The Journal of Physical Therapy Science

Original Article

Correlation between radiographic morphometry and body surface somatometry for foot arches

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Abstract. [Purpose] Foot arches are evaluated using radiographic morphometry and body surface somatometry. While several studies have examined the correlations between these methods and the medial longitudinal arch, very few studies have investigated the same for transverse arches. In this study, we analyzed the correlation between radiographic morphometry and body surface somatometry at medial longitudinal and transverse arches. [Participants and Methods] Fifty healthy adults were included in the study. Six medial longitudinal and three transverse arch evaluation methods were evaluated for the correlation, including the foot posture index. [Results] A correlation was found between the evaluation methods for the medial longitudinal arch, except the lateral talocalcaneal angle; however, no correlation was found between the navicular-metatarsal angle and transverse arch-length ratio in transverse arch evaluation. Additionally, there was no correlation between the evaluation methods for the medial longitudinal and transverse arches. The foot posture index was particularly correlated with radiographic medial longitudinal arch evaluation methods. [Conclusion] During evaluation with radiographic morphometry, it is difficult to set bone markers and differences in tarsal bone arrangement affect the relationship between them; in body surface somatometry, there were differences in measurement at sites with excessive soft tissue. Elucidating the cause for the lack of correlation between the medial longitudinal and transverse arches requires further investigation.
Key words: Medial longitudinal arch, Transverse arch, Arch evaluation methods

INTRODUCTION

The feet are the parts of the body that contact the surface of the ground. They function to support the body weight and to cushion the body from shock, especially when walking. They have many joints and can achieve a variety of movements. The arch of the foot is important for foot function. While the term "longitudinal arch" generally refers to the medial longitudinal arch, there is also a lateral longitudinal arch as well as a transverse arch at the level of the tarsal and metatarsal bones; together these arches play a role in load distribution and shock absorption.

Arch height varies according to personal development, illness, and lifestyle habits[1]. The longitudinal arch is called "pes cavus", when it is high and "pes planus" when it is low; flatness affecting the transverse arch is called "a fallen transverse

arch". Flat-footedness in particular causes fatigue and functional impairment.

There are two categories of methods for evaluating arch condition. The first includes evaluation methods of radiographic morphometry, which uses radiography to create reference lines, allowing the examiner to determine the lateral talocalcaneal angle, the calcaneal pitch angle, and the navicular index, among other measurements[2]. The second includes body surface somatometry, which measure the surface of the body including the arch-height ratio, the transverse arch-length ratio, the arch index, the footprint, the foot posture index (FPI), and so forth. The validity and reliability of these have been reported previously[3–5].

However, in radiographic evaluation methods, measurement points on bone markers differ depending on the evaluator, which results in measurement errors. Meanwhile, body surface evaluation methods are prone to inaccuracy due to issues arising from soft tissue such as the skin, as well as the evaluator's palpation technique[6, 7]. In addition, there are cutoff values for each of these methods, and there have been cases in which one method yielded a judgment of an abnormality while the other did not.

To date, there have been numerous reports on the correlation between the two measurement methods. However, there is still no consensus on the issue, and therefore evaluation methods that correlate with each other and are highly accurate have not been established. In addition, there are few reports in the literature on the correlation between medial longitudinal arch evaluation methods and transverse arch evaluation methods, and so the purpose of this study was to clarify correlations between radiographic morphometry and body surface somatometry of the medial longitudinal arch and the transverse arch in adults.

PARTICIPANTS AND METHODS

The right feet of 50 healthy adults with no history of foot disease (31 males, 19 females; age, 26.0 ± 6.8 years; height, 167.0 ± 9.0 cm; weight, 62.0 ± 12.0 kg; body mass index [BMI], 22.2 ± 2.9 kg/m^2) were analyzed. This study was approved by the Teikyo Heisei University ethics committee (approval date, September 3, 2015; approval number, 27-033). The participants were given an explanation of the study ahead of time and a written informed consent was obtained from each participant.

