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The Navicular Arch Index : a Reliable and Valid Footprint Parameter to Evaluate Arch Height

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Recent studies have shown a close correlation between arch height of the foot and activity-related injuries. In the past, attempts to evaluate arch height from footprint parameters have yielded conflicting results. This could be caused by their failure to take anatomy into consideration in the proposed footprint parameters. This study investigates the relationship between arch height and Navicular Arch Index (NAI) — a new footprint parameter developed by us to incorporate anatomical consideration into footprint measurements. NAI is defined as the ratio of modified footprint width to foot width at the site corresponding to the navicular tuberosity. The arch height of seventy healthy subjects (thirty-eight men and thirty-two women) was measured with a digital caliper and NAI was calculated by footprint landmarks. We found that NAI measurement has an excellent intrarater reliability with an intraclass correlation coefficient (ICC) of 0.95 and a good interrater reliability (ICC = 0.81). A significant correlation (Pearson correlation coefficient, **r** = －0.70, p<0.001) was found between NAI and arch height. We concluded that NAI yields reliable and valid first order approximation of arch height, and thus may be clinically used to evaluate arch structure. (J Rehab Med Assoc ROC 1999; 27(4): 183 – 188)

Key words: navicular arch index, footprint parameter, arch height

INTRODUCTION

Arch height of the foot is of great importance for good support of the body and mechanical action of the foot. Recent studies have suggested a close relationship between arch architecture and activity-related injuries[1-3]. Several methods have been proposed to measure arch height, including clinical assessment[4], radiographic techniques[2,5,6], and footprint analysis[7,8]. Clinical assessments are subjective and require professional training, while radiographic techniques are expensive and imply a potential risk of radiation exposure. Radiographic measurements may be inaccurate due to incorrect positioning of the foot and x-ray source or severe foot deformity. Footprint analysis is an inexpensive, easily accessible, and noninvasive method which can be easily set up and operated by a single operator. However, lack of accurate and efficient means to provide quantitative data from the footprint parameters has been the major disadvantage of this method.

A variety of footprint parameters have been proposed to characterize arch height and classify arch categories[9-16]. All those measurements are based on the "geometrical" consideration that a high arch produces a narrow midfoot area of the footprint, and a low arch

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causes a flattening of the cavity and thus a wide midfoot area. Hawes *et al.* [16] showed that no significant correlation existed between footprint parameters and arch height. This controversy could be caused by the lack of anatomical consideration in the proposed footprint parameters. In order to clarify this issue, we developed a new footprint parameter, the Navicular Arch Index (NAI), which incorporates anatomical consideration into the footprint measurements. The purposes of this study were to investigate the reliability of the NAI measurement and to confirm the correlation between NAI and normalized arch height.

MATERIALS AND METHODS

Subjects

A total of seventy young healthy subjects (thirty-eight men and thirty-two women) were recruited from a university. All subjects had no foot deformity and reported no pain or discomfort in natural standing or walking. The mean age, mean body height and body weight are listed in Table 1. There was no statistical significance between male and female subjects.

The intrarater and interrater reliability of the measurement were evaluated through repeated measurements of a group of sixteen subjects (eight men and eight women), ranging in age from twenty-two to twenty-six years, by two trained examiners.

Arch Height Measurement

All the measurements were performed by one examiner. Subjects stood on an elevated platform in a normal standing posture, with both feet separated shoulder-width apart. The bottom of the navicular tuberosity of both feet was then palpated and marked with a ball-point pen. We used a modified Mitutoyo digital caliper, which was similar to that used in Hawes *et al.*'s study[16], to measure the height from the floor to the bottom of the navicular tuberosity. Care was taken to ensure that the subjects had no noticeable body motion and held their breath during the measurement. Based on the study of Saltzman *et al* [6], each measure of arch height was divided by the subject's toeless footprint length (*AB* in Fig.1) to define a ratio of height-to-length. We used the normalized ratio value to describe arch height and account for individual variability in arch structure caused by differences in foot length.

