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Original Research Article

An Analysis of Foot Morphology Using a Self-Designed Foot Scanner in Preparing Custom-Made Footwear: An Anatomical Approach

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ABSTRACT

Foot morphology and morphometry knowledge is vital in several domains. 60% of the population has foot pain due to ill-fitting footwear. There is no standard device or parameters to evaluate the arches of the foot, and most of the research to assess the arches of the foot. Aim of the study: The study aimed to develop a hodoscope (foot scanner) device to evaluate the arches of the foot. The study's objective was to prepare custom–made footwear based on foot morphology. The study included 849 (405 males and 444 females) participants aged between 25 and 45. Podoscope was used to evaluate the arches of the foot. Based on the evaluation, 62 participants were provided with custom-made footwear based on the morphometry of the foot. The statistical analyses were performed using SPSS software. Wilcoxon Signed Ranks Test was used to analyze the pain scale based on positive ranks, with a statistically significant *p-value* (< 0.001). Results: 44.19% of men and 47.97% of women had a normal arch foot. 33.08% of men and 28.82% of women had a flat arch, and 22.71% of men and 23.19% of women had a high arch foot. The present study identified foot problems (forefoot, midfoot and hindfoot) using a self-designed podoscope and attempted to design custom–made footwear based on foot morphometry. The quality of the footwear was acceptable and cost-effective. Custom-made footwear based on foot morphology will benefit individuals with foot problems.

KEYWORDS: Foot Morphology, Self-Designed Foot Scanner, Custom-Made Footwear, Podoscope.

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INTRODUCTION

Foot morphology and morphometry knowledge is vital in several domains [1]. Foot anthropometrics are important in forensic research aiding recognition of the dead. Foot morphology and morphometry helps to identify sex and race of the victim or suspect [2]. Knowledge of foot morphology, morphometry and anthropometrics is an important requirement to design the proper foot wear [3].

Transverse arch (TA), Medial longitudinal arch (MLA), and Lateral longitudinal arch (LLA) are

the three categories for the foot's arches [4]. When bearing weight, the MLA, which is higher than the LLA, works like a spring. Pes planus (PP), often known as a flat arched foot, is a medical condition in which the MLA height is mostly or entirely flat and the plantar surface of the foot is in contact with the ground. High arch foot refers to an MLA's exaggerated height. When walking or standing, a person with a high arch foot puts too much weight on the ball and heel of the foot [5].

Anthropometric, radiographic and foot print indices are the classical methods in analyzing the ankle and foot. The Foot Posture Index (FPI) is a validated method for quantifying the ankle and foot posture in standing position [6]. The World Health Organization reported that more than one billion people are overweight, and 300 million are obese world-wide [7]. Although the mortality rate is low in musculoskeletal disease, it is a major cause of pain and disability in the society [8]. The relationship between the footwear and the presence of foot pain and deformity among 176 people (56 males and 120 females) aged 62-96 years (mean 80.09, SD 6.42) and found that poor and ill-fitting footwear is strongly associated with forefoot pathology and foot pain [9]. Wearing tight shoes for a prolonged period causes the toes to be in a flexed position inside the toe box; this is the cause for the acquired toe deformities [10,11].

Among 5 people 1 person is affected with foot pain in the general population and it is strongly associated with increased age, gender and obesity [12]. Foot pain has been highly prevalent in older people, affecting approxi-mately 1 in 3 people over 65 years [13]. Nunley and Queen, (2009) also described that there is no standard device or parameters to evalu-ate the arches of the foot, and most of the research to assess the arches of the foot were cross-sectional studies, many of them were done in different ethnicity and population very few studies were conducted in Indian school children [12]. A lacuna was found in the reporting of the morphology of toes, standard device for assessing the arches of foot. hence, the study aimed to develop a podoscope (foot scanner) device to evaluate the arches of the foot. The study's objective was to prepare custom–made footwear based on foot morphology.

STUDY DESIGN

Inclusion criteria: The study was conducted in 2 parts a cross-sectional study and an interventional study. A random sampling method was performed to select the participants. A total of 849 (405males and 444females) participants aged between 25 – 45 years were subjects included. The study was conducted in an orthopedic center in Chennai for one year.

