Research Report

Measurements Used to Characterize the Foot and the Medial Longitudinal Arch: Reliability and Validity

Background and Purpose. Abnormality in the structure of the medial longitudinal arch of the foot is commonly thought to be a predisposing factor to injury. The purpose of this investigation was to compare the reliability and validity of several measurements used to characterize various aspects of the foot, including the medial longitudinal arch. Subjects. One hundred two feet (both feet of 51 subjects) were measured to establish a reference database. From this group, a subset of 20 feet (both feet of 10 subjects) was used to determine intertester and intratester reliability. Radiographs of a further subset of 10 feet (right feet of 10 subjects) were used to determine validity. Methods. Five foot measurements were taken in 2 stance conditions: 10% of weight bearing and 90% of weight bearing. Results. Intraclass correlation coefficients (ICCs) for intertester and intratester measurements were between .480 and .995. The most reliable method of characterizing arch type in 10% of weight bearing between testers was dividing navicular height by foot length in 10% of weight bearing. However, this measure yielded highly unreliable measurements in 90% of weight bearing. The most valid measurements were navicular height divided by truncated foot length, navicular height divided by foot length in 10% of weight bearing, and navicular height divided by foot length in 90% of weight bearing. Dorsum height at 50% of foot length divided by truncated foot length showed relatively high intertester reliability (ICC=.811 in 10% of weight bearing, ICC=.848 in 90% of weight bearing) and validity (ICC=.844 in 10% of weight bearing, ICC=.851 in 90% of weight bearing). Conclusion and Discussion. These data suggest that, of the measures tested, the most reliable and valid method of clinically assessing arch height across 10% and 90% of weight bearing was dividing the dorsum height at 50% of foot length by truncated foot length. [Williams DS, McClay IS. Measurements used to characterize the foot and the medial longitudinal arch: reliability and validity. *Phys Ther.* 2000;80:864–871.]

Key Words: *Arch, Clinical measurement, Foot, Reliability, Validity.*

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Some combination of abnormal structure and mechanics in the foot may put an individual at an increased risk for injury.[1–5] The height of the medial longitudinal arch of the foot is commonly thought to be a predisposing factor to injuries. According to Subotnick,[5] 60% of the population have normal arches, 20% have a cavus or high-arched foot, and 20% have a planus or low-arched foot.

In a study of runners with plantar fasciitis, Warren and Jones[6] used a discriminant analysis and found that several measurements, including arch height during normal standing and lower-extremity length, were able to correctly predict inclusion in a group of runners without plantar fasciitis 76.1% of the time but were able to predict inclusion in the injured group only 15.6% of the time. James et al[7] found that no structural characteristic, including pronated and supinated feet, could be used to predict a specific injury. In contrast, Giladi et al[8] demonstrated that subjects with low arches were less likely than subjects with normal or high arches to develop stress fractures in the lower extremity. Some of the controversy in the literature may be due to the many different ways of measuring the medial longitudinal arch. Additionally, researchers often use absolute medial longitudinal arch measures rather than measures scaled to the individual's foot length, for example. Normalizing medial longitudinal arch height to foot length or some other lower-extremity anthropometric measure may result in better classifications of foot types.

There are a number of methods of measuring the medial longitudinal arch.[8–14] Although most of these methods attempt to quantify the arch, some methods are based on observation. Giladi et al[8] classified the non–weight-bearing foot as either high-arched or low-arched by a visual assessment alone. Even among experienced clinicians, however, visual categorization of the arch is highly inconsistent.[15] Although Dahle et al[11] attempted to define classification criteria, the determination of the foot in 50% of weight bearing as pronated or supinated was still based on observation.

Some researchers have incorporated the use of radiographs[9,13] or photographs[10] to classify the medial longitudinal arches of their subjects. Hawes et al[12] measured the highest point of the soft tissue along the medial longitudinal arch in full weight bearing. Although this measurement, as well as footprint measurements,[16,17] can be easily obtained, we do not believe that these measurements necessarily represent the state of the bony architecture of the foot. The soft tissue on the plantar

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surface of the foot is thick and variable and can mask the true bony architecture of the foot.