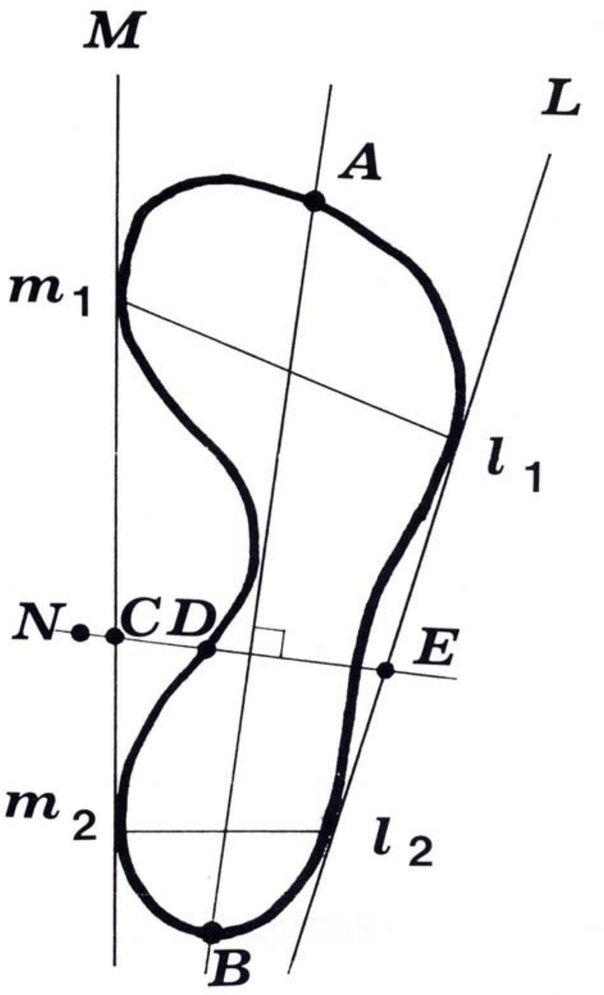

Fig. 1. Illustration of NAI calculation. NAI is defined as the ratio of *DE* to *CE*.

Footprint Acquisition

Subjects stood on a footprint mat of Harris and Beath[17], in a natural stance, with their feet positioned evenly in a distance of shoulder-width. The bottom of the navicular tuberosity which had been marked during arch height measurement was projected on the footprint mat with a vertically held stick (point *N* in Fig.1). Static footprint of one foot was made and the same procedure was then repeated for the other foot.

Table 1. The mean age, mean body height and body weight of the seventy subjects

	Age (yr)	Body height (cm)	Body weight (Kg)
Men (n=38)	23.4±1.7	169.9±4.7	64.4±7.0
Women (n=32)	24.2±4.2	160.2±5.8	51.9±6.5
Total (n=70)	23.7±3.6	165.5±5.3	58.7±6.8

Calculation of the Navicular Arch Index

The method of the NAI calculation is shown in Fig.1. First, the tangent lines of the medial, (*M*), and lateral, (*L*), borders of the footprint were drawn. The two intersections at the forefoot, m_1, l_1, and heel, m_2, l_2, regions were then connected. From this, the line passing through the centers of these two line segments could be drawn. This line intersected the distal, (point *A*), and proximal, (point *B*), borders of the toeless footprint. The distance between the two points, *AB*, was defined as the foot length for the normalization of arch height measurement. A line crossing point *N* and perpendicular to *AB* was then drawn. This line intersected line *M* at point *C*, the medial border of the footprint at point *D*, and line *L* at point *E*. *DE* and *CE* represent modified footprint width and modified foot width respectively at the site corresponding to the navicular tuberosity. Finally, NAI was defined as the ratio of *DE* to *CE*.

