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Varus Foot Alignment and Hip Conditions in Older Adults

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Objective. **Mechanical strain on the hip can result from varus malalignment of the foot. This study was undertaken to explore the cross-sectional relationship between varus foot alignment and hip conditions in a population of older adults.**

Methods. **The Framingham Osteoarthritis Study cohort consists of a population-based sample of older adults. Within this sample, we measured forefoot and rearfoot frontal plane alignment using photographs of a non–weight-bearing view of both feet of 385 men and women (mean age 63.1 years). Each foot segment was categorized according to the distribution of forefoot and rearfoot alignment among cases of ipsilateral hip pain, trochanter tenderness, hip pain or tenderness, and total hip replacement (THR). The relationship of foot alignment to these conditions was examined using logistic regression and generalized estimating equations, adjusting for age, body mass index, sex, and physical activity.**

Results. **The mean ± SD rearfoot varus alignment was 0.7 ± 5.5 degrees, and the mean ± SD forefoot varus alignment was 9.9 ± 9.9 degrees. Subjects in the highest category of forefoot varus alignment had 1.8 times the odds of having ipsilateral hip pain (*P* for trend = 0.06), 1.9 times the odds of having hip pain or tenderness (*P* for trend < 0.01), and 5.1 times the odds of having undergone THR (*P* for trend = 0.04) compared with those in the lowest category. No significant associations were found between rearfoot varus alignment and any hip conditions.**

Conclusion. **Forefoot varus malalignment may be associated with ipsilateral hip pain or tenderness and THR in older adults. These findings have implications for treatment, since this risk factor is potentially modifiable with foot orthoses.**

Approximately 14% of adults >60 years of age report having hip pain on most days (1). Despite this prevalence, we know little about the etiology of most hip conditions. Medical management remains largely dependent on palliative drugs and, in the case of radiographic findings, total hip replacement (THR). In spite of costly treatment, some pain or tenderness often persists. In the effort to develop safer, cheaper, and more effective treatment options, it is essential that we deepen our appreciation of etiologic pathways and draw attention to modifiable risk factors.

One potentially important source of repetitive stress on the hip is varus foot malalignment. Forefoot and rearfoot varus malalignments are frontal plane malalignments that alter the foot's orientation to the ground. Excessive forefoot or rearfoot varus alignment can disrupt the closed chain functioning of the lower limb and strain proximal tissues. Excessive varus alignment of the forefoot has been associated with overuse injuries of the foot (2), shank (3), and knee (4). Biomechanical models (5,6) anticipate that varus malalignment may present even greater risk for overload of the hip. However, no previous studies have evaluated the relationship of forefoot or rearfoot varus alignment to hip conditions. Moreover, all previous studies of foot alignment and proximal pain (2–4) have sampled younger adults, in whom the risk of hip pain is minimal. The purpose of this study was to assess the relationship of

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forefoot and rearfoot varus alignment to hip pain, trochanter tenderness, and THR in a population of older adults.

SUBJECTS AND METHODS

Study sample. The Framingham Osteoarthritis (OA) Study cohort consists of a population-based sample of older adult residents of Framingham, Massachusetts. Members of the cohort originate from 2 groups. The first is the Heart Study Offspring group, which consists of surviving descendants of the original Framingham Heart Study cohort. The second group was selected from the Framingham community using random-digit dialing and census tract data. To be included, subjects had to be at least 50 years old and ambulatory. Subjects with rheumatoid arthritis were excluded. From this combined OA Study cohort, we consecutively sampled all clinic attendees between May 2004 and June 2005.

Assessment of foot alignment. Forefoot and rearfoot alignment was measured using a digital photograph taken while the subject lay in the prone position. Positioning of the legs and ankles followed a strict protocol and was performed by a single trained examiner who was blinded with regard to the study question. The medial malleoli were aligned with the inferior edge of an examination table and the legs were fixed in neutral rotation so that the posterior aspect of the calcanei was uppermost. A maximum allowable distance of 16.5 cm between the sagittal midline of the body and each lateral malleolus was marked on the table. The examiner brought both ankles to neutral dorsiflexion (0 degrees) using gentle thumb pressure over the third metatarsal head. The subject maintained both feet in this position while a single digital photograph, using a PowerShot camera (Canon, Lake Success, NY), was obtained from above. The camera remained fixed to the wall throughout the study in order to ensure consistent positioning.

