Original Research

Evaluating the Medial Longitudinal Arch of the Foot: Correlations, Reliability, and Accuracy in People With a Low Arch

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Background. The medial longitudinal arch of the foot is a variable structure, and a decrease in its height could affect several functions and increase the risk of injuries in the lower limbs. There are many different techniques for evaluating it.

Objective. The objective of this study was to evaluate the correlations of the Navicular Drop Test, several footprint parameters, and the Foot Posture Index-6 in people with a low medial longitudinal arch. Intrarater reliability and interrater reliability were also estimated.

Design. This was a repeated-measures, observational descriptive study.

Methods. Seventy-one participants (53.5% women; mean age = 24.13 years; SD = 3.41) were included. All of the parameters were collected from the dominant foot. The correlation coefficients were calculated. The reliability was also calculated using the intraclass correlation coefficient, 95% CI, and kappa coefficient.

Results. Statistically significant correlations were obtained between the Navicular Drop Test and the footprint parameters, with r absolute values ranging from 0.722 to 0.788. The Navicular Drop Test and the Foot Posture Index-6 showed an excellent correlation (Spearman correlation coefficient = 0.8), and good correlations (Spearman correlation coefficient = |0.663–0.703|) were obtained between the footprint parameters and the Foot Posture Index-6. Excellent intrarater reliability and interrater reliability were obtained for all of the parameters.

Limitations. Radiographic parameters, the gold standard for evaluating the medial longitudinal arch height, were not used. In addition, the results of this research cannot be generalized to people with normal and high medial longitudinal arches.

Conclusions. In participants with a low medial longitudinal arch, the Navicular Drop Test showed significant correlations with footprint parameters; correlations were good for the arch angle and Chippaux-Smirnak Index, and excellent for the Staheli Index. The Foot Posture Index-6 showed an excellent correlation with the Navicular Drop Test and a good correlation with the footprint parameters evaluated. All of the parameters showed high reliability.

The medial longitudinal arch (MLA) is a variable structure[1] and its height could affect several functions during static standing and walking.[2,3] A decrease in the MLA height is related to modifications in the lower limb alignment, including subtalar pronation,[4] tibial internal torsion,[5] tibial internal rotation,[6] greater genu recurvatum,[5] anterior knee laxity,[7] pelvic anteversion,[8] and lumbar lordosis.[9] The height of the MLA may affect muscular activity. A Navicular Drop Test (NDT) score of ≥13 mm is associated with decreased concentric plantar flexion strength compared to normal MLA.[10] In addition, the height of the MLA is considered a relevant factor for several lower limb pathologies, including medial tibial stress syndrome,[11,12] patellofemoral syndrome,[13,14] and noncontact anterior cruciate ligament injuries[15] and foot pain.[1]

Owing to the consequences of a low MLA, it is necessary to evaluate the height of the MLA in clinical practice to obtain information for treatment decisions. The evaluation of the MLA height comprises several methods.[16] Many parameters can be calculated from the footprints, including the arch angle (AA), the Staheli Index (SI),[17] and the Chippaux-Smirnak Index (CSI).[18] Ink footprint is a noninvasive method that can be used in clinical practice and investigation[16,19,20] but has some limitations, such as the inaccuracy of measurements and difficulties in interpretation.[19] Digital systems overcome these limitations and are widely used in both clinical practice and investigation,[20] but they are expensive. Clinical techniques include the navicular measurements.[16,20]

The NDT was described by Brody[21] and shows the difference (in mm) of the height of the navicular tuberosity in 2 positions: subtalar neutral position and relaxed posture. The NDT is an inexpensive, easy, and quick method; high NDT values are associated with a low MLA and pronated foot.[21] Posture-related indices are other methods for evaluating the MLA height.[20] The Foot Posture Index (FPI) is a valid and reliable method used to quantify foot posture[22] and the height of the MLA.[20] Although the original FPI evaluated 8 items (FPI-8),[23] a 6-item version (FPI-6) was redefined and assessed across the 3 planes of the foot.[22,24] Each criterion of the FPI-6 is scored on a 5-point scale (ranging from −2 to +2), and the scores are summed to provide a total score (ranging from −12 to +12) for the determination of foot posture.[22] The FPI-6 is commonly used in both research and clinical practice.[16,20,24,25] Therefore, there are several methods for studying the height of the MLA. However, clinicians need a reliable, valid, and inexpensive measurement that is useful for clinical practice.

