Validity of a Simple Footprint Assessment Board for Diagnosing the Severity of Flatfoot: A Prospective Cohort Study

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Abstract

**Background:** A simple, non-quantitative, and cost-effective diagnostic tool would enable the diagnosis of flatfoot without need for specialized training. A simple footprint assessment board that investigates which toe the cord passes through from the centre point of the heel to the most lateral point of the medial contour of the footprint has been developed to assess flatfoot. The purpose of this study was to verify the validity of a simple footprint assessment board for flatfoot.

**Methods:** Thirty-five consecutive patients with foot pain, foot injury, or any associated symptoms who underwent computed tomography (CT) were analysed prospectively. At the time of the CT scan, a footprint analysis using a simple footprint assessment board was performed. The results for the arch height evaluated by CT using the navicular index was compared to those evaluated with the simple footprint assessment board by regression analysis.

**Results:** The navicular index generally decreased as the score of the simple footprint assessment board increased. As the scores of the simple footprint assessment board decreased by approaching the great toe, the navicular index was higher, which is indicative of a higher likelihood of flatfoot. The scores derived from the simple footprint assessment board was correlated with the navicular index measured by CT, not only when the result of simple footprint assessment board was set as a non-continuous variable but also when the result was set as a continuous variable.

**Conclusions:** The findings of this study suggest that a simple footprint assessment board can be potentially useful to detect flatfoot.

**Trial Registration:** retrospectively registered.

**Background**

Flatfoot deformity is a medical condition characterized by a flattened arch on the medial border of the plantar foot wherein the entire sole of the foot comes into near-complete contact with the ground [1]. The prevalence of flatfoot has been reported as approximately 26.5% [2, 3]. A compromised function of the foot arch may increase the risk of overuse injury and continuous pain, the former of which can cause advanced hindfoot deformity such as osteoarthritis of the subtalar and Chopart joints in patients with flatfoot [4, 5]. In addition, flatfoot is also associated with osteoarthritis of the knee and hip dysplasia, and early diagnosis and treatment are crucial for the prevention of disease progression [6, 7].

Several clinical diagnostic approaches have been adopted to identify flatfoot, including the assessment of clinical symptoms [8, 9], radiographic imaging [8, 10], and footprint analysis [11–14]. The most common diagnostic measure for flatfoot is the assessment of clinical symptoms and physical findings; however, the processes of evaluation can be subjective and may require clinical experience [15]. In the case of radiographic diagnosis, a set of angular parameters is used to assess the degree of deformity from standard dorsoplantar and lateral radiographs of the weightbearing feet [1]. There are several disadvantages associated with radiological assessment, including the difficulty in determining these angles, discrepancies in imaging quality due to varying competencies of radiologic technicians, inter- or intraobserver error, and exposure to radiation [8, 16–18].
On the other hand, footprint analysis is a simple, quick, cost-effective, and readily available method and has been recommended as a screening tool for flatfoot [11–14]. Although previous studies have developed various footprint analyses for the assessment of the arch that have been considered reliable by many researchers, these procedures require measurements of area, angle, and distance using an image of the footprint, in addition to occasional calculations to determine the ratio of the distances [11, 13, 14, 16]. A simplified and non-quantitative diagnostic tool would be greatly beneficial for medical workers to diagnose flatfoot without need for specialized training. A medical equipment manufacturer has recently developed a simple footprint assessment board that investigates which toe the cord passes through from the centre point of the heel to the most lateral point of the medial contour of the footprint with a thermochromic surface to describe the footprint and assess flatfoot; however, there has been no verification on the diagnostic accuracy obtained by this board. The purpose of this study was to verify the validity of a simple footprint assessment board for flatfoot. The hypothesis was that there is a correlation between the results of the simple assessment board and the radiological assessment for the diagnosis of flatfoot. If the hypothesis can be proven, a simple tool can be used for an accurate assessment of flatfoot without radiation exposure, high cost, and time-consuming measurements.

**Methods**

**Patients and Design**

Data for consecutive patients with foot pain, foot injury, or any associated symptoms who underwent computed tomography (CT) between January 2019 and June 2020 at a single institution were analysed prospectively. At the time of the CT scan, a footprint analysis using a simple footprint assessment board (Arch Check Board, NIPPON SIGMAX, Tokyo, Japan) was also performed. The results for the arch height evaluated by CT was compared to those evaluated by the simple footprint assessment board. The study protocol was approved by the institutional review board of the author’s institution and all patients provided informed consent. For patients under 18 years of age, informed consent was granted by their parents or legally authorized representatives. The exclusion criteria were as follows: history of lower extremity surgery, patients with symptoms that prevent them from loading their lower extremities, patients with a capillary refill time of more than 2 seconds who were not expected to produce a clear thermal impression on the thermochromic surface of the simple footprint assessment board.

