Abstract. [Purpose] The purpose was to clarify the relationship between foot morphology and toe muscle strength in female university students. [Participants and Methods] Data from 103 female university students (age, 20.4 ± 1.6 years) on height, body weight, pain in the foot and toes, heel height (cm) of shoes worn in everyday life, and the number of times (per week) shoes with heels ≥3 cm were worn were collected. The hallux valgus angle and medial longitudinal arch height ratio of the foot were measured, and toe muscle strength was evaluated according to the strength of the toe flexor and abductor hallucis muscles. [Results] Arch height ratio was significantly lower with hallux valgus angle ≥16°. In the 206 feet, a very weak negative correlation was found between hallux valgus angle and arch height ratio. In 150 feet with hallux valgus angle <16°, a very weak correlation was found between toe flexor strength and arch height ratio. [Conclusion] Body mass index was within the normal range, and the period of wearing high-heeled shoes was short; these factors have no effect on hallux valgus angle. Hallux valgus may be prevented by increasing toe flexor strength to prevent downward movement of the navicular and first cuneiform bones.

Key words: Hallux valgus, Arch height rate, Toe flexor strength

INTRODUCTION

In elderly people, falling frequently leads to deterioration of quality of life and prevention is crucial. Hallux valgus (HV) and lesser toe deformities in elderly people are reported to lower the toe grip force and increase the risk of falls1, 2). In a survey of 403 Japanese people aged ≥65 years, the prevalence of HV was 22.8% and was higher in females compared with males3). A survey of 6,000 females aged 40–79 years showed that HV increased significantly between the ages of 40 and 50 years, and at age 40, around 10% of females had an HV angle of ≥20 degrees4). It is presumed that females may already have signs of HV before the age of 40 years, and it is necessary to prevent deformation to cope with changes in physical function with age and living conditions.

Factors affecting HV include length of the first metatarsal5), stiffness of the foot medial longitudinal arch6, 7), and body mass index (BMI)8, 9). In particular, 71.3% of Japanese people have an Egyptian-type toe shape, where the first toe is longer than the second10). Compared with males, in females, the medial longitudinal arch is often deformed due to reduced stiffness6, 7) and high BMI9), and consequently leads to HV. In addition, there is an increased prevalence of HV in females due to external factors such as wearing high-heeled shoes. Therefore, more factors tend to affect the development of HV in females.

In this way, HV that increases the risk of falling in elderly people occurs more frequently in females after middle age. From the viewpoint of future prevention, we examined the morphology and toe muscle strength of young females, the relationship between use of high heel shoes, toe muscle strength, and deformity of the hallux.
PARTICIPANTS AND METHODS

Participants were excluded if they were being treated for orthopedic diseases of the lower limbs. We explained the purpose of this investigation verbally and in writing, and obtained consent from the participants. Participants were 103 female university students (age, 20.4 ± 1.6 years; height, 157.9 ± 5.3 cm; weight, 51.6 ± 6.8 kg; BMI, 20.7 ± 2.7 kg/m²). A total of 206 feet were measured. The ethics committee of Fukushima Medical University approved this study (approval number 30160).

The HV angle was measured using a foot printer, and it was classified into two groups of divergent aspiration angle ≥16 degrees and <16 degrees. We examined the two groups for BMI, pain in the foot and toes, heel height (cm) of shoes worn in everyday life, and the number of times (per week) shoes with heels ≥3 cm were worn and compared the arch height and foot toe strength of the feet.

To assess foot morphology, the HV angle and the medial longitudinal arch height ratio of the foot were measured. HV angle was measured using a foot printer (Bauerfeind, Germany) to model the contour of the foot. An outline of each foot was drawn with the participant in the standing position with both feet apart to shoulder width and the weight evenly balanced in both feet. The HV 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 (11). Using this method, the HV angle was previously reported to be highly correlated (r=0.94) with the HV angle measured by X-ray photography (11).

