Quantitative morphology of Medial Longitudinal Arch among young Indian adults

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Abstract

Introduction: Indian database on morphology of Medial Longitudinal Arch (MLA) especially in young adults is extremely limited. So the present study was undertaken to estimate quantitative morphology of MLA and to evaluate influence of demographic variables on it, in Indian young adult population from Gujarat region.

Materials and Method: Various dimensions of MLA were measured with custom made Bronnack device in 1500 (670- male, 830- female) healthy volunteers of age 17-21yrs in non weight bearing & weight bearing positions which were plotted on paper for additional measurements. Statistical analysis was done using SPSS version 23.

Result: The median(with IQR) for Truncated Foot Length (TFL), Fore Foot Length (FFL), Hind Foot Length (HFL), Arch Height (AH), Arch Spread (AS), and Navicular Drop (ND) were found to be 17.6(16.8-18.7), 8.6(8.1-9.2), 9.0(8.5-9.7), 4.5(4-5.1), 0.5(0.3-0.6) & 0.6(0.4-0.9) on right side respectively and 17.6(16.8-18.7), 8.7(8-9.3), 9.0(8.5-9.7), 4.6(4-5.1), 0.5(0.3-0.6) & 0.6(0.4-0.9) on left side respectively. Truncated Foot Length (TFL) showed strong positive correlation with both height and weight of the individual. Arch Height (AH) showed moderately positive and weak positive correlation with Height and weight of the individual. The gender differences in the morphology of MLA were statistically insignificant.

Conclusion: The comprehensive database generated by this study on morphology of MLA will be of great significance to orthopedic surgeons, podiatrists and industries related to foot prosthetics & orthotics.

Keywords: Truncated Foot Length (TFL), Fore Foot Length (FFL), Hind Foot Length (HFL), Arch Height (AH), Arch Spread (AS), and Navicular Drop (ND)

Introduction

Human foot consists of 26 bones and has three arches inherent in its design to facilitate the weight bearing. Viz. Medial, Lateral and the transverse. These are formed by the tarsal and metatarsal bones and strengthened by the muscles, ligaments and tendons of foot.[1,2] The Medial Longitudinal Arch (MLA) is formed by calcaneus, talus, navicular, three cuneiform and medial three metatarsal bones. The summit of the MLA is at the superior articular surface of the body of the talus and main joint of the MLA is Talocalcaneonavicular joint.

The foot arches are difficult to recognize in infants and their feet appear to be flat because of the presence of fat. The arches become prominent as the child starts walking and the foot starts bearing the weight of the body.[3] Arch function depends upon shape of bones,[4] ligamentous stability[5,6] and muscular fatigue[7] while factors like race[8,9] footwear[10,11] age and gender[12] influence the formation of arches.

Optimum curvature and flexibility of arches are desirable for proper functioning of foot. Pes cavus deformity is characterized by high arched foot that does not flatten during weight bearing while in Pes planus deformity the curvature of arches is more flat than normal and entire sole comes into near-complete or complete contact with the ground.[13] The medial longitudinal arch (MLA) is most important reference in determining the degree of Pes cavus and Pes planus.[14,15] It plays important role in maintaining the foot posture, shock absorption and energy transfer during the walking.[16,17]

Individuals with pes cavus are more prone to lateral ankle sprains and stress fracture of the femur and tibia. Similarly knee injuries, gait disturbances, soft tissue injuries of foot and stress fracture of metatarsals are more common in pes planus.[18,19]

Data available in literature on morphology and flexibility of MLA for Indian population especially adults, in whom the skeletal maturity is already attained, is very limited. In view of non availability of normative values for different parameters of MLA for adult population there are no uniform standards for diagnosing high arch foot (Pes Cavus) and flat foot (Pes Planus). The database on quantitative morphology of MLA will also be extremely helpful for prescription of orthotics and foot prosthesis. So the present study was done to generate quantitative data on morphology and flexibility of MLA in Indian young adult population from Gujarat region. The study also attempted to find out the influence of demographic variables like gender, height, weight & BMI of individual on morphology and flexibility of MLA.

