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Analysis of foot pressure distribution data for the evaluation of foot arch type

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Abstract— **In order to develop an evaluation system for foot arch type in the elderly using foot pressure distribution data, foot pressure distribution parameters were selected and the data thereby derived were discussed. Results from the study show that the midfoot area and pressure ratios were correlated to foot arch type determined by visual analysis and were not correlated to arch height parameters. It is assumed that foot pressure distribution parameters reflect a different phenomenon from that of arch height parameters. The inconsistency between them is considered to be a result of the effect of the forefoot arch on the arch height parameters.**

I. Introduction

The foot represents the interface between maintaining and shifting one's center of gravity. Functional limitations of the foot can cause problems in locomotion and pain in the lower extremities. Because many elderly individuals have foot problems, foot care has assumed increasing importance in maintaining their quality of life.

In Japan, the aged population has steadily been increasing, whereas the young population has been decreasing. In 2009, the proportion of the elderly in society was 21.5%, and this is estimated to rise to 40% by 2050 [1]. For this reason, expenditures related to health care have become a serious social issue; as a result, preventive care is of great importance in reducing the burden of health care cost.

One of the most important facets of preventive care is improvement in locomotors function. While fall prevention and muscle strength training have been the key planks of preventive care projects; of late, foot structure and care has also been given importance.

The foot has three types of arch structure: the medial longitudinal arch (MLA), the lateral longitudinal arch, and the forefoot transverse arch. The MLA, in particular, serves important functions in regard to shock absorption and the action of walking.

Regarding the relationship between foot arch type and risk of injury, there are some research reported. Cowan et al. surveyed 246 US Army Infantry trainees [2]. The result shows the injury risk among the high arch group was 2.0 times higher than the normal foot group and 6.1 times higher than flat foot group. Otsuka et al. reported that the elderly with flat foot tended to feel foot got tired more easily [3]. However, the evaluation method and the agreement on the relationship between the foot type and injury risk have not been established.

The footprint method is a simple and easy method to visualize foot shape. In previous studies, simple and quantified methods of foot arch assessment using footprints were proposed [4-6]; however, conflicting results in regard to the relationships between indices obtained by footprints and foot arch structure were found [5,6]. An effective alternate assessment system remains to be proposed.

As a clinical method for foot arch assessment, radiographic measurement of the distance from the navicular bone to the floor is thought to be the most reliable. However, it is not appropriate for preventive care or health support in the elderly. As an alternate method, navicular–floor distance was estimated by palpation, while in another study, this method was correlated with the radiographic measurement method [6]. However, in a non-clinical setting, the latter method is unsuitable, as accurate palpation requires specialist input.

In recent years, as a foot pressure distribution measurement device has become more popular and less expensive for both clinicians and consumers, it becomes possible to use such device for preventive care or health support in the elderly. This device is used for the qualitative measurement of foot shape, because it not only measures foot shape but also provides data on foot pressure. As a result, it enables the clinician/consumer to obtain more precise information when compared with the simple footprint technique.

Simple and quantitative classification of foot arch types such as flat foot and high arch would be helpful in preventive care and health support for the elderly. However, correlations between foot pressure distribution data and foot arch type in the elderly have not been established to date.

Therefore, the aim of this study is to determine the relationship between foot arch type and foot pressure

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distribution in order to develop a system capable of evaluating foot type.

II. Selection of the Foot Pressure Distribution Parameter

A. Method

Initially, a field test for the elderly was conducted to obtain some basic data and select the parameters to represent foot types.

A total of 35 healthy elderly Japanese subjects (nine males, 26 females) attended the class on care prevention in Tokyo. The mean age of the male subjects was 75.1 ± 6.9 years, mean height 162.2 ± 5.3 cm, and mean weight 57.4. ± 6.2 kg and the corresponding parameters for the females were 73.1 ± 6.4 years, 152.0 ± 4.9 cm, and 49.2 ± 8.0 kg.

Ethical approval for the study was obtained from the Tokyo Healthcare University Human Ethics Committee.

The device used to measure foot pressure distribution was MAT-SCAN (Nitta Corporation, Tokyo, Japan). The sensor matrix was distributed over 44 rows and 52 columns, with a sensor interval of 8.3 mm. Subjects were requested to stand on both feet with eyes open, with approximately a 150-mm distance between thumbs. When the subject was judged as stable in the standing position, the digital foot pressure distribution data were obtained. Sampling frequency was set with 20 Hz. The minimum measurable pressure was 4.6 kPa and the maximum one was 392.0 kPa.

In this study, the left foot was analyzed for all participants. The foot contact area, excluding toes, was equally divided into three equal parts: forefoot, midfoot, and hindfoot. Following calculation of the area of each part and the sum of pressure exerted by each part, these values were normalized to that of the whole foot. In addition to such quantified analysis, visual assessment was also carried out with the help of foot pressure distribution imaging, which gives a colored graphical representation of foot pressure strength. Results of the two types of analysis were then compared.