To our knowledge, the correlations of the NDT, the footprint parameters, and the FPI-6 in people with a low MLA have not yet been studied. The 2 aims of this study were to evaluate the correlations of the NDT, the footprint parameters (including the AA, SI, and CSI), and the FPI-6 in people with a low MLA, and to estimate the intrarater reliability and interrater reliability of these parameters.

Methods

Design

A repeated-measures, observational, descriptive study was carried out.

Participants

The study included university student volunteers. The participants were asked to complete a consent form and were informed about the procedure and the aims of the study. The principles outlined in the Declaration of Helsinki of 1975 were observed and the project was approved by the Research Ethics Committee of Centro de Estudios Universitarios San Pablo University.

Volunteers were included if their MLA was low. A low MLA was considered if the NDT presented a value of ≥10 mm.[3,26,27] The dominant foot was evaluated in each volunteer by using the kicking ball test to determine the dominant limb.[28] The following exclusion criteria were established: had a body mass index (BMI) of ≥30, had undergone lower extremity surgery, had lower extremity injuries in the previous 6 months, and had lower limb deformities. A clinical examination of each volunteer was performed to determine the presence of leg length discrepancy, hip anteversion/retroversion, genu recurvatum/flexum, genu varum/valgum, tibial torsion, tibial varum, or hallux valgus. Volunteers were excluded when 1 or more deformities were observed. Demographic variables, including age, sex, height, weight, and BMI, were collected.

The required sample size was calculated using the correlations between the NDT and the AA, SI, CSI, and FPI-6 for the first 20 participants (age = 25.32 years; SD = 4.96). The G-power program was used to calculate the sample size, using an alpha level of 0.05 and 80% statistical power. The minimum value in the internal pilot study and the correlation obtained by Nakhaee et al[26] between the NDT and the AI (0.44) were used. The sample size required was 71 participants.

The intrarater reliability and interrater reliability of the measurements were also evaluated in the first 20 participants, with an interval of 48 hours, by 2 physical therapists with more than 6 years of experience in the use of these techniques. The testers and participants were unaware of the reliability results.

Procedure

A modification of the Brody procedure[21] was used to collect the NDT: the participants stood barefoot, in bilateral standing, on the floor, and the navicular tuberosity was marked. The lateral and medial aspects of the talar dome of the foot were palpated. The foot was everted and inverted until the talus was in a central position. This was determined to be the subtalar neutral position. The distance between the navicular tuberosity and the floor was measured. The height of the navicular tuberosity was measured in the relaxed position; the NDT being the difference between the 2 measurements. The NDT requires previous training, proving less reliable with inexperienced raters.[29]

The footprints were collected using a pressure platform (Footchecker; Loran Engineering, Bologna, Italy). The participants were asked to stand on the pressure platform, in bilateral standing, while looking at a reference point located 1.8 m above the floor with their arms relaxed at their sides. When the participants were stable, the data were recorded. From the footprints obtained, 3 parameters were calculated using pressure platform software (Footchecker 4.0): AA, SI, and CSI (eFigure, available at https://academic.oup.com/ptj). The AA is the angle formed between the line connecting the most medial points at the heel and forefoot and the line from the most medial point of the forefoot to the apex of the concavity of the MLA.[30] The SI is obtained by dividing the minimal distance of the midfoot by the widest section of the rear foot region,[18] and the CSI is the ratio of the minimal distance of the midfoot to the maximal distance of the forefoot.[18]

The 6 items of the FPI-6 (talar head palpation; supra- and infralateral maleolar curvature; calcaneal frontal plane position; prominence in the region of the talonavicular joint; congruence of the MLA; and abduction/adduction of the forefoot on the rear foot)[24] were evaluated with the participants in a relaxed bipedal position.

