Medial Longitudinal Arch: Accuracy, Reliability, and Correlation Between Navicular Drop Test and Footprint Parameters

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Abstract

Objective: The purpose of this study was to evaluate the correlation among the navicular drop test, the arch angle, the Staheli index and the Chippaux-Smirak index. The reliability and the correlation among the footprint parameters were also estimated.
Methods: A cross-sectional study (n = 86; 59.3% women; 27.8 years, standard deviation: 4.8 years) was carried out. The navicular drop test was evaluated and footprint parameters using a plantar pressure platform were recorded in the dominant foot. Pearson correlation coefficients, intraclass correlation coefficient, standard error of measurement, and minimum detectable change were calculated.
Results: Both intrarater and interrater reliability were excellent for all the parameters evaluated (intraclass correlation coefficients > 0.880). Statistically significant correlations existed between the navicular drop test and footprints parameters (arch angle = 0,643; Staheli index = 0.633; Chippaux-Smirak index = 0.614). The footprint parameters had excellent correlation with each other (0.838-0.881). The navicular drop test and the footprint parameters studied were reproducible and thus had excellent reliability.
Conclusion: The correlations obtained between the navicular drop test and the footprint parameters evaluated were good. The navicular drop test appears to be a reproducible, valid, and simple test for evaluating medial longitudinal arch height, having fewer disadvantages than using footprint parameters. (J Manipulative Physiol Ther 2018;41:672-679)
Key indexing terms: *Data Accuracy; Foot; Reproducibility of Results*

Introduction

The medial longitudinal arch (MLA) of the foot is related to shock absorption and force transmission in the standing position and during the gait.[1] The MLA is a variable structure,[2] and changes in its height can modify plantar pressure distributions[3] and affect force absorption,[4] muscular activity,[5-7] stability,[8] and gait.[9,10] In addition, several modifications in the lower extremity alignments, including subtalar pronation,[11] tibial internal rotation,[12] genu recurvatum,[13] and anterior knee laxity,[14,15] are related to a lower MLA. In the other hand, a higher MLA is associated with a subtalar supination[11] and a varus hindfoot.[16]

Changes in the height of the MLA can increase the risk of lower limb injuries,[17] including foot pain,[2] toe deformities,[18] ankle injuries,[19] tibial stress syndrome,[20,21] knee osteoarthritis,[22] iliotibial band syndrome,[19] patellofemoral syndrome,[23] and noncontact cruciate anterior ligament injuries.[24,25] These relationships can be important in sports. Thus the evaluation of the MLA is important both in clinical practice and in research.

There are many different methods to evaluate MLA height, including visual observation, radiographs, footprints, and clinical measurements.[26] Visual observation depends on the subjectivity of the rater.[27] Radiographs present several disadvantages, including ionizing radiation exposure and cost accessibility.[28] Footprints parameters, including the arch index (AI),[29] Staheli index (SI),[30] Chippaux-Smirak index (CSI),[17] and arch angle (AA),[17] can be obtained by ink or digital systems. Although ink footprints are noninvasive and inexpensive, they present several limitations, such as difficulties in interpretation and the inaccuracy of measurements.[31] Digital systems have lesser limitations, but they are expensive.

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Clinical techniques are simple and have no side effects. These techniques include the study of navicular position because this is considered a support structure for the MLA.[11] The navicular drop test (NDT), described by Brody[32] in 1982, is one of the clinical tests most commonly used to study MLA.[13,33] It identifies the difference (in millimeters) between navicular tuberosity height in the subtalar joint in a neutral position and subtalar joint relaxed posture.[32] High NDT values are associated with subtalar pronation and lower MLA, and low NDT values are associated with subtalar supination and high MLA.[32]

The correlation between the NDT and the AI was evaluated, identifying small correlations in bipedal (r = 0.317) and single leg stance (r = 0.320)[34] and moderate correlation for the static AI (r = 0.44) and the dynamic AI (r = 0.570).[35] The AI is a measurement dependent on the contact area of the foot. There are other measurements not dependent on the contact area and commonly used in the clinical practice, like the AA, SI, and CSI. However, the correlations between these footprint parameters and the NDT were not previously evaluated. The aim of this study was to evaluate the correlation between the NDT and the AA, SI, and CSI. The correlation among the footprints parameters and the reliability of the NDT, AA, SI, and CSI were also estimated.

