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Relationship between foot type, foot deformity, and ulcer occurrence in the high-risk diabetic foot

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Abstract—We hypothesized an association between foot type, foot deformity, and foot ulceration and conducted an analysis of a well-characterized, high-risk diabetic population of 398 subjects. The average age was 62 years of age and 74% of the study population were males. Foot-type distributions were 19.5% pes cavus (high arch), 51.5% neutrally aligned (normal arch), and 29.0% pes planus (low arch). We quantified the presence of hallux valgus (23.9%), hammer/claw toes (46.7%), and hallux limitus (24.4%). A significant association was found between foot type and hallux valgus (p = 0.003); pes planus feet had the highest prevalence as compared with neutrally aligned feet (odds ratio [OR] = 2.43, p = 0.0006). Foot type was also significantly associated with fixed hammer/claw toes (p = 0.01); pes cavus feet had the highest prevalence as compared with neutrally aligned feet (OR = 3.89, p = 0.001). Foot type was also significantly associated with hallux limitus (p = 0.006) with pes planus feet having the highest prevalence as compared with neutrally aligned feet (OR = 2.19, p = 0.003). However, foot type was not significantly related to any ulcer outcome (p = 0.7). Fixed hammer/claw toes (OR = 3.91, p = 0.003) and hallux limitus (OR = 3.02, p = 0.006) were associated with increased risk of any ulcer occurrence. This study affirms that foot type and foot deformity are related and that foot deformities are associated with ulcer occurrence.

Key words: diabetes mellitus, foot, foot deformity, foot type, hallux limitus, hallux valgus, hammer/claw toes, pes cavus, pes planus, ulcer.

INTRODUCTION

Foot ulceration and subsequent amputation is a potential complication of diabetes mellitus (DM). In addition to the neuropathic and vascular components, ulcer etiology has been shown to have mechanical or structural components. These structural considerations include foot morphology or foot type (a broad spectrum

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Abbreviations: BMI = body mass index, DM = diabetes mellitus, GHC = Group Health Cooperative, OR = odds ratio, VA = Department of Veterans Affairs.

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ranging from pes cavus or high arch feet to neutrally aligned or normal arch feet to pes planus or low arch feet) and foot deformities (such as hallux valgus or hammer/claw toes).

The relationship between foot type, foot deformity, and ulceration has been explored previously. For example, studies have shown that foot morphology (e.g., calcaneal pitch angle) affects peak plantar pressure [1] and plantar pressure is related to ulceration [2–4]. Another study found, retrospectively, that everted calcanei were associated with medial metatarsal head ulcers, while inverted calcanei were associated with lateral metatarsal head ulcers [5]. Foot deformities, such as hammer/claw toe deformity or hallux limitus, have been significantly associated with ulcer incidence in a univariate analysis [6].

Thus, previous research indicates that foot morphology (foot type) and foot deformity can affect foot ulcer occurrence and foot ulcer location directly by ulcer development [5–6] or indirectly by increased plantar pressure [2–4]. Therefore, this study further explores the relationship between foot type or foot deformity and ulcer occurrence in a large scale, prospective study. Specifically, we studied the relationship between pes cavus, neutrally aligned, and pes planus feet and ulcer development. We also explored how hallux valgus, hammer/claw toes, and hallux limitus relate to ulceration. This study will further help us understand how foot shape is associated with the development of foot ulcers.

METHODS

Study subjects were recruited from two Western Washington healthcare organizations (the Department of Veterans Affairs [VA] Puget Sound Health Care System and the Group Health Cooperative [GHC]), for a randomized trial of footwear [7]. Study eligibility criteria of subjects were diagnosed diabetes, ages between 45 and 84, men from either the VA or GHC and women from GHC (few female veterans met the eligibility criteria), history of a full thickness foot lesion, no foot deformities requiring a custom shoe, and ability to walk one block and climb one flight of stairs a day. Exclusion criteria were a prior lower-limb amputation of more than one digit; presence of either an unhealed lesion or healed ulcer in the prior month; requirement of boots, custom shoes, or nontraditional footwear for daily activities; nonambulatory status; or a terminal illness with a 2-year survival unlikely. Subjects with severe foot deformities and Charcot feet were also excluded.

Between August 1997 and December 1998, 400 participants were enrolled and followed for 2 years. All subjects provided informed consent for this study approved by the institutional review board. Additional study methodology and findings are described in detail elsewhere [7].