In the correlation study, the measurements were collected by a physical therapist with more than 6 years of experience in the use of the measurements.

Data Analysis

The data normality was verified using the Kolmogorov-Smirnov test. Means and standard deviations were used for the descriptive analysis of the continuous variables, and frequencies and percentages were used for discrete variables. The reliability of the NDT and the footprint parameters was evaluated using the intraclass correlation coefficient [ICC(2,1)] and the 95% CI. The kappa coefficient (κ) was used to evaluate the reliability of the FPI-6. The ICC was determined by using mixed-effect and absolute agreement or consistency 2-factor alpha models. In addition, the standard error of measurement (SEM) and the minimum detectable change at a 95% confidence level (MDC_{95}) were also calculated. The following formulas were used to calculate the SEM and the MCD_{95}: SEM = SD $\sqrt{(1–ICC)}$[31]; MDC_{95} = SEM × 1.96 × $\sqrt{2}$.[32] Pearson correlation coefficients (r) were obtained for the NDT relative to each of the footprint parameters. The correlations between the FPI-6 and the other measurements were evaluated using the Spearman correlation coefficient (r_s). The ICC was interpreted as follows: poor reliability (≥0.5), moderate reliability (0.5–0.75), good reliability (0.75–0.9), and excellent reliability (≥0.9).[33] The interpretation of Landis and Koch[34] was used for the κ values: poor agreement (<0); slight agreement (0.00–0.20); fair agreement (0.21–0.40); moderate agreement (0.41–0.60); substantial agreement (0.61–0.80); and almost perfect agreement (0.81–1). Correlations were interpreted as follows: poor (0–0.39), fair (0.4–0.59), good (0.60–0.74), and excellent (≥0.75).[35] The statistical analysis was conducted using SPSS 20.0 (IBM SPSS, Chicago, IL), and a P value of < .05 was considered statistically significant.

Results

Reliability

Twelve women (60%) and 8 men (40%) were included in the reliability study. All of the MLA variables showed a normal distribution. Table 1 shows the ICC, 95% CI, SEM, and MCD_{95} of the NDT and the footprint parameters. Both intrarater reliability and interrater reliability were excellent for all of the parameters studied (P < .001), being higher than 0.9, except for the CSI in interrater time 2 (ICC = 0.898). The SEM and the MDC_{95} were low, giving a high level of accuracy. The FPI-6 showed almost perfect agreement for both intrarater reliability (κ = 0.872) and interrater reliability (κ = 0.829).

Correlations

Seventy-one participants (24.13 years old [SD = 3.41]; 38 women [53.5%] and 33 men [46.5%]) were included in the correlation study. The mean values were 11.83 mm (SD = 1.68) for the NDT, 25.32 degrees (SD = 3.63) for the AA, 47.43 (SD = 8.98) for the SI, and 64.71 (SD = 12.49) for the CSI. Figure 1 shows the frequencies of the FPI-6 categories.

Statistically significant correlations (P < .001) were obtained between the NDT and the footprint parameters. Pearson r absolute values ranged from 0.722 to 0.788. The correlation between the NDT and the FPI-6 was excellent (P < .001; r_s = 0.818), and that between the footprint parameters and the FPI-6 was good (P < .001; r_s = |0.663–0.703|). The footprint parameters showed an excellent correlation (P < .001) with each other (r = |0.901–0.931|). Table 2 shows the r, 95% CI, and coefficients of determination (r^2) among all of the outcome measures. Figures 2 through 4 show the correlations between the NDT and the footprint parameters evaluated.

Discussion

Reliability

The reliability and SEM are important elements for the validity and interpretation of measurements. In our research, the reliability (both intrarater and interrater) of all of the measurements was high, making them satisfactory for clinical use.

