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## Foot Function, Foot Pain, and Falls in Older Adults: the Framingham Foot Study

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### Abstract

**Background**—Although foot pain has been linked to fall risk, contributions of pain severity, foot posture or foot function are unclear. These factors were examined in a cohort of older adults.

**Objective**—The purpose of this study was to examine the associations of foot pain, severity of foot pain and measures of foot posture and dynamic foot function with reported falls in a large, well-described cohort of older adults from the Framingham Foot Study.

**Methods**—Foot pain, posture and function were collected from Framingham Foot Study participants who were queried about falls over the past year (0, 1, 2+ falls). Logistic regression was used to calculate odds ratios (OR) and 95% confidence intervals (CI) for the relation of falls with foot pain, pain severity, foot posture, and foot function adjusting for covariates.

**Results**—Of 1375 participants, mean age was 69y; 57% were female; 21% reported foot pain (40% mild pain, 47% moderate, 13% severe pain). One-third reported falls in past year (1 fall: n=263, 2+ falls: n=152). Foot pain was associated with a 62% increased odds of recurrent falls. Those with moderate and severe foot pain showed increased odds of 2+ falls (OR=1.78, CI 1.06–2.99, and OR = 3.25, CI 1.65–7.48, respectively) compared to no foot pain. Foot function was not associated with falls. Compared to normal foot posture, those with planus foot posture had 78% higher odds of 2+ falls.

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**Conclusion**—Higher odds of recurrent falls were observed in individuals with foot pain, especially severe foot pain, as well as individuals with planus foot posture, indicating that both foot pain and foot posture may play a role in increasing the risk of falls among older adults.

### Keywords

pain; recurrent falls; flat feet; foot pronation; cohort study

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## Introduction

More than 30 percent of individuals over the age of 65 fall at least once a year. This figure increases to over 40 percent for persons aged 75 years and older [1]. Among older adults, falls are a common cause of injury [2], related hospitalizations [3] and even death [4]. Moreover, fear of falling, often resulting from past falls, has been shown to heighten activity avoidance behaviors [5] and may negatively impact physical activity levels and quality of life. In addition to these effects, treatment for fall-related injuries imposes a large and rising economic cost as the elderly population in the U.S. is projected to increase [6].

The increasing risk of falls is multi-factorial, with many interacting factors ranging from age [7] and balance impairment [8], to psychological and environmental factors [1]. Foot pain has become an area of potential interest in falls outcomes. Foot pain is highly prevalent with population-based research indicating that 24 to 30 percent [9–12] of older adults report foot pain. Moreover, foot pain may have an impact upon overall health. Studies have linked foot pain to worse self-reported health status [11], impaired balance [13] and worse physical function [14–16]. Several studies have also found that foot problems [1] and foot pain [17] are associated with increased odds of falling among older adults.

While foot pain has been linked to functional impairments and risk of falls, no studies have evaluated the impact of foot pain on falls in a population-based sample of adults. Furthermore, to our knowledge, only one study [15] has examined the role of dynamic foot function upon falls in older adults. Therefore, the purpose of this study was to examine the associations of foot pain, severity of foot pain and measures of foot posture and dynamic foot function with reported falls in a large, well-described cohort of older adults from the Framingham Foot Study. We hypothesized that foot pain and the categories of non-normal foot measures would be associated with occurrence of falls and number of falls.

## Methods

### Participants

Participants were from the population-based Framingham Foot Study (2002–08) [18], a study of community-dwelling, ambulatory adults residing in and around the town of Framingham, MA, USA, derived from members of the Framingham Heart Study's Original and Offspring cohorts [19,20]. The Framingham Foot Study has been approved by the Boston University and Hebrew SeniorLife Institutional Review Boards and participants provided written, informed consent prior to enrollment. Participants with data on foot pain and falls within a year of the Foot Study exam were included in this cross-sectional analysis.

### Assessment of Foot Pain

Presence of foot pain was determined at the Foot Study visit in response to an NHANES-type question, “On most days do you have pain, aching, or stiffness in either of your feet?” Responses were categorized as: Yes, pain in one or both feet; or No, no pain in either foot. Participants who reported foot pain were then asked to categorize the severity of pain in the affected foot as mild, moderate, or severe. If pain in both feet was reported, the foot with the most severe pain was used in the analysis.