**Measurements**

For each person included in this study, anthropometric variables (age, gender, and body mass index) were examined, in addition to the reason for undergoing CT. In this study, the validity to assess arch height was evaluated with a simple footprint assessment board. Patients placed their feet on a thermochromic sheet that was placed on the top of this board to check for discoloration. The discoloration produced an accurate footprint on the board. A cord was attached to the board which was fixed to the centre point of the heel with a magnet at its other end. To measure the arch height, the cord was set up to contact the most lateral point of the medial contour of the footprint and fixed to a magnetic strip located distally to the toes (Fig. 1). The evaluation was performed by determining which toe the cord passed through and scored as follows: 1, the cord passed through the footprint of the great toe; 2, through the second toe; 3, through the third toe; 4, through the fourth toe; 5, through the fifth toe. When the cord passed through the medial region of the great toe, the evaluation was defined as 0.5, and when the cord passed between toes, a score of 0.5 was added to the score of lesser toes (i.e., 1.5 when the cord passed between the great toe and second toe, and 2.5 when passed between second and third toes) (Fig. 2). This
measurement was performed by a skilled radiologic technician who was blinded to the patient's background. A greater score indicated a greater arch height.

CT (Toshiba Aquilion, Canon Medical Systems Cooperation, Otawara, Japan) was performed with the standard bone CT protocol with 0.5-mm axial sections in three planes, with a tube voltage of 120 kV. After creating a 3D computed tomography image, the navicular index was evaluated according to a method described by Roth et al. [19]. They introduced the navicular index as a new measure to distinguish between flatfoot and normal foot. A greater navicular index suggested a higher likelihood of a flatfoot. A line connecting the lowest point of the first metatarsal head to the lowest point of the calcaneus was created with the 3D CT image. The distance between the lowest point of the first metatarsal head and the lowest point of the calcaneus was defined as “the length of the longitudinal arch.” A plane was subsequently created to pass through the lowest point of the first metatarsal head, the lowest part of the fifth metatarsal head, and the lowest part of the calcaneus. The distance of the perpendicular line from the lowest point of the navicular bone to this plane was measured and defined as “the navicular height.” The navicular index which was calculated by dividing the length of the longitudinal arch with navicular height was investigated (Fig. 3). A higher navicular index indicated a lower arch height. SYNAPSE VINCENT Ver. 3.3 (FUJIFILM Cooperation, Tokyo, Japan) was used for this measurement as an image analysis software. CT images were evaluated independently by orthopaedic surgeons with 15 years of clinical experience and were blinded to the clinical and patient data.

The relationship between the results of evaluation by the simple footprint assessment board and the navicular index by CT was evaluated.

Intrarater reliability in the measurement of the simple footprint assessment board was assessed using the intra-class correlation coefficient (ICC). Measurements were repeated three times on each of the 10 randomly selected feet in this study.

**Statistical analysis**

When examining the relationship between the result of the simple footprint assessment board and the navicular index, the current study was analysed using dummy variables because the spacing of the toes was not consistent for each individual and was not a continuous variable [20]. The results of the simple footprint assessment board were set as explanatory variables and the navicular index was set as objective variables for the analysis. With the medial side of the first toe as a reference, a dummy variable was created as the results of the simple footprint assessment board (1 if applicable, 0 otherwise). Then, a regression analysis was conducted with all dummy variables as explanatory variables to evaluate how well the navicular index could be explained or predicted from the scores of the simple footprint assessment board. In addition to this, a regression analysis was conducted with the scores of the simple footprint as a continuous variable. The ICC was calculated using SPSS version 12 software (SPSS Inc., Chicago, IL).

The number of cases were difficult to set by power analysis in this test due to the use of dummy variables, and a statistician was consulted prior to determining the number of cases. The number of cases that could be secured for each assessment board value for arch height (divided into 8 levels between the medial side of the first toe to the fourth toe) was set as over 32, which equated to approximately 4 cases each.

**Results**
The current study examined 35 feet of 30 patients with a mean age of 44.7 years. The patient characteristics are shown in Table 1. This included two patients who had already been diagnosed with flatfoot from clinical findings.