Exclusion criteria: Recent fractures, open wounds, ulcers and congenital anomalies in the lower extremities. Any major active rheumatologic, pulmonary, hepatic, renal, dermatologic disease, or inflammatory condition. Central nervous system disorders like hemiplegia, paraplegia, meningitis, and other demyelinating diseases.

MATERIALS

Self–designed podoscope (foot scanner), AutoCAD software, and polyurethane for designing footwear.

Ethical approval: The Institutional Ethics Committee (IEC) of Sri Ramachandra Medical College and Research Institute in Chennai, Tamil Nadu, granted ethical approval. REF : (IEC – NI/14/DEC/44/93). They signed a written consent form following a thorough description of the study, the participant's role, the risks and benefits, and their rights.

Instrumentation and methods: The analysis of foot (forefoot, midfoot and hindfoot) was done using the foot scanning equipment. The podoscope utilised in this study was one that the authors themselves designed out of wood, toughened glass, and a document scanner. When the person is standing above the apparatus, the gadget can support up to 200 kg. The participant's entire foot was properly cleaned with mild soap water as a pre-proce-dure. On the podoscopic device, each partici-pant was instructed to stand straight and face forward. After a few practise runs to get acclimated to the equipment, the digitalized plantar scan images were collected.

Calibration of images from the podoscope: The plantar surface images were uploaded to the computer. The calibration markings are placed on two spots that are known to be spaced apart, and the software AutoCAD calculates images by entering the centimetres of space between the spots.

Intervention: Custom made footwear and insole modifications for support and pain relief. The footwear and insole were designed based on protocol of Central Footwear Training Institute Government of India society, Guindy, Chennai. 62 participants were selected for the intervention, and foot wear was provided based on their foot morphometry.

OBSERVATIONS

The images obtained by the podoscope gadget were examined and scored using the (PSA) index.

Plantar surface area (PSA) index: The assessment of foot was carried out by the PSA index [14]

I. Morphology of the toes (Forefoot)

Fig. 1a: type 1 toe (1 > 2 > 3 > 4 > 5).

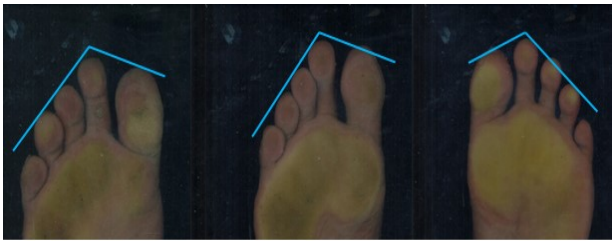

Fig. 1b: type- 2 (1 < 2 >3 > 4 > 5).

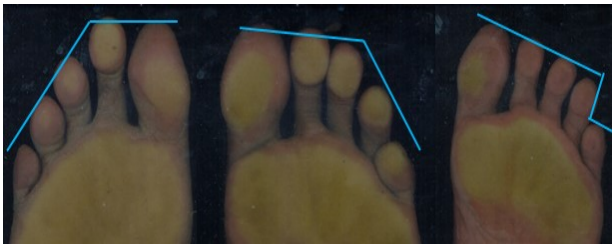

Fig. 1c: type- 3 (1 = 2) **Fig. 1d:** type- 4 (1 = 2 = 3) **Fig. 1e:** type 5(1 = 2 = 3 = 4).

Fig. 1f: type 6 Short toes almost in the same length.

I.a. Deformities of the toes (Forefoot)