To determine the medial longitudinal arch height ratio, the height of the most projecting part of the navicular bone from the floor surface was measured using a right-angle ruler, and the ratio to the foot length was obtained. Posture was measured with the foot to be measured placed one step behind, with the weight placed on the back foot. The heights of the navicular bone on the right and left sides from the floor were measured, and the ratios to the lengths of the left and right measured from the footprint were calculated as follows:

Arch height ratio (mm/mm)=height of the navicular (mm)/foot length (mm) × 100

Toe muscle strength was assessed as the strength of the toe flexor and the abductor hallucis muscle. A toe grip dynamometer (T.K.K. 3365b, Takei Scientific Instruments Co., Ltd. Japan) was used to measure toe flexor strength. The participants were placed in a sitting position, with the hip and knee joints bent at 90 degrees. Prior to the measurement, the grip bar of the toe grip dynamometer was grasped using all the toes and adjusted to a position where it was easy to grip. Furthermore, the ankle joint was fixed using a belt to suppress dorsiflexion/plantarflexion and inversion/eversion of the ankle joint.

A hand-held dynamometer (µTas F-1, Anima Co., Ltd., Japan) was used to measure abductor hallucis muscle strength. Similar to the toe gripping force measurement, participants were in a chair sitting position with the hip and knee joints bent at 90 degrees. The maximum isometric muscle force while abducting the hallux was measured. In addition, the measurement was designed not to involve flexion or extension of the hallux, and inversion of the ankle joint. Muscle strength was measured three times on the right and left feet, and the maximum value obtained was divided by the body weight for analysis.

Statistical analysis was performed as follows. Using the footprint, HV was classed as an HV angle of ≥16 degrees (11). Based on this criteria, we classified 103 participants into two groups; hemilateral foot or bilateral feet with an HV angle of ≥16 degrees (n=33) and bilateral feet with an HV angle of <16 degrees (n=70). Height and weight were compared between the two groups using the Mann-Whitney U-test. BMI, foot or toe pain, shoe heel height, and frequency of wearing high-heeled shoes were compared between the two groups using χ² test. Of the 206 feet, 56 feet had an HV angle ≥16° and 150 feet had an HV angle <16°. The Mann-Whitney U-test was used to compare the arch height ratio, toe flexor strength, and abductor hallucis muscle strength between the two groups. To clarify the correlation, Spearman’s correlation coefficient was obtained. SPSS for Windows (Version 25.0; IBM, USA) was used to perform statistical analyses. The significance level was set to less than 5%.

RESULTS

Table 1 shows height, weight, BMI, foot or toe pain, shoe heel height, and frequency of wearing high-heeled shows of the participants. Pain in the foot or toe was reported by 18.2% with an HV angle ≥16° and 2.9% with an HV angle <16°, indicating a significant difference (p<0.05). There was no significant difference between height, weight, BMI, shoe heel height, and frequency of wearing with high-heeled shoes between HV angles ≥16° and <16°.

Table 2 shows the arch height ratio, toe flexor strength, and abductor hallucis muscle strength at HV angles ≥16° and <16°. Arch height ratio was significantly lower with an HV angle ≥16° (p<0.05).

Table 3 shows the correlation coefficients between HV angle and arch height ratio and toe muscle strength. In the 206 feet, there was a very weak negative correlation found between HV angle and arch height ratio and abductor hallucis muscle strength (r=−0.15, p<0.05; r=−0.14, p<0.05, respectively). In 150 feet with an HV angle <16°, toe flexor strength showed a very weak correlation with arch height ratio and abductor hallucis muscle strength (r=0.16, p<0.05; r=0.30, p<0.01, respectively). However, no correlation was found between these factors in 56 feet with an HV angle ≥16°.
### Table 1. Comparison of height, weight, BMI, toe pain, and shoe type according to HV angle