Table 1.
Intraclass Correlation Coefficient (ICC), 95% CI, Standard Error of Measurement (SEM), and Minimum Detectable Change at 95% Confidence Level (MDC_{95}) for the Navicular Drop Test (NDT) and Footprint Parameters[a]

Reliability	Measure	Rater or Time	ICC	95% CI	SEM	MDC_{95}
Intrarater	NDT	Rater 1	0.955[b]	0.886–0.982	0.318	0.883
		Rater 2	0.950[b]	0.895–0.976	0.314	0.870
	AA	Rater 1	0.977[b]	0.941–0.991	0.739	2.048
		Rater 2	0.973[b]	0.942–0.987	0.722	2
	SI	Rater 1	0.972[b]	0.928–0.989	0.585	1.622
		Rater 2	0.975[b]	0.947–0.988	0.580	1.608
	CSI	Rater 1	0.959[b]	0.897–0.984	1.002	2.778
		Rater 2	0.946[b]	0.888–0.975	1.043	2.890
Interrater	NDT	Time 1	0.914[b]	0.795–0.965	0.440	1.220
		Time 2	0.919[b]	0.836–0.960	0.442	1.226
	AA	Time 1	0.954[b]	0.888–0.982	1.045	2.896
		Time 2	0.947[b]	0.891–0.976	1.011	2.803
	SI	Time 1	0.945[b]	0.866–0.978	0.820	2.273
		Time 2	0.951[b]	0.899–0.982	0.812	2.251
	CSI	Time 1	0.921[b]	0.813–0.968	1.391	3.857
		Time 2	0.898[b]	0.798–0.950	1.433	3.972

[a] AA = arch angle; CSI = Chippaux-Smirnak Index; SI = Staheli Index.
[b] $P < .001$.

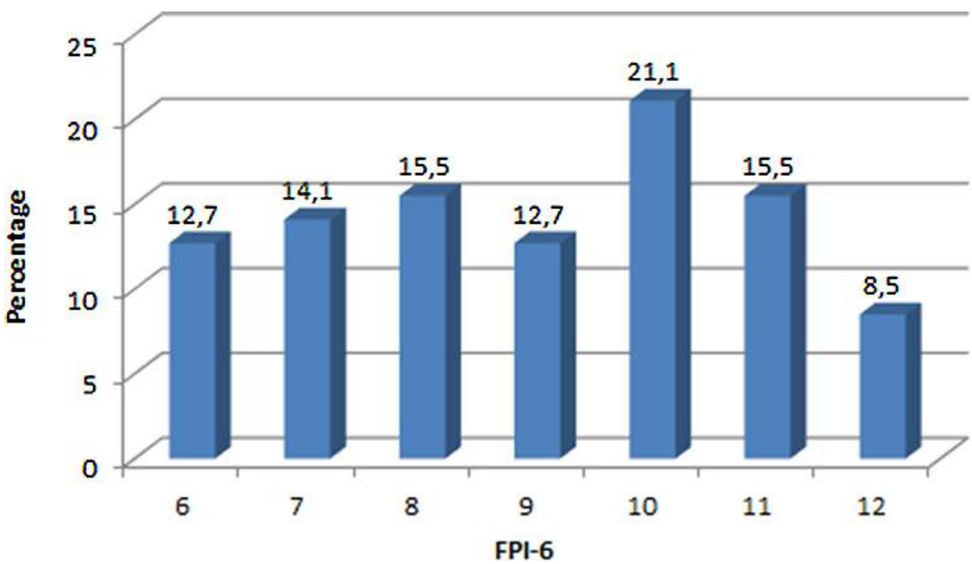

Figure 1.
Frequencies of Foot Posture Index-6 (FPI-6) categories.