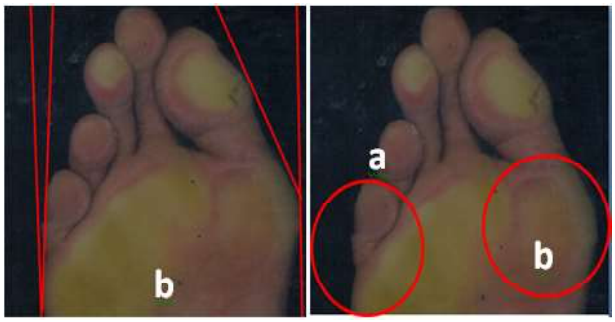

Fig. 2a: a. hallux valgus b. quintus varus
Fig. 2b: a. bunion b. bunionette

Fig. 2c: Hallux valgus with claw toes

Fig. 2d: Crossover 2nd toe

I. Morphology of Arches of the foot (Midfoot)

Fig. 3a: Normal arch **Fig. 3b:** Flat arch **Fig. 3c:** High arch foot

I. Morphology of the Hindfoot

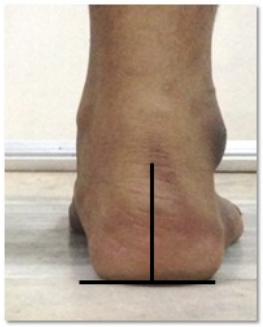

Fig.4a: Neutral foot

Fig.4b: Inverted foot

Fig.4b: Everted foot

Based on the forefoot morphology, it has been found that 55.6% of males and 73% of females exhibit normal toe morphology. This is further classified into six types. 44.4% males and 27% females in the study population were found to have abnormal toes; they were classified into four types as listed in Table 4.

Type 1 is the most common toe type characterized by a longer great toe than the other toes 1 > 2 > 3 > 4 > 5 [Fig. 1a]. Type 2 is the condition in which the first metatarsal was short in relation to the second metatarsal. It is a type of brachymetatarsia 1 < 2 >3 > 4 > 5 [Fig. 1b]. Type 3**:** the great toe and the second toe are equal in length 1 = 2 [Fig. 1c]. Type 4: the great toe, second toe, and third toe are equal in length 1 = 2 = 3 [Fig. 1d]. Type 5: the medial 4 toes are equal in length 1 = 2 = 3 = 4 [Fig. 1e]. Type 6: short toes with and without the gap in between them [Fig. 1f].

Hallux valgus (HV): Excessive lateral angulation of base of the metatarsal joint, with bony bump on the base of the 1st metatarsophalangeal joint has been observed; 8.7% [Fig. 2a & b].

Hallux valgus with Claw toe (HV & CT): Hyperextension of the metatarsophalengeal (MTP joint) and flexion at the PIP and DIP joints has been observed in addition to HV [Fig. 2c].

Cross-over toe (COT): Overlapping of any of the toes over the adjacent toe; 9.8% [Fig. 2d].

Figure 3a,3b and 3c shows the normal, flat and high arched foot. Figure 4a,4b and 4c shows the neutral, inverted calcaneus and everted calcaneus.

Intervention: Based on the forefoot, midfoot and hindfoot assessment the footwear to the participants were prepared and provided in a custom-made manner. Anti-Pronation footwear: was designed for the pronated foot with maximum support to the arches, cushioning and stability. Medial support extended to the heel to prevent calcaneal eversion. Firm midsoles were provided to prevent rolling of foot medially. Neutral footwear: The footwear was designed for the supinated foot with midsole cushioning for shock absorption. Since the high arch foot is rigid, maximum flexibility to the midsole was allowed in the supinated type of foot. Footwear designed for different types of toes, For type – 1 toe ordinary formal shoes. For type – 2 (morton's toe) the ordinary shoe will not accommodate the 2nd toe which causes uncomfortable bending so it was designed as pointed shoes as it accommodates the lengthy 2nd toe inside the toe box. For type – 3,4,5,6 the shoes were designed with box type shoe with broad forefoot width.

Statistical analyses: With a 95% confidence interval, the statistical analyses were carried out using the SPSS statistical programme (version 16.0). The results of the descriptive analysis are provided in table 1 as means and standard deviations (SD) for age, height, and weight.

RESULTS

The prevalence of normal and abnormal types of toes were tabulated as shown in table 2. Prevealce of normal and abnormal arches of the was tabulated and shown in table 3. of foot Each component received a grade ranging from poor (0) to excellent (5) based on the quality of the footwear used. Table 4 showed that participants did not assign scores of 0 to 2 in all the five components indicates that the footwear quality was not as poor. Kruskal Wallis test was used to find the mean rank between all the components. It revealed that

the lowest mean score was 4.04 provided for colour and highest mean score was 5 provided for the ventilation with a statistically significant p<0.001 as shown in the table 5.

Table 1: Characteristics of subjects.

Gender	Age Mean(SD)	Height Mean(SD)	Weight Mean(SD)
Men	43.6 ± 10.3	176±3.4	77.4±9.7
Women	48.4± 9.6	168±2.9	69.2±4.6

Table 2: Distribution of different toe types (toe morphology).