We collected data on diabetes, health, foot, and functional status from patients at baseline and after 1 and 2 years. Each foot was evaluated and examined during study visits every 17 weeks. Standing and unloaded sitting position parameters were observed and evaluated according to the study protocol by one of two examiners (an orthopaedic surgeon who completed a Foot and Ankle Fellowship and had 12 years experience or a residency-trained podiatrist with 9 years experience). Parameters measured included foot type (pes planus, neutrally aligned, and pes cavus), foot deformities (hallux valgus, hallux limitus, and hammer/claw toes, either fixed or supple), response to 5.07 monofilament, and peripheral pulses. The patients' height and weight were used to calculate body mass index (BMI), defined as the weight in kilograms divided by the height in meters squared.

We used the following study definitions to determine if a patient had a specific foot type or a specific foot deformity. Pes cavus feet have a high arch with or without an inverted hind foot, neutrally aligned feet have a normal arch with a well-aligned hind foot, and pes planus feet have a low arch with or without an everted hind foot. Hallux valgus is considered present if the great toe is deviated toward the lateral side of the foot with a prominence developed over the medial side of the first metatarsal head. Hallux limitus is present if the dorsiflexion and plantar flexion of the great toe is limited at the metatarsophalangeal joint. Hammer/claw toes are present if the metatarsophalangeal joint is hyperextended, the proximal interphalangeal joint is flexed, and the distal interphalangeal joint either is flexed or extended. The hammer/claw toe deformity is supple if it can be passively corrected with the joints returning to a neutral position. If it cannot be passively corrected, the deformity is fixed.

The study outcome was a foot ulcer defined as cutaneous erosion extending into or through the dermis to deeper tissue or other cuts not healing in 30 days. Because multiple ulcers may occur at the same time on the same foot and feet may develop ulcers repeatedly, each time the patient presented with a new ulcer, it was considered an ulcer episode.

Since we compared baseline measures with ulcer outcome, only the first ulcer episode on each foot was included. We determined ulcer etiology from patient interviews, lesion photographs, and medical record reviews. A panel of three foot-care specialists blinded to the study group determined final ulcer classification. They reviewed the descriptions, photographs, study and medical records, and causal pathway data. They also verified the assignment of all minor lesions that did not heal within 30 days, ulcers, and amputations.

This analysis focused on the relationship between foot type, foot deformity, and ulcers that developed from mechanical etiologies. Thus, ulcers from factors deemed not footwear-related (e.g., minor trauma, self-care, critical ischemia, paronychia, or decubitus) were excluded [7].

We modeled differences in means across groups using an analysis of variance with a $p = 0.05$ significance level. We used logistic regression or multinomial logistic regression to model relationships with dichotomous variables (ulcer occurrence, presence/absence of foot deformities) with results presented as odds ratios (ORs) and 95 percent confidence intervals, with a $p = 0.05$ significance level. We used Poisson regression to model count data and linear contrasts to compare means and percentages among individual foot-type groups. Two subjects (4 feet) had missing foot-type and foot-deformity data leaving 796 feet from 398 subjects for analysis. To account for dependencies created by subjects being represented in our sample more than once, we performed analyses clustering by subject using robust standard errors.

RESULTS

Study participants averaged 62 years of age and 14 years of education. The majority of participants were white (78%) and married (61%). In this population, Reiber et al. reported 95 ulcers over 84 episodes [7]. The study team investigated the pivotal event leading to ulceration. Of the 84 ulcer episodes, the pivotal event was non–shoe-related for 51 episodes, including 26 with external trauma, 6 with self-care, 6 with decubitus, 5 with paronychia, 4 with critical ischemia, and 4 with other pivotal events. When these ulcers were excluded, only 33 ulcer episodes remained, and 7 feet had repeat episodes, leaving 26 first-ulcer episodes that were related to footwear.

Foot Type

Foot types were distributed as 19.5 percent pes cavus, 51.5 percent neutrally aligned, and 29.0 percent pes planus (**Table 1**). All three groups were similar with respect to age, sex, duration of DM, and neuropathy. Mean BMI was lower for pes cavus feet than for neutrally aligned or pes planus feet ($p = 0.006$).

Foot Deformities

Hallux valgus was present in 23.9 percent of feet, hammer/claw toes in 46.7 percent, and hallux limitus in 24.4 percent (**Tables 2–4**). The presence of hallux valgus was significantly associated with increased age ($p < 0.0001$), a lower BMI ($p = 0.002$), and a higher percentage of neuropathy ($p = 0.008$). Supple hammer/claw toes were significantly associated with being male ($p = 0.02$), increased age ($p = 0.01$), lower BMI ($p = 0.0002$), and a higher percentage of neuropathy ($p = 0.001$). Fixed hammer/claw toes were significantly related to increased age ($p < 0.0001$), lower BMI ($p = 0.009$), and a higher percentage of neuropathy ($p = 0.002$). Hallux limitus was

Table 1.
Age, body mass index (BMI) (mean ± standard deviation), sex, duration of diabetes mellitus (DM) > 10 years, and neuropathy by foot type.

