Website:www.aijournals.com/journals/aanat/ DOI: 10.21276/aanat.2018.4.1.13

ORIGINAL ARTICLE ISSN: 2455-5274

A Preliminary Anthropometric Study of Footprint Dimensions as a Model for Height Estimation

Raymond Addai[1], *Chrissie Stansie Abaido*[2], *Atta Kusi Appiah*[3]

[1]*BSC, Kwame Nkrumah University of Science and Technology, Ashanti, Ghana.*

[2]*PHD (Professor), Kwame Nkrumah University of Science and Technology, Ashanti, Ghana.*

[3]*MPhil (Senior Research Assistant), Kwame Nkrumah University of Science and Technology, Ashanti, Ghana.*

Date of Submission: ***06-11-2017***

Date of Acceptance: ***14-03-2018***

Date of Publishing: ***?***

ABSTRACT

Background: Height is an important pillar used in biological profiling. Several human body parts including footprints have been employed in developed countries for forensic and biometric purposes. Little information on footprint dimensions and height is available in Ghana. Hence, this study was conducted to determine the relationship between height and footprint dimensions in a Ghanaian population. **Methods:** Bilateral footprints were obtained from 93 undergraduate students (53 males and 40 females) aged between 18 and 43 years from the Kwame Nkrumah University of Science and Technology, School of Medical Sciences from January 2016 to April 2016using an ink pad and white papers. Seven dimensions: five length dimensions from the most anterior part of each toe to the mid-rear heel point, pterion (designated PT1-PT5), breadth at ball (BAB) and breadth at heel (BAH) were obtained from each footprint. **Results:** Males were found to be taller and with longer footprint dimensions than females. Left footprint dimensions were longer than right footprint dimensions. Bilateral asymmetry were observed in PT1 and BAH in both sexes, PT2 in females only and BAB in males only. Statistically significant positive correlations were observed between height and the left or right footprint lengths from the pterion to all the toes. In males, combinations of PT1 and PT4 accounted for 57.9% variation in height estimation for the right foot and 55% of the variation for the left foot. In the female participants, PT1 of the right foot accounted for 54.9% variation in height estimation whereas PT3 of the left foot accounted for 56.5% of height prediction. **Conclusion:** PT1, PT2 and PT4 were stronger predictors of height in males whereas PT1 and PT3were better estimators of height in females. Footprint dimensions are useful in height estimation.

Keywords: *Footprint, Height, Forensic, Identification*

INTRODUCTION

Height is one of the four important characteristics in profiling an individual in any forensic investigations along with sex, age and race.[1] Many studies have been performed to establish a link between human body parts and an individual's height.[2] Generally, lower body extremities have a better correlation with height than upper extremities.[3] The shape and morphology of the foot have been used in criminal investigations and for identification purposes of recovered bodies after mass disasters like air crashes, bomb explosions, hurricanes and flooding.[2,3] Human footprints, an impression of the weight-bearing plantar surface of the foot, also appear to have a great forensic value in the estimation of height.[4] Footprints are mainly found on newly waxed floors, freshly cemented surfaces, moistened surfaces, dust, oil, paint and blood.[5,6] Footprints are usually recovered at crime scenes when offenders remove their footwear, either to avoid noise or to gain a better grip in climbing walls.[1] Height estimation from footprints also becomes necessary where the height of an individual cannot be measured directly especially in individuals (infants, bedridden, spine problems) who cannot stand upright or lie straight.[7]

Like fingerprints, footprints of an individual are unique to that individual.[8] Therefore, careful examination of

Name & Address of Corresponding Author
Dr. Chrissie Stansie Abaido
PHD (Professor), Kwame Nkrumah University of Science and Technology,
Ashanti,
Ghana.
Email: knustsmsanat1@gmail.com

foot impressions in forensic examination can provide useful clues in establishing one's height when complete or partial footprints are recovered at crime scene. Suspects who were not present at a crime scene would thus be exonerated.[9] Though several regression equations have been developed in estimating height from footprints,[10] the morphology of the human foot varies considerably due to the combined effects of heredity, ethnicity, geographical locations, lifestyle (e.g. body weight, shoe wearing habits), climatic factors, nutritional factors and physical activities.[11] Therefore the aim of the study was to develop regression equations for height estimation from footprint dimensions that is specific to our population. The specific objectives were to:

- Measure and compare heights in both male and female participants.
- Measure footprint dimensions of the study participants.
- Establish regression equations in estimating height from footprint dimensions.