The NDT demonstrated excellent intrarater reliability and interrater reliability, with ICC values higher than 0.9. With regard to intrarater reliability, rater 1 presented an ICC of 0.955 and rater 2 presented one of 0.950. Various researchers have demonstrated good to excellent intrarater reliability in people who were healthy (0.88–0.98),[13,27,29] similar to our results. In people who were injured, the intrarater reliability was good in those with patellofemoral pain (0.76–0.81),[13] excellent in people with anterior cruciate ligament injury (0.9),[36] and moderate to excellent

Table 2.
Pearson Coefficient Correlation (r), 95% CI, and Coefficient of Determination (r^2)[a]

Measure	AA		SI		CSI		FPI-6 r (95% CI)
	r (95% CI)	r^2	r (95% CI)	r^2	r (95% CI)	r^2	
NDT	−0.732 (−0.601 to −0.825)[b]	0.536	0.788 (0.680 to 0.863)[b]	0.622	0.722 (0.588 to 0.818)[b]	0.521	0.818 (0.723 to 0.882)[b]
AA			−0.901 (−0.845 to −0.937)[b]	0.812	−0.930 (−0890 to −0.956)[b]	0.865	−0.663 (−0.509 to −0.776)[b]
SI					0.931 (0.891 to 0.957)[b]	0.867	0.703 (0.562 to 0.804)[b]
CSI							0.669 (0.517 to 0.780)[b]

[a]AA = arch angle; CSI = Chippaux-Smirnak Index; FPI-6 = Foot Posture Index-6; NDT = Navicular Drop Test; SI = Staheli Index.
[b]$P < .001$.

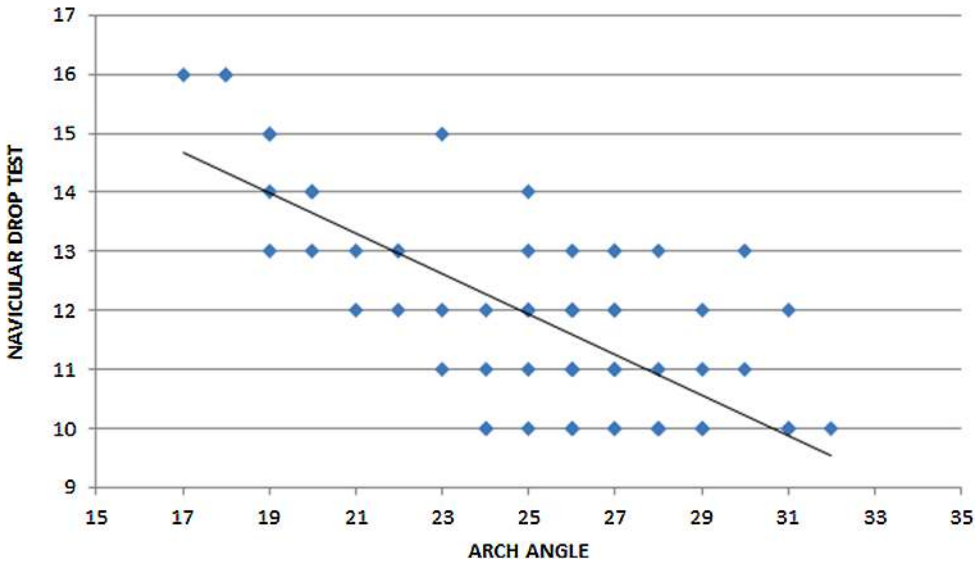

Figure 2.
Correlation between the Navicular Drop Test and the arch angle.

in people with rheumatoid arthritis (0.73–0.98).[37] The interrater reliability obtained in our study was also excellent, demonstrating lower ICC values than the intrarater reliability (0.908 and 0.917). Other researchers previously identified less interrater reliability—moderate to excellent interrater reliability in people who were healthy (0.56–0.93)[29,37] and people with rheumatoid arthritis (0.67–0.92)[37]—and good interrater reliability in those with patellofemoral pain (0.76–0.81).[13] In our research, the SEM was less than 0.5 mm in all cases; our values were lower than the SEM obtained in other studies.[29,36,38] An explanation for this result could be that only participants with a low MLA were included in our sample, being a homogeneous sample. In addition, the reliability of the NDT is related to the level of experience of the testers.[29,39] This could be related to the difficulty in locating the navicular tuberosity[40] and placing the subtalar joint in a neutral position.[39] In our research, the testers were trained in the management of the NDT and they consistently and accurately identified the navicular tuberosity, and demonstrated consistency in identifying the subtalar neutral position.