### Falls Ascertainment

Falls data were collected at the core Framingham Study visit as whether a participant fell in the past year (yes/no). The core Framingham Study visit typically occurred on the same day as the Foot Study visit, or for a small proportion within 1 year of their Foot Study exam. If a participant reported falling in the past year, they were then asked how many times they had fallen. Number of falls was categorized into three groups: no-falls (zero in past year), single fall or recurrent falls for those who reported falling two or more times in the past year. For analysis, we examined falls in two ways: first, as any falls (yes or no); secondly, as no fall, single reported fall or 2+ (recurrent) reported falls.

### Foot Posture and Dynamic Foot Function

A Tekscan Matscan foot pressure mat was used to collect plantar pressure scans during quiet standing and also while walking at a self-selected pace as reported previously [21]. Foot posture was derived from the Modified Arch Index (MAI) which was calculated using the quiet standing scans as previously described [21]. Briefly, the pressure in the middle third of the foot is divided by the total pressure under the foot. Foot posture was categorized into 3 groups using sex-specific quintiles of MAI: planus, normal and cavus. Dynamic foot function was estimated from the Center of Pressure Excursion Index (CPEI), a measure of the medial shift of the center of pressure when walking [22,23]. Foot function was categorized into 3 groups using sex-specific quintiles of CPEI: pronated, normal and supinated.

### Covariates

Covariates in our analyses included age, body mass index (BMI) and cohort of origin. Age in years was recorded at the foot examination. Also at this time, participants’ height and weight were measured and used to calculate BMI ( $\text{kg}/\text{m}^2$ ). Height was obtained using a calibrated stadiometer and rounded to the nearest quarter inch. Weight was measured with a balance beam scale and rounded to the nearest half pound. To account for any cohort differences within the Framingham Study, we created a dichotomous variable for cohort origin (Framingham Original Cohort or Offspring Cohort).

### Statistical Methods

Characteristics of the study sample were examined by the fall groups. Multivariable logistic regression was used to calculate odds ratios and 95% confidence intervals for the relation between foot pain, foot posture, and foot function with falls outcomes. Additionally, we examined the relation between severity of foot pain and falls. Multivariable analyses were

adjusted for age, BMI, and cohort origin (Framingham Original Cohort or Offspring Cohort).

## Results

Table 1 shows the characteristics of the 1375 participants with falls information reported. Participants had a mean age of 69 years (range of 40 – 98 years; 2% were ages 40–50 years, 22% were ages 51–60 and 76% were 61 and older), a mean BMI of 28 kg/m<sup>2</sup>, and 57 percent were female. Twenty one percent (n=283) of participants reported foot pain, aching, or stiffness on most days. Among those reporting pain, 113 (40%) indicated mild foot pain while 134 (47%) and 36 (13%) reported having moderate or severe foot pain, respectively (Table 1). Nearly a third of the participants (n=415), reported having fallen in the last year. Of those who fell, 263 participants fell once, and 152 reported falling two or more times. Four participants who reported falling did not indicate a number of falls, and thus were not considered in the analyses of recurrent fallers. Of the study participants, 250 were missing foot posture and dynamic foot function measures. Thus, analyses of foot posture and dynamic foot function included the subset of 1125 participants.

### Foot Pain and Falls

After adjusting for age, BMI and cohort, there was no association with any falls in the past year for those with foot pain compared to those without foot pain (OR=1.08, 95% CI 0.81–1.44). However, there was a 62% increased odds of recurrent falls (95% CI 1.10–2.39) for participants with foot pain compared to those with no foot pain. Similar patterns were seen when the severity of foot pain was examined: those who reported moderate or severe foot pain showed significantly increased odds of having recurrent falls (OR = 1.78, 95% CI 1.06–2.99; OR = 3.52, 95% CI 1.65–7.48, respectively) compared to those who reported no foot pain (Table 2).

### Foot Function, Foot Posture and Falls

There were no significant relations observed between the dynamic foot function measures with odds ratios ranging from 1.01 to 1.28 and wide confidence intervals. There was little to no association for cavus foot posture as well. However, participants with planus foot posture compared to those with normal foot posture had a 78 percent increased odds of having recurrent falls (OR=1.78, 95% CI 1.10–2.87) (Table 3).

## Discussion

This cross-sectional study of older adults showed a significant association between the severity of foot pain and falls. While mild foot pain did not affect the odds of falling, moderate to severe foot pain was associated with increased odds of recurrent falls. This cross-sectional study also showed a significant relation between foot posture and falls in which participants with a planus foot posture had an increased odds of recurrent falls compared to those with the normal foot posture. These results indicate that foot pain and foot posture may play an important role in recurrent falls among older adults. We did not

observe increased odds of falling between foot pain and any falls or single falls reported over the past year.

