Influence of Medial Longitudinal Arch Deformation on Body Characteristics, Muscle Strength, Locomotive Function in the Community-Dwelling Elderly: A cross-section study

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Research

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Abstract

Background:

Foot deformity can cause walking difficulty and posture problems in all age groups and lead to even more serious health problems in the elderly. This cross-sectional study aimed to investigate the effects of foot arch deformation on physical characteristics, muscular strength, and motor function in the community-dwelling elderly. We also assessed the reliability of the foot measurement method used in this study.

Methods:

Overall, 204 community-dwelling elderly participants, of whom 159 were women, aged 65 to 90 years old, were included in this study. This study measured and analyzed the feet arch height ratio (AHR, dorsal height/truncated foot length). Participants were classified based on the AHR values above, below, or within 1.5 SD into the High-Arched Group (HAG), Low-Arched Group (LAG), or Normal-Arched Group (NAG), respectively. Furthermore, the reliability of the foot arch measurement method was examined in 17 university students. The survey items compared body characteristics (age, height, weight, body mass index (BMI), and skeletal mass index), muscle strength (handgrip strength and foot intrinsic strength), and locomotive function (two-step value and gait speed) among the three groups based on AHR. The foot measurements and sex differences were measured using the Mann-Whitney test. The associations among the three groups were analyzed using the Kruskal-Wallis test.

Results:

There were significant differences in BMI and walking speed among the three groups categorized according to AHR. The HAG had the highest BMI and the lowest walking speed among all groups. The foot measurements demonstrated high or moderate reliability.

Conclusions:

The decreased walking speed of elderly people was found to be associated with high-arched feet. Additionally, the BMI could be associated with high-arched feet. Longitudinal studies are needed to confirm whether obesity increases the incidence of high-arched feet.

1. Background

The foot has arch structures and plays a functional role in stabilizing walking and posture. Elderly people have a large number of foot problems, especially deformity, neuropathy, and pain. Foot issues can cause walking difficulty and posture problems in all age groups and lead to even more serious health problems in the elderly [1, 2]. Reportedly, 30% of the foot deformities in community-dwelling elderly people [3–5] are associated with reduced walking speed [1, 6], difficulty in daily living activities, and increased risk of falls [6, 7]. Recent studies emphasize the link between increased health risks such as frailty syndrome and falls in the elderly and foot problems [1, 8–10].

The medial longitudinal arch (MLA) of the foot can serve as a shock absorber during the increased shock caused by upright striding, as well as the attenuation of forces transmitted during standing [11]. A very low MLA is considered a flatfoot deformity, while an excessive elevation is a high arch deformity. An increased incidence of injuries has been noted in people with both low and high arch deformities [12–14].

It has been previously reported that flat foot and high arched foot is associated with impaired standing balance and foot function. However, little is known about the association between foot arch deformation, muscle strength and motor function in the elderly. Therefore, it is important to examine the relationship between physical characteristics and motor function in community-dwelling elderly people with foot deformities.

When the foot is low-arched or high-arched, the MLA is measured and evaluated. Measuring the foot arch requires the use of techniques that are consistent and valid. Particularly when the participants are elderly, a simple and non-invasive method should be used to evaluate the reliability of the foot measurement method. The methods of MLA measurement based on the bony landmark described by Williams and McClay are highly reliable and valid[15]. Williams and McClay had previously used the Plexiglas Plate for foot measurements. They described that intra-class correlations (2,1) showed a high reliability of > 0.9 for all foot measurements. If direct foot measurements could be manually performed on community dwelling elders without use of special foot measurement equipment, this could lead to more widespread application in future. We also assessed the reliability of the method used in this study. We believed that if the foot measurements of these elderly people were performed using a simple and accurate method, the various problems related to exercise could be identified.

This cross-sectional study mainly aimed to investigate the effects of low arch and high arch deformities on physical characteristics, muscular strength, and motor function in the elderly.

2. Materials And Methods

2.1 Participants

This cross-sectional study was conducted in the city of Kaizuka, Japan from 17th August to 12th September 2019. We published a brochure for a community health check-up program and placed it in the local newspapers and public offices such as the city hall.

Overall, 204 community-dwelling elderly participants (159 women, aged 65 to 90 years old), underwent health examination in Kaizuka City, Osaka. The participants who (1) had orthopedic disease, (2) had received certified support or nursing care, and (3) had developed dementia were excluded from participation.

2.2 Evaluation Method and Reliability of Foot Measurements

The dorsal height (DH), foot length (FL), truncated foot length (TFL), and DH/TFL ratio were assessed in this study. The methods of MLA measurement performed based on the bony landmarks described by Williams and McClay are used in this study [15]. Moreover, a conservative approach produces better versatility. Herein, DH/TFL is defined as arch height ratio (AHR).

