Foot and Ankle Risk Factors for Falls in Older People: A Prospective Study

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Background. Foot problems are common in older people and are associated with impaired balance and functional ability. Few prospective studies, however, have been undertaken to determine whether foot problems are a risk factor for falls.

Methods. One hundred seventy-six people (56 men and 120 women, mean age 80.1, standard deviation 6.4 years) residing in a retirement village underwent tests of foot and ankle characteristics (including foot posture, range of motion, strength, and deformity) and physiological falls risk factors (including vision, sensation, strength, reaction time, and balance) and were followed for 12 months to determine the incidence of falls.

Results. Seventy-one participants (41%) reported falling during the follow-up period. Compared to those who did not fall, fallers exhibited decreased ankle flexibility, more severe hallux valgus deformity, decreased plantar tactile sensitivity, and decreased toe plantarflexor strength; they were also more likely to have disabling foot pain. Discriminant function analysis revealed that decreased toe plantarflexor strength and disabling foot pain were significantly and independently associated with falls after accounting for physiological falls risk factors and age.

Conclusions. Foot and ankle problems increase the risk of falls in older people. Interventions to address these factors may hold some promise as a falls prevention strategy.
Foot and Ankle Characteristics

Foot and ankle characteristics were tested across six domains: foot posture, foot ROM, foot deformity and lesions, foot strength, foot sensation, and foot pain. Foot posture was assessed using the foot posture index, arch index, and navicular height (17). Navicular height was corrected for differences in foot size by dividing it by the length of the foot. Ankle flexibility was measured in degrees using a modified version of the weight-bearing lunge test (18). First metatarsophalangeal joint (1st MPJ) ROM was measured in a non-weight-bearing position with a goniometer while the examiner maximally extended the hallux (19). The presence and severity of hallux valgus was determined using the Manchester scale (20). An overall measure of hallux valgus severity was determined by summing the scores for right and left feet. Presence of lesser digital deformity, corns, and calluses was determined (18), and a sum of the total number of each of these abnormalities for both feet was documented. The strength of the plantarflexor muscles of the hallux and lesser toes was determined using the paper grip test (21). Tactile sensitivity of the 1st MPJ was evaluated with an aesthesiometer using a two-alternative forced choice protocol (18). Foot pain was assessed using the case definition of the Manchester Foot Pain and Disability Index (MFPDI), which required participants to have current pain, to have pain lasting for at least 1 month, and to report at least one of the items on the MFPDI questionnaire (22). Reliability coefficients for each of the foot and ankle tests when administered to older people are as follows: foot posture index, 0.61; arch index, 0.99; navicular height, 0.64; ankle flexibility, 0.87; 1st MPJ ROM, 0.85; Manchester scale for hallux valgus, 0.77; paper grip test, 0.65; 1st MPJ tactile sensitivity, 0.70 (18).

Physiological Falls Risk

Participants’ falls risk was assessed using the Physiological Profile Assessment (PPA) (23). Based on performance in five physiological domains, the PPA computes a fall risk score (standardized score) for each individual; this measure has a 75% predictive accuracy for falls in older people (24,25). Falls risk scores below 0 indicate a low risk of falling, scores between 0 and 1 indicate a mild risk of falling, scores between 1 and 2 indicate a moderate risk of falling, and scores above 2 indicate a high risk of falling. The tests from the short form PPA assessment are described in Table 2.

Table 1. Self-Reported Prevalence of Major Medical Conditions, Medication Use, Participation in Physical Activity, and Mobility and Activities of Daily Living (ADL)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Number (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medical conditions</td>
<td></td>
</tr>
<tr>
<td>Heart condition</td>
<td>61 (34.7)</td>
</tr>
<tr>
<td>Poor vision</td>
<td>44 (25)</td>
</tr>
<tr>
<td>Stroke</td>
<td>9 (5.1)</td>
</tr>
<tr>
<td>Osteoarthritis</td>
<td>133 (75.6)</td>
</tr>
<tr>
<td>Diabetes</td>
<td>19 (10.8)</td>
</tr>
<tr>
<td>Incontinence</td>
<td>29 (16.5)</td>
</tr>
<tr>
<td>Medication use</td>
<td></td>
</tr>
<tr>
<td>Cardiovascular medications</td>
<td>124 (70.5)</td>
</tr>
<tr>
<td>Psychoactive medications</td>
<td>45 (25.6)</td>
</tr>
<tr>
<td>Musculoskeletal medications</td>
<td>28 (15.9)</td>
</tr>
<tr>
<td>&gt; 4 medications</td>
<td>115 (65.3)</td>
</tr>
<tr>
<td>Physical activity</td>
<td></td>
</tr>
<tr>
<td>Planned walks &lt; 1 d/wk</td>
<td>72 (40.9)</td>
</tr>
<tr>
<td>Incidental physical activity &lt; 1 h/d</td>
<td>34 (19)</td>
</tr>
<tr>
<td>Mobility and ADL limitations</td>
<td></td>
</tr>
<tr>
<td>Occasionally use a walking aid</td>
<td>44 (25)</td>
</tr>
<tr>
<td>Difficulty with housework</td>
<td>89 (50.6)</td>
</tr>
<tr>
<td>Difficulty shopping</td>
<td>36 (20.5)</td>
</tr>
<tr>
<td>Difficulty cooking</td>
<td>30 (17)</td>
</tr>
</tbody>
</table>