Saltzman et al[14] correlated measurements taken at 50% of weight bearing with measurements obtained from radiographs to determine their validity. Intraclass correlation coefficients (ICCs) were used to assess reliability on 45 subjects. Intrarater reliability values were established for talar height (ICC=.90), navicular height (ICC=.92), and arch height (ICC=.91). All 3 values were normalized to footprint length. The authors concluded that the measurements correlated well with the measurements obtained from radiographs, with Pearson correlation coefficients ranging from .51 to .86. Measurements obtained from radiographs of talar height/foot length, calcaneus to first metatarsal angle, and calcaneal inclination were compared with measurements of navicular height/footprint length, arch height/footprint length, and talar height/footprint length. The measurements obtained from radiographs were different from the clinical measurements. Therefore, we do not believe that these measurements had concurrent validity. Dividing navicular height by foot length is important because the height of the navicular may not give an accurate representation of the arch. For example, a 5-cm navicular height on a size 12 foot would be related to a very different arch structure than the same measurement on a size 6 foot.

Although some of these measures (navicular height, talar height, foot length) have been shown to have some reliability or validity, they have not been compared with one another in order to determine which measure is the most useful. Additionally, measurements taken during partial weight bearing and full weight bearing have not been compared. We contend that a foot with an arch ratio that does not change much from 10% of weight bearing to 90% of weight bearing might be considered rigid or without much mobility, whereas a foot with a large change might be considered flexible or more mobile. Establishing reliability in both weight-bearing and non–weight-bearing conditions allows for measurements that can be taken under both conditions and, therefore, may be used to describe foot mobility. A measure that has been proposed for assessing foot mobility uses both weight-bearing and non–weight-bearing conditions.[18] Both foot structure and foot mobility may play an important role in predicting injuries. Therefore, the purpose of our study was to compare the reliability and validity of several measurements of the medial longitudinal arch in both 10% and 90% of weight bearing. These reliability and validity measures will provide a rationale for choosing a measure to quantify the arches of individuals with high arches and low arches.

Table 1.
Subject Characteristics

	$\bar{X}$	SD	Range
Total (N=102 feet, 51 subjects)			
Age (y)	27.1	6.1	19–43
Weight (kg)	67.5	10.9	51.4–107.3
Height (cm)	169.4	7.9	152.4–189.0
Foot length (cm)	24.2	1.7	21.0–28.9
Female (n=56 feet, 28 subjects)			
Age (y)	26.1	5.4	19–43
Weight (kg)	63.5	7.0	51.4–81.8
Height (cm)	166.0	5.6	152.4–175.3
Foot length (cm)	23.5	1.2	21.0–25.5
Male (n=46 feet, 23 subjects)			
Age (y)	28.2	6.9	20–42
Weight (kg)	72.4	15.7	53.2–107.3
Height (cm)	173.5	10.8	167.6–189.0
Foot length (cm)	25.0	2.3	22.2–28.9
Reliability (n=20 feet, 10 subjects; 7 female, 3 male)			
Age (y)	23.9	4.2	20–31
Weight (kg)	64.7	9.3	52.3–84.1
Height (cm)	167.9	4.3	160.0–172.7
Validity (n=10 feet, 10 subjects; 7 female, 3 male)			
Age (y)	26.1	4.5	20–34
Weight (kg)	65.7	10.4	51.4–84.1
Height (cm)	167.4	4.8	157.5–172.7

Method

The right and left feet of 51 subjects (28 female, 23 male) were measured to establish a mean and standard deviation for a reference population of convenience. All subjects volunteered from the university population and surrounding community. All subjects were without lower-extremity abnormalities or injuries at the time of measurement. Subjects were included in the study after informed consent was obtained. Subject characteristics are presented in Table 1.

