

Investigation of Shoe Size and Toe Box Shape Variation Effect on Skeletal Alignment of Adult Foot

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ABSTRACT

Improper footwear has been attributed to poor fitting with discomfort, and resulting the ultimate major foot defects. Previous studies on footwear have investigated the effect of material composition, sole stiffness and thickness, heel height, motion etc. and minute amount is known regarding the effects of toe profile variation on forefoot. In consequence, the aim of this study is to investigate the impact of different toe shapes with different shoe sizes on foot bone alignment. An adult male as convenience subject with unknown foot difficulties was recruited for the study. After assessment of foot size and other associated demographic information, anteroposterior view of the participant's foot was captured for each of the nine different footwear as well as barefoot condition. Data like hallux valgus angle (HVA), intermetatarsal angle (IMA), and hallux valgus interphalangeal angle (HVIPA) were collected from the radiographs and analyzed as well. Shoes with plain toe and smaller size provided the worst result with maximum deflection of HVA 157%, IMA 40%, and HVIPA 160% compared with barefoot condition. On the other hand, pointed toe with one size larger imparted the best result with minimum deflection of HVA 100%, IMA 13%, and HVIPA 20%. So, these results clearly indicated the significance of correct toe box room with the proper shoe size as well as fitting. Thus, footwear technologists should emphasize on ergonomic shoe design via using anthropometric measurements of human foot to enhance the comfort of product.

Keywords: Toe shape, Shoe size, Foot, Bone alignment, Radiograph.

1. Introduction

In today's time footwear is considered as one of the basic requirements of a complete costume. In addition, it provides not only safety but also comfort, decoration, and fashion. Dress shoe is considered as an important fashion items which can be styled with various toe profiles such as plain toe, pointed shoe, and squared off [1]. But improper fitting is also responsible for up to 60% of foot pain simultaneously [2]. The deforming effects of inconvenient shoes can lead structural foot disorders such as hallux valgus, mallet toe, hammer toe, claw toe as well as skin lesions such as callouses, corns, metatarsalgia, and other problems [3-6]. There was also evidence that 64% of footwear users claim foot pain with loose footwear [7].

Since pain tolerance limit reported to increase with age, which could promote to wearing tight fitted footwear [8]. But wearing footwear substantially narrower than the foot was associated with disorders like hallux valgus, corns, plantar fasciitis and foot pain, whereas wearing footwear shorter than the foot was associated with toe deformities like hammer toe, mallet toe, claw toe, and curly toe [15]. Impact of improper footwear on foot function have previously analyzed based on shoe size, toe shape and volume, material composition, sole stiffness and thickness, motion control etc. [7, 9-11]. Previous study on the shoe size including one size smaller and one size larger showed that properly fitted footwear decrease peak pressure and provide greatest advantage over ill fitted footwear [7]. Forefoot shape and shoe volume are also thought to heavily contribute to the advancement of toe distortions that require therapeutic intervention [12]. Previous study on toe shape and contours of the shoe highlights that the shape of the toe box in shoe can

significantly influence the forefoot and toe region [9]. Reduced room in the toe box causing cramping of the toes has been associated with foot difficulties including the development of joint defects and forefoot lesions [13].

This study aimed to analyze the effect of toe shape and shoe size variation on foot bone alignment comparing with barefoot condition of adult male.

2. Materials and Method

2.1 Participant

A 24-year-old physically sound and young healthy male person with 176cm height and 69kg weight was selected for the experiments. Furthermore, he had no record of any physical or neurological abnormality of the lower extremities. Foot of the participant was also normal and free from any type of defects. The subject gave his full consent to participate in the study. Appropriate shoe size 42 Paris-point based on foot length of the participant was fixed using a Brannock® device.

2.2 Materials

Nine categories of male footwear with three different profiles of the box were collected from the local market of Bangladesh. The key differences among the three shoe styles were the shape and dimensions of the toe box: plain, pointed and square off toe (Fig.1). Each of the toe shapes has three alternative shoe sizes. One is 42 size perfect for the participant, one is smaller size 41 and the remaining one 43 is larger from the perfect size.