Although Williams and McClay had previously used the Plexiglas Plate for foot measurements, the effectiveness of the FL, DH and DH/TFL measurements was described in this study. They described that intra-class correlations (2,1) showed a high reliability of > 0.9 for all foot measurements. In McPoil et al.'s study using the arch height index, the intra-correlation coefficients were highly reliable with a heel to toe length of 0.99 and a dorsal arch height of 0.98 [16].

To establish intra- and inter- rater reliability for the measurements, two raters were asked to assess the right foot in 17 university students, of whom 5 were women, with a mean (SD) age of 21.0 (0.6) years. They did not have any lower-extremity deformity or injuries during the measurement. FL, DH, and DH/TFL were analyzed to determine the reliability of the foot measurement. Acceptable intra-rater and inter-rater reliabilities for the three indices of foot measurement were determined. The raters performing the measurements were two university students, who had practiced the measurement method under the supervision of a physical therapist. Each rater was instructed by a physical therapist with 18 years of experience to practice for 3 hours and precision was ensured.

During the measurement, each participant was made to stand, and the lower leg on the measurement side was placed on a 15-cm table. Furthermore, a side-cane was gripped to optimize measurement in the stable standing position. Foot measurements was no setting for the ankle angle and the amount of load during the measurement, and the load was free.

Foot length was measured using a plastic device, and the dorsal arch height was calculated at 50% of FL by a digital Vernier caliper (Shinwa Niigata, Japan). In DH, one examiner fixed a ruler on the dorsum of the foot, and another examiner measured the height of the ruler with a digital caliper (Figure 1).

The TFL value was measured using a digital photographic image and Adobe Photoshop. Two digital cameras (RX-0, SONY, Tokyo, Japan) were used to record the medial sagittal aspect and upper horizon plane of the foot in standing position. The digital image of the upper horizontal plane was used to confirm that the foot was in the neutral position, and the medial sagittal aspect was used to calculate the TFL (Figure 2). Several investigators have measured the foot using digital photographic images [17-19].

The participants were classified into three groups according to the foot AHR: normal-arched group (NAG), high-arched group (HAG), and low-arched group (LAG). The DH and FL were directly measured using the foot measurement method, and digital photography was used for the TFL.

2.3 Assessment of Body Characteristics

Physiological parameters measured using bioelectrical impedance analysis (Inbody270; Inbody, Tokyo, Japan) with 20 and 1000 kHz frequencies were obtained from the participants' electronic medical records [20]. Participants were instructed to grasp the handles of the analyzer and stand on electrodes in contact with the lower surface of their feet while they were wearing normal indoor clothing without socks or shoes. The surface of the hand electrode was placed in contact with all the five fingers, while the participants' heels and forefoot were placed on the circular foot electrode. They were asked to fast and avoid vigorous exercise for at least 1 hour before the assessment. The body mass index (BMI) was calculated by dividing the body weight (kg) by height squared (m^2). The appendicular skeletal muscle mass index (SMI) was derived from the appendicular muscle mass (kg) divided by height squared (m^2).

2.4 Muscle Strength

Handgrip strength is a well-known measure of muscle strength and is significantly associated with whole body muscle strength [21]. The maximum voluntary isometric strength of the handgrip was measured in the dominant hand while in a standing position, using a hand dynamometer Grip-D (Takei, Niigata, Japan). Other bodily movements were not permitted.

Intrinsic foot musculature plays an important role in stabilizing the foot [22–24]. For the intrinsic muscle strength, a handheld dynamometer (Mobie MT-100, SAKAImed, Tokyo, Japan) was placed distal to the MP joint of the hallux toe while in the sitting position, and the pushing force against the floor surface was measured with the MP joint extended.

2.5 Locomotive Examination (Gait Speed and Two-Step Test)

The participants were instructed to walk 6.4 m (divided into two 2.0 m zones at each end and a 2.4 m middle-zone) at a speed they found comfortable [25]. The time needed (in seconds) to pass the 2.4 m middle zone was measured for the calculation of gait speed (m/s). Participants could use a cane or walker if they were unable to perform the gait test independently. An average of five gait tests was used for evaluation.

The two-step test is one of the evaluations for the locomotive syndrome and has a high correlation with various balance tests [26]. Here, a maximum of two steps (cm) that can be performed without losing the balance was adopted, and a standardized value of the stride length divided by the height (cm) ratio was defined as a two-step value (cm/cm).

