Predicting Sex from Hand Dimensions using Statistical Models: A Cross-Sectional Study of Medical Students

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Abstract: Determining sex from dismembered body parts is crucial for forensic and medico-legal investigations. Hand anthropometry offers a practical, non-invasive approach, particularly when utilising statistical models. This study aims to assess sexual dimorphism in hand dimensions and evaluate the effectiveness of statistical methods in determining sex from various hand measurements. Data for this study were obtained from a cross-sectional survey conducted from July to December 2021 involving a sample of 150 undergraduate medical students (78 males, 72 females) aged 18 to 24 years at a private medical college in India. Medical students were selected as a relatively homogeneous population to minimize confounding factors such as occupational variation, lifestyle, and health status, thereby increasing the internal validity of the findings. Measurements of hand length, breadth, and palm length for both the left and right hands were taken. Logistic regression was employed to develop models for sex classification. By using various combinations of explanatory variables, three logistic regression models were fitted to predict sex. Among these models, the one with the best fit was selected as the final model for sex prediction. It was observed that the mean scores of male and female respondents differ significantly. All hand dimensions were significantly larger in males ($p < 0.001$). According to the best-fitting model, the Right Hand Index (RHI) along with height was identified as the most significant predictors of sex. The best-fitted logistic model achieved 90% accuracy with an AUC of 0.93. Hand dimensions, particularly the Right Hand Indices (RHI), are effective predictors of sex and logistic regression provides a reliable method for forensic identification when complete body parts are unavailable, and this model can be utilised for other types of forensic predictions.

Keywords: Hand anthropometry, sex determination, logistic regression, forensic science, India.

1. INTRODUCTION

Sex determination is a critical component of forensic science, physical anthropology, and biometric authentication [1]. When the remains of a dead body are severely damaged or decomposed, determining sex becomes challenging as genitalia may not be available. Anthropometry, also known as the Bertillon system, is an early method of identification that utilises body measurements to distinguish individuals, including sex determination [2]. Forensic anthropologists rely on skeletal features, particularly the pelvis and skull, to estimate sex based on their morphology. In situations where complete skeletal remains are not available, measurements of hand bones, such as metacarpals and proximal phalanges, can be used to estimate sex due to sexual dimorphism (observable differences between male and female skeletons) [3-7].

In forensic investigations, especially in mass disasters or criminal cases involving mutilated remains, establishing the sex of an individual is often the first step in narrowing down identity. When only partial body parts are recovered, such as hands, reliable methods are needed to infer biological sex based on available anatomical features. The human hand exhibits notable sexual dimorphism, with males generally having larger hand dimensions than females [8]. These differences in hand length, breadth, and finger ratios have been studied across populations and are frequently used for anthropometric sex estimation. Due to their accessibility and ease of measurement, hand dimensions serve as a valuable alternative when more robust skeletal indicators (e.g. pelvis or skull) are unavailable. Most of the studies have indicated that hand bone measurements are a valuable tool for sex determination even in cases with limited skeletal remains [9-14].

Among the various statistical techniques employed in forensic identification, logistic regression is particularly suited for binary classification tasks such as determining sex. It offers an interpretable, probabilistic model that quantifies the influence of each predictor (e.g., hand length, breadth) on the likelihood of an individual being male or female. Logistic regression models have the added advantage of being simple to implement and validate across different settings.

Several studies across India and other countries have investigated sex prediction using hand

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dimensions [15]. A study among the Ethnic Population from Eastern India found that hand length was a significant predictor of sex, with binary logistic regression models yielding high classification accuracy [16]. Another study on indigenous population in Eastern India found that logistic regression models incorporating hand breadth had stronger predictive performance than those based on hand length alone [17]. A forensic-anthropological study among Ladakh (Jammu and Kasmir, India) adolescents employed both linear and multiple logistic regression and identified left-hand breadth as the most accurate predictor, correctly classifying up to 90.7% of males and 79.2% of females [18]. A study conducted in North India demonstrated that logistic regression models using hand dimensions achieved classification accuracies exceeding 90% for both sexes, indicating the highest discriminative power [19]. Kumar *et al.* [14] have studied the correlation between the height and palm dimension of the respondents and reported a strong correlation between them [14]. In a cross-sectional study using both bare hand measurements and demonstrated statistically significant sex differences in hand breadth among Indian populations and confirmed handbreadth as a superior variable for sex determination [7].