| HV angle          | <16° (n=70) | ≥16° (n=33) | p-value |
|-------------------|-------------|-------------|---------|
| Height (cm, mean ± SD) | 157.3 ± 5.3 | 159.1 ± 5.3 | 0.10    |
| Weight (kg, mean ± SD) | 51.8 ± 7.4 | 51.2 ± 5.1 | 0.99    |
| BMI: |
| <18.5 (no) | 14 | 6 | 0.36    |
| 18.5 to <25 (no) | 50 | 27 |         |
| 25 to <30 (no) | 5 | 0 |         |
| ≥30 (no) | 1 | 0 |         |
| Foot or toe pain: |
| Present (no) | 2 | 6 | 0.01    |
| Absent (no) | 68 | 27 |         |
| Heel height: |
| <3 (cm, no) | 26 | 12 | 0.90    |
| 3 to <5 (cm, no) | 15 | 6 |         |
| ≥5 (cm, no) | 29 | 15 |         |
| Frequency of wearing high heels (>3 cm): |
| Never (no) | 23 | 11 | 0.70    |
| 1–3 (times/week, no) | 20 | 7 |         |
| 4–7 (times/week, no) | 27 | 15 |         |

### Table 2. Comparison of foot morphology and toe muscle strength according to HV angle

| HV angle          | <16° (n=150) | ≥16° (n=56) | p-value |
|-------------------|-------------|-------------|---------|
| HV angle (degrees) | 10.9 ± 2.6 | 19.6 ± 4.7 | <0.001  |
| Arch height rate (mm/mm) | 11.0 (9.0–13.0) | 18.0 (16.0–20.8) | 0.03    |
| Toe flexor strength (kgf/kg) | 19.4 (17.8–20.7) | 18.5 (16.1–20.1) | 0.39    |
| Abductor hallucis strength (kgf/kg) | 37.1 ± 10.2 | 36.1 ± 10.2 | 0.17    |

Mean ± standard deviation. Median (25th–75th percentile).

### Table 3. Correlation coefficient of foot morphology and toe muscle strength

#### Total feet (n=206 feet)

|           | Arch height rate (mm/mm) | Toe flexor strength (kgf/kg) | Abductor hallucis strength (kgf/kg) |
|-----------|--------------------------|------------------------------|------------------------------------|
| HV angle  | −0.15*                   | −0.07                        | −0.14*                             |
| Arch height rate (mm/mm) | 0.15*                     | 0.02                         |
| Toe flexor strength (kgf/kg) | 0.25**                   |

#### HV angle <16° (n=150 feet)

|           | Arch height rate (mm/mm) | Toe flexor strength (kgf/kg) | Abductor hallucis strength (kgf/kg) |
|-----------|--------------------------|------------------------------|------------------------------------|
| HV angle  | −0.07                    | −0.05                        | −0.12                              |
| Arch height rate (mm/mm) | 0.16*                     | −0.02                         |
| Toe flexor strength (kgf/kg) | 0.30**                   |

#### HV angle ≥16° (n=56 feet)

|           | Arch height rate (mm/mm) | Toe flexor strength (kgf/kg) | Abductor hallucis strength (kgf/kg) |
|-----------|--------------------------|------------------------------|------------------------------------|
| HV angle  | −0.01                    | 0.09                         | −0.01                              |
| Arch height rate (mm/mm) | 0.04                      | −0.09                         |
| Toe flexor strength (kgf/kg) | 0.17                      |

*p<0.05, **p<0.01.
DISCUSSION

The present study examined factors affecting the HV angle in female university students. There were no significant differences between BMI, shoe heel height, and frequency of wearing high-heeled shoes between HV angles ≥16° and <16°.

Okuda et al.12) investigated the relationship between HV angle and BMI in female university students, but found no correlation. They studied female university students with an average BMI of 20.6 kg/m², all of whom were in the normal range. In our study, the average BMI was 20.7 kg/m² and 97 (94.2%) participants had a BMI of <25 kg/m². Okuda et al.12) suggested that BMI is unlikely to affect HV angle in young females with a BMI in the normal range. On the other hand, in a study of participants >40 years old, females with HV had a high BMI9,10,13). Furthermore, one study showed that 67% of females aged ≥70 years had a BMI ≥25 kg/m²13). In females, aging is associated with an increase in body fat, decrease in muscle volume, and increase in degree of obesity14). Consequently, BMI continues to increase, and the relationship between HV and BMI becomes significant at age ≥40 years.