Rearfoot alignment was defined by the angle between a vertical bisection of the calcaneus and a horizontal reference line drawn across the inferior edge of the examination table (Figure 1). Forefoot alignment was defined by the angle between the same horizontal reference line and a line connecting the first and fifth metatarsal heads (7) (Figure 1). A single investigator (KDG), who was blinded with regard to outcome status, used Canvas software, version 9.0.3 (ACD Systems, Vancouver, British Columbia, Canada) to measure the alignment of each foot segment to the nearest 0.1 degree. Measurements of varus alignment were recorded as positive values, while measurements of valgus alignment were assigned negative values.

A comparison of measurements taken before and after subject repositioning revealed a test–retest reliability (intraclass correlation coefficient [ICC]) of 0.88 for the forefoot and 0.81 for the rearfoot. Repeated assessment of the photographs 6–12 months later showed that the ICC for intrarater reliability was 0.91 for the forefoot and 0.87 for the rearfoot. Comparison with measurements obtained by an outside rater showed that the ICC for interrater reliability was 0.93 for the forefoot and 0.85 for the rearfoot.

Identification of hip conditions. To identify hip pain, subjects indicated whether they felt "pain, aching, or stiffness on most days" by placing a written mark over the anterior hip on a labeled body chart. To identify trochanter tenderness, the examiner calibrated 3 pounds of palpatory pressure with a dolorimeter prior to examining each hip while the subject lay on his or her side. Training ensured that the examiner's performance matched that of an experienced rheumatologist (DTF). Digital pressure was applied to the bony prominence of the greater trochanter and to the soft tissues immediately posterior and superior to the greater trochanter. Tenderness in any of these neighboring areas indicated a positive response (8). A case of hip pain or tenderness was identified by a positive response to either of the above. Finally, subjects responded "yes" or "no" to the examiner's inquiry about whether or not they had undergone a THR. If they answered "yes," then they were asked to indicate which hip had been replaced.

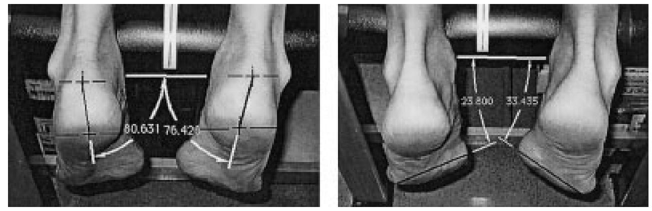

Figure 1. Measured rearfoot (left) and forefoot (right) varus alignment.

Covariates. Age, sex, and body mass index (BMI) were assessed in all subjects. BMI was calculated as weight (kg) divided by height (m^2). Height was measured to the nearest 0.25 inch using a stadiometer. Weight was measured to the nearest 0.25 pound using a balance scale.

Each subject completed a Physical Activity Scale for the Elderly (PASE) questionnaire (9). The derived score was a weighted sum of 12 categories of physical activity related to daily living, recreation, and work. Activities performed while seated were not counted. In adults 67–80 years of age, PASE scores correlated with average daily measurements obtained using an accelerometer (10). The ICC for test–retest reliability was 0.75 (9).

Statistical analysis. Five categories of forefoot or rearfoot varus alignment were created using the quintile distribution among hip pain cases to define category cut points. We examined the relationship of forefoot or rearfoot varus alignment to the prevalence of ipsilateral hip pain in each category using a logistic regression model that adjusted for age, sex, BMI, and PASE score. The same approach was used to examine the relationship of forefoot or rearfoot varus alignment to trochanter tenderness and to hip pain or tenderness. When assessing the relationship of forefoot or rearfoot varus alignment to THR, only 3 categories were created, using the tertile distribution among THR cases. We did this because the number of THR cases was small ($n = 11$). In all analyses, generalized estimating equations were used to adjust for the correlation between 2 hips in the same subject. The lowest category served as the reference group for calculation of an odds ratio (OR).