Methods

Participants

University student volunteers were recruited for this research. Participants were informed about the aims and the procedure of the study and completed a consent form. The principles outlined in the Declaration of Helsinki of 1975, revised in 2013, were followed and the research was approved by de Research Ethics Committee of the Centro de Estudios Universitarios San Pablo University. The following exclusion criteria were established: history of acute injuries in lower limbs, history of lower limb surgery, presented with lower limbs deformities, and body mass index (BMI) ≥ 30. The dominant foot[36] was evaluated in each participant. Demographic variables, including age, sex, height, weight, and BMI, were collected.

To calculate the sample size required, the G*Power program (an α level of .05 and 80% of statistical power) and the data from the first 20 participants were used. The lowest correlation between the NDT and the footprints parameters obtained in these participants (r = 0.633) and the correlation obtained by Nakhaee et al[35] between the NDT and the AI (0.44) were used. The sample size required was 86 participants. Table 1 shows demographic variables.

The intrarater and interrater reliability of the NDT and footprints parameters were estimated in the first 20 participants by 2 physiotherapists with more than 6 years of experience in the use of the techniques. The NDT and the footprints parameters were collected 3 times in each session, with an interval of 48 hours between sessions. Participants and testers were blinded to the reliability results.

Table 1. *Means and Standard Deviations of Age, Height, Weight, and Body Mass Index*

Demographic Variables	Mean	Standard Deviation
Age	27.8 (y)	4.8 (y)
Height	168.5 (cm)	11 (cm)
Weight	66.5 (kg)	13.6 (kg)
Body mass index	23.2 (kg/m^2)	2.5 (kg/m^2)

Procedure

The NDT was evaluated using a modification of the Brody[32] process: With the participants standing barefoot on the floor, the tester marked the navicular tuberosity with a washable marker. The lateral and medial aspect of the talar dome of the foot was palpated with the thumb over the sinus talus and the index over the anteromedial portion of the talar dome. The foot was slowly inverted and everted until the talus was in a central position and the depressions felt under both fingers were equal. With the subtalar joint in neutral position, the distance between the navicular tuberosity and the floor was measured, in millimeters, with a ruler. The same process was repeated in non–weight-bearing stance, measuring again the height of the navicular tuberosity. The NDT was the difference in the navicular tuberosity height between both measurements. The procedure was repeated 3 times in each participant.

Footprints were collected using a plantar pressure platform with a sample frequency of 30 Hz (Footchecker; LorAn Engineering; Bologna, Italy) placed on a firm surface. To collect footprints, participants were stood on the plantar pressure platform, with their arms relaxed by their sides, and were asked to look at a reference point located 1.8 meters from the floor (3 meters in front of them). The participants had to hold the bipedal stance for 15 seconds. The trials were repeated if the participants lost their balance. Three parameters were calculated (Footchecker 4.0): the AA, SI, and CSI (Fig 1). The AA is the angle between the medial line of the footprint and the line connecting the most medial aspect of the metatarsus and the most lateral point of the medial foot.[17] The SI is obtained by dividing the minimal distance of the midfoot by the widest section of the rearfoot region,[30] and the CSI is the ratio of the minimal distance of the midfoot to the maximal distance of the forefoot.[17] The procedure was repeated 3 times in each participants. In the correlation study, the measures were collected by a physiotherapist with more than 6 years' experience in the use of the techniques.

Statistical Analysis

The normal distribution of the quantitative variables was assessed using the Kolmogorov-Smirnov test. Descriptive analysis was conducted using means and standard deviations (SDs). The reliability the NDT and of the footprints parameters was estimated using the intraclass correlation