Foot measurements were taken in 2 stance conditions: 10% of weight bearing and 90% of weight bearing. We chose 10% of weight bearing because we observed that the entire plantar surface of the foot is in contact with the support surface while the foot is in a minimally, but controlled, weighted position. Ninety percent of weight bearing allows the foot to change under load. Measurements taken at 10% and 90% of weight bearing may be important in establishing a description of arch mobility. Subjects were weighed on a standard scale, and 10% and 90% of each subject's total weight were calculated. Subjects stood with their hands resting on a countertop, which they used to assist in controlling their amount of

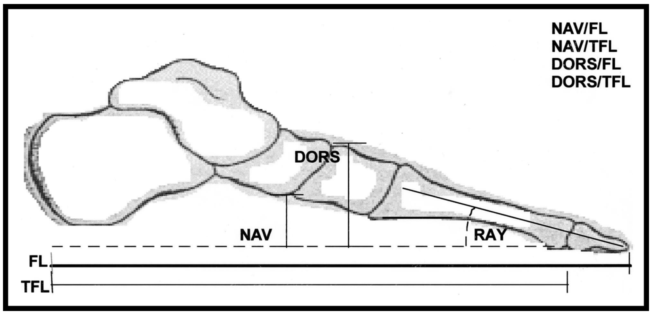

Figure 1.
Schematic of anatomical landmarks used to determine the measurements of the foot. FL=foot length, TFL=truncated foot length, NAV=navicular height, DORS=dorsum height, RAY=first ray angle.

weight bearing. They then placed one foot on the scale and the other foot on an even adjacent surface. The subjects were asked to lower their amount of weight bearing by lifting the foot on the scale straight up and not leaning to either side until the scale showed that 10% of weight bearing had been achieved. Foot measurements were then taken. The process was repeated for 90% of weight bearing. We chose 10% and 90% of weight bearing because we found during pilot testing that these conditions are close to full weight bearing and non–weight bearing and that subjects could maintain a stable and upright posture in these conditions.

All measurements were taken based on our use of bony landmarks. These measurements were (1) navicular height, (2) height of the dorsum of the foot at 50% of foot length, (3) angle of the first ray, (4) navicular height divided by foot length, (5) navicular height divided by truncated foot length, (6) dorsum height divided by foot length, and (7) dorsum height divided by truncated foot length. The measurement of foot length can be skewed by foot deformities such as hallux valgus and claw toes. Claw toes are sometimes found in individuals with high arches, whereas hallux valgus is often found in individuals with low arches. These deformities have less of an impact on the measurement of truncated foot length. The angle of the first ray was measured between the floor and the long axis of the first metatarsal using a goniometer with a resolution of 2 degrees. Navicular height was measured from the floor to the most anterior-inferior portion of the navicular. Dorsum height was measured from the floor to the top of the foot at 50% of foot length. Foot length was measured from the most posterior portion of the calcaneus to the end of the longest toe. Truncated foot length was measured from the most posterior portion of the calcaneus to the center of the first metatarsophalangeal joint (Fig. 1). Lengths were measured with calipers with a resolution of 1 mm. Dorsum height was established with the same calipers mounted on a Plexiglas* plate (Fig. 2). Finally, arch mobility was assessed using an equation for calculating relative arch deformity (RAD) modified from that described by Nigg et al[18]:

$$RAD = \left(\frac{AHU - AH}{AHU}\right)\frac{10^4}{BW}$$

where non–weight-bearing arch height (AHU) is defined as dorsum height at 10% of weight bearing, arch height (AH) is defined as dorsum height at 90% of weight bearing, and body weight (BW) is expressed in newtons.

A subset of 20 feet (both feet of 10 subjects) was used to determine intertester and intratester reliability, and a further subset of 10 feet (right feet of 10 subjects) was used in the validity portion of the study. Intertester reliability was established using the ICC (2,k) model, and intratester reliability was established using the ICC (2,1) model. Validity was established using the ICC (2,k) model.

In the reliability portion of the study, 2 physical therapists with different levels of experience (3 and 20 years) took 3 blinded measurements of each variable in each weight-bearing condition. Both testers were experienced in taking foot and ankle measurements daily. The specific measures used in this study were practiced together by both testers on approximately 10 subjects before collecting data. For repeated measures, transparent tape was placed over the skin with the bony landmark underneath. A mark was placed on the tape at the level of the bony landmark, the measurement was taken, the tape was removed, and the process was repeated. The process was then repeated for each subsequent measure.