RESULTS

Four hundred ten subjects in the Framingham OA Study were consecutively sampled. Twenty-five were

Table 1. Characteristics of the study subjects*

Age, mean ± SD years	63.1 ± 8.0
BMI, mean ± SD	28.2 ± 5.1
Sex, % female	54.6
Race, % white	94.8
PASE, mean ± SD score	132 ± 72.5
Forefoot varus angle, mean ± SD degrees	9.9 ± 9.9
Rearfoot varus angle, mean ± SD degrees	0.7 ± 5.5
Hip findings, no. of hips/no. studied (%)	
Pain	120/750 (16.0)
Trochanter tenderness	112/649 (17.3)
Pain or tenderness	191/770 (24.8)
THR	11/770 (1.4)

* BMI = body mass index; PASE = Physical Activity Scale for the Elderly; THR = total hip replacement.

excluded because of an inability to lie in a prone position. Clinical and demographic characteristics of the subjects are presented in Table 1. Among 385 eligible adults, 54.6% were women and 94.8% were white. Compared with all other members of the Framingham OA Study cohort, subjects in this study were slightly younger (mean ± SD age 63.1 ± 8.0 years versus 65.8 ± 9.1 years) and had a greater prevalence of hip pain (16.0% versus 11.6% of hips). The mean PASE score of the cohort (132 ± 72.5) did not differ significantly from that of the parent cohort ($P = 0.75$) or from the reported mean PASE scores of a sample of adults of similar age (11). In this study, trochanter tenderness was noted in 17.3% of hips, and either pain or tenderness was noted in 24.8%. THR had been performed in 1.4%. The mean ± SD forefoot varus alignment was 9.9 ± 9.9 degrees, while the mean ± SD rearfoot varus alignment was 0.7 ± 5.5 degrees.

Table 2. Hip conditions, by quintile of forefoot and rearfoot varus alignment*

	Quintile					*P* for trend
	1	2	3	4	5	
Hip pain						
Forefoot						
No. of hips	185	166	150	151	90	
% painful	12.4	14.5	16.0	15.9	25.6	0.06
Adjusted OR (95% CI)	1.00 (referent)	0.91 (0.6–1.5)	0.96 (0.6–1.6)	1.32 (0.8–2.2)	1.83 (0.9–3.6)	
Rearfoot						
No. of hips	155	163	153	175	103	
% painful	15.5	14.7	15.7	13.7	23.3	0.27
Adjusted OR (95% CI)	1.00 (referent)	0.98 (0.6–1.6)	1.11 (0.6–1.9)	1.22 (0.7–2.1)	1.37 (0.7–2.7)	
Trochanter tenderness						
Forefoot						
No. of hips	151	160	122	106	102	
% tender	14.6	14.4	18.0	21.7	21.6	0.09
Adjusted OR (95% CI)	1.00 (referent)	0.89 (0.5–1.6)	1.01 (0.5–1.9)	1.90 (1.0–3.6)	1.41 (0.7–2.7)	
Rearfoot						
No. of hips	159	143	143	81	121	
% tender	13.8	16.1	15.3	28.4	18.2	0.20
Adjusted OR (95% CI)	1.00 (referent)	1.21 (0.6–2.3)	1.06 (0.6–2.0)	1.99 (1.0–4.0)	1.32 (0.7–2.4)	
Hip pain or tenderness						
Forefoot						
No. of hips	196	180	150	133	103	
% painful or tender	18.9	21.1	25.3	28.6	36.9	<0.01
Adjusted OR (95% CI)	1.00 (referent)	0.95 (0.6–1.5)	1.23 (0.8–2.0)	1.91 (1.2–3.2)	1.87 (1.1–3.3)	
Rearfoot						
No. of hips	182	154	180	145	108	
% painful or tender	20.3	25.3	21.7	26.2	35.2	0.12
Adjusted OR (95% CI)	1.00 (referent)	1.25 (0.7–2.1)	1.06 (0.7–1.7)	1.51 (0.9–2.5)	1.49 (0.9–2.5)	
THR†						
Forefoot						
No. of hips	442	186	134	–	–	
% THR	0.7	2.2	3.0			0.04
Adjusted OR (95% CI)	1.00 (referent)	3.26 (0.6–17.3)	5.11 (1.0–26.5)			
Rearfoot						
No. of hips	401	227	141	–	–	
% THR	0.8	1.8	2.8			0.05
Adjusted OR (95% CI)	1.00 (referent)	2.42 (0.5–12.2)	4.47 (0.9–21.7)			

* OR = odds ratio; 95% CI = 95% confidence interval; THR = total hip replacement.
† Tertile distribution of THR cases was used because of the small number of cases.