Data Analysis

The intrarater and interrater reliability of the measurements of arch height and NAI were evaluated. Intrarater reliability of measurements was determined by the intraclass correlation coefficients (ICCs) of the data of sixteen subjects measured by the same examiner on two different occasions which were temporarily separated by three days. The mark on the navicular tuberosity was cleared before the second examination was conducted. The interrater reliability of measurements was assessed by the ICCs from the data of the same sixteen subjects measured by two different examiners. The strength of correlation (validity) between NAI and normalized arch height was assessed with Pearson correlation coefficients.

RESULTS

Reliability of Arch Height and NAI Measure-ments

The calculated intrarater and interrater reliabilities are summarized in Table 2. NAI measurement has an excellent intrarater reliability (ICC = 0.95) and a good interrater reliability (ICC = 0.81). In addition, all considered measures had high intrarater reliability with ICCs over 0.91 and moderate interrater reliability with ICCs over 0.77. Intrarater reliability coefficients were consistently better than interrater reliability coefficients for both arch height and NAI measurement.

Table 2. Intraclass correlation coefficients for reliability of measurements of arch height and Navicular Arch Index (NAI)

	Intrarater	Interrater
Arch height	0.92†	0.78†
Arch height*	0.91†	0.77†
Foot length	0.98†	0.97†
NAI	0.95†	0.81†

*Normalized to footprint length
† $p<0.001$

Validity of NAI as a Measure of Arch Height

Means and standard deviations of the calculated NAI and the measured arch height taken on seventy subjects are shown in Table 3. Pearson correlation coefficients were calculated for NAI and normalized (foot length-adjusted) arch height. These results are also presented in Table 3. Significant correlations existed between NAI and foot length-adjusted arch height with coefficients between −0.68 and −0.72 ($p<0.001$).

DISCUSSION

Arch height of the foot has been one of the primary criteria for the classification of foot structures. In this

Table 3. Mean (SD) of the calculated Navicular Arch Index (NAI) and the measured arch height. The last column shows the slope and intercept of the regression line and the Pearson correlation coefficient, r, for NAI versus normalized arch height

	NAI	Arch height (cm)	Foot length (cm)	slope,	intercept,	r
Total feet	0.6743	2.81	19.83	− 0.192,	0.271,	− 0.70*
(n=140)	(0.0971)	(0.57)	(0.68)			
Right feet	0.6685	2.90	19.87	− 0.202,	0.280,	− 0.71*
(n=70)	(0.0918)	(0.55)	(0.64)			
Left feet	0.6800	2.72	19.79	− 0.185,	0.263,	− 0.70*
(n=70)	(0.1022)	(0.59)	(0.71)			
38 men	0.6771	2.90	20.57	− 0.206,	0.289,	− 0.72*
(n=76)	(0.1067)	(0.65)	(0.59)			
32 women	0.6685	2.69	18.96	− 0.172,	0.256,	− 0.68*
(n=64)	(0.0902)	(0.79)	(0.79)			

* $p<0.001$

study we assessed the reliability and validity of our new footprint parameter, the Navicular Arch Index, as a means to measure arch height. Our choice of digital caliper technique as the "gold standard" for describing arch height was based on the previous work of Hawes *et al.* [16] because of the caliper's accuracy and easy use. There are various points along the soft tissue margin of the foot that may be selected to represent arch height. In this study, we measured arch height as the distance between the bottom of the navicular tuberosity and the floor. Each measure of arch height was divided by the subject's toeless footprint length to define a normalized (foot length-adjusted) arch height. This measurement was based on the study of Saltzman *et al.* [6], who concluded that the navicular height-to-foot length ratio correlated most closely with the radiographic parameters of arch height, and thus might serve as the best anthropometric measurement to characterize arch structure.

Saltzman *et al.* [6] reviewed earlier studies on the reliability of clinical foot measurements and pointed out that highest reliability can be achieved when examiners are experienced in taking the measurement, when the same measurement device is used through testing conditions, and when measurements are taken in a weight-bearing position. We had considered these factors in this study and our results matched closely with those reported in published studies [6,16]. Our results were consistent with the literature in the finding that intrarater reliability was higher than interrater reliability for the antropometric and footprint measurements[6,16].