Materials and Method

The present study was cross sectional, observational study done on 1500 (670- male, 830- female) young Indian adults of age between 17-21yrs randomly selected from medical institute of Gujarat region. Informed written consent was obtained from all

the participants before enrolling them for the study. None of the participants had lower limb pain, injury, deformity or any neuro-muscular disorder at the time of assessment. Approval from institutional ethical committee (IEC) was obtained before the commencement of the study. Age, gender, height, weight and BMI of all the participants were recorded. The materials used for this study were custom made Bronnack device, ruler scales, marker and pencil (Fig. 1).
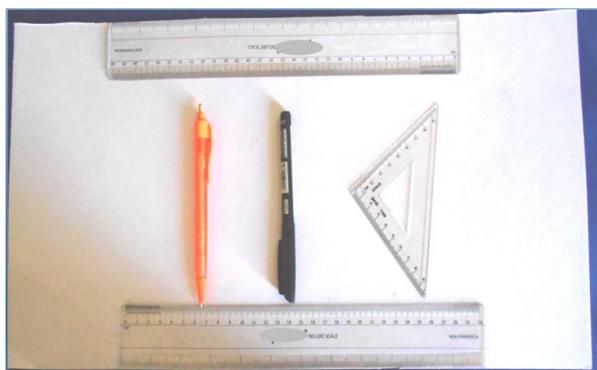

Fig. 1: Materials required for the study

Navicular tuberosity and head of first metatarsal was palpated and marked by an observer in each participant before carrying out various measurements on foot. Medial tubercle of calcaneum forms the posterior end of Medial Longitudinal Arch. Palpation of this point was difficult so the present study considered posterior most end of foot as reference point for measurements of length & angles of MLA.

Initially each participant was asked to sit in relaxed position, hip & knee joint flexed at 90 degrees and his/her foot gently placed flat on a custom made Bronnack device. The observer ensured that the marking on head of first metatarsal matched with the zero mark on the ruler of Bronnack device. The non weight bearing Truncated Foot Length (TFL), Fore Foot Length (FFL), Hind Foot Length (HFL), Arch Height (AH) were measured in this position (Fig. 2). Similar measurements were carried for other foot of the participant in non weight bearing position. A triangle was drawn on paper using above dimensions for each participant. Anterior Arch Angle (AAA) and Posterior Arch Angle (PAA) were recorded (Fig. 3). Thus using these six parameters quantitative morphology of medial longitudinal arch of each individual is assessed.

Fig. 2
A= Truncated Foot length (TFL) on a custom made Bronnack device
B= Arch Height (AH) on a Ruler Scal
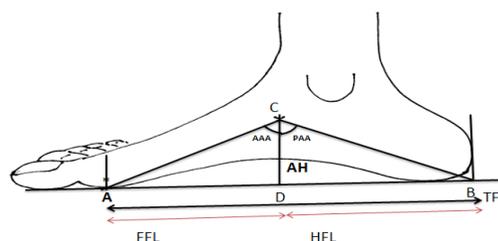
Truncated foot length (TFL): Distance between head of the 1st meta tarsal bone and posterior end of foot = AB
Arch Height (AH): perpendicular distance from the navicular tuberosity to the supporting surface = CD
Fore foot length (FFL): Distance between head of the 1st meta tarsal bone and perpendicular line drawn from navicular tuberosity = AD
Hind foot length (HFL): Distance between posterior end of foot and perpendicular line drawn from navicular tuberosity = BD
Anterior Arch angle (AAA): angle formed by anterior slope of Medial longitudinal arch with perpendicular line drawn from navicular tuberosity = Angle ACD
Posterior Arch angle (PAA): angle formed by posterior slope of Medial longitudinal arch with perpendicular line drawn from navicular tuberosity = Angle =BCD

Fig. 3

Then the participant was asked to stand erect with equal weight on both the feet. The truncated foot length and Arch height in this position (weight bearing) were measured in similar fashion by an observer for both the feet. The difference in truncated foot length of individual during weight bearing and non weight bearing position constituted Arch Spread (AS). The difference in Arch height of individual during non weight bearing & weight bearing position constituted Navicular Drop (ND). Thus, using Arch Spread (AS) and Navicular Drop (ND), the flexibility of Medial longitudinal arch was assessed in each individual.