The relationship of forefoot and rearfoot varus alignment to hip pain is shown in Table 2. Generally, with increasing forefoot varus alignment, there was increasing prevalence of hip pain (P for trend = 0.06). In the highest quintile of forefoot varus alignment, more than one-fourth of the subjects (25.6%) had ipsilateral hip pain on most days. The odds of hip pain in this quintile (>22 degrees of varus alignment) were 1.8 (95% confidence interval [95% CI] 0.9–3.6) times those in the lowest quintile (<3 degrees varus alignment). No association was discernible in the relationship of rearfoot varus alignment to hip pain (P for trend = 0.27).

A linear trend was suggested in the relationship of forefoot varus alignment to ipsilateral trochanter tenderness, but this association failed to reach statistical significance (P for trend = 0.09). No relationship was found between trochanter tenderness and rearfoot varus alignment (P for trend = 0.20) (Table 2).

Table 2 also shows the relationship of forefoot and rearfoot varus alignment to hip pain or tenderness. Among 762 hips, we found a highly significant association (P for trend < 0.01) between increasing forefoot varus alignment and the prevalence of ipsilateral hip symptoms. Among subjects in the highest quintile of forefoot varus alignment, 36.9% of hips were either painful on most days or tender to palpation yielding an OR of 1.9 (95% CI 1.1–3.3) compared with the lowest quintile. There was no association between rearfoot varus alignment and hip pain or tenderness (P for trend = 0.12).

Despite the small number of cases (11 hips), we found a significant association between increasing forefoot varus alignment and the prevalence of THR (P for trend = 0.04) (Table 2). In the highest tertile of forefoot varus alignment, the OR for THR was 5.1 (95% CI 1.0–26.5). The relationship of rearfoot varus alignment to THR was less evident (P for trend = 0.05).

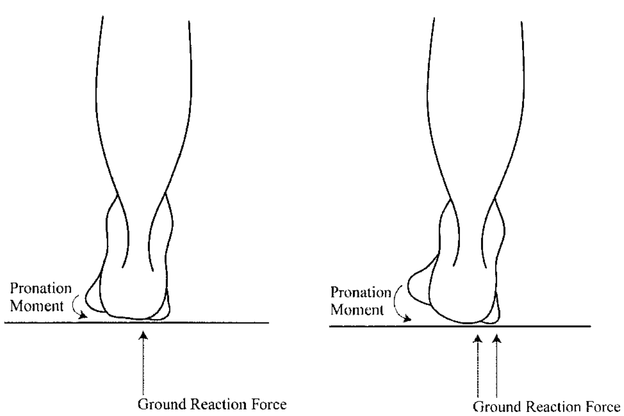

Figure 2. Effect of ground reaction force on foot pronation and rotation. Ground reaction force is applied at the center of ground contact. In a normally aligned foot, the ground reaction force generates a small moment for pronation (**left**). As ground contact is shifted laterally in varus foot malalignment, there is an increase in the moment for pronation (**right**).

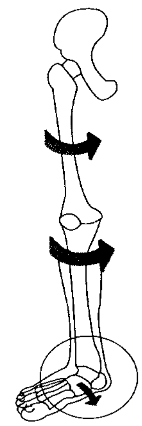

Figure 3. Coupling of pronation to internal rotation. This action results in the transfer of stress from the foot to the hip.

DISCUSSION

These findings suggest that forefoot varus alignment is associated with hip pain or tenderness and THR in the population of older adults. No associations were found between rearfoot varus alignment and any hip conditions. These data therefore support the assertion that varus malalignment of the forefoot presents a more powerful risk for hip conditions than comparable varus malalignment of the rearfoot.

Because of its frequent presence in overuse injuries, clinical commentators have referred to forefoot varus malalignment as "the destructive foot" (6). Its role as a risk factor for patellofemoral conditions (4) is consistent with the predictions of biomechanical models (5,6). However, prior to this study, the association of forefoot varus malalignment with hip conditions had remained speculative.

