INTRODUCTION

In community-dwelling elderly people, foot problems increase the risk of falling; hallux valgus and lesser toe deformities are reported to be related to falls. Aging is associated with significant changes in foot posture and strength. Several studies have demonstrated a relationship between toe flexor strength and toe deformities in elderly people. However, these studies included participants with conditions such as cerebrovascular disorders, heart disease, visual impairment, gait disturbance, and those taking multiple drugs. Therefore, factors other than foot problems may have been responsible for falls in these studies.

In some studies, the toe flexor strength was assessed using a pressure sensor or the paper grip test. Because of hallux valgus and deformity of the lesser toes, toe flexor strength is often significantly reduced in older people. Planar pressure during walking was found to be significantly lower in those with hallux valgus than in those without. A reduction in the foot’s contact area with the ground resulting from hallux deformity is considered to be the cause of reduced planar pressure. Furthermore, the toe flexor muscle moment exerted while standing on a force plate was found to decrease significantly with age. Consequently, we believe that foot morphology might influence decreases in toe flexor strength.

The most common method of measuring toe flexor strength is by using a portable strain gauge, as described in several studies. The cross-sectional areas of the plantar intrinsic and extrinsic muscles are important factors for determining toe flexor strength. Toe flexor strength also decreases significantly with age. Moreover, foot morphology is affected as the foot arch height changes with age and by lower medial longitudinal and lateral arches of feet with hallux valgus. However, the relationship between foot morphological changes and toe flexor strength has not been fully elucidated.

Keywords: elderly women; hallux valgus; lateral arch; medial longitudinal arch; toe flexor strength
phology and toe flexor strength in the elderly is unknown. Many studies have shown that hallux valgus and lesser toe deformities decrease toe flexor strength and increase the risk of falling in elderly people.\textsuperscript{1,3,17} However, the relationships between hallux valgus and falls and between foot morphology, including hallux valgus, and the toe flexor strength in active elderly individuals are unclear. The purpose of this study was to investigate the relationship between hallux valgus and falls and toe flexor strength in community-dwelling elderly people who were relatively healthy and able to function independently. We also aimed to determine the association between foot morphology and toe flexor strength.

METHODS

Study Design

This cross-sectional study was approved by the Ethics Committee of Fukushima Medical University (approval number 30068). The study was conducted from January to March 2019.

Participants

We recruited participants aged 60 years or more among women who participated in physical activities every 2 weeks at a local meeting place in a nearby community center. All study participants were women. The purpose of the study was explained on paper, and informed consent was obtained from all individual participants included in the study. We excluded those with stroke, neuromuscular disease, hallux valgus after operation, and plantar sensory disorders that affect toe flexor strength. Finally, 70 women were included in the study (age: 79.2±5.6 years, height: 150.6±6.1 cm, weight: 52.6±8.9 kg, body mass index [BMI]: 23.1±3.4 kg/m\textsuperscript{2}). We checked the participants’ age, height, weight, self-declared medical conditions, whether they had had a fall during the past year, and toe pain at the local meeting place where they participated in regular physical activities. Physical therapists also measured the toe flexor strength and foot morphology. Moreover, foot problems, such as ingrown nails, were checked.

Toe Flexor Strength

The toe flexor strength was measured using a Toe-Grip Dynamometer II (T.K.K. 3364b; Takei Scientific Instruments, Niigata, Japan), which is a reliable instrument for toe flexor strength measurement.\textsuperscript{18} The participants were seated with their hip and knee joints at 90°. Before the measurement, we asked the participants to hold the measuring bar of the device using all their toes as firmly as possible and to adjust the foot to a position that was easy to maintain. Furthermore, the ankle joint was fixed with a belt to suppress ankle joint plantar flexion and dorsiflexion. The maximum isometric strength was measured three times for each foot, and the maximum value was taken as the representative value of each. The measured toe flexor strength values were normalized using the subject’s body weight (kg/bw).

Foot Morphology

The participants stood with their feet apart at shoulder width and with their body weight evenly distributed. The outline of each foot was traced with a ballpoint pen. The hallux valgus angle was measured as the angle between the line connecting the first metatarsal head and the first phalanx head and the line connecting the first metatarsal head and the calcaneus on the outline contour.\textsuperscript{19} To obtain the foot outlines, we followed the recommendation of Shimizu et al\textsuperscript{19} and placed one foot in the forward position at a distance of 45% of the individual’s height, while the other foot was remained in the normal standing position. The diagnostic criterion for hallux valgus, as stated in the Japanese Orthopaedic Association’s clinical practice guidelines on the management of hallux valgus is an angle ≥20° determined using radiography. A hallux valgus angle of 20° determined using radiography is equivalent to a first phalangeal angle of 16°, as measured on the foot outline.\textsuperscript{19} The hallux valgus angle, as obtained using this measurement, was reported to have a significant correlation with the value of the hallux valgus angle obtained using radiography, with a correlation coefficient of 0.94.\textsuperscript{19} However, it was assumed that standing with one leg forward at a distance equal to 45% of their height could be an unstable posture for elderly people. Therefore, in this study, we measured with both the subjects’ feet in the neutral position.