Previous investigations in the assessment of arch height from footprint parameters have yielded conflicting results. Cureton *et al.* [18] reported a significant correlation of 0.857 and 0.958 between arch angle and arch height on two sets of data. While Hawes *et al.* [16]performed regression analysis on the measured arch height to the five footprint parameters : arch angle, footprint index, arch index, arch length index, and truncated arch index and found no significant correlation between the arch height and each of the footprint parameters. However, results of our study showed that significant correlation did exist between NAI and arch height.

As we pointed out earlier, these conflicting results were probably caused by their failure to take anatomy into consideration in the previously proposed footprint parameters. Unlike other footprint parameters, NAI incorporated the concept of anatomy by calculating NAI from footprints corresponding to the site of the navicular tuberosity. In addition, there are two major differences in arch height measurement between this study and the study conducted by Hawes *et al.*. First, Hawes *et al.* measured arch height as the distance between the highest point along the soft tissue margin of the medial plantar curvature and the floor. This point seems to be more susceptible to soft tissue variation than the navicular tuberosity used in our study. Second, we describe arch height with normalized (foot length-adjusted) arch height rather than directly measured arch height under the consideration of individual variability in arch structure caused by differences in foot length.

Earlier large-scale foot surveys used footprint parameters to evaluate arch structure [6,8,15,19]. Compared with direct arch height measurement, NAI method is less expensive, timesaving, and easy to operate in evaluating arch structure and thus a more ideal parameter for a large-scale foot survey. In addition, we can obtain useful information of foot condition other than arch height by footprint analysis, such as outline of the foot, the length of foot arches, foot length, foot width, and plantar pressure points. These additional measures can not be provided by direct arch height measurement alone[21].

In summary, we developed a new footprint parameter, the NAI, to evaluate arch height and we assessed its reliability and validity. The unique feature of NAI is that it incorporates anatomical consideration into the calculation of footprint parameters. We concluded NAI to be a reliable and valid measurement of arch height, and thus may be clinically used to evaluate arch structure. For classification of foot arches by NAI, we are planning a large-scale foot survey to determine the means and standard deviations of NAI for people of different age groups.

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舟狀骨足弓指數：能信實有效評估足弓高度的足印參數

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近年來許多文獻指出足弓高度和運動相關性的傷害有密切的關係。足印分析在臨床上常用來評估足弓高度，具有便宜、簡單、無侵犯性的特色。然而現有的足印參數在評估足弓高度的效度方面結論並不一致。這可能是由於現有的足印參數只有幾何學的概念，缺乏解剖學的考量，因此無法眞切地代表足弓高度。

本研究提出一種新的足印參數 — 「舟狀骨足弓指數」，並研究該指數與足弓高度的相關性。「舟狀骨足弓指數」定義爲對應於舟狀骨粗隆位置的修正後足印寬度與足寬的比值。由於該指數是以舟狀骨粗隆爲測量標的，因此具有解剖學的考量。我們用數位化測量器直接測量 70 位健康成人（38 位男性，32 位女性）舟狀骨粗隆下緣的足弓高度，用足印分析計算出「舟狀骨足弓指數」，以簡單線性迴歸來分析「舟狀骨足弓指數」與足弓高度的相關性。研究結果顯示「舟狀骨足弓指數」的測量具有極佳的信度 (intrarater intraclass 相關係數爲 0.95; interrater intraclass 相關係數爲 0.81) 並和足弓高度呈現有意義的相關性（Pearson 相關係數爲－0.70, p＜0.001）。因此用「舟狀骨足弓指數」來評估足弓高度具有良好的信度與效度，可應用在臨床上評估足弓結構。（中華復健醫誌 1999; 27(4): 183 - 188）

關鍵詞： 舟狀骨足弓指數(navicular arch index)，足印參數(footprint parameter)，足弓高度(arch height)

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