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ORIGINAL ARTICLE

Morphometrics in action: Predictive modelling of height using toe and hand dimensions.

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ABSTRACT… Objectives: To explore the link between hand and foot dimensions with stature, emphasizing gender-specific variations to improve personal identification or clinical measures. **Study Design:** Observational Cross-sectional study. **Setting:** Rai Medical College Teaching Hospital, Sargodha. **Period:** March to May 2025. **Methods:** Which analysed MBBS students from Rai Medical College, Sargodha, comprising 200 males and 205 females after getting informed consent. Ethical approval was obtained from the institutional review committee prior to conducting the research. The data were statistically analysed using SPSS version 27. Multiple linear regression analyses were performed separately for male and female participants for possible predictive association. **Results:** Separate regression models were conducted for males and females to assess the relationship between toe lengths, hand heights, and overall height. In males, left pinky toe length ($B = -0.088$, $p = 0.020$) and left hand height ($B = 0.081$, $p = 0.008$) were significant predictors of height, while other variables were not significant. In females, none of the measured variables significantly predicted height (all $p > 0.05$). **Conclusion:** In males, left-hand height and pinky toe length showed a dependable indicator of stature estimation models based on foot and hand measurements, which suggests the sex obligations of specific approaches in forensic biometric assessments.

Key words: Anthropometric, Biometrics, Morphometrics, Mis-identification, Multiple Linear Regression, Podiatry, Stature.

INTRODUCTION

Anthropometry measurements elaborated the mass proportions, and various ratios of the human body and established important and unbiased perceptions into phenotypic variation and dysmorphology.[1,2] Hand and feet development is interlaced due to its serially homologous structures, which shares their common genetic blueprint, signaling pathways, and embryological timeline, despite their functional divergence. During the 4th week of embryogenesis both the upper forelimb limb and lower hind limb buds begin to develop, precisely around day on 26–27 for the upper limb buds and day 28–29 for the lower limb buds These limb buds arise from the lateral plate mesoderm, which contributes to the skeletal elements, while somites provide muscle precursors, and neural crest cells contribute to the connective tissues.[3,4] Similar genes directed the both structures like H-ox, Shh, FGF, and Wnt pathways with little time variation.[5,6,7] Due to the alterations in one structure phenotypic covariation happens which is driven by evolutionary pressure like bi-pedalism in humans which can influences on the morphometry and their functions of other.[8,9,10] From ancient times scientific approaches taken while linking the individuals at crime scene or determining the legal questions associated with human foot. Further forensic podiatrists help in aiding traces of foot prints with reconstruction of biological profiles with their statures which serves as main role with sex, age, and ancestry. Stature estimation from foot measurements is very critical with incomplete remnants.[11,12] It is also pertinent to mention that foot prints analysis importance also found in many disciplines like Pediatrics where foot prints taken at birth for preventing misidentification in hospital along with early diagnosis of foot deformities.[13]

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The medicolegal records of child birth in obstetrics and gynecology for disputed paternity or institutional hospital error also administered in hospitals.[13] It is further added that foot morphology helps and guide the postoperative recovery and orthopedic future planning in trauma and amputation cases.[14] In mass casualty events, when other identifiers are destroyed, intact footprints or footwear impressions can aid identification.[15] As a unique and non-invasive identifier, footprints are gaining traction in access control technologies, especially in underserved populations where conventional biometrics may be impractical.[16]

Previous research has underscored the individuality of footprints[17], their morphological characteristics[18], and their utility in determining traits such as sex[19], body mass[20,21], and stature. Various studies have introduced footprint-to-stature ratios[21,22-25] and regression equations to enhance accuracy. Given that foot structure is influenced by genetic and environmental factors, developing region-specific stature estimation models is essential. Many earlier studies concentrated solely on maximum footprint length, limiting their utility in cases with only partial prints. Only few studies were conducted to address this limitation, the present study introduces a multi-metric approach, analyzing five toe-based length measurements among the medical students of Rai medical College, Sargodha. Our study objective is to explore the relationship between hand and foot dimensions with stature, emphasizing gender-specific variations to improve personal identification or clinical measures which enhances the practicality and precision of stature estimation from the footprints within the Sargodha Punjab population, using robust statistical modeling.

METHODS

The study involved MBBS students from Rai Medical College, Sargodha, comprising 200 males and 205 females. Ethical approval was obtained from the institutional review committee prior to conducting the research. After getting approval from the Institutional Review Board (IRB), it approved the research proposal via letter No. RMCS/ERC/03 /25 dated February 6, 2025. Data was collected after getting verbal informed consent from the participants during the month of March to May, 2025. Data was collected through the non-probability convenience sampling method. The assumption of normality was assessed for all continuous variables separately for male and female participants using both the Kolmogorov-Smirnov and Shapiro-Wilk tests.