Foot problems and falls

Table 2. Physiological Profile Assessment (PPA) Short Form Assessment

<table>
<thead>
<tr>
<th>PPA Test</th>
<th>Description</th>
<th>Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Postural sway</td>
<td>Individuals were asked to stand as still as possible for 30 s on a 15 cm-thick medium-density foam rubber mat with eyes open, wearing the Lord swaymeter, a 40 cm-long rod with a vertically mounted pen at its end. The rod is attached to the participants by a firm belt and extends posteriorly. The pen records sway on a sheet of millimeter graph paper fastened to the top of an adjustable height table.</td>
<td>Total sway path (mm) determined from the path traced</td>
</tr>
<tr>
<td>Quadriceps strength</td>
<td>A simple strain gauge was used to assess dominant quadriceps (isometric) strength to the nearest 0.5 kg. Participants were seated with the hip and the knee joint at 90° of flexion.</td>
<td>Best of 3 trials (kg)</td>
</tr>
<tr>
<td>Hand reaction time</td>
<td>A light was used as the stimulus and depression of a switch by the finger as the response.</td>
<td>Average of 10 trials (ms)</td>
</tr>
<tr>
<td>Proprioception</td>
<td>Participants, seated with eyes closed, were asked to align the lower limbs on either side of a clear acrylic sheet (60 cm × 60 cm × 1 cm) standing on edge and inscribed with a protractor.</td>
<td>Difference (°) in matching the great toes</td>
</tr>
<tr>
<td>Edge contrast sensitivity</td>
<td>The Melbourne edge test was used to assess this aspect of visual function. This test presents 20 circular patterns containing edges with reducing contrast. Correct identification of the orientation of the edge on the patches provides a measure of contrast sensitivity in decibel units (dB), where dB = −10 log10 contrast.</td>
<td>Number of the last correctly identified circle (dB)</td>
</tr>
</tbody>
</table>
were assessed using independent samples physiological falls risk scores between fallers and nonfallers formed. Differences in foot and ankle characteristics and was excluded from the analysis. One participant died soon after commencement of the study month follow-up were included in the analysis as fallers. Participants who fell but did not complete the entire 12-month follow-up period. Fallers were significantly older than nonfallers (81.4 ± 6.4 vs 79.1 ± 6.3 years, \( t_{173} = -2.32, p = .022 \). There were no differences in the prevalence of major medical conditions between the two groups.

### Statistical Analysis

Variables with right-skewed distributions were log transformed. Differences in foot and ankle characteristics and physiological falls risk scores between fallers and nonfallers were assessed using independent samples \( t \) tests (for continuously scored variables), Mann–Whitney \( U \) tests (for nonparametric variables), or chi-square tests (for dichotomous variables). Variables found to significantly differ between nonfallers and fallers were then entered into two separate discriminant function analyses to determine their relative importance in discriminating between the two groups. The first analysis involved entering the foot and ankle variables in isolation using the enter method. The second analysis used the stepwise method, with foot and ankle variables, physiological risk factor scores, and age included. After deriving each discriminant function, cross-validation was carried out using the jackknife procedure. The data were analyzed using SPSS for Windows (SPSS, Inc., Chicago, IL).

### RESULTS

#### Falls

Of the 175 participants included in the follow-up analysis, 71 (41%) fell at least once during the 12-month follow-up period. Fallers were significantly older than nonfallers (81.4 ± 6.4 vs 79.1 ± 6.3 years, \( t_{173} = -2.32, p = .022 \). There were no differences in the prevalence of major medical conditions between the two groups.

#### Foot and Ankle Characteristics

Foot and ankle characteristics for nonfallers and fallers are shown in Table 3. There were no differences between the groups for any of the foot posture variables, 1st MPJ ROM, or the number of coms, calluses, or lesser toe deformities. However, fallers exhibited reduced ankle flexibility, more severe hallux valgus deformity, reduced tactile sensitivity, and were more likely to fail the paper grip test of the lesser toes and to have disabling foot pain than nonfallers.