To establish concurrent validity, lateral radiographs were taken of the right foot of each subject in 10% and 90% of weight bearing. The subject stood with the right foot on the scale and the lateral border of the foot against the radiographic film cassette. The source-to-image ratio was held consistent between subjects at 101.6 cm (40 in), and intensities were set at 30 mA and 72 kV peak. The left lower extremity was placed on a step in front of the subject with the knee at an angle that was comfortable to the subject. A Bell-Thompson ruler was also placed against the cassette in an attempt to ensure appropriate scaling during measurement from the films. The same measurement techniques described earlier were used. Essentially, we used the measurements obtained from the radiographs and expected all other measurements to agree with those measurements if validity was present.

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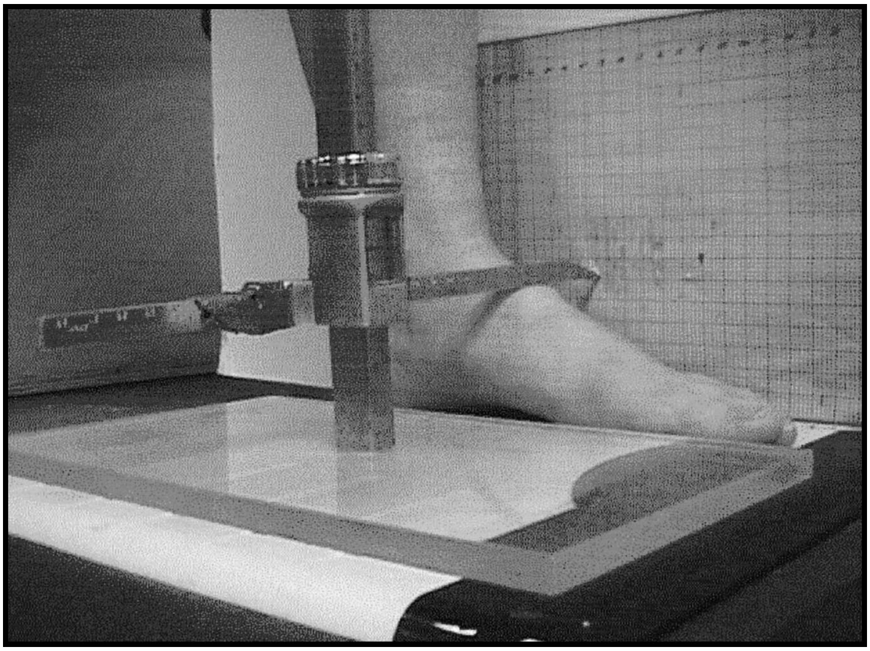

Figure 2.
Calipers mounted to Plexiglas plate used to measure the height of the dorsum of the foot.

Validity was established using the measurements taken by tester 1 compared with measurements of the same bony landmarks taken from the radiograph. Tester 1 was the less experienced therapist, and we used this tester's data because we expected that ICC values may be lower for a less experienced therapist.

Results

Average values and values previously reported for all measures from 102 feet are shown in Table 2. Within-tester reliability (ICC [2,1]) for measurements 1 through 7 for tester 1 were all above .93 in both weight-bearing conditions.

Within-tester reliability for measurements 1 through 7 for tester 2 were all above .94 in both weight-bearing conditions, except for first ray angle, which ranged from .804 to .868. Even higher values (ICC=.939–.982) for measurements normalized to foot length or truncated foot length (measurements 4–7) were found for both testers (Tab. 3).

In general, between-tester reliability was lower than within-tester reliability, with ICC (2,k) values ranging between .480 and .924. Of the normalized measures, the measure with the highest ICC for characterizing arch type between testers was navicular height divided by foot length in 10% of weight bearing (ICC=.924). However, this measure had a lower ICC of .565 in 90% of weight bearing. Dorsum height divided by foot length and dorsum height divided by truncated foot length had high ICC values (ICC=.811–.854) and maintained consistent levels of reliability across both weight-bearing conditions (Tab. 4).