Results indicated that height, right foot breadth, and left foot breadth significantly deviated from a normal distribution in both males and females ($p < .001$ for all). MBBS candidates of Rai Medical College who have given written and verbal informed consent were physically fit without any injury or deformity on the limbs were included in the study . Any candidate who have history of deformity, fractures congenital anomalies affecting limb proportions, orthopedic surgeries or who have declined to participate were excluded from the study.

Stature measurement is the vertical distance between the point vertex and the floor. The candidates were asked to stand in an erect posture against a wall without any wear on head and foot. The feet axis was parallel or slightly divergent and head was in Frankfort horizontal plane when the stature was noted. Footprints were obtained from left and right feet of each candidate. The candidates were asked to wash their foot clean with soap and water. A clean plain glass plate was uniformly smeared with black duplicating ink with the help of a roller. The candidates were asked to apply their feet on the smeared plate and then transfer them on to a white paper. Regular pressure was applied on the foot area to obtain the footprints. The footprints were taken one by one from both the feet in each candidate. Measuring the footprints Five measurements were taken in centimeters on right and left footprints obtained from each candidate with the standard procedures followed from Robbins[7] and Krishan.[17]

The measurements were taken from the Height Right Foot Breath, Left Foot Breath, Maximum Height of Right Foot, Maximum Height of Left

Foot, Right Big Toe, Right Pointer Toe, Right Middle Toe, Right Ring Toe, Right Pinky Toe, Left Big Toe, Left Pointer Toe, Left Middle Toe, Left Ring Toe, Left Pinky Toe, Height of Rt.Hand, Height of Left Hand respectively. The data were statistically analyzed using SPSS version 27. Sex differences in stature and foot measurements were analyzed using Student's t-test asymmetry between sides the measurements on footprints was calculated and multiple linear regression analyses were performed separately for male and female participants to investigate the association between various toe lengths, hand heights, and overall height.

RESULTS

The anthropometric data from 405 participants (200 males, 205 females) were analyzed to determine the relationship between hand, foot dimensions, and stature. As mentioned in table -01 all hand and foot dimensions were recorded in centimeters (cm) and a one-sample t-test was conducted to determine whether the mean values of various anthropometric measurements significantly differ from zero in both male and female participants one-sample t-test confirmed that all measured parameters (height, foot breadth, toe lengths, and hand heights) were significantly greater than zero for both genders (all $p < 0.001$), confirming the robustness of the collected data. The largest mean values were detected from the maximum height of right foot (24.91 ± 0.44 cm) and right big toe length (24.93 ± 0.43 cm) in males. Likewise maximum right foot height (25.07 ± 0.43 cm) and right big toe length (25.22 ± 0.46 cm) were the highest documented measurements in females. The extremely low p-values (< 0.001) across all variables indicate highly significant results, confirming that the observed measurements are not due to chance and are statistically meaningful in both male and female groups. Table -02 demonstrated that multiple linear regression analyses were performed separately for male and female participants to investigate the association between various toe lengths, hand heights, and overall height. Males regression measurements highlighted the left pinky toe length ($\beta = -0.088$, $p = 0.020$) and the left hand height ($\beta = 0.081$, $p = 0.008$) emerged as significant predictors of stature and whole model explained 36% of the variance ($R^2 = 0.36$, $p < 0.001$) in male stature. Females highlighted the none of the measured toe or hand dimensions significantly predicted stature (all $p > 0.05$) and variable closest to significance was right big toe length ($\beta = -0.071$, $p = 0.064$). In females whole model accounted for only 12% of the variance ($R^2 = 0.12$, $p > 0.05$). it has been evident that such outcomes indicating that toe and hand dimensions served as modest predictors for the height in males and in females no any statistically significant predictors were identified.

DISCUSSION

The present study explored the relationship between various anthropometric measurements—including foot breadth, toe lengths, and hand heights—and overall stature among male and female participants. One-sample t-tests demonstrated that all measured parameters were significantly greater than zero in both genders, reflecting consistent anthropometric dimensions in the population studied. Remarkably the similar patterns peak values were observed in both males and females for the maximum height of the right foot and right big toe which establishes standard anthropometric outlines among them and underlining its relevance in stature estimation and forensic investigations. It is pertinent to mentioned that gender based variations in prediction of height observed in regression analyses.