MATERIALS AND METHODS

The present study was conducted at the Department of Anatomy, School of Medical Sciences, Kwame Nkrumah University of Science and Technology (KNUST). A total of 93 participants were recruited for the study, out of which 50 were males and 43 were females aged between 18 and 43 years. Informedparticipants' consentswere sought and Ethical approval was givenby the Committee on Human Research and Publication Ethicsat the Kwame Nkrumah University of Science and Technology, Ghana. Participants with any apparent foot-related diseases or other injury of the foot were excluded from the study.

Standing height of each participantwas measured as a vertical distance from the lowest part of the body to the vertex, with the individual standing bare-footed in the Frankfort plane without headgear,using Shahe's height meter (Shanghai, China).[12] Considering the diurnal variation in stature, the heights of the subjects were measured approximately at the same time in the evening.

A total of 186 footprints were obtained using the inked foam methodand 6 bare-footprint dimensions (5 length dimensions and 2 breadth dimensions) were measured in centimetersfor each foot using Shahe's digital vernier calliper (Shanghai, China).[13] To establish a definite axial orientation for measurement, two important landmarks: the designated longitudinal axis (DLA) and base line (BL) were marked on the footprints following procedures described by Krishan (2008).[9] The DLA was drawn as a straight line from the pternion (the most posterior point of the mide-rear heel point) to the lateral side of the first toe pad margin. The BL was drawn at the rear edge of the foot and perpendicular to the DLA. Five diagonal footprint length measurements were taken from the pternion (P) to the most anterior point of each toe (T1, T2, T3, T4, T5), and designated PT1, PT2, PT3, PT4 and PT5. Again, the widest distance across the heel, Breadth at heel (BAH), and the maximum breadth between the medial margin of the head of the metatarsal print and lateral margin of the fifth metatarsal print, Breadth at ball (BAB), were measured [Figure 1]. All the measurements were taken twice and averaged by the same person to avoid inter-observer error.

Data collected were analysed using the IBM Statistical Package for Social Sciences (SPSS) version 20. A paired t-test was used to compare the footprint dimensions on the right and left foot and between male and female footprint. A p-value less than 0.05 or 0.01 was considered significant at a confidence interval of 95% and 99% respectively.

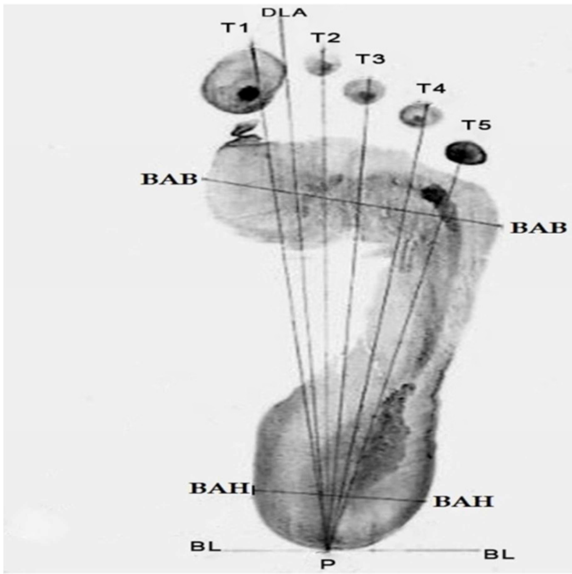

Figure 1: Photograph showing the measurements of right footprint dimensions (x 0.2).(P: pternion; DLA: designated longitudinal axis; BL: baseline;BB:Breadth at ball; BH:Breadth at heel.