With regard to the reliability of the footprint parameters, both intrarater reliability and interrater reliability showed ICC values near to or higher than 0.9. Previous studies obtained excellent reliability for the SI and the CSI (0.914–0.998).[30,41] However, the reliability of the AA shown previously ranged from moderate to excellent (0.605–0.993).[30,41,42] These findings could be related to the variations in identifying footprint landmarks.[41] With regard to the SEM, our values were low. No previous studies evaluating the SEM in the footprint parameters were found.

The FPI-6 also showed almost perfect agreement for both intrarater reliability and interrater reliability, presenting κ values higher than 0.8. Previous studies showed excellent intrarater reliability[23,43] and moderate[44] to excellent interrater reliability[23,24,43] in adults who were healthy, and

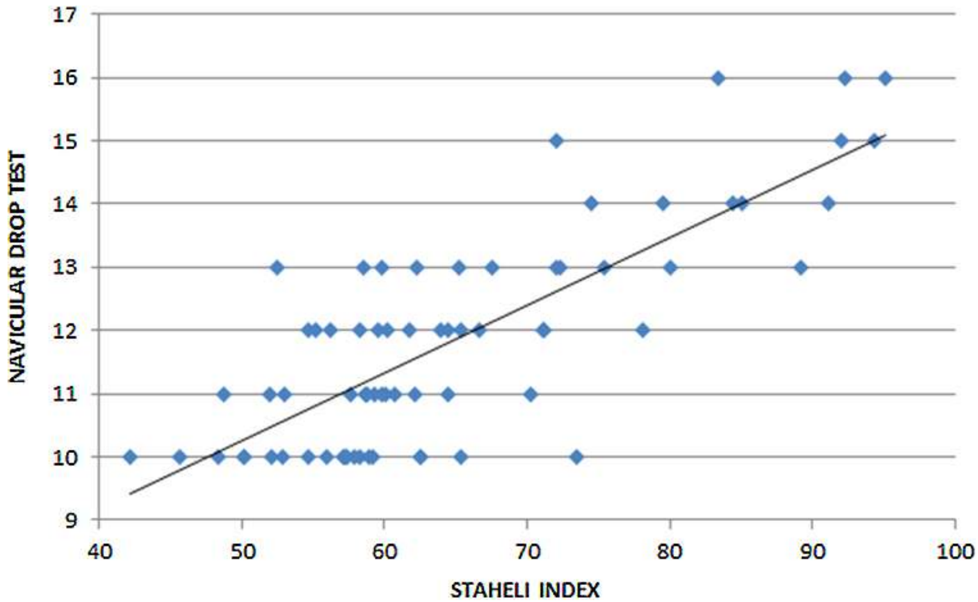

Figure 3.
Correlation between the Navicular Drop Test and the Staheli Index.