We analyzed radiographic morphometry and body surface somatometry by using methods to evaluate the medial longitudinal arch and transverse arch. Both evaluations were performed barefoot. Radiographic imaging was performed while in a standing position loading only one leg, with a tube voltage of 50 kV and a current of 100 mA. In lateral imaging, the point of entry was placed at the talus, with a distance of 100 cm and an exposure time of 0.2 s. In a frontal radiograph, the point of entry was placed at the talus 10° to the cranio-caudal direction, with a distance of 100 cm and an exposure time of 0.06 s. The irradiated area was the minimum to contain the entire foot. Here, participants wore protectors to reduce their exposure during imaging. The resulting lateral and frontal radiographs were used to calculate various angles and distances using the measurement software PDI Viewer Version 2.20 R03 (Konica Minolta Inc., Tokyo, Japan).

Six methods were used to evaluate the medial longitudinal arch. For the radiographic morphometry, 1) the lateral talocalcaneal angle, 2) the calcaneal pitch angle, 3) the lateral talo-first metatarsal angle (Méary's angle), 4) the calcaneo-first metatarsal angle (Hibbs angle), 5) the navicular index (navicular index=arch length/navicular height)[2] were used. For the body surface somatometry, 6) the arch-height ratio (measured in a natural stance on both feet, with the arch-height ratio = foot length/navicular height × 100), which is commonly used in the clinical setting, was employed.

Three methods were used to evaluate the transverse arch. From the frontal radiograph, 1) the naviculo-metatarsal angle (NM angle), 2) the first-fifth intermetatarsal angle (M1M5 angle) for the radiographic morphometry, and 3) the transverse arch-length ratio (transverse arch-length ratio = first-fifth intermetatarsal distance / foot length × 100) for body surface somatometry were applied.

For somatometry of the entire foot, we measured the FPI, which evaluates foot pronation and supination at the body surface. The FPI consists of the six elements of 1) talar head palpation, 2) supra and infra lateral malleolar curvature, 3) calcaneal frontal plane position, 4) bulging in the region of the talonavicular joint, 5) height and congruence of the medial longitudinal arch, and 6) abduction/adduction of the forefoot on the rearfoot. Each element was scored on a five-point scale consisting of −2 points, −1 point, 0 points, 1 point, 2 points, and the scores from the six elements were summed. Minus twelve points is marked supination, while 12 points is marked pronation. The measurements were taken in accordance with the User Guide Manual[8].

The evaluators in this subjective assessment are two physiotherapists with about 20 years of experience. At the time of evaluations, preliminary practices were carried out sufficiently, and two evaluations were conducted at intervals of 2 weeks, and the average value was used in this study.

We used the statistics software SPSS Statistics version 19 (IBM Inc., New York, USA), and calculated Spearman's rank correlation coefficient to confirm a correlation between the evaluation methods from the obtained measurement data. The significance thresholds were p<0.05 and p<0.01.

The FPI average, standard deviation, maximum value, and minimum value for the methods of evaluating the medial longitudinal arch and the transverse arch are shown in Table 1. The correlation coefficients between the different methods are indicated in Table 2.

Of the five evaluation methods of radiographic morphometry for the medial longitudinal arch, the four excluding the lateral talocalcaneal angle exhibited a weak to strong correlation (p<0.01) (Table 2, Figs. 1, 2). The lateral talocalcaneal angle only exhibited a weak correlation with Méary's angle and the navicular index (p<0.05) (Figs. 1, 2), and was found to have a strong negative correlation with the calcaneal pitch angle and the Hibbs angle (p<0.01) (Fig. 1). Meanwhile, among the arch-height ratio and the radiographic evaluation methods, only the lateral talocalcaneal angle (Fig. 1) did not exhibit a correlation, with only a weak correlation found between Méary's angle and the navicular index (p<0.05) (Figs. 1, 2), and a moderate correlation between the lateral talocalcaneal angle and the Hibbs angle (p<0.05) (Fig.1).