RESULTS

The mean age of males was 22.04 ± 2.58 years (range: 18 - 33 years) whereas the mean age of female was 22.16 ± 3.78 years (range: 18 - 43 years). The measured standing height of males ranged from 155.35 cm to 183.65 cm, with a mean height of 171.20 ± 6.34 cm whereas in females, the measured standing height ranged from 145.55cm to 175.05 cm, with a mean height of 162.13 ± 5.72 cm.

[Table 1] shows the means, standard deviations and differences between left and right footprint dimensions in both males and females. The mean PT1 of the right and left footprints were longer than their corresponding footprint dimensions for both male and female participants. This decreased gradually from PT1 to PT5. A higher difference was observed between PT4 and PT5 than between PT1 and PT3 in both foot. Except for BAH, the left footprint dimensions of females were numerically greater than the right footprint dimensions. This was statistically significant for PT2($p < 0.05$), PT1 and BAH ($p < 0.01$). In males however, all the left footprint dimensions were greater than the right footprint dimensions, and the differences were statistically significant for PT1 ($p < 0.05$), BAB and BAH ($p < 0.01$).

Table 1: Descriptive Statistics and Right-Left of Footprint Dimensions in Males and Females.

	Male			Female		
Footprint dimensions	**Right Mean ± SD (n = 53)**	**Left Mean ± SD (n = 40)**	**Paired t-test**	**Right Mean ± SD (n = 53)**	**Left Mean ± SD (n = 40)**	**Paired t-test**
PT1	25.20 ± 1.25	25.37 ± 1.28	-0.168*	23.64 ± 1.12	23.99 ± 1.11	-0.347**
PT2	24.91 ± 1.21	25.04 ± 1.22	-0.123	23.08 ± 1.14	23.24 ± 1.10	-0.162*
PT3	23.94 ± 1.18	24.06 ± 1.18	-0.116	22.14 ± 1.07	22.19 ± 1.13	-0.053
PT4	22.79 ± 1.15	22.90 ± 1.16	-0.111	21.04 ± 1.04	21.09 ± 1.07	-0.040
PT5	21.43 ± 0.96	21.50 ± 0.95	-0.069	19.71 ± 1.01	19.76 ± 1.03	-0.047
BAB	9.26 ± 0.61	9.49 ± 0.66	-0.239**	8.49 ± 0.50	8.68 ± 0.51	0.026
BAH	5.57 ± 0.55	5.80 ± 0.70	-0.230**	5.12 ± 0.47	5.09 ± 0.46	-0.183**

SD = Standard Deviation; cm = Centimeter.BAB = Breadth at ball; BAH = Breadth at heel;* p<0.05;**p<0.01.

[Table 2] shows the differences between male and female footprint dimensions for both the right and left foot. All the footprint dimensions were statistically greater in males than females ($p<0.01$).

Table 2: Paired t-test Analysis for Sexual differences in Right and Left Footprint Dimensions.

	Footprint dimensions						
	PT1	**PT2**	**PT3**	**PT4**	**PT5**	**BAB**	**BAH**
Right	-1.639*	-1.901*	-1.887*	-1.804*	-1.794*	-0.511*	-0.800*
Left	-1.451*	-1.933*	-1.999*	-1.949*	-1.839*	-0.807*	-0.864*

*p<0.01

Correlation between Height And Footprint Dimensions

[Table 3] showsthe correlations between height and right or left footprint dimensions in males and females. There was a strong statistically significant correlations between height and left and right footprint dimensions of the male participants except between height and BAH of the left footprint (r = 0.110, p = 0.435). For the female participants, except for BAH of the right foot (r = 0.245, p = 0.128) and BAB in both feet (right: r = 0.312, p = 0.050; left: r = 0.269, p = 0.093), strong statistically significant correlations were observed between height and all the footprint dimensions.