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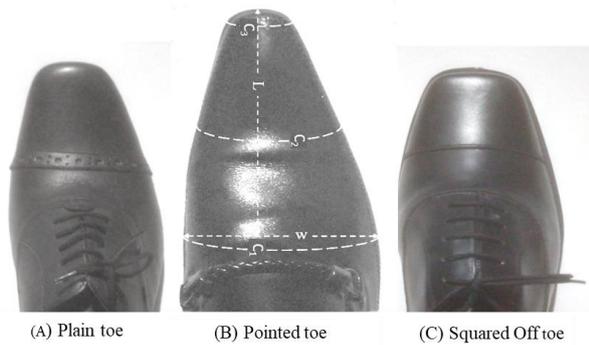


Fig.1 Three toe box profile, (A) plain, (B) pointed and (C) square off; Indication of the key parameters on toe box such as width (W), length (L), depth (D) and circumferences C.

Table 1 Dimensional measurements of the toe box key parameters

Toe Profile	Key Parameters (cm)						
	Width (W)	Length (L)	Depth (D)	Circumference			
				C ₁	C ₂	C ₃	
41	A	8.8	9.0	4.0	26.1	18.2	13.5
	B	9.4	10.3	5.3	27.0	19.0	13.1
	C	9.0	8.2	5.0	28.7	24.0	17.1
42	A	9.3	9.5	4.5	26.8	18.7	14.1
	B	9.8	10.8	5.6	27.6	19.3	13.5
	C	9.6	8.7	5.3	29.6	24.7	17.5
43	A	10.0	10.3	5.0	27.5	19.2	14.6
	B	10.2	11.3	5.9	28.2	19.6	13.8
	C	10.1	9.1	5.6	30.7	25.2	18.0

Dimensional characteristics of the nine types of shoes were measured using vernier calipers and measuring tape and presented in Table 1. Six key parameters of the toe box such as width (W), length (L), depth (D) and three circumferences [circumference through the instep point (C₁), circumference through the vamp point (C₂) and circumference through the tip of toe (C₃)] helped to understand the differences among toe profiles and shoe sizes. Width and depth of the profiles are larger in pointed toe and smaller in plain toe for all sizes of shoe. This means pointed toe has extra room around joint girth region whereas in plain toe claim least room around joint girth. Though circumference around the tip of toe is quite lowered in pointed toe, length of the forefoot is much longer than plain and square off profiles.

2.3 Experimental setup

The system is consisted of 1000mA HITACHI X-Ray machine, a foot template to ensure similar positioning of foot of the participant, and sample footwear that shown in Fig.2. Anteroposterior view of the participant's foot with weight-bearing and straightly stand position were captured from the X-Ray machine. Radiographs were taken for barefoot as well as nine different shoe conditions with ensuring similar positioning through the marked pattern paper to eradicate the random error.

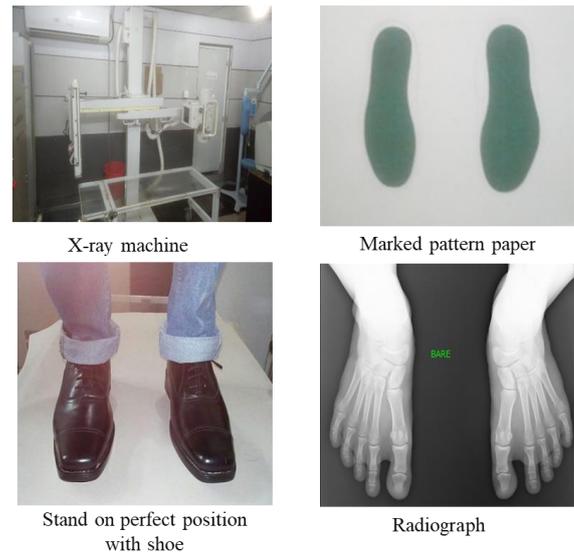


Fig.2 Experimental setup for radiograph

2.4 Data collection

Three distinct foot bone angles such as hallux valgus angle (HVA), intermetatarsal angle (IMA), and hallux valgus interphalangeal angle (HVIPA) for barefoot as well as nine other shoe worn condition were collected from obtained radiographs and shown in Fig.3. Three times manual measurements of the angles were made to minimize error using the 360° circular protractor and their average values are shown in Table 2.