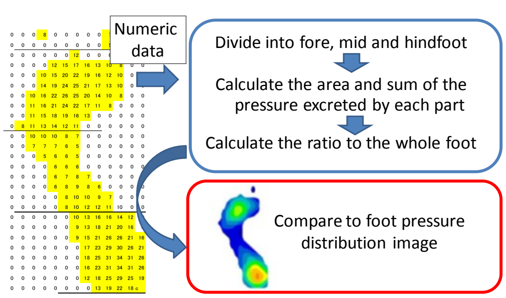


Fig. 1. Processing of foot pressure distribution data.

B. Results

Typical examples of foot pressure distribution imaging are shown in Fig. 2. According to the results of visual analysis, five subjects were categorized into the flat foot group and 14 in the high arch group. Of the six parameters, there was a correlation of the midfoot area and pressure ratios (midfoot:whole foot) to the visual analysis. Midfoot area and pressure ratios were higher in the flat foot group and lower in the high arch group (Fig 3). Results for other parameters did not appear to relate to those obtained by visual analysis (Fig. 3).

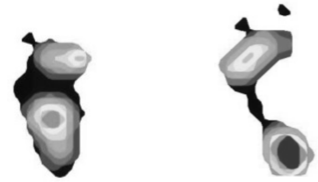
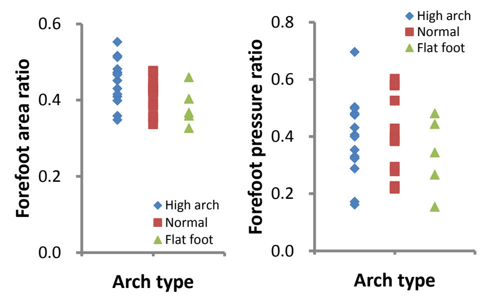
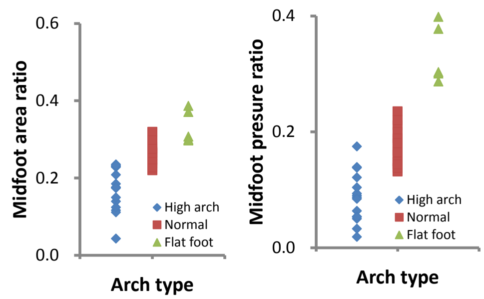


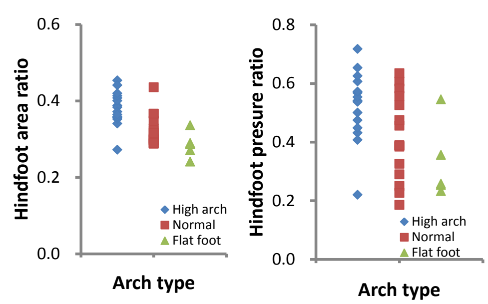
Fig. 2. Foot pressure distribution images. Left, flat foot; right, high arch.



a) forefoot area ratio (left) and pressure ratio (right)



b) midfoot area ratio (left) and pressure ratio (right)



c) hindfoot area ratio (left) and pressure ratio (right)

Fig. 3 Relationship between foot arch type and six foot pressure parameters.

C. Discussions

In regard to the parameters derived from foot pressure distribution data, results for the midfoot tended to correspond to those of visual analysis. In terms of anatomy, the findings shown in Figs 3 were considered reasonable. In regard to flat foot, lowering of the foot arch would lead to increase in both contact area and pressure on the midfoot, whereas for high arch, raising of the foot arch would lead to decrease in both contact area and pressure on the midfoot.

In a similar previous study, Cavanagh et al. aimed to evaluate foot arch types, such as flat and high arches, among young healthy subjects using the midfoot area [2]. Their results demonstrated that frequency distribution of the midfoot was such that the frequency around the mean value was higher, and that around both ends was lower. When the foot types of the subjects; i.e., flat and high arches were classified by the first and third quartiles, the classification was almost consistent with that obtained by qualitative clinical analysis.

Fig.4 shows the frequency distribution of the midfoot area in our subjects, the results being similar to those from the study by Cavanagh et al [4]. The first and third quartiles in our study were 0.18 and 0.27, respectively. The results of Cavanagh et al's study were 0.21 and 0.26, respectively. The results of midfoot pressure in our study showed a similar tendency, the first and third quartiles being 0.09 and 0.19, respectively (Fig. 5). The relationship between these quartile values and foot arch type by visual analysisis shown in Fig.6. Table 1 shows sensitivity and specifity of the foot arch classified by the quartiles of midfoot parameters. We classified these with the value less than the first quartile as the high arch group and classified these with the value more than the third quartile as the flat foot group. The result suggests that the first and third quartiles could be candidates of the thresholds for the classification.