Table 3: Correlations between Height and Right or Left Footprints in Males and Females

Sex			**PT1**	**PT2**	**PT3**	**PT4**	**PT5**	**BAB**	**BAH**
Male	Right	r	0.738	0.736	0.708	0.709	0.689	0.296	0.301
		p-value	0.000**	0.000**	0.000**	0.000**	0.000**	0.031*	0.029*
	Left	r	0.733	0.741	0.700	0.642	0.668	0.372	0.11
		p-value	0.000**	0.000**	0.000**	0.000**	0.000**	0.006**	0.435
Female	Right	r	0.741	0.692	0.704	0.731	0.717	0.312	0.245
		p-value	0.000*	0.000*	0.000*	0.000*	0.000*	0.050	0.128
	Left	r	0.712	0.681	0.751	0.746	0.702	0.269	0.406
		p-value	0.000*	0.000*	0.000*	0.000*	0.000*	0.093	0.009*

PT = Pternion to toe length; BAB = Breadth at ball; BAH = Breadth at heel; r = correlation coefficient;* p< 0.05;**p< 0.01.

Regression Analysis For Predicting Height From Footprints Dimensions

[Table 4] shows linear regression equations for estimating height from footprint dimensions followinga stepwise multiple regression analysisusing the equation Y=b1*X1 + b2* X2+ a.The PT1 and PT4 of the right foot and the PT2 of the left foot were the best predictors of height in males. On the other hand, the PT1 of the right foot and PT3 of the left foot were the best predictors of height in females.

Table 4: Regression Equations for Height Estimation Using Footprint Dimensions in Males and Females

		Regression Equations	R2	SEE
Males	Right	2.41 PT1 + 1.79 PT4 + 69.73	0.579	4.19
	Left	74.94 + 3.85 PT2	0.550	4.29
Females	Right	72.51 + 3.79 PT1	0.549	3.89
	Left	77.84 + 3.798 PT3	0.565	3.82

PT= Pternion to toe length; R2 = Coefficient of determination; SEE= Standard error of estimate.

DISCUSSION

In this study, the mean height of male participantswas significantly higher ($p < 0.05$)than that of female participants. This finding is in agreement with similar studies byBidmos (2008)in a South African population,[14] Numan and friends 2013 in a Nigerian population,[15] Hemy et al. 2013 in a Western Australian population andChoksi 2014 in an Indian population.[16,17] The significant difference in height of malescompared to femalescould be attributed to the earlier fusion of the epiphyseal plates in females.[18] Sex hormones are known to affect bone development. During puberty, females produce higher amount of oestrogen compared to males. The heightened levels of oestrogen increase apoptosis of chondrocytes in the epiphyseal plate slowing down bone ossification and growth.[19] High levels of testosterone in males prolong growth phases of long bones.

All the lengths of the footprint dimensions, in both right and left foot in males, were statistically greater than females. This is expected since males were found to be taller than female and would concomitantly have greater measured footprint lengths.[19,20] The mean PT1 for both right and left footprints in both sexes was the longest in comparison with other footprint dimensions. This is in contrast with the result of a study by Hairunnisa (2014) where the mean PT1 and PT2 of both feet were found to be the same in female adult Ibans, an indigenous group residing in Sarawak state of Eastern Malaysia.[21] Except for BAH, left footprint dimensions were longer than right footprint dimensions in the female participants. We observed bilateral asymmetry in female footprint dimensions for PT1, PT2 and BAH. This is in contrast to an earlier report by Ableduet al. (2016) in a Ghanaian population who observed bilateral symmetry.[22] A study among Malays of Malaysia by Moorthy and Zulkifly (2015) also report bilateral symmetry in female footprint dimensions.[23]

In the male participants, left footprint dimensions werelonger than right footprint dimensions. Peters (1988) however reported the mean right footprint dimensions of Russian male adults to be numerically higher than the left.[24] Our finding is consistent with studies by Krishan (2008) except for BAB and also with Moorthyet al. (2014) and Ableduet al. (2016) who reportedBilateral asymmetry for PT1, BAB and BAH. In addition, Ableduet al. (2016) reported bilateral asymmetry for PT2, PT3, PT4 and PT5.Among male Guijars of Northern India, PT1, PT4 and BAB showed bilateral asymmetry as reported by Krishan, 2008. Bilateral asymmetry were also reported for all footprint length measurements (PT1 to PT5) and BAH among male Tamils of India (Moorthy et al, 2014). Robbins (1986), Philip (1990) and Hemyet al. (2013) found no significant bilateral asymmetry in footprint dimensions in both males and females in the American, South Indian and West Australian populations respectively.[16,25,26] The disparity between studies may be due to sample size,geographical location and occupations of study participants.