Table 1. Data from each evaluation method

		Mean	SD	Maximum	Minimum
Longitudinal arch	Lateral talocalcaneal angle	47.1°	± 6.5°	62.6°	29.9°
	Calcaneal pitch angle	15.6°	± 4.7°	27.0°	7.5°
	Méary's angle	6.7°	± 5.8°	21.8°	0°
	Hibbs angle	137.0°	± 7.1°	155.6°	120.7°
	Navicular index	5.3	± 1.2	8.4	3
	Arch-height ratio	17.7	± 2.9	25.0	11.8
Transverse arch	Naviculo-metatarsal angle	97.0°	± 5.6°	113.6°	82.3°
	First-fifth intermetatarsal angle	27.1°	± 3.5°	35.2°	20.7°
	Transverse arch-length ratio	41.3	± 2.8	47.7	36.7
Foot posture index		2.8	± 2.6	10.0	−3.0

Table 2. Correlation coefficients between each evaluation method

|		Lateral talocalcaneal angle	Calcaneal pitch angle	Méary's angle	Hibbs angle	Navicular index	Arch-height ratio	NM angle	M1M5 angle	Transverse arch-length ratio
Longitudinal arch	Lateral talocalcaneal angle									
	Calcaneal pitch angle	0.14								
	Méary's angle	0.30*	−0.45**							
	Hibbs angle	−0.20	−0.75**	0.48**						
	Navicular index	0.35*	−0.54**	0.45**	0.56**					
	Arch-height ratio	0.15	0.49**	−0.28*	−0.59**	−0.32*				
Transverse arch	Naviculo-metatarsal angle	0.32*	0.12	0.24	0.04	0.31*	0.07			
	First-fifth intermetatarsal angle	0.22	0.17	0.12	0.04	0.19	0.11	0.48**		
	Transverse arch-length ratio	−0.03	0.06	−0.12	−0.16	0.03	0.06	−0.01	0.34*	
Foot posture index		0.25	−0.39**	0.38**	0.58**	0.61**	−0.29*	0.30*	0.20	0.02

**p<0.01, *p<0.05.
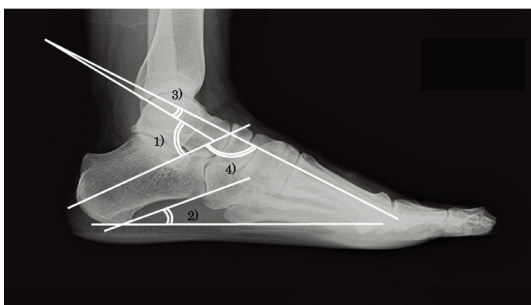
Fig. 1. Longitudinal arch measurement angles.
1) Lateral talocalcaneal angle, 2) Calcaneal pitch angle,
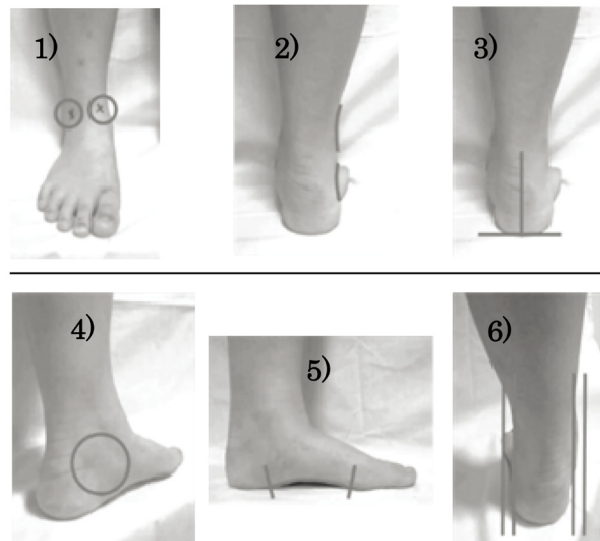3) Méary's angle, 4) Hibbs angle.
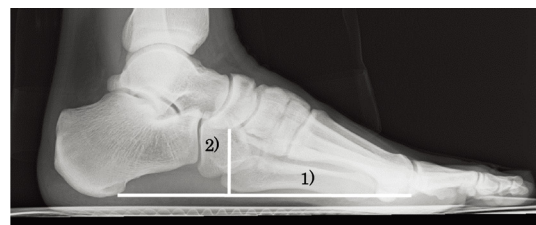
Fig. 2. Navicular Index.
Navicular Index=1) Arch length / 2) Navicular height.
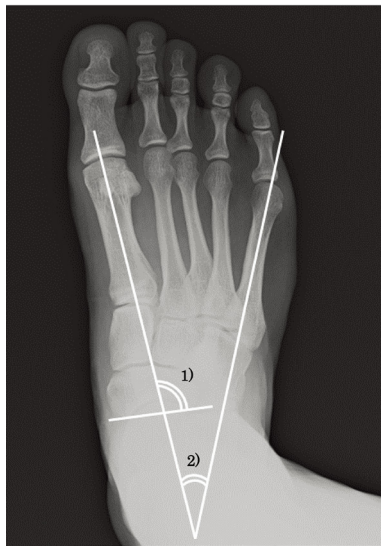
Fig. 3. Transverse arch measurement angles.
1) Naviculo-Metatarsal (NM) angle, 2) First-fifth intermetatarsal angle (M1M5) angle.

