

The validity and reliability of various footprint analysis in flatfoot diagnosis of competitive athletes

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The validity and reliability of various footprint analysis in flatfoot diagnosis of competitive athletes



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ABSTRACT

Background: Foot morphology is an essential intrinsic factor in athlete performance. Therefore, abnormality of the foot morphology, such as flatfoot, can affect the foot biomechanics, reduce motor performance, and increase the risk of injury. Assessment of flatfoot in the competitive athlete is essential to decide on the appropriate management; however, the imaging evaluation method needs special equipment and experience. Footprint analysis using Clarke's angle (CA), Chippaux Smirak Index (CSI), and Staheli Index (SI) offers a cheaper, faster, more effective, and easier method for flatfoot diagnosis. This study aims to determine the validity and reliability of various footprint analysis with calcaneal inclination angle (CIA) from the radiographic image as the standard examination.

Method: This is an analytic observational study with a retrospective cohort design. The data of CIA, CA, CSI, and SI were collected from 70 athletes' medical records from 6 different sports that met inclusion criteria. The validity, reliability, diagnostic performance, and determination of the cut-off point were performed.

Results: The correlation test and intraclass correlation coefficient showed that CSI and SI were valid and reliable in diagnosing flatfoot, while CA was invalid but reliable in diagnosing flatfoot. Area under the curve of the ROC curve and the cut-off point of CA were 0.427 ($p=0.403$) and 39.32°; CSI was 0.446 ($p=0.537$) and 33.58; and SI was 0.418 ($p=0.347$) and 73.59, respectively. The sensitivity and specificity of CA were 26.78% and 100%; CSI was 10.71% and 100%; and SI was 78.57% and 78.57%, respectively.

Conclusion: Footprint analysis using CA is not valid but reliable in diagnosing flatfoot, while CSI and SI are valid and reliable in diagnosing flatfoot. The Staheli Index has the best diagnostic performance compared to others.

Keywords: competitive athlete, flatfoot, footprint analysis.

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INTRODUCTION

Flatfoot or pes planus is characterized as the collapsed medial longitudinal arch of the foot. The medial longitudinal arch is an essential element of stability and resistance to the foot. It also acts as the main load-bearing and shock-absorbing component of the foot.¹

The normal foot consists of the medial and lateral longitudinal and transversal arch. The bones and fibrous tissue maintain the integrity of the arch as the passive component and the intrinsic muscle of the foot as the dynamic support.² The foot arch has several points of contact with the surface, including the head of the first and fifth metatarsal, posteromedial tubercle, and lateral calcaneus. Each point of contact was connected to the medial and

longitudinal foot arch and drawn as the footprint.³

Flatfoot and high arch are the most common deformity occurred in the athlete. The prevalence of flatfoot in adults ranges from 5% to 20%, and flexible flatfoot is the most common type. The prevalence of flexible flatfoot is 13.6%, with a ratio of 12.8% for males and 14.4% for females.⁴ The incidence of flatfoot differs in each country, which is 20% of the population in the United States and 5% in Saudi Arabia.⁵ Several studies in Indonesia showed that 40.4% of 57 college students had flatfoot, and 7 out of 28 basketball athletes had flatfoot.⁶

Foot morphology is essential to the lower extremity performance of competitive and contacts sports athletes

that require weight-bearing, running, and jumping activities, for example, handball, wrestling, marathon, soccer, basketball, and gymnastics.⁷ Foot morphology is one of the intrinsic factors affecting foot biomechanics and motoric performance that affects postural control resulting in balance disorder. It increases the risk of lower extremity injury, mainly on the ankle, followed by the knee, hip, and thigh.^{8,9}

Arch deformity must be identified as early and accurately as possible. The standard examination to determine the arch structure is the lateral view of the foot plain radiographic examination in a weight-bearing position to measure the calcaneal inclination angle.¹⁰ Because the examination was limited to the

radiologist, a simple diagnostic tool would be advantageous to another clinician for flatfoot diagnosis in competitive athletes. On the other hand, footprint analysis using Clarke's angle (CA), Chippaux Smirak Index (CSI), and Staheli Index (SI) provides a simple and non-invasive method that has a high level of consistency and validity for flatfoot diagnosis.^{11,12} However, the validity and reliability of various footprint analysis in flatfoot diagnosis of competitive athletes have not been determined. The objective of our study was to determine the validity and reliability of various footprint analysis using the calcaneal inclination angle of the radiographic image as the standard examination.