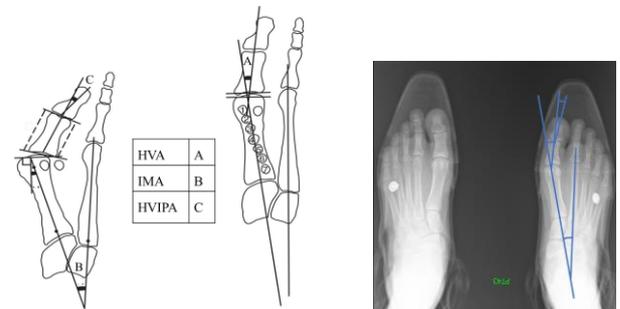


Fig.3 identification and calculation of bone angle from the radiograph

Table 2 Value of foot bone angles (degree)

Shoe Size	Toe Profile	Name of Angles		
		HVA	IMA	HVIPA
41	A	18	9	13
	B	16	11	8
	C	17	10	11
42	A	17	10	11
	B	15	12	7
	C	16	11	9
43	A	16	11	9
	B	14	13	6
	C	15	12	7
Bare Foot		7	15	5

3. Results

Percentages of foot skeletal deflection with respect to unshod condition for shoe size 41 to 43 are presented in Fig.4 to Fig.6. In shoe size 41, percentage of HVA deflection with respect to barefoot was found maximum 157% in plain toe and minimum 128% in pointed toe. IMA deflection also found maximum 40% in plain toe and minimum 26% in pointed toe. Among other parameters, HVIPA deflected maximum of 160% in plain toe whereas it was found 60% in pointed toe.

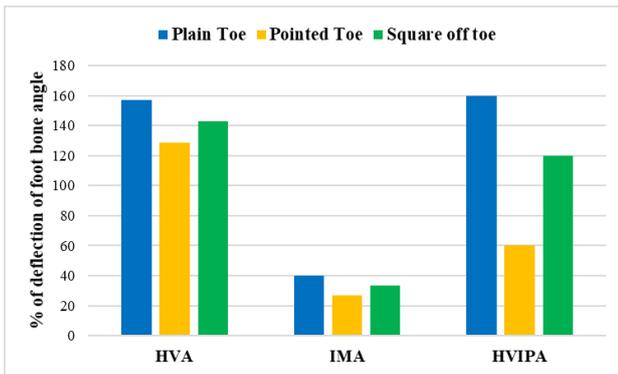


Fig.4 Percentage of angle deflection in relation to three different toe profiles for size 41

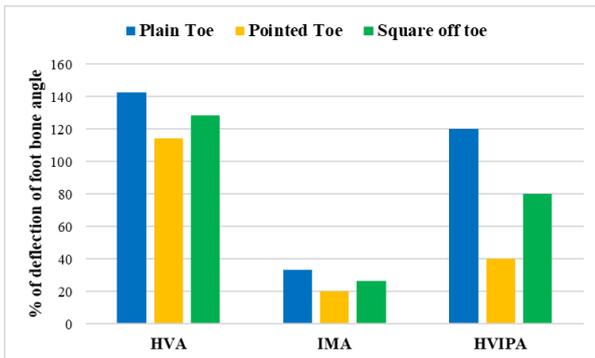


Fig.5 Percentage of angle deflection in relation to three different toe profiles for size 42

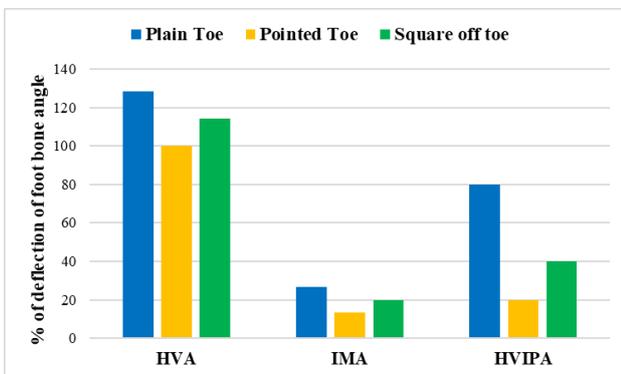


Fig.6 Percentage of angle deflection in relation to three different toe profiles for size 43

Respective deflection appeared to diminish during shifting of shoe size from 41 to 42 where maximum value reduced to 142% in plain toe and minimum value reduced to 114% in pointed toe. Deflection of IMA lowered to maximum 33% and minimum 22% for respective toe profiles. Similarly, with the increase of shoe size, deflection against HVIPA also reduced to 120% maximum value in plain toe and 40% minimum value in pointed toe.

With similar consequences, HVA deflection for 43 shoe size again reduced to 128% maximum value and 100% minimum value for same toe box. Deflection of IMA and HVIPA also diminished with the shoe size from 42 to 43. IMA reduced to 26% and 13% whereas HVIPA reduced to 80% and 20% for plain and pointed toe, respectively.