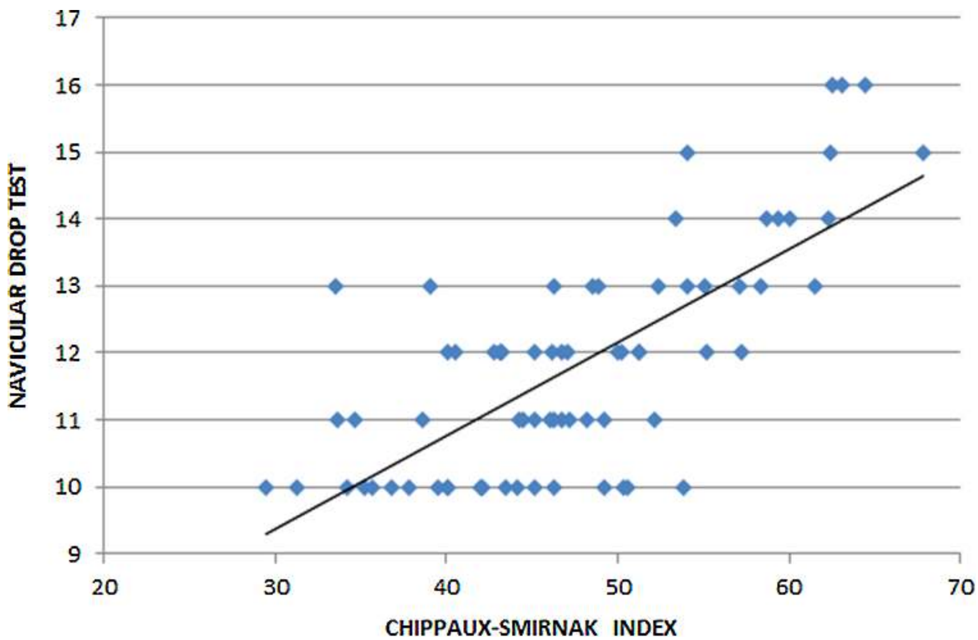

Figure 4.
Correlation between the Navicular Drop Test and the Chippaux-Smirnak Index.

excellent interrater reliability in people with patellofemoral pain syndrome.[13] Problems in the type of the foot have been found previously[45,46] and a previous training in the management of the FPI-6 is recommended to increase the reliability.[24,45,47] According to our findings, the NDT, AA, SI, CSI, and FPI-6 were reproducible and showed high reliability in participants with a low MLA.

Correlations

With regard to the principal aim of the study, the correlations of the NDT, the footprint parameters, and the FPI-6 in participants with a low MLA were significant ($P < .001$).

In terms of the correlations between the NDT and the footprint parameters, the r values were higher than 0.7, and the correlation was good for the AA ($r = -0.732$) and the CSI ($r = 0.722$) and excellent ($r = 0.788$) for the SI. To our knowledge, this is the first research to evaluate this relationship. However, the correlations between other navicular measurements and the footprint parameters have been studied before. Thus, the correlation between the navicular height and the AA ranged from poor ($r = 0.39$)[42] to fair ($r = 0.457$ to 0.571).[30,48] The correlation between the navicular height and the CSI was fair ($r = -0.483$ to 0.498),[30,48] and the correlation between the navicular height and the SI ranged from poor ($r = 0.302$)[48] to fair ($r = -0.469$).[30] The correlation increased when normalized navicular height was used (ranging from 0.619 to 0.645).[30] The normalized navicular height is obtained by dividing the navicular height by the total length of the foot.[49] In the present research, we included only a low MLA, whereas previous studies[30,42,48] included a broad spectrum of MLA heights. Moreover, we did not include people with a BMI of $\geq$30 because the body composition and BMI could influence the interpretation of the footprints.[50–52]

The correlation between the NDT and the AI was also studied. Billis et al[53] obtained, in 26 people, a poor correlation between the NDT and the AI, both in single-leg stance AI ($r = 0.320$) and bipedal stance AI ($r = 0.317$). Nakhaee et al[26] found a fair correlation between the NDT and the AI ($r = 0.44$). The correlations obtained by us were higher. This could be related to the fact that the AI is influenced by the soft tissues[53] and the body composition.[51] In our study, there were no people with a BMI of $\geq$30, and our sample included only individuals with a low MLA. In addition, we used footprint parameters related to the width of the foot, not dependent on the contact area, such as the AI. Billis et al[53] evaluated the correlation between the NDT and the Valgus Index, finding values similar to our own ($r = 0.631$–0.657). This could be explained by the fact that the Valgus Index, like the footprint parameters studied in this work, does not depend on the contact area of the foot.

The NDT and the FPI-6 showed an excellent correlation in our study ($r_s = 0.818$). Our research included only individuals with a low MLA (NDT values of $\geq$10 mm).

The observed category frequencies of the FPI-6 (Fig. 1) also fell into ranges that indicated a low MLA.

Menz and Munteanu[49] studied the correlations among several parameters, including the FPI-8, the navicular height, and the normalized navicular height in older people, and included a broad spectrum of MLA height. They obtained r values ranging from -0.722 to -0.735.

