoil in 1988.[28] In that study, forefoot valgus represented 44.8% of the feet studies compared to 36.7% found in this study. Only 8.8% of the feet studied by McPoil were classified as having a forefoot varus compared with 15% in this study.

With the exception of a shorter time to maximum HF eversion (MAXEVR) during the stance phase of those classified as having a forefoot varus deformity, the motion patterns for the entire three groups of subjects were essentially the same (Table 1 and Figure 4). As such, the present study does not support the proposed relationship between forefoot alignment and HF motion during the stance phase of gait that has been previously purported by the literature. In addition, the results of this study are in disagreement with that reported by Donatelli et al.[20] That study showed that there was an association between a forefoot varus deformity and excessive pronation during stance.

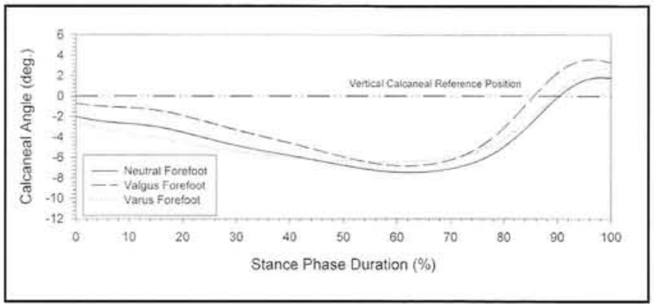

Figure 4. Mean frontal plane rearfoot motion patterns for subjects classified as having a varus forefoot, neutral forefoot, or valgus forefoot alignment. Positive values represent inversion and negative values represent eversion.

Sixty feet from thirty individuals were clinically evaluated for forefoot alignment. The magnitude and pattern of frontal plane hindfoot motion was then measured using a three-dimensional motion analysis system as they walked barefoot. The results of this study showed no statistical difference in the magnitude of HF motion during gait between any of the three groups of subjects. These findings provide no support for the theoretical relationship between forefoot alignment and HF motion during the stance phase of walking.

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Table 1

MEAN VALUES FOR THE FOUR REARFOOT DEPENDENT VARIABLES FOR EACH FOREFOOT DEFORMITY CLASSIFICATION.

	VARIABLE			
	HSANG degrees	**MAXEVR degrees**	**TMAXEVR degrees**	**TOTEVR degrees**
Forefoot Valgus	-0.1	-6.3	60.1*	-5.7
(n = 22)	(2.5)	(2.3)	(6.4)	(2.2)
Neutral	-1.2	-7.0	59.7*	-5.0
(n = 29)	(3.2)	(4.4)	(9.7)	(2.4)
Forefoot varus	-1.5	-6.4	44.1*	-4.0
(n = 9)	(2.5)	(2.7)	(19.8)	(2.3)

*Significantly ($p<.05$) different from Forefoot Varus. Positive degree values represent inversion, negative degree values represent eversion. Values in parentheses are standard deviations.

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