Nguyen et al.13) reported that the incidence of HV was higher in older females who wore high-heeled shoes almost every day between the ages of 20 and 64 years compared with those who did not wear high heels. Wearing high-heeled shoes increases the impact and load on the forefoot15) and is often accompanied by discomfort and pain. On the other hand, Bac et al.16) reported that there was no relationship between shoe type and HV angle in a survey of university students. This survey also showed no significant difference in shoe heel height and frequency of wearing high heels. In other words, it is thought that it would take a long time of wearing high shoes to have an impact.

Based on the above, it is apparent that both the period of young age in which BMI is in the normal range and the period of wearing high-heeled shoes are short; therefore, the influence on HV is small. For future prevention of HV, attention must be paid to increases in BMI accompanied by aging, as well as wearing high-heeled shoes for many years. This can be observed as aging directly or by retrospectively assessing younger years in middle-aged and elderly people.

Assessment of foot morphology and toe muscle strength in female university students revealed that the arch height ratio was significantly lower with an HV angle ≥16°. Furthermore, the arch height ratio showed a very weak correlation with toe flexor strength.

The medial longitudinal arch is composed of the calcaneus, talus, navicular, first cuneiform, and first metatarsal bones. A study by Komeda et al.17) into the position of these bones at the time of loading using X-ray photography in the standing position showed that the navicular bones moved downward in HV. In our study, as the arch height ratio, the height of the navicular bone at the time of loading in the standing position was measured on the body surface.

As the navicular bone declines downwards, the first cuneiform bone also decreases downward so as to become linked to it, and the first metatarsal bone varus and the proximal phalanx of the hallux are involved. However, the results from our study were unable to clarify whether the decrease in the arch height ratio was the cause of the onset of HV or the result of deformation.

Nagano et al.18) showed a correlation between arch height ratio, toe flexor strength, and tibialis posterior muscle strength in females. Toe flexor strength was measured by pulling the bar connected to the dynamometer using the toes. Therefore, to flex the toes, the flexor hallucis longus/brevis muscle and flexor digitorum longus/brevis muscles act directly. Furthermore, the tibialis anterior and tibialis posterior muscles adhering to the bone that constitutes the medial longitudinal arch act to increase the arch, and as a result, it is possible that the bars are drawn even further. In this study, a very weak correlation was obtained between arch height ratio and toe flexor strength. Our results confirmed a similar tendency to the results reported by Nagano et al18). On the other hand, while Uritani et al.19) reported reliability as the cause of the very weak correlation, other factors include: (1) toe length, which determines whether or not the participant is able to grasp the bar for measurement with five toes, (2) those with long toes were able to lift the bars by bending the toes and the bar could not be drawn horizontally, and (3) muscles that act adjunctively, such as the tibialis anterior and tibialis posterior muscles, were thought to be influential. However, one of the mechanisms involved in the occurrence of HV is downward movement of the navicular bone and the first cuneiform bone, the first metatarsal bone varus and the proximal phalanx hallux, as well as the medial longitudinal arch; therefore, it may also be helpful to increase toe flexor strength and prevent downward movement of the navicular bone and the first cuneiform bone.

The present study has some limitations. First, minimally invasive measurements such as measurement of the HV angle using a footprint and measurement of the navicular height from the body surface were performed. The results of these measurements may differ compared with direct measurement using X-ray imaging. Second, family history of the participants was not recorded for all participants, we had to examine the influence of family history in HV cases from a young age. Third, as the accuracy of the muscle force measurement may have not been optimum, it is difficult to measure only limited muscle force when measuring the maximum muscular strength of a young healthy person, and it is possible that complex muscular strength was measured. Fourth, while relationships were identified between various factors, causality was not clear. Therefore, future studies to clarify causal relationships are necessary.

From this study result, it seems that increasing the toe flexor strength may be useful in young females to prevent downward movement of the navicular bone and the first cuneiform bone in order to prevent HV that increases the onset of HV in females after middle age.
Funding and Conflict of interest

None.