With regard to the correlations between the FPI-6 and the footprint parameters, we obtained good correlations ($r_s = |0.663$–$0.703|$). We were unable to find studies that considered them. The few studies that have evaluated the correlations between the FPI and the footprint parameters used the FPI-8. Redmond et al[22] compared the FPI-8 and the Valgus Index, showing that the FPI-8 total scores predicted 59% of the total variance of the Valgus Index. Menz and Munteanu[49] studied the correlation between the FPI-8 and the AI in older people, finding a fair correlation ($r = 0.424$).

The evaluation of the MLA height should be included in the clinical exploration of the foot posture. The decrease of the height of the MLA is related to several lower limb injuries,[1,11,13–15] back pain,[54,55] and foot mobility.[56] To our knowledge, this is the first research which has evaluated the correlations of the NDT, the footprint parameters, and the FPI-6 in people with a low MLA. In our study, the NDT was well correlated with the footprint parameters and the FPI-6 in the evaluation of the height of the MLA in people with a low arch. Therefore, the clinicians can use different measurements in the study of the MLA in such individuals. However, the characteristics, advantages, and disadvantages of these parameters need to be considered.

The NDT had fewer disadvantages than digital footprint parameters and is an inexpensive method for evaluating the MLA height. Pressure platforms are expensive and many clinicians cannot use them in their clinical practice. An alternative to this could be ink footprints, but they present several disadvantages, including inaccurate measurements and difficulties in interpreting them.[19] In addition, footprint parameters could be affected by body composition,[50,51] while having no influence on measurements of navicular height.[57] The FPI is commonly used to quantify foot posture,[22] being correlated to radiographs,[49] as it presents good interval construct validity.[58] The FPI evaluates the foot position using 6 or 8 items, whereas the NDT uses only 2 measurements. In addition, the NDT is also correlated with radiographs.[59] Therefore, clinicians should consider the NDT as the first option for examining foot posture in individuals with a low MLA. The NDT is less time-consuming, has less opportunity for error (compared with the other forms, which require multiple measurements), and is highly correlated with the other options.

Study Limitations

A limitation of the study is that we have not used radiographic parameters, the gold standard for evaluating the MLA height.[16] A further study including radiographs may be necessary to validate the NDT, the footprint parameters, and the FPI-6. We have only evaluated the dominant foot. However, asymmetries could be found between the dominant foot and the nondominant foot[60] and could affect the results of the research. Another limitation is that the results of this research were from individuals who were healthy, and they cannot be generalized to individuals with normal and high MLAs.

Especially important is the high MLA, which is a less flexible structure[61,62] and which is related to several injuries.[1,11–15] Further research should focus on a higher MLA.

In addition, the examiner bias needs to be considered. The NDT is a test related to the level of experience of the testers[29,39] and has shown less reliability in inexpert raters.[29] A previous experience is needed to locate the navicular tuberosity[40] and place the subtalar joint in a neutral position.[39]

Conclusion

From our research findings, in people with a low MLA, the NDT showed significant correlations with the footprint parameters, being moderate for the AA and CSI and excellent for the SI. In addition, an excellent correlation was found between the NDT and the FPI-6. All of the evaluated parameters showed high intrarater reliability and interrater reliability. We recommend the use of the NDT as the first choice for examining foot posture in individuals with a low MLA.

Author Contributions

Concept/idea/research design: J.C. Zuil-Escobar, C.B. Martínez-Cepa, J.A. Martín-Urrialde, A. Gómez-Conesa
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Providing facilities/equipment: J.C. Zuil-Escobar, C.B. Martínez-Cepa, J.A. Martín-Urrialde, A. Gómez-Conesa
Providing institutional liaisons: J.C. Zuil-Escobar, A. Gómez-Conesa
Clerical/secretarial support: J.C. Zuil-Escobar, C.B. Martínez-Cepa
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Ethics Approval

The project was approved by the Research Ethics Committee of Centro de Estudios Universitarios San Pablo University.

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Disclosure

The authors completed the ICJME Form for Disclosure of Potential Conflicts of Interest. They reported no conflicts of interest.

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