### Foot Pain and Falls

This study found that moderate or severe foot pain was associated with increased odds of recurrent falls. Similar results have been reported in other studies relating foot problems (e.g., pain, foot deformities) to falls. A 1988 falls study of 336 older adults found that “serious foot problems” significantly increased falls risk [1], but it was unclear if that study’s definition of foot problems included foot pain or pain severity. While large, population-based data that relate foot pain with falls are scarce, the results of this study are consistent with smaller studies of falls in older adults. Notably, a prospective study of 313 Australian participants over the age of 60 years reported that fallers had a significantly greater prevalence of foot pain [17]. A similar result was observed in a study of 176 adults aged 62–96 years in which fallers reported significantly higher rates of disabling foot pain [24]. One novel finding of the current study was that foot pain was significantly associated with recurrent falls and the association was stronger with worsening pain severity, suggesting that not only foot pain, but the worsening of foot pain, is linked to more falls.

Evaluating the functional aspects of foot pain and foot problems may offer insight into potential mechanisms for how foot pain can lead to falls. Individuals with foot pain have significantly worse self-reported health-related quality of life [11,25] along with higher self-reported disability [26] and functional limitation [27]. Functional tests (e.g., stair ascent and descent, alternate stepping test, timed walks) and tests of dynamic balance (e.g., coordinated stability test, leaning balance test) [13,28] also show diminished performance among those with relatively worse foot health. Thus, it may be that the increase in falls among those with foot pain observed in this and previous studies is the result of related functional impairments. Future work should explore interventions to mitigate foot pain in relation to falls and functional performance measures.

### Foot Pain Severity and Falls

Few studies have directly investigated the effect of foot pain severity on falls. Studies in older adults which classified disabling foot pain using the Manchester Foot Pain and Disability Index (MFPDI) have found greater odds of falling [17], as well as reduced gait speed and higher reported functional limitations [25], but neither study included categories of severity of foot pain. By comparison, the Women’s Health and Aging Study found that the presence of self-reported moderate to severe foot pain resulted in a significant increase (35%) in fall risk [29].

A notable finding of the current study was the association between increased odds of recurrent falls for those participants who reported moderate or severe foot pain. Studies of overall health, physical function, and disability may offer additional insight into these data. A 1998 study of more than 1,000 older women found that participants with moderate or severe foot pain had significantly worse performance on timed walking and chair stand tests relative to those with mild or no foot pain [14]. Menz et al. noted in a study of 135 older adults aged 75 to 93 years that recurrent fallers had worse overall foot health than both non-

fallers and those who only fell once as indicated by a weighted score of foot health that included a dichotomous pain response [28]. This finding is consistent with results of this study showing that those with severe foot pain have greatly increased odds of being recurrent fallers, as these individuals likely have worse foot health overall. Future studies should examine the effects of pain severity on physical performance, functional limitation, and disability.

### **Foot Posture, Dynamic Foot Function and Falls**

There were no significant relations observed between the dynamic foot function measures in the study participants. However, those participants who had planus foot posture compared to those with normal foot posture had a 78% increased odds of having recurrent falls in the past year. Cavus foot posture measure showed little association with falls. There is scant literature on foot function and falls.

The association observed between planus foot posture and falls may be due to a direct effect on balance. Several studies have shown that individuals with planus foot posture have impaired postural stability [30–33], possibly because the planus foot type is inherently more mobile when standing [34]. Alternatively, this association could be indirect, mediated by the association between planus foot posture and foot pain [35].

The lack of association between dynamic foot function and falls was unexpected, but may be explained by the fact that all pressure measurements were obtained while barefoot. Footwear has been shown to modify center of pressure patterns [36] and as such may have confounded the association between dynamic foot function and falls. Although this will also have affected static foot posture measures, it is likely that footwear has a greater influence on dynamic function than static alignment. We were unable to assess these aspects in our current study.

### **Strengths and Limitations**

A major strength of this study is that the study participants are derived from the Framingham Study, a well-characterized cohort that contains large numbers of both men and women within a wide age range. We also used a validated foot examination to assess foot pain and foot pain severity along with measures of foot function and posture. A novel aspect of the current study is the consideration of foot function and posture as well as foot pain. However, a number of limitations need to be considered when interpreting the findings. We did not examine peripheral neuropathy or nociceptive versus neuropathic pain in our study. We also did not collect data on injurious falls. Thus, the study is limited by this lack of information on type of pain or injury from fall. Our study was cross-sectional and thus causal inferences cannot be ascribed. Prospective studies are needed to further evaluate the question. Also, the Framingham Study is primarily comprised of Caucasians and thus the results may not be generalizable to non-Caucasian groups. In addition, participants provided a reporting of falls in the past year either at the time of their foot exam or for <5%, within a year of the foot exam. Thus, for some participants, the falls data were ascertained at a different time point than their foot assessment. Falls were documented retrospectively, which may have limited accuracy due to the difficulties older people may have in recall over a 12 month period [37].