4. Discussion

From the results of investigation, we found that shoe size and toe profile have significant impact on foot skeletal system. The severity of these impacts varied with the variation of shoe size and shapes of the toe box. Amount of angular bone deflection with respect to barefoot, gradually decreased with the increase of shoe size from 41 to 43. But for individual shoe size 41 (one size smaller than perfect), maximum HVA deflection found in plain toe which is 15% larger than square of and 29% larger than pointed shoe. Similarly, other parameters like IMA and HVIPA showed variation of 7% and 40% larger than square of as well as 14% and 100% than pointed toe, respectively. Shifting from size 41 to proper shoe size 42 decreased the angular variation up to 15%, 14% and 14% in HVA, 7%, 6% and 7% in IMA, and 40%, 20% and 40% in HVIPA respectively. Again, respective deflection reduced from the conversion of proper shoe size 42 to 43 such as 14% in HVA, 7% in IMA and 40%, 20% and 40% in HVIPA.

Surprisingly, in 41 shoe size all of the values of HVA and HVIPA found larger than normal value (normal range of HVA is $<15^\circ$ and normal range of HVIPA is $<10^\circ$ [14-15]) with maximum deviation in plain toe up to 18° and 13° and minimum in pointed toe up to 16° and 8° . This extra stress and deflection could create greater tendency to lead hallux valgus deformity [14]. On the other hand, in case of proper shoe size 42, pointed toe provide the normal range of HVA and HVIPA angle. Although both pointed toe and square off gave normal values of HVA and HVIPA within the shoe size 43, IMA deflected maximum from the marginal line (normal range of IMA is $<9^\circ$ [15]).

Since the plain toe having less toe room with inappropriate width, depth, and circumferences, it was difficult to provide enough space to accommodate the feet into shoe. Hence the plain toe exerts extra pressure on the first metatarsophalangeal, proximal and distal interphalangeal joints. Therefore, the shaft axes of the metatarsal, proximal and distal phalanges bone were compelled to deflect from its original alignment. As a result, the corresponding HVA, HVIPA angles have been experienced to be deflected at higher rate than

others. This high rate of angular distortion could apply excessive stress and cramps on the metatarsophalangeal and distal interphalangeal joints which can lead hallux valgus, bunion and bunionette etc. [16-18]. When the phalanges subjected to extensive pressure, they get overlapped with each other which may lead to mallet toe, hammer toe and similar physiological disorders.

The pointed toe is extremely narrow and relatively elongated so that the narrowest part can be dragged out. This type of shoe featured with longer distance between the tip of toe and the shoe's front [19]. Though pointed toe designed with narrowest and most acute toe shape, it has extra toe box room with quite appropriate width (6mm larger than plain toe and 4mm larger than square off), depth (13mm larger than plain toe and 3mm larger than square off), circumference through instep (9mm larger than plain toe), and circumference through vamp point (8mm larger than plain toe). The taper part of the toe proceeds gradually towards the end of the shoe and the circumference of this tip of toe having lowered than others. It is because the pointed toe box featured with longest length (13mm than plain toe and 21mm than square off) of forepart. Therefore, pointed toe box have more room on the back of longest toe profile compared with square off and plain toe. Although pointed toe has shown a noticeable amount of deflection, provided the best alignment of the foot bone with respect to unshod condition in comparison with plain toe and square off.

With the increase of shoe size from 42 to 43, toe box room increases proportionately and side by side angular deflection reduced simultaneously. But with the increase of toe box room, other parameters of the shoe increased proportionately which could lead difficulty with loose fitting. As 64% footwear user reports foot pain from loose fitting, this result should be discarded [7]. Therefore, it needs extensive research work to optimize the proper toe box room. So, designers and manufacturers should have to emphasize on perfect toe box room during shoe design with keeping suitable shoe size and fit in count using anthropometric measurements of the foot.

5. Conclusion

Variations of shoe size and toe shapes have significant impact on foot musculoskeletal alignment of adult male. Plain toe with shoe size 41 (one size smaller than proper shoe size) provide worst result and affect most in the foot bone alignment. On the other hand, pointed toe with 43 size (one size larger than proper shoe size) gave the best result in comparison with other toes and sizes. These alignments of deflection could lead severe permanent deformation if consumers stay prolongs time with this kind of inappropriate footwear. These results provide a clear indication about the importance of toe box room with the proper shoe size and fit. Hence shoe designers and manufacturers should provide more attention on ergonomic design of products with fashion to avoid foot defects and pain. Footwear users also must be conscious about their selection of footwear with proper size and fit. From the investigation

it can be concluded that a proper shoe size with adequate toe box room can give best fit and comfort of the product.

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