We therefore selected the midfoot area and pressure ratios as foot pressure distribution parameters for each arch type.

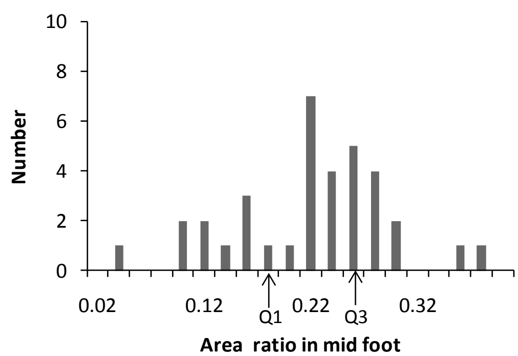


Fig. 4. Histogram of foot area ratio for midfoot. Q1 indicates the first quartile and Q3 indicates the third quartile.

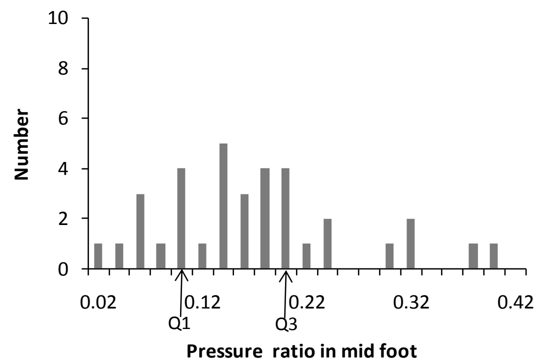


Fig. 5. Histogram of foot pressure ratio for midfoot. Q1: the first quartile, Q3: the third quartile.

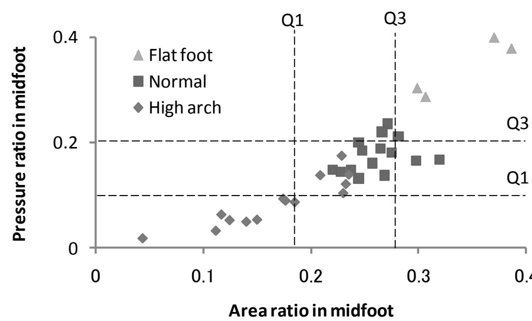


Fig. 6. Relationship between foot shape and midfoot parameters. Q1 indicates the first quartile and Q3 indicates the third quartile.

Table1. Sensitivity and specifity of the foot arch classified by the quartiles of midfoot parameters. Area indicates midfoot area ratio and pressure indicates midfoot pressure ratio.

a) High arch

Classification parameters	Sensitivity	Specifity
Area	0.60	1.00
Pressure	0.60	1.00
Area and Pressure	0.53	1.00
Area or Pressure	0.67	1.00

b) Flat foot

Classification parameters	Sensitivity	Specifity
Area	0.60	1.00
Pressure	0.60	1.00
Area and Pressure	0.53	1.00
Area or Pressure	0.67	1.00

III. CORRESPONDENCE TO ARCH HEIGHT RATIO.

A. Method

Clinically, arch height was used to evaluate arch type morphology. We next conducted another field test for the elderly and analyzed the correlation between arch morphology and foot pressure distribution parameters, using the same methods and equipment from the previous study.

Subjects are 23 healthy Japanese female elderly attended the class on care prevention in Tokyo. The mean age of the subjects was 74.9 ± 7.7 years, mean height 150.1 ± 5.3 cm, and mean weight 49.1 ± 8.6 kg.

Data from studies on the left foot were analyzed. The foot pressure distribution parameters such as midfoot area and pressure were calculated.

As a morphological parameter, the navicular bone of the left foot was detected by palpation and its vertical distance from the floor was measured as arch height.

The body posture was similar to that during measurement of foot pressure distribution. In order to remove the effect of foot size difference, the arch height ratio (arch height divided by foot length) was also derived. Foot length was defined as the longitudinal distance between the tips of the forefoot and hindfoot.

In order to investigate the relationship between foot pressure distribution and morphological parameters, correlation analysis was conducted among the midfoot area and pressure ratios, arch height, arch height ratio, and the height and weight. Visual analysis of foot pressure distribution imaging was also performed.

B. Results

Results of the correlation analysis are shown in Table 1. The correlation coefficient between foot pressure distribution parameters was 0.90 (relatively high), and between arch height and arch height ratio was also 0.90. On the other hand, the correlation coefficient between arch height and midfoot area ratio was –0.08. The coefficient between the arch height ratio and the midfoot pressure ratio was 0.08. The correlation coefficients of the foot pressure distribution and arch height parameters to height and weight were both < 0.3.

