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Original Research

Examination of the Correlation Between Foot Morphology Measurements Using Pedography and Radiographic Measurements

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A R T I C L E I N F O

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A B S T R A C T

Pedography provides excellent visualization of the footprint. However, the correlation between the footprint images and radiographic measures has not been thoroughly evaluated. Therefore, the objectives of our study were to examine the correlation between the pedography-based measures of foot morphology and radiographic measurements and to propose reference values for the diagnosis of flatfoot using footprint imaging. The plantar footprints of 100 right feet were photographed using a pedography standing platform. The sole and arch areas were measured to calculate the footprint index (FPI). The lateral talar–first metatarsal angle (LTM) and calcaneal pitch angle (CP) were measured on standing lateral radiographs, and the talonavicular coverage angle was measured on frontal radiographs. The Pearson moment correlation between the FPI and radiography-based measures was calculated. The area under the receiver operating characteristic curve was calculated using an LTM of $<-4°$ as the identifying criterion of flatfoot. The sensitivity and specificity of FPI were calculated for LTM values $<-4°$. The FPI correlated with the LTM ($y = -17.964 \pm 52.644x$, $R = 0.588$) and CP ($y = 9.2304 \pm 27.739x$, $R = 0.659$) but not with the talonavicular coverage angle ($y = 26.01 \pm 15.78x$, $R = 0.207$). The area under the receiver operating characteristic curve was 0.753, with a cutoff FPI of 0.208, yielding a sensitivity of 0.462 and specificity of 0.934 for flatfoot identification. Pedography could provide an easy screening tool for flatfoot, with an FPI cutoff of 0.208, yielding a specificity of 93.4%.

Flatfoot is a deformity characteristically defined by a visible collapse of the medial longitudinal arch. The following anatomic abnormalities are commonly associated with the collapsed medial longitudinal arch: a valgus posture of the heel; mild subluxation of the subtalar joint, resulting in a medial and plantigrade tilt of the head of the talus, which will appear foreshortened on standing dorsoplantar radiographs; eversion of the calcaneus at the subtalar joint; lateral angulation (abduction) at the talonavicular and calcaneocuboid joints (i.e., the midtarsal joints); and supination of the forefoot relative to the hindfoot, placing the first ray in a plantigrade position (1). Flatfoot commonly develops in sports injuries as a secondary adaptation to lower limb injuries, including medial tibiofemoral cartilage damage (2), anterior knee pain (3), and musculoskeletal overuse injury (4). Orthotic treatment and other conservative therapies have been considered effective for correction of the foot position and relief of clinical symptoms of a flatfoot (5). Orthotics can also play a role in the prevention of sport injuries by supporting the appropriate alignment of the foot. Thus, it follows that screening procedures could be beneficial from the standpoint of sport injury prevention, providing early identification of flatfoot in athletes, combined with effective management, such as the use of orthotics.

Flatfoot is typically diagnosed through a comprehensive physical examination. The following features are characteristic of flatfoot: collapse of the medial longitudinal arch, external rotation of the calcaneus, and eversion of the anterior foot (6). Weightbearing radiographs are used to confirm the diagnosis of flatfoot, with the following measurements widely used: the talonavicular coverage angle (TNC), measured on anteroposterior images (7), and the lateral talar–first

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metatarsal angle (LTM) (8) and calcaneal pitch angle (CP) (9), measured from lateral images. Although useful, radiographic examination can only be performed in medical centers. Radiation exposure further limits the use of radiographs as a tool for primary sports screening.

Footprint imaging can provide an efficient method for flatfoot screening and evaluation. Among the methods available, pedography standing systems are well suited for direct visualization of the footprint, making them applicable to primary screening of athletes to identify foot deformities. A variety of methods have been reported to categorize foot morphology using footprint images. The arch angle, footprint index (FPI), arch index (AI), arch length index, truncated AI, Staheli's index, and Chippaux-Smirak index (10–12) have been described and used. Queen et al (13) studied the relationships between different image-based measurements and the physical findings, reporting a strong correlation between the FPI and navicular height and between the FPI and the normalized navicular height. Despite the clinical need to better define the usefulness of image-based evaluation of the foot, few studies have examined the relationship between the footprint findings and radiographic measurements (12,14,15). Therefore, the applicability of pedography as an alternative to radiographic examination remains unclear. We hypothesized that the changes associated with flatfoot seen on radiographs could be predicted from the footprint assessed by pedography. Accordingly, the objectives of our study were to examine the relationship between pedography-based measures of foot morphology and radiographic measurements and to propose reference values for the diagnosis of flatfoot using footprint imaging.

Materials and Methods

Our study was conducted using the ethical screening standards of our institution, in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) and was approved by the institutional review board of Kyoto Prefectural University of Medicine (approval no. ERB-C-296). The participants were 105 patients who had visited our hospital for outpatient surgical foot care and consented to undergo radiographic and pedographic examinations. The participants provided informed consent, and the rights of the participants were protected. The radiographs of the patients who had undergone foot or ankle surgery or presented with joint deformities were excluded. The radiographs of 100 right feet, contributed by 100 patients (24 males, 76 females, age 12 to 85, mean 57.8 ± 20.2 years) were included in the present analysis. The patients' height and weight were measured during the outpatient visit and used to calculate the body mass index (BMI).