Demographics	All Feet (n = 796*)	Pes Cavus (n = 155) 19.5%	Neutrally Aligned (n = 410) 51.5%	Pes Planus (n = 231) 29.0%	p-Value
Mean Age (yr)	62.4 ± 10.1	62.7 ± 10.1	62.4 ± 10.3	62.2 ± 9.6	0.9†
Mean BMI (kg/m^2)	32.9 ± 7.0	30.9 ± 5.7‡	33.5 ± 7.7	33.2 ± 6.2	0.006†
Male (%)	77.4	83.9	76.6	74.5	0.3§
Duration of DM > 10 yr (%)	43.7	42.6	45.6	41.1	0.7§
Neuropathy (%)	57.7	60.0	58.1	55.4	0.8§

*Four feet had missing foot-type classification.
†Analysis of variance.
‡Significantly different from neutrally aligned and pes planus.
§Logistic regression.

Table 2.
Means ± standard deviations or percentages, odds ratios (ORs) (95% confidence intervals [CIs]), and *p*-values calculated from logistic regression models of hallux valgus and sex, age, body mass index (BMI), duration of diabetes mellitus (DM) > 10 years, neuropathy, and foot type.

Demographic/Foot Variables	Absent (*n* = 606)	Present (*n* = 190)	OR (95% CI)	*p*-Value
Male (%)	79.4	71.1	0.64 (0.39–1.05)	0.08
Mean Age (yr)	61.2 ± 10.0	66.2 ± 9.3	1.67* (1.34–2.08)	<0.0001
Mean BMI (kg/m^2)	33.4 ± 7.2	31.2 ± 6.0	0.77† (0.65–0.91)	0.002
Duration of DM > 10 yr (%)	44.6	41.1	0.87 (0.55–1.35)	0.5
Neuropathy (%)	54.1	69.0	1.88 (1.18–3.00)	0.008
Foot Type (%)‡				0.003
Neutrally Aligned	55.5	39.0	1.00	—
Pes Planus	25.4	40.5	2.43‡§ (1.47–4.03)	0.0006
Pes Cavus	19.1	20.5	1.52‡§ (0.79–2.90)	0.2

*Per 10 yr increase.
†Per 5 kg/m^2 increase.
‡OR, CI, and *p*-value adjusted for sex, age, BMI, and neuropathy.
§OR computed relative to neutrally aligned foot type.

Table 3.
Means ± standard deviations or percentages, odds ratios (ORs) (95% confidence intervals [CIs]), and *p*-values calculated from multinomial logistic regression models of hammer/claw toes and sex, age, body mass index (BMI), duration of diabetes mellitus (DM) > 10 years, neuropathy, and foot type.

Demographic/Foot Variables	None (*n* = 424)	Supple (*n* = 285)	Fixed (*n* = 87)	Supple vs None		Fixed vs None	
				OR (95% CI)	*p*-Value	OR (95% CI)	*p*-Value
Male (%)	73.1	83.2	79.3	1.82 (1.09–3.02)	0.02	1.41 (0.65–3.06)	0.4
Mean Age (yr)	60.6 ± 10.2	63.1 ± 9.2	68.9 ± 9.3	1.29* (1.05–1.59)	0.01	2.42* (1.66–3.51)	<0.0001
Mean BMI (kg/m^2)	34.2 ± 7.3	31.4 ± 6.2	31.2 ± 6.2	0.73† (0.62–0.87)	0.0002	0.71† (0.55–0.92)	0.009
Duration of DM > 10 yr (%)	40.6	50.5	36.8	1.50 (0.99–2.27)	0.06	0.85 (0.44–1.65)	0.6
Neuropathy (%)	48.8	65.6	74.7	2.00 (1.31–3.06)	0.001	3.10 (1.51–6.36)	0.002
Foot Type (%)‡					0.01§		
Neutrally Aligned	55.2	48.8	42.5	1.00	—	1.00	—
Pes Planus	30.7	29.5	19.5	1.10‡¶ (0.68–1.78)	0.7	0.89‡¶ (0.39–2.03)	0.8
Pes Cavus	14.2	21.8	37.9	1.59‡¶ (0.88–2.86)	0.1	3.89‡¶ (1.71–8.89)	0.001

Note: In addition to ORs presented, significant differences for age were found when fixed hammer/claw toes vs supple (OR = 1.87, $p = 0.0009$) and pes cavus vs normal foot shape (OR = 2.45, $p = 0.027$) were compared.
*Per 10 year increase.
†Per 5 kg/m^2 increase.
‡OR, CI, and *p*-value adjusted for sex, age, BMI, and neuropathy.
§Overall significance for foot type.
¶OR computed relative to neutrally aligned foot type.