Statistical Analysis: SPSS version 23 has been used for analyzing the data. The normality of the data was tested using Shapirov-Wilk test. Since the data was not normally distributed Median and Inter Quartile Range (IQR) were calculated. The parameters used by present study for assessment of quantitative morphology and flexibility of MLA were compared between male & female groups among study population using Mann-Whitney U test. Spearman's Correlation coefficient was calculated for estimation of correlation among different foot parameters & demographic variables. *P*- Value of less than 0.05 was considered statistically significant.

Result

1500 young adults of age 17 to 21 participated in present study. Distribution of age, height, weight, BMI and parameters used for assessment of quantitative

morphology of foot in non weight bearing position i.e. Truncated Foot Length (TFL), Fore Foot Length (FFL), Hind Foot Length (HFL), Anterior Arch Angle (AAA) and Posterior Arch Angle (PAA) among study population is shown in Table 1. This table also shows gender wise distribution of all above mentioned parameters. The Median and Inter Quartile Range (IQR) for all the parameters are expressed as the data was found to be not normally distributed.

For assessment of flexibility of MLA among study population the present study utilized two parameters viz. Arch Spread (AS) and Navicular Drop (ND). The details of AS and ND among study population are shown in Table 2.

The present study attempted to find out correlation between demographic variables viz. Height, Weight & BMI of individual and various foot parameters considered in the study using spearman's correlation. Table 3 shows the details of this. Very strong positive correlation was found between Truncated Foot Length (TFL) and Height of individual for both feet which was

statistically significant. Truncated Foot Length (TFL) also showed strong positive correlation with Weight and weak positive correlation BMI of individual which were statistically significant. The correlation of Arch Height (AH) with demographic variables i.e. height and weight of individual were moderately positive, weak positive respectively. The Truncated Foot Length (TFL) also showed weak positive correlation with Arch height (AH). Arch Spread (AS) showed weak positive correlation with Height and Weight of individuals. There was no significant correlation between ND and other above mentioned variables.

The Present study also compared differences between male & female groups of study population for various foot parameters using Mann Whitney U Test. The results showed that the differences between these two groups for Truncated Foot Length (TFL), Arch Height (AH), Arch Spread (AS) & Navicular Drop (ND) were statistically not significant except for the Navicular Drop (ND) for left foot (Table 4).