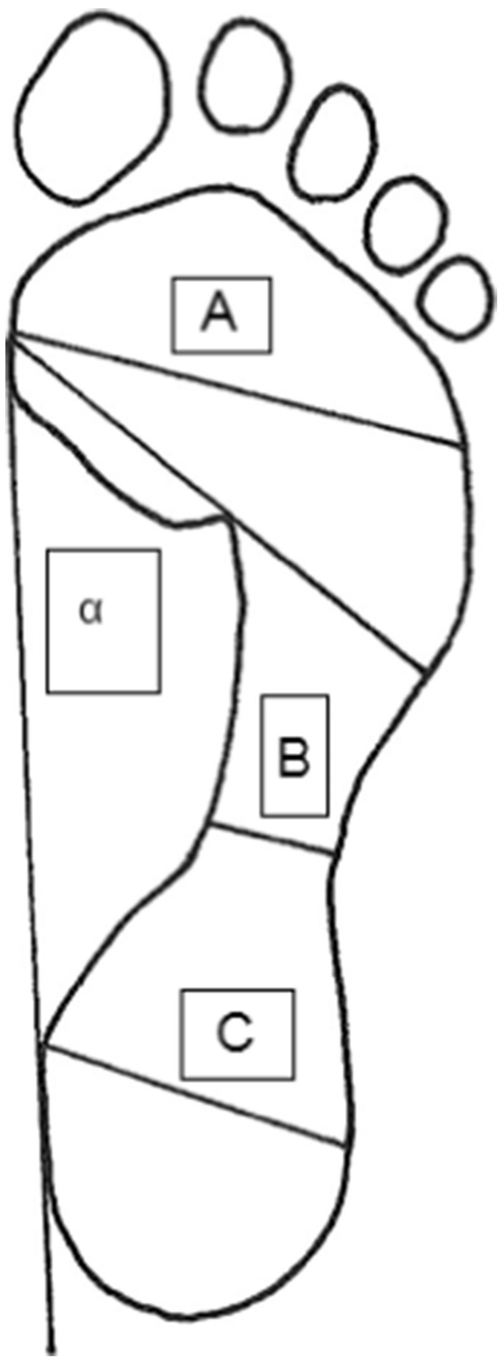

Fig 1. *Representative illustration of the arch angle (α), the Staheli index (B/C), and Chippaux-Smirak index calculation (B/A).*

coefficient ($ICC_{(3,k)}$). The standard error of measurement (SEM) and the minimum detectable change were also calculated. The correlations were studied using the Pearson correlation coefficients *(r),* 95% confidence intervals, and coefficients of determination (r^2). The average value for each test for each participant was used. Reliability was interpreted as poor (0-0.39), moderate (0.4-0.74), or excellent (≥0.75).[37] Correlations were interpreted as poor (0-0.39), fair (0.4-0.59), good (0.6-0.74), or excellent (≥0.75).[38] Statistical analysis was conducted using SPSS Statistics Version 20.0 (IBM Corp, Armonk, New York), and the results were considered statistically significant at $P < .05$.

Results

Reliability

Eleven women (55%) and 9 men (45%) were included in the reliability study. The NDT, AA, CSI, and SI had a normal distribution in the Kolmogorov-Smirnov test ($P > .05$). Both intrarater and interrater reliability were excellent in all parameters evaluated, with ICC values > 0.880. Table 2 shows the ICC, 95% confidence interval, SEM, and minimum detectable change for the MLA parameters intrarater and interrater reliability.

Correlations

A total of 51 women (59.3%) and 35 men (40.7%) were included in the study (age = 27.8 years, SD = 4.8 years). The MLA measures had a normal distribution in the Kolmogorov-Smirnov test ($P > .05$). The mean was 6.7 mm (SD = 2.9) for the NDT, 44.4° (SD = 7.4°) for the AA, 46.1 for the SI (SD = 7.4), and 29.9 for the CSI (SD = 6.3). Statistically significant ($P < .001$) correlations existed between the NDT and the footprints parameters studied, with the absolute values ranging from 0.614 to 0.643. The highest correlation was found between the NDT and the AA. Although good correlation was identified, coefficients of determination ranged from 0.377 to 0.414. Footprints parameters had excellent correlation with each other (r = 0.838-0.881). The Pearson correlation coefficients, 95% confidence intervals, and coefficients of determination for all MLA parameters collected are shown in Table 3 and Figures 2, 3, and 4.

Discussion

The evaluation of the MLA is necessary in clinical practice and research to obtain information related to potential mechanism of injures and also for diagnosis and treatment purposes. The NDT and the footprint parameters are techniques commonly used in clinical practice. There are no previous studies in which the correlation between the NDT and footprint parameters that are not dependent on the contact area of the foot has been evaluated.