The length of left pinky toe and left hand height arisen as significant stature predictors. The length of left pinky toe also showed negative association which probably may be due to the genetically or biomechanical growth factors persuading the foot morphology growth patterns comparative with stature, which is dependable on recent findings demarcating sexual dimorphism and asymmetry in foot proportions.[27,28,30] On the other hand our results positive relationship amongst the height of left hand and stature supporting the previous studies which highlighting their effectiveness in anthropological and forensic fields for estimating the stature in which significant association amongst the hand dimension and height found.

Gender		Test Value = 0						
		(Mean ± SD, cm)	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
							Lower	Upper
Male	Height	171.2 ± 6.8	270.164	199	.000	5.5135	5.473	5.554
	Right Foot Breath	9.53 ± 0.28	135.427	199	.000	9.5255	9.387	9.664
	Left Foot Breath	9.40 ± 0.27	135.699	199	.000	9.4010	9.264	9.538
	Maximum Height of Right Foot	24.91 ± 0.44	223.949	199	.000	24.9110	24.692	25.130
	Maximum Height of Left Foot	24.71 ± 0.44	221.045	199	.000	24.7050	24.485	24.925
	RightBigToe	24.93 ± 0.43	227.635	199	.000	24.9285	24.713	25.144
	RightPointerToe	24.34 ± 0.46	207.011	199	.000	24.3400	24.108	24.572
	RightMiddleToe	23.42 ± 0.46	203.287	199	.000	23.4215	23.194	23.649
	RightRingToe	22.31 ± 0.45	196.616	199	.000	22.3076	22.084	22.531
	RightPinkyToe	20.79 ± 0.53	154.364	199	.000	20.7895	20.524	21.055
	LeftBigToe	26.00 ± 2.26	22.646	199	.000	26.0035	23.739	28.268
	LeftPointerToe	24.34 ± 0.45	213.630	199	.000	24.3380	24.113	24.563
	LeftMiddleToe	23.44 ± 0.45	203.686	199	.000	23.4410	23.214	23.668
	LeftRingToe	22.31 ± 0.44	205.642	199	.000	22.3120	22.098	22.526
	LeftPinkyToe	20.86 ± 0.47	185.116	199	.000	20.8595	20.637	21.082
	Height of Rt.Hand	18.66 ± 0.40	184.949	199	.000	18.6605	18.462	18.859
	Height of Left Hand	18.67 ± 0.37	198.086	199	.000	18.6730	18.487	18.859
Female	Height	158.9 ± 6.1	250.916	204	.000	5.5368	5.493	5.580
	Right Foot Breath	9.55 ± 0.29	129.189	204	.000	9.5522	9.406	9.698
	Left Foot Breath	9.42 ± 0.29	126.500	204	.000	9.4151	9.268	9.562
	Maximum Height of Right Foot	25.07 ± 0.43	229.770	204	.000	25.0668	24.852	25.282
	Maximum Height of Left Foot	24.92 ± 0.44	226.011	204	.000	24.9176	24.700	25.135
	RightBigToe	25.22 ± 0.46	213.320	204	.000	25.2215	24.988	25.455
	RightPointerToe	24.56 ± 0.48	200.274	204	.000	24.5600	24.318	24.802
	RightMiddleToe	23.61 ± 0.47	192.271	204	.000	23.6088	23.367	23.851
	RightRingToe	22.41 ± 0.45	184.980	204	.000	22.4118	22.173	22.651
	RightPinkyToe	21.08 ± 0.46	183.016	204	.000	21.0805	20.853	21.308
	LeftBigToe	27.27 ± 3.11	17.297	204	.000	27.2702	24.162	30.379
	LeftPointerToe	24.56 ± 0.48	199.919	204	.000	24.5629	24.321	24.805
	LeftMiddleToe	23.62 ± 0.47	192.515	204	.000	23.6210	23.379	23.863
	LeftRingToe	22.48 ± 0.47	190.400	204	.000	22.4800	22.247	22.713
	LeftPinkyToe	21.13 ± 0.46	183.562	204	.000	21.1312	20.904	21.358
	Height of Rt.Hand	18.82 ± 0.41	181.218	204	.000	18.8166	18.612	19.021
	Height of Left Hand	18.88 ± 0.39	191.483	204	.000	18.8790	18.685	19.073