Table 4.
Means ± standard deviations or percentages, odds ratios (ORs) (95% confidence intervals [CIs]), and *p*-values calculated from logistic regression models of hallux limitus and sex, age, body mass index (BMI), duration of diabetes mellitus (DM) > 10 years, neuropathy, and foot type.

Demographic/Foot Variables	Absent (*n* = 602)	Present (*n* = 194)	OR (95% CI)	*p*-Value
Male (%)	73.4	89.7	3.15 (1.56–6.36)	0.001
Mean Age (yr)	62.2 ± 10.0	63.0 ± 10.3	1.07* (0.86–1.35)	0.5
Mean BMI (kg/m^2)	32.7 ± 7.0	33.4 ± 6.7	1.07† (0.92–1.25)	0.4
Duration of DM > 10 yr (%)	43.2	45.4	1.09 (0.69–1.72)	0.7
Neuropathy (%)	52.5	73.7	2.54 (1.55–4.15)	0.0002
Foot Type (%)‡				0.006
Neutrally Aligned	53.8	44.3	1.00	—
Pes Planus	25.4	40.2	2.19‡§ (1.31–3.68)	0.003
Pes Cavus	20.8	15.5	0.89‡§ (0.44–1.78)	0.7

*Per 10 yr increase.
†Per 5 kg/m^2 increase.
‡OR, CI, and *p*-value adjusted for sex, age, BMI, and neuropathy.
§OR computed relative to neutrally aligned foot type.

significantly associated with being male ($p = 0.001$) and with increased neuropathy ($p = 0.0002$). Duration of DM was not associated with any of the foot deformities.

Logistic regressions of each foot deformity on foot type adjusted for sex, age, BMI, and neuropathy resulted in a significant association between foot type and hallux valgus ($p = 0.003$) with pes planus feet having the highest prevalence as compared with neutrally aligned feet (OR = 2.43, $p = 0.0006$) (**Table 2**). Foot type was significantly associated with hammer/claw toes ($p = 0.01$) with pes cavus feet having the highest prevalence for fixed hammer/claw toes (OR = 3.89, $p = 0.001$) as compared with neutrally aligned feet (**Table 3**). Foot type was also associated with hallux limitus ($p = 0.006$) with the pes planus feet having the highest prevalence as compared with neutrally aligned feet (OR = 2.19, $p = 0.003$) (**Table 4**).

Ulcer Development

Subjects who developed ulcers had increased neuropathy ($p = 0.003$) (**Table 5**). Thus, subsequent analyses describing the relationship between foot type, foot deformities, and ulcer occurrence were adjusted for neuropathy.

Foot type was not significantly related to ulcer outcome ($p = 0.7$). A nonsignificant trend was found for the presence of hallux valgus to be associated with increased risk of ulceration (OR = 1.97, $p = 0.09$), while fixed hammer/claw toes (OR 3.91, $p = 0.003$) and hallux limitus were strongly associated with increased risk of ulcer occurrence (OR = 3.02, $p = 0.006$).

DISCUSSION

Foot morphology and foot deformities have been associated with ulcer development. In this study, we further explored these relationships in a well-characterized population of people with diabetes and foot-risk conditions.

The literature has conflicting data on the relationship between hallux valgus and the pes planus foot type. Some studies on adult and juvenile hallux valgus have found a significant relationship [8–10], while others have not [11–12]. Our data indicated a significant relationship between hallux valgus and pes planus feet when contrasted with the neutrally aligned foot. The feet may possibly share a similar etiology in most cases, such as a

Table 5.
Means ± standard deviations or percentage, odds ratios (ORs) (95% confidence intervals [CIs]), and *p*-values calculated from logistic regression models of ulcer outcome and sex, age, body mass index (BMI), duration of diabetes mellitus (DM) > 10 years, neuropathy, foot type, and foot deformities.