#### Physiological Falls Risk

Physiological falls risk scores ranged from −1.47 to 5.17, indicating that participants’ levels of risk ranged from very low to very high. Fallers exhibited significantly higher physiological falls risk scores compared to nonfallers (1.23 ± 1.51 vs 0.67 ± 1.20; \( t_{173} = -2.70, p = .008 \).

#### Discriminant Function Analysis

The discriminant function analyses are presented in Table 4. The first discriminant model, in which only the foot and ankle variables were considered, revealed that
disabling foot pain, the paper grip test of the lesser toes, tactile sensitivity of the 1st MPJ, ankle flexibility, and hallux valgus severity were significantly and independently associated with falls. The second discriminant model, in which foot and ankle variables, physiological risk factor scores, and age were entered in a stepwise manner, revealed that only the paper grip test of the lesser toes and disabling foot pain were independently associated with falls. The classification accuracy of the two models was similar.

**DISCUSSION**

The aim of this study was to determine whether a series of tests of foot and ankle characteristics are associated with falls in older people. Compared to nonfallers, fallers exhibited reduced ankle flexibility, more severe hallux valgus deformity, and reduced plantar tactile sensitivity. Fallers were also more likely to have weak toe plantarflexor muscles, and had a higher prevalence of disabling foot pain. Interestingly, many of the foot and ankle variables found to differ between fallers and nonfallers were also found to be independent predictors of balance and functional ability in our cross-sectional analysis of the baseline data (7), which suggests that the increased risk associated with these characteristics is mediated by reduced balance and reduced ability to perform functional tasks. Two of these foot and ankle characteristics (toe plantarflexor weakness and disabling foot pain) remained significantly and independently associated with falls after including age and physiological falls risk in the discriminant function model.

The observation of reduced ankle flexibility in fallers is consistent with two previous retrospective studies (26,27). Reduced ankle dorsiflexion may increase risk of falling by impairing balance and the ability to perform functional tests integral to daily living. Mecagni and colleagues (15) found significant associations between ankle ROM and Performance-Oriented Mobility Assessment and functional reach scores. Similarly, our analysis of baseline data revealed ankle flexibility to be an independent predictor of postural sway, leaning balance, alternate stepping, sit to stand, and walking speed (7).

Hallux valgus was found to be more pronounced in fallers than in nonfallers. This finding is consistent with those of Koski and colleagues (13), who found that the presence of an undefined "bunion" was associated with a 2-fold increased risk of falls. We have previously shown that hallux valgus impairs balance (7) and that older people with moderate to severe hallux valgus demonstrate less rhythmic movements of the upper body when walking on uneven ground (28), which may contribute to falls. Similarly, reduced tactile sensation was evident in fallers, consistent with previous prospective studies (24,25) and investigations reporting associations between sensory loss and impaired balance (7,29).

An interesting finding was the higher prevalence of toe plantarflexor weakness in fallers. Although age-related reductions in toe plantarflexor strength have been previously reported (30), to our knowledge the association between toe weakness and falls is a novel finding. The toes appear to play an important role in stabilizing the body when the center of mass is displaced in both standing and walking; therefore, the reduced grasping ability of the toes may contribute to loss of balance and falls. In our analysis of the baseline data, we found reduced toe strength to be a significant independent predictor of balance tasks involving forward leaning, an alternate stepping test, and sit to stand (7).

The strengths of this study are the use of clearly defined, validated measures of foot and ankle characteristics and the inclusion of a well-established physiological falls risk score in the multivariate model. It is acknowledged, however, that the study has certain limitations. First, the participants were recruited from a retirement village, and the results may not be generalizable to a more active community-dwelling population. Indeed, the falling rate (41%) is considerably higher than the 30% rate commonly reported in community samples. Second, we used a simple faller versus nonfaller comparison as the study was not sufficiently powered to evaluate differences between once-only and multiple fallers, which may explain the relatively low classification accuracy of the discriminant function model.

These findings have implications for falls prevention, as the identified risk factors are potentially modifiable. Ankle flexibility may be increased with stretching (31), Tai Chi (32), and water exercise (33) programs. Similarly, preliminary evidence suggests that "grasping" exercises to strengthen the muscles of the toes results in improved standing balance in older people (34). Reduction in foot pain is associated with improved functional ability (35), and surgical realignment of hallux valgus deformity has been shown to normalize the loading patterns under the hallux (36), which may improve gait stability (28). Finally, there is emerging evidence that augmenting tactile sensory information from the sole of the foot by the use of insoles with raised projections improves responses to perturbation (37). The efficacy of each of these interventions in reducing falls warrants further investigation.

**Conclusion**

This study provides prospective evidence that foot and ankle characteristics—particularly reduced ankle flexibility, hallux valgus deformity, decreased tactile sensitivity, decreased toe plantarflexor strength, and foot pain—are important risk factors for falls in older people. Intervention strategies to address these modifiable risk factors may be beneficial in reducing falls.

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