REFERENCES

1) Mickle KJ, Munro BJ, Lord SR, et al.: ISB Clinical Biomechanics Award 2009: toe weakness and deformity increase the risk of falls in older people. Clin Biomech (Bristol, Avon), 2009, 24: 787–791. [Medline] [CrossRef]

2) Menz HB, Morris ME, Lord SR: Foot and ankle risk factors for falls in older people: a prospective study. J Gerontol A Biol Sci Med Sci, 2006, 61: 866–870. [Medline] [CrossRef]

3) Nishimura A, Fukuda A, Nakazora S, et al.: Prevalence of hallux valgus and risk factors among Japanese community dwellers. J Orthop Sci, 2014, 19: 257–262. [Medline] [CrossRef]

4) Sako S, Sugiuira H, Enishi K, et al.: Gender difference in first phalangeal angle after age 40. Kutsuigaku, 2011, 25: 150–154.

5) Munuera PV, Polo J, Rebollo J: Length of the first metatarsal and hallux in hallux valgus in the initial stage. Int Orthop, 2008, 32: 489–495. [Medline] [CrossRef]

6) Zifchock RA, Davis I, Hillstrom H, et al.: The effect of gender, age, and lateral dominance on arch height and arch stiffness. Foot Ankle Int, 2006, 27: 367–372. [Medline] [CrossRef]

7) Fukano M, Fukuyabashi T: Gender-based differences in the functional deformation of the foot longitudinal arch. Foot, 2012, 22: 6–9. [Medline] [CrossRef]

8) Menz HB, Iarr EL, Brown WJ: Predictors and persistence of foot problems in women aged 70 years and over: a prospective study. Maturitas, 2011, 68: 83–87. [Medline] [CrossRef]

9) Cho NH, Kim S, Kwon DJ, et al.: The prevalence of hallux valgus and its association with foot pain and function in a rural Korean community. J Bone Joint Surg Br, 2009, 91: 494–498. [Medline] [CrossRef]

10) Tanaka Y, Takakura Y, Takaoka T, et al.: A radiological study of the alignment of the normal toes. Cent Jpn J Orthop Traumat, 1992, 35: 801–802.

11) Shimizu S, Maeda T, Kato Y, et al.: Effective evaluation of hallux valgus angle and digitus quintus varus angle for footprint. J Jpn Soc Surg Foot, 2010, 31: 35–39.

12) Okuda H, Juman S, Ueda A, et al.: Factors related to prevalence of hallux valgus in female university students: a cross-sectional study. J Epidemiol, 2014, 24: 200–208. [Medline] [CrossRef]

13) Nguyen US, Hillstrom HI, Li W, et al.: Factors associated with hallux valgus in a population-based study of older women and men: the MOBILIZE Boston Study. Osteoarthritis Cartilage, 2010, 18: 41–46. [Medline] [CrossRef]

14) Morita Y, Iwamoto I, Mizuma N, et al.: Precedence of the shift of body-fat distribution over the change in body composition after menopause. J Obstet Gynecol Res, 2006, 32: 513–516. [Medline] [CrossRef]

15) Yung-Hui L, Wei-Hsien H: Effects of shoe inserts and heel height on foot pressure, impact force, and perceived comfort during walking. Appl Ergon, 2005, 36: 355–362. [Medline] [CrossRef]

16) Bac A, Bogacz G, Ogrodzka-Ciechanowicz K, et al.: Characteristics of selected anthropometric foot indicators in physically active students. J Am Podiatr Med Assoc, 2018, 108: 236–244. [Medline] [CrossRef]

17) Komeda T, Tanaka Y, Takakura Y, et al.: Evaluation of the longitudinal arch of the foot with hallux valgus using a newly developed two-dimensional coordinate system. J Orthop Sci, 2001, 6: 110–118. [Medline] [CrossRef]

18) Nagano K, Okuyama R, Taniguchi N, et al.: Gender difference in factors affecting the medial longitudinal arch height of the foot in healthy young adults. J Phys Ther Sci, 2018, 30: 675–679. [Medline] [CrossRef]

19) Uritani D, Fukumoto T, Matsumoto D: Intrarater and interrater reliabilities for a toe grip dynamometer. J Phys Ther Sci, 2012, 24: 639–643. [CrossRef]