Fig. 4. Foot posture index.
1) Talar head palpation, 2) Supra and infra lateral malleolar curvature, 3) Calcaneal frontal plane position, 4) Bulging in the region of the talonavicular joint, 5) Height and congruence of the medial longitudinal arch, 6) Abduction / adduction of the forefoot on the rearfoot.

Among the transverse arch evaluation methods, there was a moderate correlation between the radiographic evaluation methods of the NM angle and the M1M5 angle (p<0.01) (Table 2, Fig. 3). However, although the transverse arch-length ratio was found to be weakly correlated with the M1M5 angle (p<0.05), there was no correlation with the NM angle.

In the relationship between the methods for evaluating the medial longitudinal arch and the methods for evaluating the transverse arch, only the NM angle among the latter exhibited a weak correlation with the lateral talocalcaneal angle and the navicular index among the former (p<0.05). However, there was no correlation between the other methods for evaluating the medial longitudinal arch and the transverse arch (Table 2, Figs. 1–3).

In addition, weak to moderate correlations were found between the FPI and the evaluation methods of the medial longitudinal arch except with the lateral talocalcaneal angle. Among these, the strongest was with the Hibbs angle and the navicular index (p<0.01). Between the FPI and the methods for evaluating the transverse arch, only the NM angle was weakly correlated (p<0.05) (Table 2, Figs. 1–4).

DISCUSSION

Of the methods for evaluating the medial longitudinal arch, there is currently no consensus on the relationship between various radiographic morphometry. The Méary's angle clearly differentiated between flatfoot and normal foot[9], while the calcaneal pitch angle was important for diagnosing flat foot according to Lo et al.[10] and Roth et al.[2], who reported in a postoperative pediatric study that there was a correlation between the navicular index and the various evaluation methods. In our study, the lateral talocalcaneal angle had a low correlation with the Méar's angle or the navicular index, but not with the calcaneal pitch angle or the Hibbs angle. On the other hand, correlations were observed among the calcaneal pitch angle, Méary's angle, Hibbs angle and the navicular index. The lateral talocalcaneal angle is affected by the mobility of the subtalar joint. The subtalar joint undergoes a compound motion at the anterior, middle, and posterior subtalar facets, primarily moving by adduction-abduction and internal-external rotation due to the morphology of the articular surfaces and the ligaments, with little sagittal motion. In addition, since the reference line is the midline of the polygonal talus and calcaneus, it is considered to be prone to error. Furthermore, a strong correlation between the calcaneal pitch angle and the Hibbs angle is believed to be due to the calcaneal pitch angle being the angle formed by a straight line at the inferior border of the calcaneus and a straight line at the bottom surface of the first metatarsal head, and the Hibbs angle being the angle formed between the longitudinal axis of the calcaneus and the longitudinal axis of the first metatarsal. Here, the reference is the calcaneus in both cases, while the other reference lines are the floor and side of a triangle formed with the bottom of the foot and the arch apex; hence we considered that the measurement errors were low. In addition, when considering the difference between the arch-height ratio and the radiographic morphometry, soft tissue could plausibly have had an effect, with variance primarily due to the amount of muscle and fat. Coughlin et al.[11] found a correlation between the Harris mats and radiographic morphometry,