Table 1
Patient characteristics

|                      | 35 (30 patients) |
|----------------------|------------------|
| Mean age             | 44.7 (14–85)     |
| Sex                  | Male, 21; Female, 9 |
| Affected side        | Right, 20; Left, 15 |
| Mean height (cm)     | 163.8 ± 9.5      |
| Mean weight (kg)     | 62.5 ± 14.7      |
| Mean BMI             | 23.2 ± 5.1       |
| Reason for undergoing CT |       |

Foot injury: 14
Foot pain: 5
Hallux valgus: 4
Lisfran osteoarthritis: 4
Accessory navicular: 3
Flat foot: 2,
Ankle sprain: 1,
Plantar fasciitis: 1
Sesamoid bones: 1

Regression analysis with the scores of the simple footprint assessment board as a dummy variable showed that when a footprint assessment board score of 0.5 was set as the reference point, the regression coefficients generally decreased as the simple footprint assessment board score increased (Table 2). Although the coefficient factor for a score of 2.5 was greater than that of 2, the rest of the results showed that the navicular index decreased as the scores of the simple footprint assessment board increased. As the scores of the simple footprint assessment board decreased by approaching the great toe, the navicular index was higher, which is indicative of a higher likelihood of flatfoot. In addition, regression analysis with the value of the simple footprint assessment board as a continuous variable showed that there was a significant correlation between the score of simple footprint assessment board and navicular index: $y = -0.883x + 6.505$, $p < 0.001$.

ICC of the simple footprint assessment board based on the data of 10 feet in this study was 0.94.
Table 2

A: Regression analysis with the value of the simple footprint assessment board as a dummy variable

| Score of arch check board | n | Mean navicular index | Regression factor | Standard error | t-value | P-value | Coefficient of determination | Adjusted coefficient of determination |
|---------------------------|---|----------------------|-------------------|----------------|---------|---------|-----------------------------|---------------------------------------|
| (Intercept)               |   |                      | 6.370             | 0.479          | 13.299  | 0.000   | 0.658                       | 0.569                                 |
| Score 0.5 (Reference)     | 2 | 6.4                  |                   |                |         |         |                             |                                       |
| Score 1                   | 5 | 6.0                  | -0.382            | 0.567          | -0.674  | 0.506   |                             |                                       |
| Score 1.5                 | 5 | 5.2                  | -1.200            | 0.567          | -2.117  | 0.044   |                             |                                       |
| Score 2                   | 9 | 4.4                  | -1.974            | 0.530          | -3.729  | 0.001   |                             |                                       |
| Score 2.5                 | 6 | 4.5                  | -1.905            | 0.553          | -3.444  | 0.002   |                             |                                       |
| Score 3                   | 6 | 3.9                  | -2.465            | 0.553          | -4.457  | 0.000   |                             |                                       |
| Score 3.5                 | 1 | 3.7                  | -2.670            | 0.830          | -3.218  | 0.003   |                             |                                       |
| Score 4                   | 1 | 3.0                  | -3.370            | 0.830          | -4.062  | 0.000   |                             |                                       |

Score of arch check board (explanatory variables: x)
Navicular index (objective variables: y)

Table 2

B: Regression analysis with the value of the simple footprint assessment board as a continuous variable

| Score of arch check board | Regression factor | Standard error | t-value | P-value | Coefficient of determination | Adjusted coefficient of determination |
|---------------------------|-------------------|----------------|---------|---------|-----------------------------|---------------------------------------|
| (Intercept)               | 6.505             | 0.277          | 23.470  | 0.000   | 0.602                       | 0.590                                 |
| Score                     | -0.883            | 0.125          | -7.060  | 0.000   |                             |                                       |

Score of arch check board (explanatory variables: x)
Navicular index (objective variables: y)

Discussion

Our results clearly indicate that arch height which was evaluated by the simple footprint assessment board was correlated with the navicular index by CT. This means that simple footprint assessment board can potentially be a substitute to CT for the diagnosis of flatfoot.

Various footprint-based analyses for foot arch assessment have been developed in previous studies. A previous report by Cavanagh and Rodgers measured and calculated the arch index as defined as the proportion of area for
the middle third and total toeless footprint [21]. Other reports have described the use of Irwin's footprint index or similar modified approaches to determine the severity of flatfoot by calculating the area of the arch in a footprint [12, 22, 23]. Another common assessment is the use of Clarke's angle, which is calculated by the angle between 1) the medial tangential line joining the medial margin of the first metatarsal head/heel, and 2) the line joining the first metatarsal head and apex of the concavity in the medial longitudinal arch [12, 14, 24, 25]. Forriol and Pascual described the use of Chippaux-Smirak index to determine foot arch development, which was calculated by the ratio of the maximum width of the metatarsals to the minimum width of the arch [12, 14, 25–27]. In addition, Staheli et al. developed an index for plantar arch as defined by the ratio of the midfoot- to hindfoot-width that is used as an indicator of foot arch development [12, 14, 27, 28]. Many researchers have recommended these procedures for foot arch assessment as a reliable screening method [12, 13]. These procedures are simple and do not require any special equipment; however, the diagnostic methods require difficult and time-consuming tasks such as the measurement of area, angle, distance in addition to the calculation of their ratio [14].