The arch height ratio was measured as the medial longitudinal arch, and the spread ratio was measured as the lateral arch. The arch height ratio was obtained by measuring the height of the most protruding part of the navicular bone from the floor surface with a rectangular ruler to determine the ratio to the foot length. The participants stood with their feet a shoulder width apart and their weight evenly distributed. The height of the navicular bone on both sides was measured from the floor surface.

Arch height ratio (mm/mm)=navicular bone height (mm)/foot length (mm)×100.

The spread ratio was determined using the foot outline and by dividing the foot width (the line connecting the first
and fifth metatarsal heads) by the foot length. The spread ratio obtained using this measurement was reported to be significantly correlated with the angle between the first and fifth metatarsal bones, obtained using radiography, with a correlation coefficient of 0.75.\(^{20}\)

Spread ratio (mm/mm) = foot width (mm) / foot length (mm) × 100.

**Statistical Analysis**

Hallux valgus is diagnosed when the hallux angle on the foot outline is ≥16°. Based on this criterion, the women (n=70) were classified into two groups: those with both hallux valgus angles <16° and those with at least one hallux valgus angle ≥16°. Mann-Whitney U-tests and chi-square tests were used to compare age, height, weight, BMI, the presence or absence of a fall in the previous year, and the presence or absence of toe pain or ingrown nails. The Mann-Whitney U-test was used to compare the toe flexor strength, arch height ratio, and spread ratio between feet with a hallux valgus angle <16° and ≥16° for the 140 feet analyzed. Furthermore, Spearman’s correlation coefficient was calculated to assess the correlation. For statistical processing, SPSS for Windows version 25.0 (IBM Corporation, Armonk, NY, USA) was used, and the significance level was set at 5%.

### RESULTS

#### Falls and Toe Pain in Subjects with and without Hallux Valgus

The comparisons of falls and toe pain in participants with and without hallux valgus are shown in Table 1. Hallux valgus angles <16° for both feet were seen in 31 (44.3%) participants, and hallux valgus angles ≥16° in at least one foot were seen in 39 (55.7%) participants. Participants with hallux valgus had a significantly lower body weight and BMI (P=0.036, β=0.426 and P=0.048, β=0.520, respectively). There was no significant difference in the number of people who had experienced a fall during the previous year: 4 (12.9%) without hallux valgus and 6 (15.4%) with hallux valgus. The number of participants with toe pain or ingrown nails was not significantly different between the two groups. In addition, the four participants with toe pain and a hallux valgus angle of ≥16° did not experience falls during the previous year.

#### Toe Flexor strength and foot morphology according to the hallux valgus angle

The hallux valgus angle was <16° in 86 feet and ≥16° in 54 feet. Because of a toe chilblain, the toe flexor strength of one foot could not be measured. The toe flexor strength was not different between feet with and without hallux valgus. Feet with a hallux valgus angle ≥16° had a significantly lower arch height ratio (P<0.01, β=0.173) and a significantly higher spread ratio (P<0.001, β<0.001) (Table 2).

Although there was no correlation between toe flexor strength and foot morphology, a correlation was noted between the hallux valgus angle and the arch height (r=−0.228, P<0.01, β=0.222) and the spread ratio (r=0.494, P<0.001, β<0.001) (Table 3).

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**Table 1. Falls and toe pain in participants with and without hallux valgus**

<table>
<thead>
<tr>
<th></th>
<th>HV angle &lt;16° both feet (n=31)</th>
<th>HV angle ≥16° at least one foot (n=39)</th>
<th>P-value</th>
<th>Effect size β</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>79.0±6.5</td>
<td>79.3±4.9</td>
<td>0.758</td>
<td>0.043</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>151.4±6.1</td>
<td>150.0±6.1</td>
<td>0.845</td>
<td>0.226</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>55.2±8.9</td>
<td>50.5±8.4</td>
<td>0.036</td>
<td>0.537</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>24.0±3.1</td>
<td>22.5±3.5</td>
<td>0.048</td>
<td>0.477</td>
</tr>
<tr>
<td>Fall Presence/absence</td>
<td>4/27</td>
<td>6/33</td>
<td>0.768</td>
<td>0.033</td>
</tr>
<tr>
<td>Toe pain or (ingrown nail) Presence/absence</td>
<td>0 (4)/27*</td>
<td>4 (1)/34*</td>
<td>0.992</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Data for age, height, body weight, and BMI are presented as mean±standard deviation. Data on falls and toe pain are presented as the number of participants.

HV, hallux valgus.

*Toe pain (only ingrown nail).*
DISCUSSION

We examined the relationship between falls and toe flexor strength/foot morphology in community-dwelling elderly women who could walk outdoors without aids. Those with hallux valgus had significantly lower body weights and BMIs. No significant difference was seen in the fall incidence and toe pain/ingrown nail between participants with and without hallux valgus in at least one foot. Moreover, although there was no correlation between the hallux valgus angle and toe flexor strength, significant correlations were found between the hallux valgus angle and both the arch height ratio and the spread ratio.