Reliability

First of all, we evaluated the reliability of the MLA parameters collected in 20 participants. The NDT had excellent reliability, both intrarater and interrater, with ICC values ranging from 0.914 to 0.945, and had SEM values of <1 mm. Regarding the intrarater reliability, rater 1 obtained a higher ICC (0.945) than rater 2 (0.922). Several authors have reported

Table 2. *Intraclass Correlation Coefficient, 95% Confidence Interval, Standard Error of Measurement and Minimum Detectable Change of Navicular Drop Test, Arch Angle, Staheli Index and Chippaux-Smirak Index*

NDT and Footprints Parameters		ICC	95% CI	SEM	MDC
Intrarater reliability					
NDT	Rater 1	0.945	0.898-0.970	0.63	1.746
	Rater 2	0.922	0.857-0.958	0.781	2.165
AA	Rater 1	0.941	0.879-0.971	1.487	4.122
	Rater 2	0.939	0.853-0.975	1.595	4.421
SI	Rater 1	0.969	0.924-0.988	1.410	3.908
	Rater 2	0.964	0.925-0.982	1.582	4.385
CSI	Rater 1	0.976	0.940-0.990	1.135	3.146
	Rater 2	0.957	0.912-0.979	1.565	4.338
Interrater reliability					
		ICC	95% CI	SEM	MDC
NDT	Time 1	0.914	0.844-0.954	0.821	2.276
	Time 2	0.939	0.888-0.967	0.642	1.780
AA	Time 1	0.884	0.708-0.954	2.342	6.492
	Time 2	0.899	0.763-0.959	2.139	5.929
SI	Time 1	0.910	0.829-0.952	2.586	7.168
	Time 2	0.912	0.834-0.954	2.507	6.949
CSI	Time 1	0.920	0.848-0.958	2.221	6.157
	Time 2	0.936	0.845-0.974	1.926	5.339

AA, arch angle; *CI,* confidence interval; *CSI,* Chippaux-Smirak index; *ICC,* intraclass correlation coefficient; *MDC,* minimum detectable change; *NDT,* navicular drop test; *SD*, standard deviation; *SEM,* standard error of measurement; *SI,* Staheli index.
P values for ICC < .01.

excellent intrarater reliability in both healthy[23,32,39,40] and injured participants.[23,41] The NDT interrater reliability obtained in this research was also excellent, with lower ICC values than intrarater reliability: 0.914 for time 1 and 0.939 for time 2. Several authors also reported excellent interrater reliability.[23,41,42] The NDT reliability is related to the training level of the rater, with lower reliability in the case of inexperienced tester.[42-44] Experience is necessary to place the subtalar joint in a neutral position[44,45] and to locate the navicular tuberosity.[46] The raters in our research were physiotherapists trained in the management of the NDT.

The SEM obtained in our study was <1 mm for both intrarater and interrater reliability. These values are lower than the SEM obtained by other authors[39,47,48] but similar to the results reported by Shultz et al.[42] According to the findings of our study and the literature reviewed, the NDT was a reproducible test and had high reliability.

The footprint parameters studied also had excellent reliability, both intrarater and interrater. Intraclass correlation coefficient values for the SI and the CSI were >0.9. Although the SI and the CSI are commonly used in research and in clinical practice, not many studies have evaluated the reliability of these parameters in static conditions. Queen et al[17] reported both intra- and interrater reliability >0.96 for both parameters, whereas Papuga and Burke[49] obtained ICCs > 0.880. The SI and the CSI, according to our results and the literature reviewed, had a high degree of repeatability. In our study the AA had an ICC intrarater > 0.930 and an ICC interrater > 0.880. Previous studies reported controversial results. Papuga and Burke[49] obtained excellent intrarater reliability (ICCs = 0.817-0.993). In contrast, Queen et al[17] reported moderate intrarater reliability (ICC = 0.677). These authors suggested that the intrarater reliability correlation could in fact be related to the time between time measurements. Queen et al[17] reevaluated participants after 7 and 10 days. In the present study, measurements were repeated after 48 hours. Regarding interrater reliability, Papuga and Burke[49] obtained an ICC of 0.605, whereas Queen et al[17] reported excellent interrater reliability (ICCs = 0.807). It is assumed that lesser reliability of the AA could be due to inherent variations in identifying footprint landmarks and the beginning of the midfoot and the end of the forefoot.[49] The SEM of all the footprint parameters tested was low.