Because flatfoot is a common disorder, a simpler and quicker diagnostic tool for flatfoot may be useful for a more diverse range of medical and healthcare professionals. The diagnosis of the disorder has to be dealt with across a spectrum of practitioners that is not limited to orthopaedic surgeons but also those who do not normally perform radiographic examinations, such as family practitioners, non-physicians, physical therapists, athletic trainers, orthotic prosthetists, and shoemakers. In this study, the effectiveness of a simple footprint assessment board that investigates which toe the cord passes through from the centre point of the heel to the most lateral point of the medial contour of the footprint with a thermochromic surface was evaluated. This board features the ability to accurately reproduce a footprint by the discoloration of its surface according to the patient's foot temperature, and the degree of flatfoot can be examined using the image of the footprint on the board by checking which toe the cord passes through from the centre point of the heel to the most lateral point of the medial contour of the footprint. Traditionally, a pedograph has been used for footprint analysis. This device consists of an inked rubber membrane of small grid lines that are imprinted on an underlying sheet of paper when a foot passes over it. In contrast, the simple footprint assessment board can be repeatedly used without ink or paper.

As a result of this study, the scores of the simple footprint assessment board was correlated with the navicular index measured by CT, not only when the result of the simple footprint assessment board was set as a non-continuous variable but also when the result was set as a continuous variable. The intrarater reliability of the simple footprint assessment board, which was measured three times on each of the 10 randomly selected feet in this study, was high. Therefore, the data obtained from this simple footprint assessment board proved to be reproducible and reliable.

In the present study, we used the navicular index reported by Roth et al. [19]. They reported that values of the navicular index for flatfoot were in the interval from 4.75 to 31.20 (median 8.98) and for normal-arched foot 3.58 to 22.6 (median 5.48). Two of 35 feet had already been diagnosed as flatfoot based on clinical findings. The navicular index values of these 2 feet were 7.32 and 6.76, and the scores in the simple footprint assessment board were 0.5 and 1, respectively. These results for known cases of flatfoot suggest that the diagnosis of flatfoot is highly likely if the cord of the simple footprint assessment board either passes through the great toe or over its medial side.
The height of the navicular bone was assessed using CT images instead of radiographic images in this study. The measurements of various angles on radiographs are always challenging due to superimposition of the bones. Furthermore, radiographs lack reproducibility and are associated with rotational and fan distortions [18]. In contrast, CT images have the advantage of multiplanar capabilities and higher resolutions. Thus, this allowed for more accurate measurements than radiographic images.

This study has limitations. Firstly, CT images were taken in the supine position and did not undergo imaging under load. Compared with nonweightbearing images, weightbearing images better demonstrate the severity of osseous derangement in patients with flat foot [29]. The results of the present study can show the usefulness of the simple footprint assessment board to diagnose rigid flat foot which is a loss of medial arch in an unloaded condition. On the other hand, the validity of this board for the diagnosis of flexible flatfoot, which is loss of the inner arch in a loaded condition and more common in children, could not be examined because nonweightbearing CT images were applied to measure the navicular index. Future research should be conducted with weightbearing CT images for radiological evaluation to clarify the usefulness of simple tools like the simple footprint assessment board for diagnosis of flexible flatfoot. Secondly, all included patients suffered from foot pain, foot injury, or symptoms around the foot and underwent CT due to further examination for diagnosis. The disorders of the patients included in the study may influence the results. Nevertheless, the findings of this study suggest the possible clinical application of the simple footprint assessment board to detect flatfoot.

Conclusions

The findings of this study suggest that a simple footprint assessment board can be potentially useful to aid the detection of flatfoot without need for specialized training. Further studies with a larger sample size and greater variation of comparative radiological indices should be conducted to validate the simple footprint assessment board as a standard procedure for the diagnosis of flatfoot.

Abbreviations

CT: computer tomography

ICC: intraclass correlation coefficient

Declarations

Ethics approval and consent to participate:

The study protocol was approved by the institutional review board of Teikyo University and all patients provided informed consent. For patients under 18 years of age, informed consent was granted by their parents or legally authorized representatives. All experiments were performed in accordance with the Declaration of Helsinki.

Consent for publication:

Not applicable.
Availability of data and materials:
The datasets generated and/or analysed during the current study are available in the UMIN repository. UMIN000042719

Competing interests:
The authors declare that they have no competing interests.

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Authors' contributions:
ST and NS conceived and designed the study, analysed and interpreted the patient data, and wrote the initial draft of the manuscript. YY, SA, and TN were major contributors in writing the manuscript. HK aided in the interpretation of results. WM was in charge of overall direction and planning. All authors read and approved the final manuscript.

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**Figures**
Figure 2

Scoring for the simple footprint assessment board

Figure 3

The methodology of measuring the longitudinal arch length and navicular height with 3DCT imaging 3A: The length of the longitudinal arch 3B: The navicular height