2.6 Statistical Analysis

The Shapiro-Wilk test was used to confirm the normality of the distribution of each evaluation item. The Mann-Whitney test was used to compare the values for the foot measurements based on sex. The foot

AHR was used to classify the foot deformities into the three groups (NAG, HAG, and LAG). The Kruskal-Wallis test of variance was used to compare the three groups for characteristics, muscle strength, and locomotive examination. The statistical software used was IBM SPSS Statistics 26 (IBM Corp., Armonk, NY, US) with the significance level set at < 5%.

3 Results

3.1 Reliability of Foot Measurements

Table 1 shows the intra-rater (1.1) type Intraclass Correlation Coefficients (ICCs) for FL and DH. Only rater 1 measured on the digital image. TFL and AHR were measured under a physical therapist’s supervision. The intra-rater reliability ICC ranged from 0.92 to 0.98 for FL, TFL, and AHR, and from 0.70 to 0.76 for DH. The inter-rater reliability ICCs for FL and DH were 0.98 and 0.70, respectively.

3.2 Comparison of Foot Measurements between the sexes and Classification by Arch Height Ratio

Table 2 shows the comparison of right and left foot measurements between the sexes. There was a significant difference in the evaluation items FL, DH, and TFL. Based on AHR, three groups of foot arches were determined: NAG (< AHR + 1.5SD ~ > AHR + 1.5SD), HAG (> AHR + 1.5SD), and LAG (≤ AHR-1.5SD). Previously, several investigators had set the standard by using the one-sided foot measurements ± 1.5 SD from the mean value [27, 28]. Utilizing the results of mean ± 1.5SD based on AHR, LAG was < 0.280 on the right foot and < 0.280 on the left foot, and HAG was > 0.379 on the right foot and > 0.367 on the left foot. The distribution of men and women by the type of foot arch group is shown in Table 3.

3.3 Comparison of Body Characteristics, Muscle Strength, and Locomotive Function

Table 4 shows the results of the comparison of the three groups in terms of body characteristics, muscle strength, and locomotive examination. Regarding the characteristics, BMI showed a significant difference among the three groups, and HAG (24.2 kg/m^2) had the highest value among the groups (vs NAG, 22.2 kg/m^2 and LAG, 21.9 kg/m^2). Locomotive examination showed significant differences among the three groups in gait speed, where the average value was lowest in HAG (1.16), while it was 1.26 and 1.33 in NAG and LAG, respectively.

4. Discussion

This study had two purposes: (1) to determine the reliability of static measurements of foot posture and (2) to clarify the effect of foot arch deformity on motor function in the elderly.

Acceptable inter-rater reliability for the two indices were determined by direct measurement. Intra-rater reliability for the TFL measurement was determined by digital imaging. Inter-rater reliability of ICC was 0.98 for FL and 0.70 for DH. Intra-rater reliability for TFL measured from the digital images was ICC 0.92, and for foot arch ratio was ICC 0.96. The ICC values for the two raters would be classified as "almost perfect" for intra-rater and "substantial" for inter-rater reliability based on Landis and Koch's classification [29].

The foot measurements in our study were found to be smaller than those previously reported [15, 16]. In our study, the AHR of the mean value for men was 0.332 and 0.329 for the right and left feet, respectively, and the mean value for women was 0.330 and 0.323 for the right and left feet, respectively.

The AHR values reported here are lower than those previously reported by McPoil et al. [16], where the mean AHR values were 0.345 and 0.341 for the right and left feet, respectively based on measurements in 850 participants. Similarly, Zifchock et al [30] reported mean AHR values of 0.340 and 0.336 for 68 male and 77 female participants, respectively.

McPoil et al. reported that the average FL, TFL, and DH in the right foot of men were 27.0 cm, 19.8 cm, and 6.85 cm, respectively. Those for the men in this study were 24.0 cm, 18.8 cm, and 6.16 cm, respectively. Additionally, the average value in the study by McPoil et al. was lower, and the average value for women was similar. The mean foot measurements in this study may be smaller than those previously reported because of bony structure differences based on race and age. Song et al. reported that Asians have flexible feet that are prone to pronation at the subtalar joint [31] and that foot measurements in the Japanese population tend to have a smaller AHR than those in Western countries.

Moreover, we examined the proportions of the three groups based on the arch height. The proportion in this study were as follows: normal foot was 79.2% for men and 77.7% for women; low-arched foot was 9.4% for men and 9.6% for women, and high-Arched foot was 12.7% for men and 12.7% for women.