The existence of bilateral asymmetry in different footprint dimensions suggest that the left and right foot of the same individual may not make identical footprints. Bilateral asymmetry may be attributed to the ‘dominant foot’ phenomenon postulated by Moorthyet al. (2014) who stated that the left lower limb appears to be the dominant foot. Since it supports the limb during walking and weight-bearing, greater strain is put on it causing it to develop via adaptationand thereby producing larger foot dimensions. This hypothesis is in accordance with Lamarck’s theory of use and disuse.[10]

We observed stronger positive correlations between height and footprint dimensions fromPT1 to PT5 in both right and left foot of males. There was however no significant correlation between height and BAH of the left foot. A higher correlation was recorded between height and PT1 of the right foot ($r = 0.738$),and PT2 of the left foot ($r = 0.741$). In the female participants however strongerpositive correlationswere observed between height and all footprint dimensions except for BAB of the left footand BAB or BAH of the right foot. Toes-to-heel length measurements are therefore more reliable in estimating height than any other measurements (that isBAB and BAH). These findings are in accordance with several previous reports.[2,27,28]

Stepwise multiple regression analysis were employed in determining best footprint dimension(s) in estimating stature. In males, combinations of PT1 and PT4accounted for 57.9% variation in stature estimationfor the right foot and 55% of the variation for the left foot with standard error of estimate (SEE) of 4.19 cm and 4.29 cm respectively. In the female participants,PT1 of the right foot accounted for 54.9% variation in height estimation with SEE of 3.89 cm whereasPT3 of the left foot accounted for 56.5% variation in height prediction with SEE of 3.82 cm.

It should be noted that the regression equations derived for stature estimation using footprint dimensions are specific to our population and it would be incorrect to utilize these equations to any other populations in the world.

CONCLUSION

Males were found to be taller and with longer footprint dimensions than females. Left footprint dimensions were longer than right footprint dimensions. Bilateral asymmetry were observed in PT1, PT2 and BAH in females and PT1, BAB and BAH in males. The lengths of footprint from the pternion to the toes correlated strongly with height. Hence, PT1, PT2 and PT4 were stronger predictors of height in males whereas PT1 and PT3were better estimators of height in females. Footprint dimensions are useful in height estimation.