When the foot initially contacts the ground during routine walking, it does so with the ankle in neutral dorsiflexion. Muscles control the forefoot's descent. With impact, a ground reaction force is imparted that results in an external moment to drive the foot into pronation (Figure 2) and the lower limb into internal rotation (5). This obligatory coupling of internal rotation with foot pronation (Figure 3) loads the hip by pulling taut the powerful lateral rotator muscles of the greater trochanter and drawing the femoral head more deeply into the acetabulum.

Evidence (12) suggests that a foot aligned in varus will, as expected, strike the ground further laterally on its plantar surface (Figure 2). A lateral shift in the ground reaction force implies an exaggerated moment to drive both foot pronation and limb rotation (5). The findings of Lafortune and colleagues (13) confirm that internal rotation increases when walking with the feet in excessive varus alignment with the ground. Where malalignment extends into the forefoot, the mechanical incentives for pronation and internal rotation are not only amplified, but also persist. As the knee locks in extension during midstance, the hip is obliged to absorb all continued demands for rotation (13). It is an obligation that renders the hip vulnerable to eventual overload.

As a cross-sectional study, this investigation cannot confirm that forefoot varus malalignment truly precedes the onset of hip conditions. Confidence comes from knowing that forefoot varus malalignment is frequently observed in young adults as well as in older adults (2). Varus foot malalignment is believed to originate in the failure of the talar neck to fully derotate from its fetal position, a process that is completed during childhood.

In skeletally mature adults, screening for persistent forefoot varus malalignment is carried out with subjects in a prone position (14). Additional examination when the subjects are standing and walking is required to determine how forefoot varus malalignment interacts with other anatomic, environmental, and task constraints to alter the posture and motion of the limb during weightbearing. Foot and ankle flexibility, joint axis orientation, shoes, walking surface, tibiofemoral and coxafemoral joint alignment, and history of injury or dysplasia are among many relevant factors that were not assessed during this study's brief screening examination. To the extent that these factors modify the relationship of foot alignment to hip conditions, they should be kept in mind when evaluating this study's conclusions and their relevance to individual patients. Nevertheless, screening for foot malalignment with subjects in a prone position is a salient component of the clinical examination for several lower extremity conditions (6,14). Forefoot varus malalignment is not observable when the patient is standing.

While screening for foot malalignment continues among clinicians, disagreement has arisen among researchers as to exactly how the foot should be prepositioned for measurement. Various methods attempt to place the rearfoot in a theoretical "subtalar joint neutral" position. Unfortunately, these methods are known to have poor reliability (15). In addition, since the subtalar joint neutral position is not achieved while walking, the functional relevance of the posture remains unclear. By simplifying our protocol to avoid subtalar joint neutral prepositioning, we were able to obtain clinically reproducible and functionally relevant measurements with high intrarater, interrater, and test–retest reliability. As suggested by Chen et al (7), the presentation of measured malalignment relative to a horizontal facilitates recognition of the likely functional consequences as well as the needed features of an accommodating orthosis. Caution is indicated when comparing the results of studies in which measurement procedures differ.

A final comment pertains to the condition defined by the presence of either hip pain or trochanter tenderness. While the inclusion of this composite end point increased the study's power to detect a true association, clinical interpretation of this finding may be problematic. Self-reported anterior hip pain and confirmed trochanter tenderness often arise from distinct diagnoses. Although linear trends were suggested in the relationship of forefoot varus alignment to each separate finding, the association was stronger for hip pain (P for trend = 0.06) than for trochanter tenderness (P for trend = 0.09). One explanation is that forefoot varus malalignment is more closely associated with diagnoses such as osteoarthritis, which commonly produce anterior hip pain, and is less closely associated with diagnoses such as trochanteric bursitis, which commonly produce tenderness. We made no attempt in this study to distinguish these diagnoses or to rule out the possibility of pain referral from extrinsic sources.

We encourage further studies to clarify the association of forefoot varus malalignment with distinct diagnoses at the hip and to evaluate the response of these diagnoses to orthotic intervention.

AUTHOR CONTRIBUTIONS

Dr. Gross had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study design. Gross, Zhang, Holt, Hunter.

Acquisition of data. Gross, Felson, McLennan, Hunter.

Analysis and interpretation of data. Gross, Niu, Zhang, Felson, Hannan, Holt, Hunter.

Manuscript preparation. Gross, Hannan, Holt, Hunter.

Statistical analysis. Gross, Niu, Zhang.

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