Table 1: Quantitative Morphology

		Male (N=670)			Female (N=830)			Total(N=1500)		
		Mean (±SD)	Median (IQR)	Range	Mean (±SD)	Median (IQR)	Range	Mean (±SD)	Median (IQR)	Range
	Height(cm)	169 (±8.7)	170 (163-175)	140-190	156.2 (±6.4)	155 (152-160)	125.5-182	161.8 (±9.8)	160 (155-170)	125-190
	Weight(kg)	67.13 (±15.1)	65 (56-75)	36-114	53.2 (±10.3)	51 (45-59)	36-90	59.4 (±14.4)	56 (48.5-68)	36-114
	BMI(kg/m^2)	23.45 (±4.7)	22.8 (20.3-25.9)	15.4-39	21.8 (±3.8)	21.08 (19-23.7)	15.6-35.4	22.5 (±4.3)	21.6 (19.3-24.9)	15.4-39
Right	TFL	18 (±1.13)	18.1 (17.3-18.7)	14.1-21	16.6 (±0.82)	16.6 (16.2-17.2)	14.2-19.5	17.7 (±1.3)	17.6 (16.8-18.7)	14.6-21.5
	FFL	9.2 (±0.82)	9.2 (8.7-9.8)	6.7-12.1	8.6 (±0.68)	8.6 (8.1-9)	6.7-11.1	8.7 (±0.84)	8.6 (8.1-9.2)	6.2-11.6
	HFL	8.8(±0.75)	8.8 (8.3-9.3)	6.4-10.6	8.0 (±0.62)	8.1 (7.5-8.5)	6.4-9.9	9.0 (±0.82)	9.0 (8.5-9.7)	6.9-11.7
	AH	5.5 (±0.65)	5.5 (5.1-5.9)	3.6-7.3	5.0 (±0.67)	5.0 (4.6-5.5)	3.4-6.8	4.5 (±0.78)	4.5 (4-5.1)	2.0-6.5
	AAA	56.6 (±3.1)	56.3 (54.4-58.4)	48.9-65.3	57 (±3.1)	57 (54.6-58.8)	49-65.3	59.3 (±4.1)	59.1 (56.3-62)	48.1-73.6
	PAA	55.5 (±3.1)	55.2 (53.7-57.1)	46-65.6	55.5 (±3.5)	55.1 (53-57.5)	47.6-67.3	60.2 (±3.3)	59.8 (58.1-62.2)	49.6-72.6
Left	TFL	18 (±1.13)	18.2 (17.3-18.8)	14.-21.1	16.6 (±0.81)	16.6 (16.2-17.1)	14.3-19.5	17.8 (±1.3)	17.6 (16.8-18.7)	14.4-21.4
	FFL	9.2 (±0.78)	9.2 (8.7-9.8)	6.7-11.9	8.5 (±0.65)	8.5 (8-9)	6.8-10.6	8.7 (±0.84)	8.7 (8-9.3)	6.0-11.6
	HFL	8.8 (±0.72)	8.8 (8.4-9.3)	6.3-10.6	8.1 (±0.62)	8.1 (7.7-8.5)	6.3-10.1	9.1 (±0.82)	9.0 (8.5-9.7)	6.9-11.6
	AH	5.4 (±0.63)	5.5 (5.1-5.8)	3.5-7.0	5.0 (±0.67)	5.0 (4.5-5.5)	3.4-6.6	4.5 (±0.8)	4.6 (4-5.1)	2.2-6.5
	AAA	56.6 (±2.9)	56.6 (54.4-58.2)	49-64.4	56.8 (±3.2)	57 (54.4-58.9)	49-64.5	59.3 (±4.3)	58.7 (56.2-62.)	48.1-72.8
	PAA	55.7 (±3.0)	55.2 (53.7-57.1)	41-65.6	55.7 (±3.4)	55.4 (53.3-57.7)	47-64.5	60.2 (±3.5)	59.8 (57.8-62)	49.2-73.1

TFL=Truncated Foot Length, FFL=Fore Foot Length, HF=Hind Foot Length, AH=Arch height, AAA=Anterior Arch Angle, PAA=Posterior Arch Angle

Table 2: Flexibility of Arch

		Right		Left	
		Arch Spread (AS)	**Navicular Drop (ND)**	**Arch Spread (AS)**	**Navicular Drop (ND)**
Male (N=670)	Mean(±SD)	0.6(±0.33)	0.65(±0.37)	0.59(±0.33)	0.66(±0.33)
	Median(IQR)	0.5(0.4-0.8)	0.6(0.4-0.8)	0.5(0.4-0.8)	0.6(0.4-0.8)
	Range	0.0-3.2	0.0-2.2	0.0-3.2	0.0-2.2
Female (N=830)	Mean(±SD)	0.45(±0.22)	0.74(±0.42)	0.44(±0.22)	0.69 (±0.4)
	Median(IQR)	0.4(0.3-0.6)	0.7(0.4-1.0)	0.4(0.3-0.5)	0.5(0.4-0.9)
	Range	0.0-1.4	0.0-2.1	0.0-1.3	0.0-2.2
Total (N=1500)	Mean(±SD)	0.51(±0.29)	0.7(±0.4)	0.51(±0.29)	0.7(±0.4)
	Median(IQR)	0.5(0.3-0.6)	0.6(0.4-0.9)	0.5(0.3-0.6)	0.6(0.4-0.9)
	Range	0.0-3.2	0.0-2.2	0.0-3.2	0.0-2.2