REFERENCES

1. Krishan K. Determination of stature from foot and its segments in a north Indian population. Am J Forensic Med Pathol. 2008;29(4):297–303.
2. Kanchan T, Menezes RG, Moudgil R, Kaur R, Kotian MS, Garg RK. Stature estimation from foot dimensions. Forensic Sci Int. 2008;179(2):241-e1.
3. Özaslan A, İşcan MY, Özaslan İ, Tuğcu H, Koç S. Estimation of stature from body parts. Forensic Sci Int. 2003;132(1):40–5.
4. Deepashini H, Omar B, Paungmali A, Amaramalar N, Ohnmar H, Leonard J. An insight into the plantar pressure distribution of the foot in clinical practice: Narrative review. Polish Ann Med. 2014;21(1):51–6.
5. Ilayperuma I, Nanayakkara BG, Palahepitiya KN. A model for reconstruction of personal stature based on the measurements of foot length. Gall Med J. 2009;13(1).
6. Krishan K, Kanchan T, Sharma A. Sex determination from hand and foot dimensions in a North Indian population. J Forensic Sci. 2011;56(2):453–9.
7. Choksi A, Babu GR, Dahiya MS, Numan AI, Idris MO, Zirahei J V, et al. Analysis of stature prediction from foot anthropometry: a South Korean case study. Forensic Sci Int. 2008;5(1):9–21.
8. Moorthy TN. Stature Estimation from the Anthropometric Measurements of Footprint in Iban Ethnics of East Malaysia by Regression Analysis. J Forensic Sci Criminol. 2014;1:501.
9. Krishan K. Estimation of stature from cephalo-facial anthropometry in north Indian population. Forensic Sci Int. 2008;181(1):52-e1.
10. Moorthy TN, Mostapa AM Bin, Boominathan R, Raman N. Stature estimation from footprint measurements in Indian Tamils by regression analysis. Egypt J Forensic Sci. 2014;4(1):7–16.
11. Zeybek G, Ergur I, Demiroglu Z. Stature and gender estimation using foot measurements. Forensic Sci Int. 2008;181(1):54-e1.
12. Jakhar JK, Pal V, Paliwal PK. Estimation of height from measurements of foot length in Haryana Region. 2010;
13. Reel S, Rouse S, Obe WV, Doherty P. Estimation of stature from static and dynamic footprints. Forensic Sci Int. 2012;219(1):283-e1.
14. Bidmos MA. Estimation of stature using fragmentary femora in indigenous South Africans. Int J Legal Med. 2008;122(4):293–9.
15. Numan AI, Idris MO, Zirahei J V, Amaza DS, Dalori MB. Prediction of stature from hand anthropometry: a comparative study in the three major ethnic groups in Nigeria. 2013;
16. Hemy N, Flavel A, Ishak N-I, Franklin D. Sex estimation using anthropometry of feet and footprints in a Western Australian population. Forensic Sci Int. 2013;231(1):402-e1.
17. Choksi A, Babu GR, Dahiya MS. Study on the primary characteristics of identification: estimation of stature from palm length among the native Guajarati population. NHL J Med Sci. 2014;3(2).
18. El-Meligy MMS, Abdel-Hady RH, Abdel-Maaboud RM, Mohamed ZT. Estimation of human body built in Egyptians. Forensic Sci Int. 2006;159(1):27–31.
19. Ebite LE, Ozoko TC, Eweka AO, Otuaga PO, Oni AO, Om'Iniabohs FAE. Height: ulna ratio: a method of stature estimation in a rural community in Edo state, Nigeria. Internet J Forensic Sci. 2008;3(1):12–8.
20. Krauss I, Grau S, Mauch M, Maiwald C, Horstmann T. Sex-related differences in foot shape. Ergonomics. 2008;51(11):1693–709.
21. Hairunnisa MAK. Stature estimation from the anthropometric measurements of footprint in Iban ethnics of east Malaysia by regression analysis. J Forensic Sci Criminol. 2014;2(2):1.
22. Abledu JK, Abledu GK, Offei EB, Antwi EM. Estimation of stature and body weight from footprint dimensions among a female population in Ghana. Aust J Forensic Sci. 2016;48(2):195–202.
23. Moorthy E, Zulkifly N. Regression analysis for stature determination from hand anthropometry of Malaysian Malays for forensic investigation. Sri Lanka J Forensic Med Sci Law. 2015;5(2).
24. Peters M. Footedness: Asymmetries in foot preference and skill and neuropsychological assessment of foot movement. Psychol Bull. 1988;103(2):179.
25. Robbins LM. Estimating height and weight from size of footprints. J Forensic Sci. 1986;31(1):143–52.
26. Philip TA. Formulae for estimating stature from foot size by regression method. J Ind Acad Forensic Med. 1990;12:57–62.
27. Krishan K, Sharma A. Estimation of stature from dimensions of hands and feet in a North Indian population. J Forensic Leg Med. 2007;14(6):327–32.
28. Chikhalkar BG, Mangaonkar AA, Nanandkar SD, Peddawad RG, Danborno B, Elukpo A. Estimation of stature from measurements of long bones, hand and foot dimensions. Internet J Forensic Sci. 2010;3(1):379–83.

How to cite this article: Addai R, Abaido CS, Appiah AK. A Preliminary Anthropometric Study of Footprint Dimensions as a Model for Height Estimation. Acad. Anat. Int. 2018;4(1):62-67.

Source of Support: Nil, **Conflict of Interest:** None declared.