Foot deformities, including bunions, are reported to increase the risk of falling.1–4) These studies identified the relationship between lower toe flexor strength with toe deformities and the risk of falling. However, these studies included individuals who needed walking aids, those with low activity levels, and those with limited mobility and activities of daily living in whom falls may have resulted from other factors. Therefore, in this study, we included only those who could walk outdoors without walking aids and measured their comprehensive toe flexor strength.

The participants of this study had a mean age of 79.2±5.6 years. The toe flexor strength was 16.9±5.7 (kg/bw) in feet with a hallux angle <16° and 16.5±6.0 (kg/bw) in feet with a hallux angle ≥16°. These values were slightly higher than the average value of 14.6 (kg/bw) for women in their 70s.11) It was concluded that the toe flexor strength is maintained in elderly women who do not need any assistance during outdoor walking, even in the presence of hallux valgus; moreover, the presence or absence of hallux valgus may be less related to falling in this population. Furthermore, it was reported that falls in the elderly are caused by foot pain rather than hallux valgus and lesser toe deformities.20) Foot pain from plantar fasciitis or callus increases the risk of falls in healthy older people.21) A meta-analysis indicated that individuals who experienced falls were more likely to have foot pain.17,22) However, in our study, participants with toe pain and hallux valgus did not experience falls, which differs from the results of previous studies. It is possible that this was because the participants in the current study could walk independently; even if they did have toe pain, it was likely not to the degree that could affect their daily activities.

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The toe flexor strength of feet with hallux valgus was slightly lower than that of feet without hallux valgus, but the difference was not significant. This was the same as the result of a study that included only young women.23) The superficial tendon fibers extend to the medial and plantar sides of the base of the proximal phalanx; therefore, the abductor hallucis muscle performs not only abduction but also plantar flexion of the first metatarsophalangeal joint.24) Moreover, the motor-unit potential amplitude of flexion of the abductor hallucis muscle performs not only abduction but also plantar flexion of the first metatarsophalangeal joint.24) Therefore, the action of the flexor involved in toe flexor strength may not be significantly different between persons with and without hallux valgus.

Participants with hallux valgus had significantly lower body weight and BMI in our study, although the mean BMI of 23.1±3.4 kg/m² was within the normal range. Some studies
report high BMIs for patients with hallux valgus,\textsuperscript{26} whereas others report low BMIs.\textsuperscript{27,28} In the studies by Nguyen et al.\textsuperscript{27} and Nishimura et al.,\textsuperscript{28} the participants were in their late 70s, and similar to that observed in the current study, the subjects with hallux valgus had a low mean BMI. The differences in these findings may result from differences in the age, race, and soft tissue thickness of the participants.

Although we found no correlation between toe flexor strength and foot morphology, the medial longitudinal and lateral arches had sunk as the hallux valgus angle increased. In young women, a very slight correlation between toe flexor strength and arch height ratio was recognized, and it is believed that improvement of the toe flexor strength can help prevent medial longitudinal arch decrease.\textsuperscript{23,29} However, it was also reported that toe flexor strength is affected by foot flexibility, arch height ratio, and body weight.\textsuperscript{30} Based on these findings, it is presumed that elderly people who have reduced medial longitudinal and lateral arches, hallux valgus, and decreased mobility of the sole have difficulty exerting force. However, this may not be related to the toe flexor strength because of differences in foot morphology. In this study, the larger the hallux valgus angle was, the lower were the medial longitudinal and lateral arches, which affected the shape of the sole. Hypermobility of the first ray\textsuperscript{16} with plantar flexion of the talus and the sinking of the navicular\textsuperscript{16} have been seen on the radiographs of feet with hallux valgus. Similarly, in this study, the relationship between hallux valgus and the arch of the foot was clarified.

The current study has several limitations. First, the evaluation of the foot morphology of healthy community-dwelling elderly women was limited to the method that uses foot outlines. The results may differ from those obtained using radiography. We classified into two groups participants with both hallux valgus angles <16° and those with at least one hallux angle ≥16° measured using foot outlines; however, the standing posture used for the foot outline method in the current study might have influenced the measurement of the hallux valgus angle. Second, in elderly women who can walk independently outdoors, the presence or absence of hallux valgus did not affect their 1-year fall incidence. However, it was necessary to evaluate standing balance based on the presence or absence of hallux valgus. Third, this study did not find any relationship between hallux valgus and the incidence of falls. Among the 70 participants, only 10 experienced falls, and this low number may be insufficient to positively indicate the proposed relationship between hallux valgus and falls. The relationships between foot morphology and falls should be further investigated with larger samples. Nevertheless, the lack of correlation between foot morphology and toe flexor strength may support this study’s conclusion, that foot morphology (e.g., hallux valgus) does not affect the fall rate.

**CONCLUSION**

In the current study, the presence or absence of hallux valgus did not affect the incidence of falls in community-dwelling elderly women who could independently walk outdoors without aids. The absence of correlation between toe flexor strength and foot morphology may support this conclusion.

**CONFLICTS OF INTEREST**

The authors declare that there are no conflicts of interests.

**REFERENCES**