The rate of foot arch deformation was 60% for normal arch, 20% for flat foot, and 20% for high-arched foot in previous studies [32]. However, flat foot had a 2.4% incidence in adults [33], and high arches occurred with an incidence of 8 to 15% on both feet [34, 35]. Thus, the proportion of low-arched foot and high-arched foot is not constant. However, a foot deformity of approximately 10% in this study is consistent with the findings in other studies.

This cross-sectional study mainly aimed to clarify the effect of foot arch deformity on physical characteristics and muscle strength, and locomotive function in the elderly.

On comparing the foot arches among the three groups in the community-dwelling elderly, the physical characteristics showed a significant difference in BMI, with the HAG having the highest BMI. Locomotive examination showed a significant difference in walking speed, with the HAG being the slowest. The bone structure of a high-arched foot may influence the decreased walking speed in the HAG.

Regarding the association between foot and balance functions in the elderly, Menz et al. reported that foot flexibility, plantar sensation, and plantar flexor strength are important and independent predictors of stable performance [4]. Tanaka et al. revealed that toe muscle function is particularly important for maintaining balance in the elderly and that elderly people place greater pressure on their toes than younger people to maintain their standing position to obtain sensory information [36]. However, in this study, there were no significant differences in the SMI, grip strength, and foot intrinsic muscle strength, which are the muscle strength indicators.

A high-arched foot is more rigid than the normal foot, reducing the range of motion and lessening shock absorption [12, 32]. Several researchers have reported that the center of gravity pressure shifts laterally during walking because of the effect of a high-arched foot [37, 38]. Additionally, Hösl et al. showed that there was no significant difference in gait propulsion between the normal foot and the asymptomatic flatfoot [39].

A high BMI reportedly increases the center of gravity displacement to maintain posture balance [40], and it is significantly associated with decreased walking speed in the elderly [41]. LaRoche showed that older women who are obese have low plantar flexor stiffness, which may limit propulsive forces during walking and require greater muscle activation for active force generation [42].

In contrast, the foot arch reportedly decreases as the BMI increases [43, 44]. Therefore, the BMI affects the structural changes of the MLA of the foot and may be involved in the foot arch height. However, foot deformity is more likely to occur at any age, and when the BMI is higher. However, it is unclear whether BMI is related to deformation. Longitudinal studies are needed to confirm whether obesity increases the incidence of having a high-arched foot.

There are some limitations to consider in the interpretation of these findings. The first limitation is that the inter-rater reliability of the measured values was lower for DH in the foot measurements than in the previous report using a measurement device. Moreover, the measurement of the foot was performed in the standing position, and the load was not adjusted.

The second limitation is that we did not consider pain evaluation, which is a factor related to the decrease in the walking speed of the elderly. High-arched deformity is a common finding in patients with foot pain [45], and the possibility that pain affects walking speed cannot be ruled out. Although this study did not show a difference in muscle strength among the three groups, Muchna et al. found that foot problems, especially foot pain and peripheral neuropathy, became more prominent as the frailty level worsened [10]. Further, they were not associated with decreased walking speed and stride length. We have described the effects of the high-arched foot and BMI on the factors that impaired gait in the elderly, although it is necessary to measure and examine the effect of foot pain and peripheral neuropathy.

5 Conclusions

This cross-sectional study assessed the physical characteristics, muscle strength, and locomotive function of community-dwelling elderly people with foot deformities by categorizing them into High Arch, Low Arch, and Normal Arch groups. The results of this study suggest that BMI and foot deformation, especially a high-arched foot, have a significant negative effect on walking speed in the elderly. However, it is unclear which factor has a greater effect on walking speed, and this is a subject that requires further study.

Abbreviations

MLA
Medial Longitudinal Arch
DH
Dorsal Height
FL
Foot Length
TFL
Truncated Foot Length
AHR
Arch Height Ratio
BMI
Body mass Index
HAG
High-Arched Group
NAG
Normal-Arched Group
LAG
Low-Arched Group
BMI
Body Mass Index
SMI
Skeletal Muscle Mass Index
HS
Handgrip Strength
IFS
Intrinsic Foot Muscle Strength.
FLPS
Foot Length by Photoshop
HL
Hallux length
HLPS
Hallux Length by Photoshop

Declarations

Ethics approval and consent to participate

This cross-sectional study was approved by the Osaka Kawasaki Rehabilitation University Research Ethics Review Board (approval number: OKRU-A019), and written informed consent was obtained from each participant prior to study inclusion.

Consent for publication

Not Applicable

Availability of date and materials

Not Applicable

Competing interests

The authors have no conflicts of interest to declare.

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Authors contribution

All authors have contributed to date analysis, drafting, and revising the article, gave final approval of the version to be published, and agree to be accountable for all aspects of the work.