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for body surface somatometry similar to the arch-height ratio, while Chen et al.[12] reported a correlation between variables calculated from the footprint and radiographs. However, the arch index was affected by the amount of fat[6], while there was no relationship between the arch height and the foot sole surface indicator in male participants[7]. Thus, it is clear that soft tissue affects body surface somatometry. The participants in the present study had BMI values in the standard range, so the effect is believed to have been small. However, since the measurement sites for the arch-height ratio include the toes, which are unrelated to arches, toe shape (morphology) is believed to decrease the correlation with radiography. Although the computational concept is the same for the arch-height ratio and the navicular index, the arch-height ratio includes toe length while the navicular index includes arch length, and so they differ in whether the toes are included in the measurements. The amount of soft tissue at the heel and the ball causes differences individually, resulting in the calcaneal pitch angle rather than the navicular index having a greater correlation coefficient with the Hibbs angle. Based on our results and those of prior studies, although it is necessary to take BMI values into consideration, the arch-height ratio exhibits a correlation with the radiographic morphometries, and is a valid and useful evaluation method in the clinical setting. In addition, when a detailed and accurate judgment is required, it is necessary to use radiographic evaluation methods that can eliminate the effects of soft tissue and the toes. In each radiographic morphometry for the medial longitudinal arch, the calcaneal pitch angle and the Hibbs angle, for which the reference lines are easily determined, are believed to involve a low amount of variation from measurement technique. In addition, there is a need when determining the navicular index to clearly stipulate the end of the arch length.

Within methods for evaluating the transverse arch, there is little soft tissue at the measurement sites for the transverse arch-length ratio and the M1M5 angle, and the foot width measurement site is also similar, and so a correlation was found. In addition, the moderate correlation coefficient between the NM angle and M1M5 angle is believed to be due to the NM angle indicating transverse arch at the level of the tarsal bones, while the transverse arch-length ratio and M1M5 angle indicate the transverse arch at the level of the metatarsal bones. Loading causes ligaments to stretch between the tarsal bones, and expanding both the NM angle and the M1M5 angle in step with the bones. However, since there was no correlation between the NM angle and the transverse arch-length ratio, we infer that displacement of the talonavicular joint and differences in tarsal bone arrangement caused abduction-adduction or internal-external rotation of the foot through a three-dimensional movement of the numerous joints in this part of the body.

There are few prior studies on the correlation between evaluation methods for the longitudinal arch and the transverse arch. Murley et al.[13] reported that in a study of adults, there was a correlation between the calcaneal inclination angle and the calcaneal-first metatarsal angle in a lateral radiograph, as well as between the talo-navicular coverage angle and the talus-second metatarsal angle in a frontal radiograph. However, our results found that among transverse arch evaluation methods, only the NM angle was weakly correlated with the lateral talocalcaneal angle and the navicular index. No other correlation was found among the other evaluation methods. This appears to be attributable to the fact that the height of the longitudinal arch does not necessarily vary proportionally to the height of the transverse arch, which is believed to be due not only to displacement in the talonavicular joint but also to the morphology of the bones and the state in which they are joined together. In a frontal cross-section of the medial, intermediate, and lateral cuneiform bones constituting the transverse arch at the tarsal level, they are wedge-shaped, resulting in a support mechanism like an arch-shaped bridge, and they are secured together solely through their morphology and arrangement. In addition, there is believed to be an effect from the ligaments that connect between the tarsal bones connecting them together, and since these ligaments have a radial course, this distributes force, resulting in displacement of the bone arrangement of the tarsals.

As a method for evaluating FPI and the longitudinal arch, Lee et al.[14] reported that in a study of children, there was a relationship between FPI, Méary's angle, and the calcaneal pitch angle, but not with the lateral talocalcaneal angle, which was the same result found in this study of adults. The fact that a correlation was found with the methods other than the lateral talocalcaneal angle is believed to be due to the low impact of BMI on the soft tissue in the reference areas of the participants, and the fact that most of the FPI variables observe the longitudinal arch. Of the methods for evaluating the transverse arch, only the NM angle had a weak correlation because the FPI is an indicator that classifies the internal-external rotation of the foot, while the navicular bone, which is one of the reference lines for the NM angle, is affected by its relative positioning with the neighboring talus bone. As stated earlier, the direction of motion of the subtalar is abduction-adduction and internal-external rotation, which is inferred to be the reason a correlation was observed.

In the future, the relationship between the transverse arch and longitudinal arch should be clarified by collecting data from people with different BMIs to understand the effects of soft tissue and by confirming the cross section of the arch using various methods such as images from computed tomography. In addition, there remains the task of elucidating the relationship between measurement methods and changes in bone morphology during growth, which differs between children and adults. Ultimately, the mechanism for arch structure and function should be clarified and a new, more accurate, and simpler arch evaluation method should be established.

Conflict of interest
None.

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