METHOD

This study is an analytic observational study with a retrospective cohort study design. The population of this study was 87 footprints from all medical records of six competitive athletes' sports branches (wushu, athletics, fencing, handball, wrestling, and gymnastics) that underwent screening examination in Sports Clinic dr. Soetomo General Hospital, Surabaya in March 2020. The sample size was measured with a confidence interval level of 95%, a power level of 80%, and a precision of $\pm 5\%$. A total of 70 athletes' footprints are enrolled in this study. Sixty-four (128-foot) competitive athletes suspected of having flatfoot at screening underwent lateral view of plain foot radiograph and conventional water-soluble ink footprints. The screening was done at Sports Clinic dr. Soetomo General Hospital Surabaya in March 2020. Eighty-seven-foot competitive athletes were categorized as having flatfoot based on the Calcaneal Inclination Angle (CIA) from foot radiograph (less than 20°) were included in the study population. A simple random sampling of 70 feet aged 17 – 30 years (mean age \pm SD of 22.30 ± 4.13) were recruited from the study population and already met the inclusion criteria.

The inclusion criteria are male or female from six competitive athletes' sport branches (wushu, athletics, fencing, handball, wrestling, and gymnastics), aged 17 – 30 years diagnosed with flatfoot from lateral view radiograph (CIA less than 20°)

and have a medical record that contains complete data of subject and variable characteristics. The exclusion criteria are the medical records that did not contain complete data on the subject and variable characteristics.

Procedures

Our study protocol has obtained ethical approval from the institutional review board of the author's institution with an ethical clearance number 0477/LOE/301.4.2/V/2021. The characteristics of each athlete were obtained and examined from the medical record, including age, gender, Body Mass Index, type of sport, history of injury and surgery, and frequency of strengthening exercise.

The lateral view of the plain foot radiograph (GE - Optima XR646 - Digital Radiography X-Ray System) collected from the medical record was done by a qualified radiographer and standardized method in a weight-bearing - standing position. The calcaneal inclination angle is obtained from the angle between the lines extending from the inferior border of the calcaneocuboid joint to the horizontal line throughout the plantar aspect of the calcaneus to the plantar surface of the fifth metatarsal head. The measurement of CIA was done by an experienced radiologist. An experienced radiologist was defined as a radiologist with considerable practical and research experience to distinguish between normal anatomy, variations in anatomy, and aberrations in anatomy that showed in x-ray examination.

The footprints collected from the medical record were obtained using the standard method. Each athlete was seated and asked to stand up and press intensely over the inked rubber pad. The athlete was then asked to back to the sitting position and lift their foot from the inked rubber pad. The athlete then requested to stand steady on the graph sheet with equal pressure on both feet. The athlete then requested to be back in a sitting position and lift their foot from the graph sheet.

Clarke's angle was measured by a tangent line connecting the medial edges of the first metatarsal head and the heel and the line that connects the first metatarsal head and the acme of the medial longitudinal arch concavity. The

Chippaux-Smirak index was measured as the ratio of the maximum width of the metatarsals to the minimum width of the midfoot. The Staheli index was calculated as the ratio of the midfoot's width to the rearfoot's width.

Athletes are defined as someone who has a profession disengaged in a particular sport and excel in that sport and requires strength, agility, and speed to develop the physical, spiritual, and social potential that attends regular training and championships with total dedication to achieving achievements.

Statistical analysis

Descriptive data analysis was performed to determine the subject and variable characteristics using IBM SPSS Statistics 26.0 software. The continuous data were expressed as mean (standard deviation [SD]), whereas the categorical data were expressed as an absolute value (n) and percentage (%). Data normality and homogeneity were investigated using One-Sample Kolmogorov - Smirnov test. Pearson's correlation was performed to determine the validity of CA, CSI, and SI to CIA. The intraclass correlation coefficient (ICC) was examined to determine the intrarater reliability of each footprint analysis. The Cronbach's alpha was compared to the r values on the distribution table with a sample size of 70 and a significance of 0,05 ($r = 0,235$). If Cronbach's alpha exceeded the r values on the distribution table, it could be concluded that the footprint analysis is reliable. We calculate diagnostic performance, including sensitivity, specificity, positive predictive value, and negative predictive value for each footprint analysis. ROC curve analysis was performed to determine the cut-off point of each footprint analysis.