	Toe types	Males n=405	Females n=444
Normal	Type-1	21.20%	24.20%
	Type-2	12.40%	15.00%
	Type-3	8.60%	10.20%
	Type-4	6.40%	11.00%
	Type-5	4.80%	8.20%
	Type-6	2.20%	4.40%
Abnormal	HV	10.60%	6.80%
	HV & CT	0.00%	2.00%
	COT	15.00%	4.60%
	RTM	18.80%	13.60%

Table 3: Normal and Abnormal Arches of the foot.

Types of arches	Males N=405	Females N=444
Normal arch	44.19%	47.97%
Flat arch	33.08%	28.82%
High arch	22.71%	23.19%

Table 4: shows the provided score based on the comfort of the footwear.

Components	Score				N =62	
	0	1	2	3	4	5
Comfort	-	-	-	1	23	38
Grip & stability	-	-	-	-	9	53
Aesthetic Look	-	-	-	3	14	45
Colour	-	-	-	13	33	16
Ventilation	-	-	-	0	0	62

Table 5: Shows Kruskal wallis test for showing mean score in all five components.

	N=62			
Components	Score out of 310	Mean Score	Kruskal Wallis	p-value
Comfort	285	4.59		
Grip & stability	301	4.85		
Aesthetic Look	290	4.67	96.07	<0.001*
Colour	251	4.04		
Ventilation	310	5		

DISCUSSION

The normal arch, (PP), and (PC) have been identified in this study's 849 subjects. The goal of the current study was to prepare a custom made footwear for the participants based on their foot morphology using a self-designed podoscope.

Diply (2011) said that the feet can describe the type of personality of an individual [15]. The foot is classified based on the length of the toes into: Roman foot in which the toes are proportionate and straight, Square foot- the foot type which is the most rectangular in appearance, Greek foot - the extended second toe being its most distinctive feature and Stretched foot - lengthier and thinner looking foot. To the best of our knowledge, not many studies have categorized the types of toes based on morphology. In the present study, six different types of toes were identified among 849 subjects as shown in table 2; Type 1 resembled the Roman foot and Type 2 resembled the Greek foot of Diply. Toe morphology is a major finding to design comfortable footwear.

Podiatrists referred forefoot as the common anatomic region involved in pathological conditions such as Hallux valgus, Hallux rigidus and Morton's neuroma [16]. Hill *et al*., (2008) reported that 53.7% of foot pain is located in the toes; 24.3% to 37.2% is located on the dorsal side of the forefoot [17]. In the present study, among the participants with Hallux valgus and Hallux valgus with Claw toes have been identified. Footwear with great toe separator was provided and a significant pain reduction was observed (by visual analogue scale). Wülker N *et al*., (2012) opined that therapeutic treatment may alleviate the symptoms but does not correct the deformity of the great toe as it was purely an enlargement of the soft tissue, with the first metatarsal head, or both [18]. In case of Claw toes, the over-action of the Flexor digitorum longus compared to the action of Extensor digitorum longus causes the flexion deformity of the 2^{nd}- 5^{th} toes; prolonged fixation of the toes in the flexed position leads to joint stiffness and contracture of the muscles.

Polyurethane material was used to design the footwear, most of the sports footwears are manufactured using polyurethane for comfort and stability. The present study also utilized the polyurethane as the primary material to design the footwears. The designed footwears was assessed by the participants using a self-designed grading scale. The results showed

that the footwear quality was acceptable. The present had implemented only footwear as intervention but along exercises, lifestyle modifications yields the best results.

The present study focussed only on designing custom–made footwear based on foot morphology; other factors, such as body composition, were not considered, which is the study's limitation.

CONCLUSION

The present study identified foot problems (forefoot, midfoot and hindfoot) using a self-designed podoscope and attempted to design custom–made footwear based on foot morphometry. The quality of the footwear was acceptable and cost-effective. Custom-made footwear based on foot morphology will benefit individuals with foot problems.

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Author Contributions

K. Vijayakumar: Concept and design of the study.
Pranali Pal: Recording the study outcomes and data analysis.
T. Vijayasagar: Data Interpretation and final drafting.

Conflicts of Interests: None

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