.Foot type groups based on visual analysis Correlations between arch height ratio and foot pressure distribution parameters were not observed in all groups.

The distributions of arch height, midfoot area midfoot pressure ratios subdivided by visual analysis grouping are shown in Fig. 7. The distribution of arch height ratio was not consistent with visual grouping. On the other hand, the values of midfoot pressure ratio in the high-arch group were low while those in the flat-foot group were high.

Table 2 Correlation ratio between foot pressure data and arch height ratio. Area indicates midfoot area ratio; pressure indicates midfoot pressure ratio; arch indicates arch height and arch (ratio) indicates arch height ratio.

	Height	Weight	Area	Pressure	Arch	Arch (ratio)
Height	1.00					
Weight	0.58	1.00				
Area	0.11	0.22	1.00			
Pressure	0.07	0.27	0.90	1.00		
Arch	0.06	0.32	−0.12	0.07	1.00	
Arch (ratio)	−0.07	0.15	−0.08	0.08	0.90	1.00

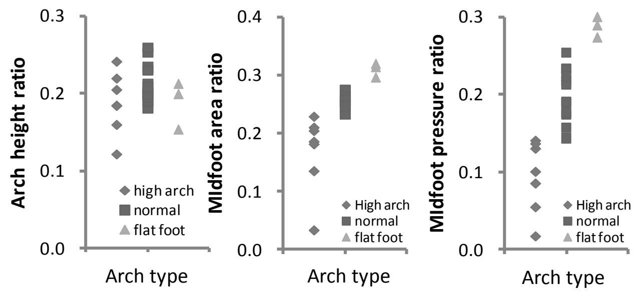


Fig. 7. Distribution of midfoot area, midfoot pressure and arch height ratios divided by visual classification..

C. Discussion

From the results of correlation analysis, the correlation coefficients between foot pressure distribution and morphological parameters were low, and no correlations could therefore be confirmed.

The distribution of arch height ratio was not consistent with visual analysis grouping, although that of midfoot pressure ratio was consistent.

From these results, it is assumed that foot pressure distribution parameters reflect a different phenomenon from that of the arch height ratio. Anatomically, the MLA is supported by the plantar aponeurosis. If this latter structure becomes too flaccid, arch height would be reduced and midfoot contact would be greater; thus the foot arch type would be classified as flat foot. However, if the plantar aponeurosis is excessively stretched, arch height would be increased and midfoot contact reduced; thus the foot arch type would be classified as high arch.

Typical foot pressure distribution images and arch height ratios are shown in Fig. 8. On the basis of visual analysis, subjects in the high arch group were observed to have both high and low arch height ratios. If we consider the forefoot of a subject whose arch height was 0.12, the pressure around the base of the second toe was higher than normal. However, because of the presence of the transverse arch in the forefoot, the pressure around the base of the second toe should ideally be lower. This suggests a functional decline in the forefoot arch rather than in the MLA. It was observed that the subjects in the visual high arch group tended to have low arch height ratios; foot pressure distribution imaging suggests a lowered forefoot arch.

Therefore, it is assumed that inconsistency between arch height ratio and foot pressure distribution parameters resulted from the effect of the forefoot arch on arch height ratio.

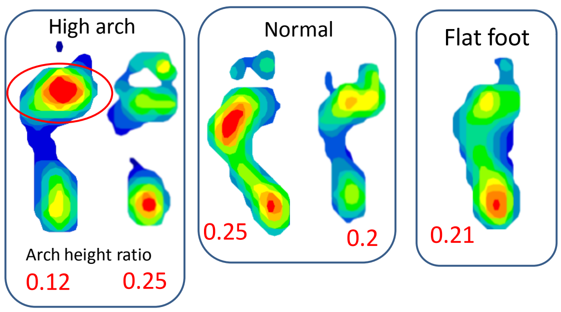


Fig. 8. Typical foot pressure distribution images and arch height ratios.

IV. Conclusion

In order to develop an evaluation system for foot arch type in the elderly using foot pressure distribution data, foot pressure distribution parameters representing the foot arch were selected and the data thereby derived were discussed. These parameters were then compared with morphological parameters such as arch height ratio; this proved to be a simple clinical method.

Results from the initial study show that the midfoot area and pressure ratios were correlated to foot arch type determined by visual analysis.

Results from correlation analysis could not confirm correlation between foot pressure distribution and morphological parameters. It is assumed that foot pressure distribution parameters reflect a different phenomenon from that of arch height ratio. The inconsistency between arch height ratio and foot pressure distribution parameters is considered to be a result of the effect of the forefoot arch on the arch height ratio.

The subjects of this study were all healthy and elderly. However, 54% had a foot arch problem, such as flat foot or high arch. Therefore, an evaluation system for foot type is considered very important.

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