RESULTS

The current study assesses 70 footprints of 34 male and 36 female competitive athletes (Figure 1).

The characteristics of competitive athletes are shown in Table 1. The mean age of the subjects is 22.30 ± 4.13 years old. The mean body mass index of the subjects is 24.44 ± 4.79 kg/m². The ligament laxity of the subjects is 2.63 ± 2.71 . The research subjects were from six different sports

branches, 19 wushu athletes (27.14%), two athletics athletes (2.85%), 21 fencing athletes (30%), six handball athletes (8.57%), 18 wrestling athletes (25.71%), and four gymnastic athletes (5.71%).

Thirteen (18.57%) athletes have had a history of a knee injury, 16 athletes

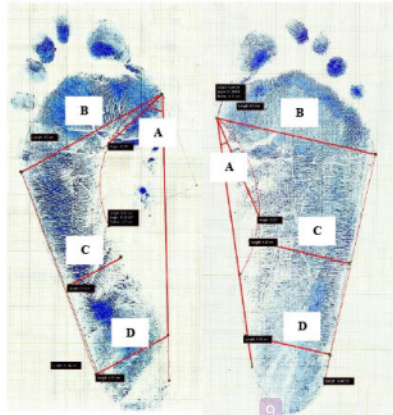


Figure 1. The result of Clarke's angle (A), Chippaux - Smirak Index (B/C), and Staheli Index (C/D) measurement from athlete's footprint.

(22.85%) athletes had a history of an ankle injury, and 5 athletes (7.14%) had a history of both knee and ankle injuries. Four athletes (5.71%) had a history of knee surgery, and two (2.85%) had a history of ankle surgery. Fifteen (21.42%) athletes had 1-2 times strengthening exercise in a week, 35 (50%) athletes had 3-5 times strengthening exercise in a week, and 20 (28.57%) athletes had more than 5 times exercise in a week.

Variable characteristics are shown in Table 2. The mean Calcaneal Inclination Angle of subjects was $15.70 \pm 1.90^\circ$. The mean Clarke's Angle of subjects was $40.49 \pm 12.29^\circ$. The mean Chippaux Smirak Index of subjects was 36.20 ± 9.16 . The mean Staheli index of subjects was 70.52 ± 16.76 . Kolmogorov - Smirnov test showed that the data distribution was normal ($p = 0,200$).

The correlation coefficient and intraclass correlation coefficient for validity and reliability assessment of each footprint analysis, diagnostic performance, the area under the curve, and cut-off point, are shown in Table 3. There were no missing

data in our study.

The coefficient of Pearson's correlation for SI was the highest ($r=-0.250$ [$p=0.037$]) compared to CSI ($r=-0.236$ [$p=0.049$]) and CA ($r=-0.004$ [$p=0.973$]). The result also showed that SI and CSI were valid, while CA was not valid for flatfoot diagnosis in competitive athletes. The intraclass correlation coefficient showed that the CA, CSI, and SI were reliable in the flatfoot diagnosis of competitive athletes. The area under the curve of the ROC curve and the cut-off point of CA, CSI, and SI were 0.427 ($p=0.403$) and 39.32° ; 0.446 ($p=0.537$) and 33.58 ; 0.418 ($p=0.347$) and 73.59 , respectively. The sensitivity and specificity of CA, CSI, and SI were 26.78% and 100%; 10.71% and 100%; 78.57%, and 78.57%, respectively.

DISCUSSION

The mean age of the subjects of this study is 22.30 ± 4.13 years old. The mean age is similar to the previous study by Hahn *et al.* (14-24 years), Dingenen *et al.* (16-27 years), and Troester *et al.* (24.5 ± 3.7 years). Age could affect foot structure and function, including force and pressure on the dynamic components that maintain the foot arch.¹³⁻¹⁵ The gender comparison of this study was similar. Gender needs to be considered because it can affect the structure of the pelvis and foot arch alteration. Females tend to have relatively larger hip circumferences than males, affecting quadriceps angle at age 10 - 19 years old.¹⁶ A larger quadriceps angle could lead to valgus compensation and flatfoot deformity. Ligament laxity causes joint hypermobility in the subtalar joint and loss of mechanic efficiency of tibialis posterior muscle insertion to the navicular bone as foot arch stabilization.^{17,18}

Our subjects came from six different competitive sports. In competitive sports, exercises are carried out earlier as the musculoskeletal system is immature, increasing the development of a flatfoot. As competitive sports frequently do strengthening exercise, as much as 3 - 5 times a week, repetitive movements exerts a higher load on the feet and affect the arch structure.