Table 3: Details of correlation among different foot parameters and demographic variables (Sample size = 1500; correlation expressed in spearman's rho & p value)

	Height	**Weight**	**BMI**	**TFL**	**AH**	**ND**
RTFL	.807(<0.001)	.617(<0.001)	.248(<0.001)	1	.259(<0.001)	-.046(0.078)
LTFL	.803(<0.001)	.618(<0.001)	.250(<0.001)	1	.244(<0.001)	.068(0.008)
RAH	.446(<0.001)	.301(<0.001)	.083(0.001)	.259(<0.001)	1	.076 (0.003)
LAH	.464(<0.001)	.322(<0.001)	.096(<0.001)	.261(<0.001)	1	0.001 (0.99)
RAS	.275 (<0.001)	.179 (<0.001)	.044 (0.088)	.117(<0.001)	.265(<0.001)	-.095(<0.001)
LAS	.312 (<0.001)	.259 (<0.001)	.112 (<0.001)	.151(<0.001)	.235(<0.001)	-.079(0.002)
RND	-.091(<0.001)	-.108(<0.001)	-.064(0.014)	-.046(0.078)	.076(0.003)	1
LND	.009(0.729	.024(0.348)	.026(0.309)	.068(0.008)	-.041(0.112)	1

RAS=Right Arch Spread, LAS=Left Arch Spread, RND=Right Navicular Drop, LND=Left Navicular Drop, RTFL=Right Truncated Foot Length, LTFL=Left Truncated Foot Length, AH=Arch Height, T FL=Truncated Foot Length, ND=Navicular Drop

Table 4: Comparison between Male & Female groups of study population for different foot parameters using Mann-Whitney –U test

	RTFL	**LTFL**	**RAH**	**LAH**	**RAS**	**LAS**	**RND**	**LND**
Mann-Whitney U	90782.5	90767.0	171684.5	172515.0	199789.0	194823.5	242716.0	265906.0
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.144

RTFL=Right Truncated Foot Length, LTFL=Left Truncated Foot Length, RAH=Right Arch Height, LAH=Left Arch Height, RAS=Right Arch Spread, LAS=Left Arch Spread, RND=Right Navicular Drop, LND=Left Navicular Drop

Tab 5: Details of comparison between results of previous similar studies & present study

Researcher	**FL (cm)**	**AH (mm)**	**ND (mm)**
Umesh Adhikari et al[24]	Median (IQR): Total=24.1 (22.5-25.4) Male=25.5 (24.5-26) Female=22.7 (22-23.9)	---------------	Median (IQR): RND for Males = 6 (3-8); RND for Females = 4(3-5); LND for Males = 4 (3-6); LND for Females = 3(2-5);
Rasmus G Nielsen et al [25]	Total=25.3 (21-31) Male=26.5 Female=24.1	---------------	------------------
Williama & Mc Clay et al[19]	Total=24.2 (21-28.9) Male=25 (22.2-28.9) Female=23.5 (21-25.5)	10% W.B=39.7 90% W.B=34.6	----------------------
Thomas G McPoil et al[26]	Total=24.87 Male=26.36 Female=23.73	Non WB=49.4 WB=43.2	---------------------

	FL	AH	ND
Yi-Wen Chang[27]	--------------------	Non WB=42 WB=34.7	Mean (±SD) = 7.38 ± 3.04
Fiolkowski[28]			Mean (±SD) = 6 ± 2
Presnt study	**Median (IQR):** **Total** Right=17.6 (16.8-18.7) Left=17.6 (16.8-18.7) **Male** Right=18.1 (17.3-18.7) Left=18.2 (17.3-18.8) **Female** Right=16.6 (16.2-17.2) Left=16.6 (16.2-17.1)	**Median (IQR):** **Total** Right=40.5 (40-50.1) Left=40.6 (40-50.1) **Male** Right=50.5 (50.1-50.9) Left=50.5 (50.1-50.8) **Female** Right=50 (40.6-50.5) Left=50 (40.5-50.5)	**Median (IQR):** **Total** Right=0.6 (0.4-0.9) Left=0.6 (0.4-0.9) **Male** Right=0.6 (0.4-0.80 Left=0.6 (0.4-0.8) **Female** Right=0.7 (0.4-1.0) Left=0.5 (0.4-0.9)