The normalized measurements with the highest ICC (2,k) values for validity were navicular height divided by truncated foot length and navicular height divided by foot length in 10% of weight bearing and navicular height divided by foot length in 90% of weight bearing. Dorsum height divided by truncated foot length showed high validity across both weight-bearing conditions (Tab. 5).

Discussion

In our study, mean values and ICC values were calculated for 7 chosen measures used to characterize the medial longitudinal arch of the foot. In general, the mean values were found to be in agreement with values reported previously.[9,14,19–21] However, the absolute values for navicular height and dorsum height were lower than those reported by Cowan et al.[10] Cowan and colleagues took their measurements from photographs, which may account for the differences between their measurements and our measurements. However, the normalized value for navicular height divided by foot length in Cowan and colleagues' study ($\overline{X}$=0.17, SD=0.02) is more consistent with our value ($\overline{X}$=0.164, SD=0.025), which suggests that their absolute value for foot length would be higher. These higher values might suggest a sampling of individuals with larger feet in the study by Cowan et al. In addition, the mean relative arch deformation value in our study was consistent with relative arch deformation values reported previously.[18]

Within-tester reliability values were excellent, in our opinion, for all measurements taken (ICC=.804–.995) (Tab. 3), based on the values recognized by Landis and Koch.[22] Other researchers[23–26] who have assessed within-tester reliability for various foot measures have found varying results. The results of our study show generally higher ICC values for intratester reliability than for intertester reliability. This finding may be due to our testers' wide range of experience (3 years versus 20 years) and previous practice in taking the measurements. Between-tester reliability showed mixed results across the 2 weight-bearing conditions. Reliability dropped considerably from the 10% of weight bearing condition for navicular height (from ICC=.924 to ICC=.608), navicular height divided by foot length (from ICC=.924 to ICC=.565), and for navicular height

Table 2.
Foot Measurements (N=102) Compared With Previously Reported Values

	10% of Weight Bearing			90% of Weight Bearing			
	$\bar{X}$	SD	SEM	$\bar{X}$	SD	SEM	Reported Literature
Navicular height (cm)	3.97	0.56	0.056	3.46	0.56	0.056	3.71–4.6[9,10,14,19,20]
Height of dorsum of foot (cm)	5.62	0.44	0.044	5.23	0.45	0.046	6.76[10]
First ray angle (°)	25.47	3.06	0.308	23.09	2.86	0.289	21.3[9]
Foot length (cm)	24.20	1.69	0.171	24.40	1.69	0.171	24.97[9]
Truncated foot length (cm)	17.83	1.13	0.114	17.94	1.14	0.115	19.9[14]
Navicular height/foot length	0.164	0.025	0.003	0.142	0.026	0.003	0.17[10]
Navicular height/truncated foot length	0.223	0.034	0.003	0.193	0.034	0.003	0.23–0.24[10,21]
Height dorsum of foot/foot length	0.233	0.034	0.002	0.214	0.033	0.002	
Height of dorsum of foot/truncated foot length	0.316	0.027	0.003	0.292	0.027	0.003	
Relative arch deformation (N^{-1})			$\bar{X}$=1.05, SD=0.51				1.0–2.0[18]

Table 3.
Intraclass Correlation Coefficients (2,1) for Intratester Reliability of Arch Measurements[a]

	Tester 1		Tester 2	
	10% of Weight Bearing	90% of Weight Bearing	10% of Weight Bearing	90% of Weight Bearing
Navicular height	.982	.977	.977	.971
Dorsum height	.940	.979	.961	.979
First ray angle	.944	.937	.868	.804
Foot length	.968	.977	.995	.910
Truncated foot length	.943	.972	.911	.919
Navicular height/foot length	.980	.971	.971	.968
Navicular height/truncated foot length	.979	.973	.970	.969
Dorsum height/foot length	.949	.982	.947	.971
Dorsum height/truncated foot length	.939	.975	.948	.972