Correlations

The correlation between the NDT and the footprints parameters collected was significant ($P < .05$), with r values ranging from 0.614 to 0.643. The AA had the highest correlation ($r = –0.643$), followed by the SI ($r = 0.633$) and the CSI ($r = 0.614$). Although significant correlation was found, it can explain only 37.7% to 41.4% of the variance of the NDT. There are no previous studies in which the correlation between the NDT and the AA, SI, and the CSI has been evaluated, so this study is the first to do this. The relationship between the NDT and other footprint parameters was previously evaluated. Billis et al[34] reported moderate correlation between the NDT and the valgus index for both single leg stance ($r = 0.613$) and bipedal stance ($r = 0.657$). These results are similar to our findings. However, the correlation between the NDT and the AI was poor ($r = 0.317$-0.320)[34] to fair ($r = 0.44$-0.57).[35] Although the AI is a measurement depending on the contact area, the footprint parameters used in our study and the valgus index are related to the width of the foot. In addition, it was reported that the AI is related to the BMI.[50,51]

Other studies have previously evaluated the correlation between the AA, SI, and CSI and the navicular. Hawes et al[52]

Table 3. *Pearson Correlations and 95% Confidence Intervals*

	AA	SI	CSI	NDT
AA	1	–	–	–
SI	-0.838 (-0.761 to 0.892)	1	–	–
CSI	-0.876 (-0.816 to 0.918)	0.881 (0.823-0.921)	1	–
NDT	-0.643 (-0.499 to 0.752)	0.633 (0.486-0.745)	0.614 (0.462-0.731)	1

AA, arch angle; *CSI,* Chippaux-Smirak index; *NDT,* navicular drop test; *SI,* Staheli index.
P values for $r < 0.05$.

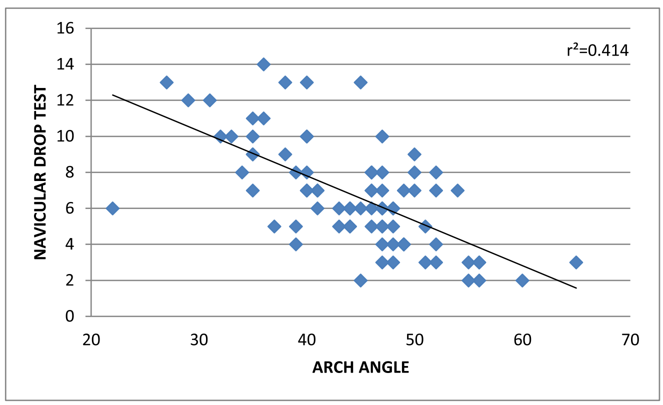

Fig 2. *Correlation between arch angle and navicular drop test ($r = -0.643$). The coefficient of determination (r^2) is shown.*

reported poor correlation between the AA, obtained by ink footprints, and navicular height ($r = 0.39$) in 115 participants. Shiang et al[53] reported a fair correlation for the AA ($r = 0.457$) and the CSI ($r = -0.483$) and poor correlation for the SI ($r = -0.302$) using digital footprints. Fair correlations were obtained by Queen et al[17] for all parameters, ranging *r* values from 0.469 to 0.517. Levels of correlation increased using the normalized navicular height, with *r* values ranging from 0.619 to 0.645, which is similar to our findings.

The correlation between the NDT and the footprints parameters indicates that maybe other factors can affect footprint parameters. The footprints could be influenced by soft tissues.[48,50] It was reported that the BMI was associated with the AI but not with the radiographic measures of the MLA[51] or the navicular height.[54] The present research only included participants with BMI < 30.

Regarding descriptive NDT values, it is commonly considered that normal MLA ranges from 5 to 9 mm,[8,35,55] although Brody[32] considered 15 mm as the limit of normal values. We obtained a mean value NDT of 6.7 (±2.9), which is within the range.

Nonstandardized values are commonly used for the AA, CSI, and SI. With respect to the AA, 42° is considered the lowest value for normal AA.[56] Staheli[30] considered that, in adults, normal values of the SI ranged from 0.3 to 1. The CSI normal values ranged from 0.1% to 29.9%.[56] However, others values are used to categorize MLA, as presented by other authors.[53,57,58] This could be a limitation to the categorization of the MLA using footprints parameters.