Table-I. One-Sample test sample size = 405

Gen-der	Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
			B	Std. Error	Beta			Lower Bound	Upper Bound
Male	1	(Constant)	4.416	.439		10.050	.000	3.549	5.282
		RightBigToe	-.012	.034	-.066	-.358	.720	-.079	.055
		RightPointerToe	-.024	.058	-.138	-.412	.681	-.138	.091
		RightMiddleToe	.050	.048	.281	1.035	.302	-.045	.144
		RightRingToe	-.038	.046	-.209	-.819	.414	-.128	.053
		RightPinkyToe	.005	.019	.032	.255	.799	-.033	.043
		LeftBigToe	-.002	.001	-.094	-1.312	.191	-.004	.001
		LeftPointerToe	.068	.058	.379	1.167	.245	-.047	.182
		LeftMiddleToe	-.048	.053	-.271	-.907	.366	-.153	.057
		LeftRingToe	.098	.052	.524	1.890	.060	-.004	.201
		LeftPinkyToe	-.088	.037	-.485	-2.356	.020	-.161	-.014
		Height of Rt.Hand	-.043	.028	-.212	-1.521	.130	-.098	.013
		Height of Left Hand	.081	.030	.375	2.679	.008	.021	.141
Fe-male	1	(Constant)	6.289	.471		13.357	.000	5.361	7.218
		RightBigToe	-.071	.038	-.380	-1.866	.064	-.146	.004
		RightPointerToe	.067	.073	.371	.912	.363	-.077	.211
		RightMiddleToe	-.040	.058	-.222	-.686	.494	-.155	.075
		RightRingToe	.031	.058	.171	.535	.594	-.084	.146
		RightPinkyToe	-.069	.057	-.359	-1.202	.231	-.182	.044
		LeftBigToe	.001	.001	.063	.859	.392	-.001	.003
		LeftPointerToe	-.037	.071	-.206	-.524	.601	-.176	.102
		LeftMiddleToe	-.016	.061	-.091	-.270	.788	-.137	.104
		LeftRingToe	.041	.070	.217	.575	.566	-.099	.180
		LeftPinkyToe	.088	.055	.460	1.599	.111	-.021	.197
		Height of Rt.Hand	.002	.032	.008	.055	.956	-.062	.066
		Height of Left Hand	-.023	.034	-.105	-.694	.489	-.090	.043

a. Dependent Variable: Height

Table-II. Regression analysis of Coefficients[a]

These types of associations are very much important in forensic field of identification where the only partial remains recovered from crime scenes. In females, no any measurement of foot toe lengths or hand lengths predicted significantly the stature which may indicate the less variability or lower degree of sexual dimorphism in limb proportions relative to height.[29,33,34]

Growth and skeletal proportions may be influenced by genetic and hormonal factors and lead to contribute the differences which potentially diminished its predictive value among the females. Further occupational, cultural values, foot ware habits may vary among the genders, that could have impact on foot and hand morphology and their association with the height.[28,30] The practical implications of these findings are significant, particularly in forensic and medico-legal investigations. In males, specific toe and hand measurements could provide supplementary data for more accurate stature estimation, improving identification processes. However, the absence of significant associations in females underscores the need for alternative measurement approaches or predictive models specifically tailored to female

populations, as population- and sex-specific variations in anthropometric dimensions are well-documented.[28,29,33]

LIMITATIONS

Our study is not with the limitations which has several limitations like specific regional population sample size which may limit generalizability in other ethnic or among the geographic sets in considerable variability of anthropometric measurements may due to their geographic or ethnic, genetic and environmental and socio cultural sets across the populations[27,29,30] Various other limitations like in males, the proportion of variance explained by the regression models (R^2) was not reported, preventing although significant predictors were a full assessment of their practical predictive power. tests of normality indicated significant deviations from normal distribution in several variables, potentially affecting the reliability of parametric analyses, although the large sample size reduces this concern to some extent.[28,32,33,34,35,36]

Future research should aim to include larger, more diverse samples to validate these findings and explore additional anthropometric parameters that might improve stature estimation, especially in females. Incorporating advanced statistical methods or machine learning approaches may also enhance predictive accuracy by capturing complex, non-linear relationships between body measurements and stature.[30,34,35,36]

CONCLUSION

In conclusion, this study demonstrates that certain toe and hand measurements, particularly the left pinky toe length and the left hand height, serve as modest predictors of height in males, whereas in females, these relationships were not significant. These findings contribute to the growing body of knowledge regarding anthropometric estimation of stature and highlight the necessity of sex-specific approaches in forensic and anthropological applications.

Ethical Considerations

This study was conducted following the Declaration of Helsinki. Ethical approval was obtained from the Institutional Review Board of Rai Medical College, Sargodha. Informed written consent was obtained from all participants prior to data collection.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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AUTHORSHIP AND CONTRIBUTION DECLARATION	
1	**Farooq Ahmed Abro:** Conception, design, acquisition of data.
2	**Filza Ali:** Data compilation, interpretation.
3	**Samra Ali:** Critical review, methodology.
4	**Hamna Malik:** Conception, design.
5	**Mudaser Hussain Abbasi:** Data compilation, statistics, manuscript drafting.
6	**Zahid Masood:** Manuscript writing, final approval.