[a] n=20, *df*=2.

divided by truncated foot length (from ICC=.909 to ICC=.563). Both testers found palpation of the navicular head to be more difficult in 90% of weight bearing than in 10% of weight bearing. This finding may have occurred because the soft tissue on the medial border of the arch becomes taut in 90% of weight bearing. Although the testers were consistent within themselves, each tester may have been palpating a slightly different landmark in the 90% of weight bearing condition. Tester 2 showed consistently higher values for navicular height, suggesting that perhaps the posterior portion of the navicular was being measured rather than the anterior portion.

The ICC values for first ray angle were consistently low across both weight-bearing conditions. We believe that this finding is most likely due to the difficulty in taking this measurement, which required alignment of the goniometer along the floor and the long axis of the first metatarsal in the sagittal plane. Although there is little soft tissue overlying this bone, the extensor tendons overlying the bone, in our opinion, may have influenced the visualization of the long axis of the first metatarsal itself. No consistent offset was found between testers 1 and 2.

Although higher values for intertester reliability have been reported when measurements were taken in a weight-bearing condition,[27] the results of our study suggest that this may not be true for the measure of navicular height. Other researchers[11,14] used a 50% of weight bearing condition (with weight evenly distributed on both feet), which may make palpation of the navicular easier. Reliability of measurements is important, in our opinion, because we believe that measurements obtained in 10% and 90% of weight bearing are needed to assess mobility of the arch.

We examined concurrent validity by using a measure of the same thing as was measured on the radiographs. All ICC (2,k) values were ≥.704 (Tab. 5). The normalized measurements (measurements 4–7) had high ICCs, with associated low standard errors of measurement (Tab. 2), which, in our view, adds to evidence for validity.[28] Normalizing these foot measurements appears to decrease the variability in arch height that is attributed

Table 4.
Intraclass Correlation Coefficients (2,k) for Intertester (Tester 1 Versus Tester 2) Reliability of Arch Measurements[a]

	10% of Weight Bearing	90% of Weight Bearing
Navicular height	.924	.608
Dorsum height	.790	.765
First ray angle	.512	.480
Foot length	.872	.706
Truncated foot length	.804	.719
Navicular height/foot length	.924	.565
Navicular height/truncated foot length	.909	.563
Dorsum height/foot length	.854	.848
Dorsum height/truncated foot length	.811	.848

[a] n=20, *df*=1.

Table 5.
Intraclass Correlation Coefficients (2,k) for Agreement Between Clinical and Radiographic Measurements[a]

	10% of Weight Bearing	90% of Weight Bearing
Navicular height	.874	.918
Dorsum height	.835	.813
First ray angle	.872	.747
Foot length	.979	.875
Truncated foot length	.765	.712
Navicular height/foot length	.914	.924
Navicular height/truncated foot length	.942	.896
Dorsum height/foot length	.704	.749
Dorsum height/truncated foot length	.844	.851

[a] n=10, *df*=1.

to foot size. The absolute height of the navicular or the dorsum may not accurately reflect the structure of the arch. For example, when using a criterion of 1.5 standard deviations above the mean, 7 arches were classified as high based on measurements of dorsum height divided by truncated foot length. Although 6 arches were classified as high based on measurements of dorsum height, only 2 of these arches were classified as high based on the normalized measurements.

Summary and Conclusions

We attempted to establish mean values and to determine the reliability and validity of measurements obtained for 7 measures used to characterize various aspects of the foot, including the medial longitudinal arch. These measurements, which can be obtained in clinical practice, were compared with measurements obtained from radiographs. Based on the results of our study, the most reliable and valid measurements across the 2 weight-bearing conditions (10% and 90% of weight bearing) were those obtained for dorsum height divided by truncated foot length. Future studies will focus on selection of individuals with high and low arches based on this measure. Based on the mean and standard deviation of this reference population of feet, selection of individuals with high and low arches can be made. Once grouped accordingly, differences in mechanical and injury patterns can be studied based on these arch characteristics.

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