Footprint Imaging

The footprints were photographed using a standing platform foot morphology imaging device (foot stand analyzer; Rehabitech, Kyoto, Japan). The foot stand analyzer consists of a 4-legged table with a flat glass plate built into the top, allowing a plantar view of the sole of the foot as the individual stands on the glass plate (Fig. 1*A*). The images were uploaded to an image analysis program (ImageJ, version 1.48v; National Institutes of Health, Bethesda, MD), and the area of the sole that was in contact with the glass plate was colored in manually with a single color to create the footprint. The arch area was defined as the area between a line tangent to the medial border of the footprint and the medial border of the footprint. The sole area was defined as the area of the sole that was in contact with the glass plate, minus the area under the toes. The arch and sole areas were calculated using ImageJ software (National Institutes of Health). The FPI was calculated by dividing the arch area by the sole area (Fig. 1*B*) (10).

Radiography

The LTM (8) and CP (9) were measured on lateral, weightbearing radiographs of the foot (Fig. 2*A*). TNC (7) was measured on dorsoplantar, weightbearing radiographs (Fig. 2*B*). Flatfoot was defined as an LTM $<-4°$.

Statistical Analysis

We investigated the repeatability of FPI, LTM, CP, and TNC measurements by determining the intrarater and interrater repeatability in 20 randomly selected cases. The intrarater repeatability of the measurement was determined by the correlation of the data from 20 subjects measured on 2 different occasions by same person. The interrater repeatability of the measurement was examined by computing the correlation of the same 20 subjects measured by 2 different persons.

The mean ± standard deviation was calculated for all variables. Pearson's correlation coefficient and the linear regression line for each analysis was calculated for the relationship between the FPI and the BMI, LTM, CP, and TNC, with the level of significance set at $p < .05$. Using the statistical methods described by Colton (16), we considered correlation coefficients of 0.00 to 0.24 to be indicative of little or no association between variables, 0.25 to 0.49 to be indicative of a fair association, 0.50 to 0.74 to be indicative of a moderate to good association, and 0.75 to 1.00 to be indicative of a good to excellent association. To determine the optimal FPI cutoff to differentiate a normal foot from a flatfoot, a receiver operating characteristic curve was constructed

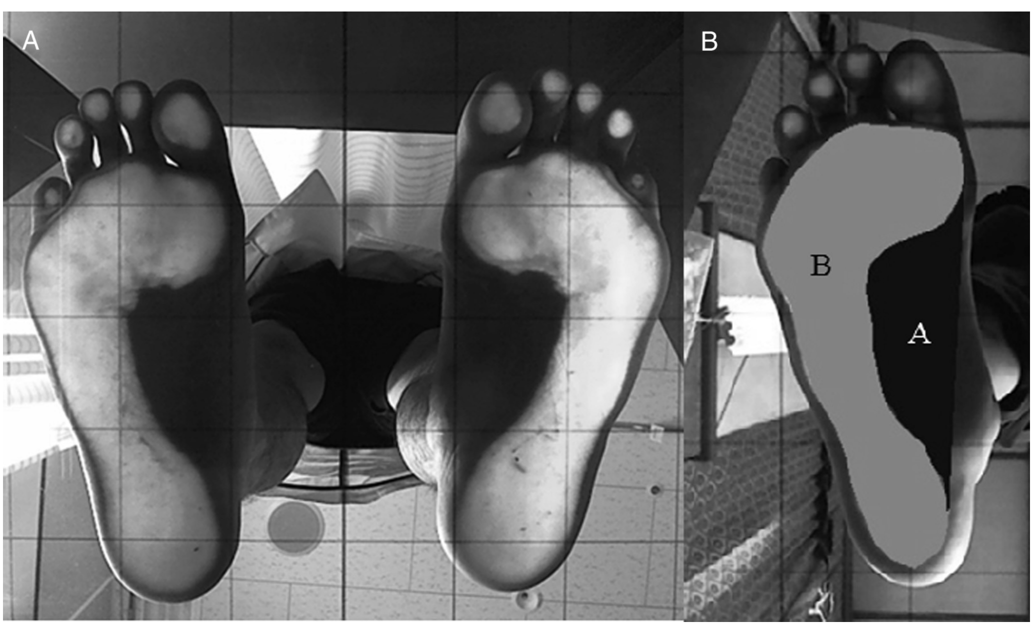

Fig. 1. Footprint measurements, showing *(A)* a participant standing comfortably on the glass plate of the pedography system, the feet shoulder-width apart, with the soles of the feet photographed from underneath, and *(B)* the area of the sole in contact with the glass plate filled in with a single color to create the footprint. The area of the arch was defined as the area enclosed between a straight line drawn along the medial footprint and the medial border of the footprint (A). The area of the sole was defined as the area in contact with the glass plate, minus the toes (B). The footprint index was calculated as A divided by B.