Limitations

First, this study was performed only with adults. This relationship should be evaluated in other samples, like children and older people. Second, this research has not included radiographic parameters. Radiographs are considered the gold standard for the evaluation of the MLA,[28] and the use of them may be necessary to validate the NDT and the footprints parameters. Finally, our sample included all the spectrum of MLA height, and our results cannot be generalized for a specific foot type.

Conclusion

The correlations obtained between the NDT and the footprints parameters evaluated (the AA, SI, and CSI) were good. In addition, the NDT and footprints parameters, being reproducible, had an excellent intrarater and interrater reliability. The NDT is a reproducible, valid, and simple test for evaluating MLA height. It is commonly used in clinical

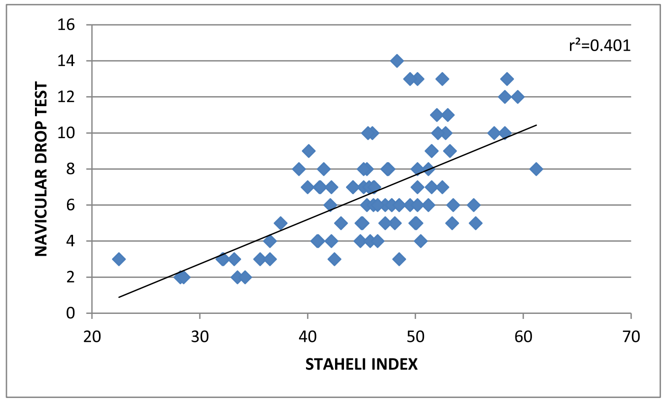

Fig 3. *Correlation between Staheli index and navicular drop test (r = 0.633). The coefficient of determination (r^2) is shown.*

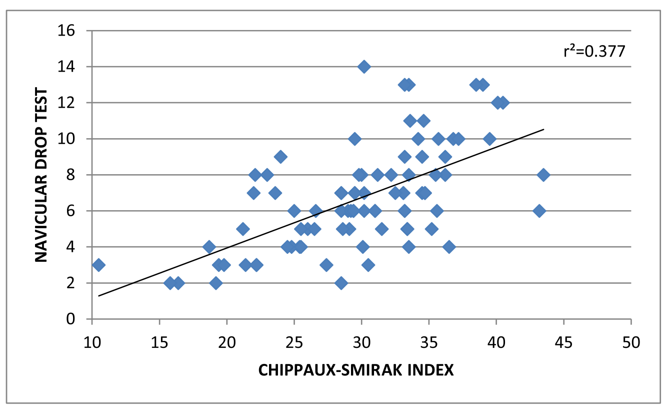

Fig 4. *Correlation between Chippaux-Smirak index and navicular drop test (r = 0.614). The coefficient of determination (r^2) is shown.*

practice and research and has fewer disadvantages than using footprint parameters.

Funding Sources and Conflicts of Interest

No funding sources or conflicts of interest were reported for this study.

Contributorship

Concept development (provided idea for the research): J.C.Z.-E., C.B.M.-C., J.A.M.-U., A.G.-C.
Design (planned the methods to generate the results): J.C.Z.-E., C.B.M.-C., J.A.M.-U., A.G.-C.
Supervision (provided oversight, responsible for organization and implementation, writing of the manuscript): J.C.Z.-E., C.B.M.-C., J.A.M.-U., A.G.-C.
Data collection/processing (responsible for experiments, patient management, organization, or reporting data): J.C.Z.-E., C.B.M.-C.
Analysis/interpretation (responsible for statistical analysis, evaluation, and presentation of the results): J.C.Z.-E., C.B.M.-C., J.A.M.-U., A.G.-C.
Literature search (performed the literature search): J.C.Z.-E., C.B.M.-C.
Writing (responsible for writing a substantive part of the manuscript): J.C.Z.-E., C.B.M.-C., J.A.M.-U., A.G.-C.
Critical review (revised manuscript for intellectual content, this does not relate to spelling and grammar checking): J.C.Z.-E., C.B.M.-C., J.A.M.-U., A.G.-C.

Practical Applications

- The navicular drop test and the footprint parameters had a high reliability.
- Good correlations were identified between the navicular drop test and footprint parameters.

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