Demographic/Foot Variables	**No Ulcer ($n = 722$)**	**Ulcer ($n = 26$)**	**OR (95% CI) Ulcer vs None**	***p*-Value**
Male (%)	76.3	88.5	2.38 (0.71–7.99)	0.2
Mean Age (yr)	62.3 ± 10.1	65.8 ± 10.5	1.43^{*} (0.95–2.16)	0.09
Mean BMI (kg/m^2)	33.0 ± 7.0	30.9 ± 6.3	$0.78^{\dagger}$ (0.56–1.07)	0.1
Duration of DM > 10 yr (%)	42.9	53.9	1.55 (0.71–3.38)	0.3
Neuropathy (%)	55.0	88.5	6.28 (1.88–21.0)	0.003
Foot Type (%)				0.7
Neutrally Aligned	51.0	50.0	1.00	—
Pes Planus	29.2	34.6	$1.25^{\ddagger\S}$ (0.53–2.98)	0.6
Pes Cavus	19.8	15.4	$0.77^{\ddagger\S}$ (0.25–2.37)	0.7
Hallux Valgus (%)	23.6	42.3	$1.97^{\ddagger}$ (0.90–4.31)	0.09
Hammer/Claw Toes (%)				0.001
None	53.2	38.5	1.00	—
Supple	36.8	23.1	$0.68^{\ddagger}$ (0.25–1.87)	0.5
Fixed	10.0	38.5	$3.91^{\ddagger}$ (1.57–9.71)	0.003
Hallux Limitus (%)	23.1	53.9	$3.02^{\ddagger}$ (1.37–6.66)	0.006

*Per 10 yr increase.
†Per 5 kg/m^2 increase.
‡Adjusted for neuropathy.
§OR computed relative to neutrally aligned foot type.

tight gastrocnemius or heel cord. Less controversy exists about the relationship between hammer/claw toes and pes cavus feet, because both the literature [10,13–16] and our data support the relationship. Potentially, the loss of intrinsic musculature with the pes cavus foot may result in a muscle imbalance that leads to overpulling of the extrinsic musculature and the development of the characteristic hammer/claw toes. Finally, hallux limitus has been associated with the pes planus foot both in the literature [10,17] and in our data. The lower medial column in the flat foot can affect the mechanics of the first metatarsophalangeal joint, resulting in limited range of motion. Limited joint mobility has been well documented in patients with DM [18].

Foot type was not associated with ulcer development—the data indicated that all foot types were equally likely to develop plantar ulcers. This was somewhat surprising since foot morphology has been associated with higher plantar pressure [1]. The lack of a relationship between foot type and ulceration indicates that foot type is not a sensitive enough measure of foot shape.

However, in our study, both fixed hammer/claw toes and hallux limitus were strongly associated with ulceration. The relationship between hammer/claw toes and ulceration is supported by the literature [6,19–20] as is the association between ulceration and hallux limitus [6,19,21–23]. This is not unexpected because both foot pathologies have mechanical factors that can lead to increased plantar pressure, which has been associated with ulceration [2–4]. Specifically, Ahroni et al. found that hammer/claw toes are associated with increased metatarsal head pressure, while hallux limitus is associated with increased hallux pressure [24]. Furthermore, Mueller et al. found that an extended metatarsophalangeal joint (i.e., hammer/claw toes) was a strong predictor of forefoot plantar pressure [25].

The limitations of this study included the small number of ulcers of mechanical etiology. Also, when patients were screened, severely deformed feet at either end of the foot-type spectrum (from high to low arches) were excluded. Thus, potential differences between foot types may have been obscured by the relative homogeneity of our patient population. Finally, classifying feet as one of three foot types is a relatively blunt instrument. While the literature widely accepts that feet of varying type function differently, the use of a discrete, clinically determined descriptor with only three "steps" may not be sensitive enough to quantify the often subtle differences in foot function. A continuous measure of foot structure, such as resting calcaneal stance position [26–27] or the relative angles between the bones of the foot [28], would be a more sensitive measure of foot structure.

This study indicates several potential clinical implications. Most importantly, since the data demonstrate that feet with deformities such as fixed hammer/claw toes or hallux limitus are more likely to develop ulcers, these deformities should be considered as potential etiologic factors. Thus, primary care physicians who treat diabetic patients need to recognize and address these deformities, both before and after an ulcer develops, to either prevent the occurrence or remove the damaging loading and prevent reoccurrence.

CONCLUSION

In this prospective study, we have found a strong relationship between foot deformity (fixed hammer/claw toes and hallux limitus) and ulceration and between foot deformity and foot type. Our results do not preclude a relationship between foot type and plantar ulcer occurrence, because the lack of sensitivity in our foot-type classification may have contributed to the negative findings. To fully explore these issues, further research is needed in this area with continuous measures of foot morphology.

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