Table 1. Characteristics of competitive athletes.

Subject Characteristics	n	Mean \pm SD	p
Age (year)	70	22.30 \pm 4.13	0.463
Gender (male/female)			
Male	34		
Female	36		
Body mass index (kg/m ²)	70	24.44 \pm 4.79	0.000*
Ligament laxity	70	2.63 \pm 2.71	0.000*
Sport branches			0.056
Wushu	19		
Athletic	2		
Fencing	21		
Handball	6		
Wrestling	18		
Gymnastic	4		
History of injury			0.664
Knee	13		
Ankle	16		
Knee & ankle	5		
History of surgery			0.019*
Knee	4		
Ankle	2		
Knee & ankle	0		
Frequency of strengthening Exercise			0.067
1 - 2x/ week	15		
3 - 5x/ week	35		
\geq 5x/ week	20		

*Significant if $p < 0.05$

Validity of Footprint Analysis in Diagnosing Flatfoot of Athlete

This study demonstrated that Staheli Index has good validity, reliability, and diagnostic performance compared to Clarke's angle and Chippaux Smirak Index. Our study was consistent with Queen *et al.*, which demonstrates that the rearfoot angle affects the footprint; therefore, the Calcaneal Inclination Angle best correlates with Staheli Index because both are measured in the rearfoot.¹⁷

On the other hand, our study was inconsistent with Kanatli *et al.*, which demonstrated a positive correlation between CA with lateral talo - horizontal and lateral talo first metatarsal angle from a radiograph. Villaroya *et al.* also showed that CA and CSI have significant correlation talus - first metatarsal angle and calcaneal inclination angle. Koirala *et al.* also suggest that variability in sample characteristics, sample age group, and diagnostic procedures also affect the result flatfoot measurement.¹⁸⁻²⁰ In addition, variability of the medial longitudinal arch decreases the accuracy of bony landmark identification.²¹

Our study uses calcaneal inclination angle from lateral view radiographs as the gold-standard examination. It has good reliability yet has several disadvantages, including the difficulty in obtaining the correct angle, the disparity in radiograph quality due to varied competency of the radiographer, and inter or intraobserver

error. Therefore, advanced imaging method such as computed tomography (CT) as gold-standard examination provides higher resolution and increased measurement reliability.²¹

In addition, a previous study by Toyooka *et al.* used the thermochromic discoloration footprint analysis method. This method could increase footprint reproduction accuracy using discoloration of the foot surface based on the foot's temperature. In contrast, the conventional method can show inconsistent results if done repeatedly or using inadequate ink. Variable soft tissue thickness around the foot also complicates arch landmark identification.²¹ On the other hand, conventional footprints are easy to perform, inexpensive, have a strong visual impact, and can be retained as a permanent record for future comparisons. Hence, the diversity of footprint acquisition methods needs to be verified in competitive athletes as the supporting examination of flatfoot diagnosis.¹⁷

Reliability of Footprint Analysis in Diagnosing Flatfoot of Athlete

Using CA, CSI, and SI, footprint analysis demonstrated low to moderate intrarater reliability with intraclass correlation coefficients of 0.414, 0.251, and 0.649, respectively. Our study was inconsistent with the result of Queen *et al.*, which shows excellent intrarater reliability of the Chippaux Smirak Index and Staheli Index

(ICC = 0.96). Moreover, their population (healthy participants), sample size (n = 60 feet), inclusion criteria, and footprint measurement differed from our study. Furthermore, their study used mirrored foot photo box that demonstrates excellent reliability. On the other sides, the difference in the timing of radiograph examination and footprint analysis can lead to low-reliability values.¹⁷

In addition, several points throughout the soft tissue border of the foot may be chosen to indicate arch height. Toyooka *et al.* show that the intraclass correlation coefficient of footprint analysis was 0.93, while interobserver and intraobserver variability of calcaneal inclination angle were 0.93 and 0.89. Furthermore, the value is similar to the navicular index (0.99 and 0.89) and tibio-calcaneal angle (0.92 and 0.94); hence, landmark selection differences can affect the reliability of footprint analysis. A standardized method of footprint recording and experienced examiners can improve the reliability of footprint analysis and describe the actual foot arch condition.²¹

Diagnostic Performance of Footprint Analysis in Diagnosing Flatfoot of Athlete

Our study showed that SI had good sensitivity (78.57%) and specificity (78.57%) in the flatfoot diagnosis of competitive athletes. Our study was consistent with a previous study from Koirala *et al.*, which reported that the Staheli index had good reliability and sensitivity (AUC = 0.942, p < 0.01) for flatfoot diagnosis.²⁰

On the other hand, Toyooka *et al.* describe a different cut-off point, sensitivity, and specificity of various footprint analysis. The optimal cut-off

Table 2. Variable Characteristics.