However, the rate of falls reported here is similar to large prospective studies that have found strong associations between past falls and subsequent falls [38,39]. Finally, severity of foot pain was self-reported and hence misclassification may have occurred.

Falls are often devastating events for older adults. More insights on these occurrences may lead to better interventions. In this study, foot pain was associated with increased odds of recurrent falls after controlling for possible confounders. Moderate foot pain and severe foot pain were even more strongly associated with recurrent falls. No significantly increased risk for falls were indicated between foot pain and occurrence of any fall or one fall in the past year. Further, recurrent falls were more likely in those with planus foot posture. The results indicate that foot pain and foot posture, may play a role in the occurrence of falls in older adults. Future work should examine the mechanisms by which foot pain affects risk of falls, as well as the potential of interventions to reduce foot pain and reduce the risk of falls in older adults.

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**Table 1**

Characteristics of study participants by occurrence of falls in the past year: none, single or recurrent falls.

	<b>Total Sample</b>	<b>No Falls</b>	<b>Single Falls</b>	<b>Recurrent Falls</b>
N (%)	1375	960 (69.8)	263 (19.1)	152 (11.1)
Age (years)	69.1 ± 10.9	68.4 ± 10.5	71.5 ± 12.0	69.1 ± 11.2
BMI (kg/m <sup>2</sup> )	28.3 ± 5.4	28.3 ± 5.2	28.1 ± 6.1	28.5 ± 5.3
% Female	56.5	55.4	66.1	47.4
No Pain (%)	1092 (79.4)	767 (70.2)	217 (19.9)	108 (9.9)
Mild Pain (%)	113 (8.2)	83 (73.5)	19 (16.8)	11 (9.7)
Moderate Pain (%)	134 (9.8)	88 (65.7)	24 (17.9)	22 (16.4)
Severe Pain (%)	36 (2.6)	22 (61.1)	3 (8.3)	11 (30.6)

Age and BMI presented as mean ± standard deviation; other characteristics presented as N (%)

**Table 2**

Odds ratios (ORs) and 95% confidence intervals (95% CIs) for the association between self-reported foot pain, foot pain severity, and falls, adjusting for age, BMI and cohort.

	<b>Any Falls</b>	<b>1 Fall</b>	<b>2+ Falls</b>
Foot Pain (Y/N)	1.08 (0.81, 1.44)	0.81 (0.56, 1.16)	1.62 (1.10, 2.39)
Severity			
No Foot Pain (referent)	1.0	1.0	1.0
Mild Foot Pain	0.87 (0.56, 1.35)	0.82 (0.49, 1.40)	0.95 (0.49, 1.84)
Moderate Foot Pain	1.19 (0.81, 1.75)	0.91 (0.56, 1.47)	1.78 (1.06, 2.99)
Severe Foot Pain	1.39 (0.70, 2.78)	0.42 (0.12, 1.43)	3.52 (1.65, 7.48)

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**Table 3**

Odds ratios and 95% confidence intervals for the association between foot posture, dynamic foot function and falls, adjusting for age, BMI and cohort.

	<b>Any Fall</b>	<b>1 Fall</b>	<b>2+ Falls</b>
Foot posture			
Normal (referent)	1.0	1.0	1.0
Cavus	0.93 (0.67, 1.28)	0.92 (0.63, 1.35)	0.95 (0.57, 1.58)
Planus	1.23 (0.89, 1.71)	0.99 (0.67, 1.46)	1.78 (1.10, 2.87)
Dynamic foot function			
Normal (referent)	1.0	1.0	1.0
Pronated	1.09 (0.78, 1.51)	1.28 (0.88, 1.87)	0.75 (0.44, 1.30)
Supinated	1.10 (0.81, 1.50)	1.01 (0.69, 1.47)	1.24 (0.79, 1.93)

Foot posture was derived from the Modified Arch Index, measured during quiet standing. Dynamic foot function was estimated from the Center of Pressure Excursion Index measured while walking at a self-selected pace.