FL= Foot Length, AH= Arch height, ND= Navicular Drop

Discussion

The human foot is a masterpiece of engineering, uniquely designed with two longitudinal arches & two transverse arches. These springs helps the foot to act as an effective flexible surface essential for adapting to ground planes, shock absorption, weight transfer and locomotion. The morphology of these arches determines the normal biomechanics of foot and entire lower extremity. The common congenital or developmental deformities of foot include Pes planus, Pes cavus, Talipes Equinus, Talipus Equinovarus, Talipes Equinovalgus, Metatarsus adductus, Calcaneovalgus and Planovalgus etc.

It has been proven by various researches that the height of the medial longitudinal arch of the foot is a predisposing factor to injuries in the lower extremity.[20,21,22] Individuals with both pes cavus and pes planus feet are more at risk for the development of stress fractures in the foot and lower leg.[20,21,22] There is no consensus about exact radiological or clinical criteria to define these abnormalities. Thus the normative values for different parameters of Medial longitudinal arch are imperative for clinicians and podiatrists. Majority of previous studies on foot morphology were done on childhood age groups.[23] Indian database on this area is very limited.

Present study was a cross sectional, observational study which has generated a database on quantitative morphology & flexibility of Medial Longitudinal Arch (MLA) among young Indian adult population of age 17 to 21 years belonging to Gujarat region. This study found the TFL (median with IQR) to be 17.6 (16.8-18.7) & 17.6 (16.8-18.7) on right & left side respectively. The Arch Height (median with IQR) was 4.5 (4-5.1) & 4.5 (4-5.1) on right & left side respectively. The database generated by present study also provides values of Fore Foot Length (FFL), Hind Foot Length (HFL), Anterior Arch Angle (AAA) & Posterior Arch Angle (PAA).

After extensive review of literature, the author did not come across any study which has provided values for all above mentioned parameters in Indian young adults. Table 5 gives the details of comparison between results of previous similar studies around the world & present study. None of the previous studies have studied Truncated Foot Length (TFL), Arch Height (AH), Arch Angles, Arch Spread (AS) and Navicular Drop (ND) simultaneously for assessment of morphology of MLA. Moreover, only the present study has reported gender-wise separate values of all above mentioned parameters. The comparison between male and female groups for various foot parameter resulted into statistically no significant difference.

The present study also evaluated the correlation among different foot parameters and demographic variables. Truncated Foot Length (TFL) showed strong positive correlation with both height and weight of the individual. Arch Height (AH) showed moderately positive and weak positive correlation with Height and weight of the individual. Thus, it can be deduced that the demographic variables influence the morphology of the foot.

Adhikari[24] et al found all the demographic variables did not show significant co-relation with Navicular Drop (ND) except low co-relation between weight and BMI. Nielson et al found that age and BMI did not significantly influence the ND but Foot length had a significant influence on the ND in both men and women. In present study, ND did not show any significant correlation with any demographic variables or other foot parameters.

The present study has generated a broad database for various foot parameters for young Indian adults. The results of this study will be of immense help for clinicians who deal with the foot problems. The normative values for various foot parameters reported by the present study are also essential for the provision of appropriate foot prosthetics and orthotics services.

Conclusion

The present study has generated a comprehensive database for young Indian adults of age 17 to 21 years on morphology of Medial Longitudinal Arch (MLA). The demographic variables have significant influence on the morphology of the MLA which there is no gender differences in the morphology of MLA. None of the previous studies on this topic has provided values for Arch Height (AH), Truncated Foot Length (TFL), Arch Angles, Fore foot Length (FFL), Hind foot Length (HFL), Arch Spread (AS), Navicular Drop (ND) in a single report. The database reported by this study will be of great significance to orthopedic surgeons, podiatrists and industries related to foot prosthetics & orthotics.

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