Variable characteristics	Mean ± SD	p
Calcaneal Inclination Angle (degree)	15.70 ± 1.90	0.200
Clarke's angle (degree)	40.49 ± 12.29	0.200
Chippaux Smirak index	36.20 ± 9.16	0.200
Staheli index	70.52 ± 16.76	0.200

*Significant if p < 0.05

Table 3. The validity, reliability, diagnostic performance, the area under the curve, and cut-off point of each footprint analysis.

Parameter	Clarke's angle	Chippaux-Smirak Index	Staheli Index
Correlation coefficient	-0.004 (p=0.973)	-0.236* (p=0.049)	-0.250* (p=0.037)
Intraclass correlation coefficient	0.414**	0.251**	0.649**
Sensitivity (%)	26.78	10.71	78.57
Specificity (%)	100	100	78.57
Positive Predictive Value (%)	100	100	93.61
Negative Predictive Value (%)	25.45	28.00	47.82
The area under the curve	0.427 (p=0.403*)	0.446 (p=0.537)	0.418 (p=0.347*)
Cut-off point	39.32	33.58	73.59

*Significant if p < 0.05; **Footprint analysis was described as reliable if ICC exceeded the r table for n = 0.235.

point of CA was 14.04°, CSI was >62.70%, and SI was >107.42%. The sensitivity, specificity, positive predictive value, and negative value were better than our study; for CA were 86.1%, 79%, 84%, and 82%; for CSI, were 87.6%, 88.4%, 91%, and 85%; for SI were 89.2%, 80.6%, 85%, and 85%, respectively.²¹

Pita – Fernandez *et al.* also showed different cut-off points with our study. The cut-off for CA was 31.50° for samples aged 40 – 64 years old and 30.50° for samples aged ≥65 years old; for CSI was 45.05 for samples aged 40 – 64 years old and 46.03 for samples aged ≥65 years old, and for SI was 0.98 for both samples aged 40 – 64 and ≥65 years old. The study also showed different sensitivity, positive predictive value, and negative predictive value for Clarke's angle 89.8%, 69.5%, and 97.4%; for Chippaux Smirak Index 94.2%, 33.5%, and 97.6%; and for Staheli Index 81.8%, 31.7%, and 93.2%, respectively.²²

The most significant finding of our study was the ability to verify the validity and reliability and determine the diagnostic performance of various footprint analysis toward the gold standard radiograph examination in flatfoot diagnosis of competitive athletes, which is substantial for both researchers and clinicians. Using a valid footprint analysis in flatfoot diagnosis of competitive athletes is required to decide on further management. Our study recommends using the Staheli index for flatfoot diagnosis in the competitive athlete because it showed better sensitivity, specificity, positive predictive value, and negative predictive value than Clarke's angle and Chippaux Smirak Index.

The limitation of this study is that the footprint and foot radiograph were obtained at different times; also, the footprint measurement was done only by an observer, thereby affecting the validity and intra and inter-rater reliability of the measurements.

Future research requires a larger sample size, type of sports, and modern footprint imaging such as thermochromic discoloration and computed tomography as a standard examination. We suggest taking footprint and foot radiographs at the same time, and several observers will do the footprint measurement in future research.

CONCLUSION

The findings of our study suggest that footprint analysis using Staheli Index can be potentially valuable for flatfoot diagnosis because it shows good validity, reliability, and diagnostic performance compared to the Clarke angle and the Chippaux Smirak Index.

RESEARCH ETHICS

Ethics approval for this study was obtained from Health Research Ethics Committee at Dr. Soetomo General Hospital with ethical clearance number 0477/LOE/301.4.2/V/2021.

CONFLICT OF INTEREST

The authors of this paper do not have any conflicts of interest.

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AUTHOR CONTRIBUTION

All authors contributed equally in preparing the research project, assembling data for the research undertaken, conducting statistical analysis, interpreting results, manuscript preparation, and literature review.

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