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Tables

Please see the supplementary files section to view the tables.

Figures

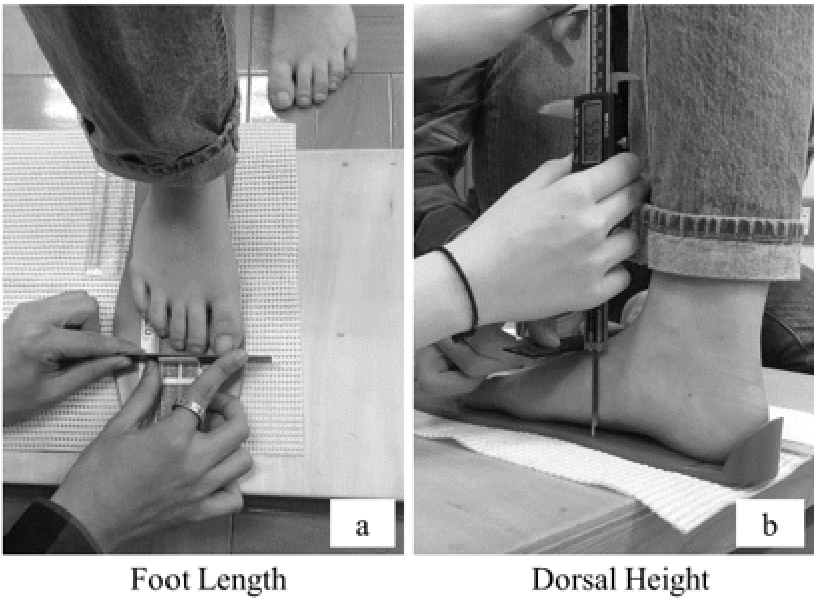

Figure 1

Direct Measurement of FL (a) and DH (b).

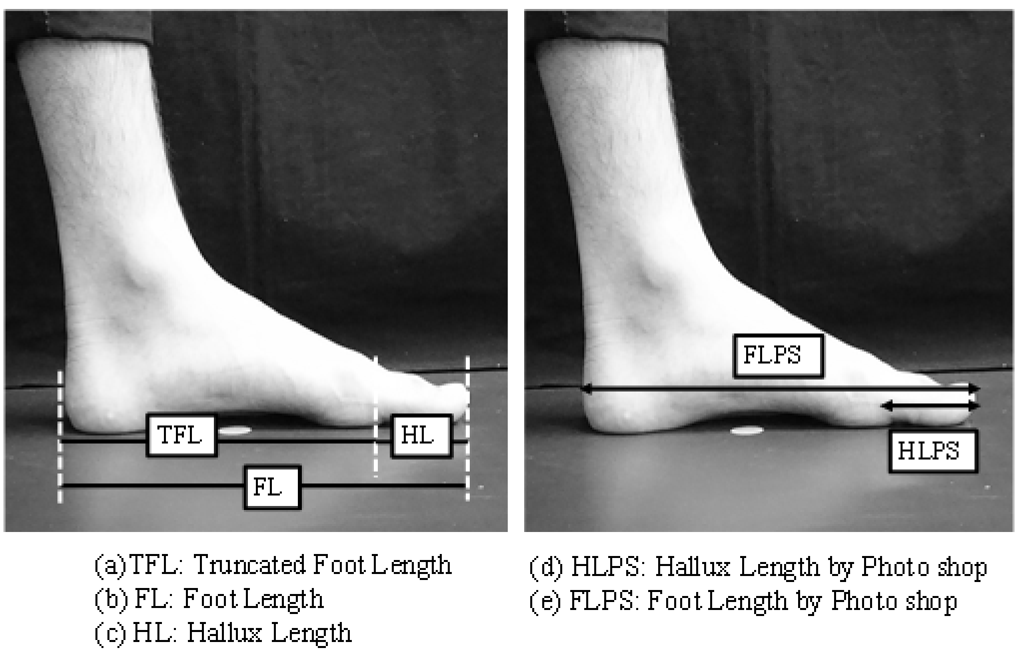

Figure 2

Method of calculating Truncated foot length (TFL) using digital images. TFL(a) is calculated by measuring the Foot Length (b) in the digital image of the medial sagittal aspect of the foot using the grading function of the image editing software Adobe Photoshop. The Hallux Length (c) is then calculated using the measured Foot Length (b) value in the following formula “HLPS(d) × FL / FLPS(e)”. The TFL is derived from the FL and HL with the following formula: FL-HL

Supplementary Files

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- Table4.PNG
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