Despite the increasing literature, few studies have focused on educated young adults, such as medical students in India, who may exhibit distinct hand dimensions due to ethnic homogeneity or lifestyle factors. Medical students represent a relatively homogeneous group in terms of age, health status, and socio-economic background, which helps reduce confounding variables and enhances internal validity. Therefore, a population-specific approach is crucial to validate the utility of hand dimensions for sex determination within this demographic. This study aims to assess sexual dimorphism in hand dimensions among Indian medical students and to evaluate the effectiveness of logistic regression techniques in predicting biological sex based on hand anthropometric data. The findings could improve the accuracy of sex estimation protocols used in forensic and medico-legal applications.

2. MATERIAL AND METHODS

2.1. Study Design and Setting

The data for the study were extracted from a study conducted by Kumar *et al*. (2022) on a group of medical students to investigate the association between human height and hand dimensions [14]. As such, this study utilized secondary data from the study of Kumar *et al*. [14]. The study was a cross-sectional observational study conducted in the Departments of Community Medicine and Anatomy at Noida International Institute of Medical Sciences - a private medical college - in Gautam Buddh Nagar, Uttar Pradesh, India, over six months from July 2021 to December 2021**,** after obtaining consent from the respondents**.**

2.2. Study Population

The study population consisted of undergraduate medical students, aged 18 to 24 years, enrolled in the MBBS program at the institution. Adult medical students were selected as a homogeneous population to reduce confounding factors related to occupation, health status, and ethnicity. Besides, hand dimensions do not change much after attaining adulthood. The study subjects were selected with the following inclusion and exclusion criteria.

Inclusion Criteria

- Students aged between 18 and 24 years
- No history of congenital hand deformities, orthopedic trauma, or surgeries involving the hand
- Provided written informed consent

Exclusion Criteria

- Presence of any hand abnormalities or conditions affecting measurement
- History of recent hand injury or surgery
- Non-consenting participants

Following the above inclusion and exclusion criteria, data were collected from a sample of 150 students over a six-month study period. Among the participating students, 78 were male and 72 were female. The sample provides a moderately adequate basis for conducting a cross-sectional study on sex determination using hand dimensions, particularly when logistic regression models are applied. The sample size allows for basic statistical power and the development of predictive models, as the sample includes a relatively balanced distribution of male and female participants.

2.3. Data Collection Tools and Procedure

The anthropometric measures of all the students who consented to participate in the study were

recorded. Data collection was carried out under standardized conditions. To ensure inter-rater reliability and reduce measurement variability, all anthropometric measurements were performed by a single trained researcher using a consistent protocol. A digital Vernier caliper with an accuracy of 0.01 cm was used to measure hand dimensions. Each participant was seated comfortably, and both hands were measured with palms facing upward and fingers extended. Measurements were taken thrice, and the average was taken in order to avoid any bias.

Hand length (HL) was measured as the distance between the distal creases (inter-styloid line) of the wrist to the tip of the middle finger. Hand width was measured as the distance between the most laterally placed point on the head of the 2nd metacarpal bone to the most medially placed point located on the head of the 5th metacarpal bone. Height was measured to the nearest centimetres (cm) using a stadiometer with the subject standing erect on a horizontal resting plane, barefooted, having the palms of the hands turned inward and the finger pointing downwards.

It is well known fact that even among people of same population group, measurements of various parts of body and therefore Hand dimensions varies from individual to individual. To decrease effect of such variations, ratio of hand dimensions was derived in the present study for sex determination. Ratio of hand dimensions, i.e. Hand Index was calculated from Hand Length and Hand Breadth up to the accuracy of two decimals as below.

Hand index = (Hand Breadth X 100) / Hand Length.

The detailed measurements of the dimensions can be found in Chandra *et al*. [15].

2.4. Statistical Analysis

Data were analysed using R software version 4.2.2. Both descriptive and inferential statistical techniques were used for data analysis. Univariate and bivariate tables and graphs/figures were used to present the descriptive statistics. Mean and standard deviation (SD) were calculated for each hand measurement. Independent t-tests were used to compare male and female hand dimensions. Multivariable binary logistic regression models were used to predict sex (Male = 1, Female = 0) considering hand measurements, age, height and weight of the students as predictors.

The binary logistic regression model can be represented by

$$ln\left(\frac{P}{1-P}\right) = B_0 + B_1X_1 + B_2X_2 + \ldots\ldots\ldots\ldots + B_kX_k$$

Where P is the probability of male, $B_0, B_1, B_2, \ldots B_k$ are regression coefficients, and $X_0, X_2 + \ldots\ldots\ldots X_k$ are predictor variables such as age, height, weight, and hand indexes of respondents.

Three different logistic regression models were fitted with different combinations of predictors to identify the best-predicting model. Residual analysis was done to check the adequacy of the model's fits. The best-fitted model was selected based on the minimum AIC value and residual analysis. The accuracy of the final model was estimated using ROC plots.

2.5. Ethical Consideration

As this study involved secondary analysis of anonymized data from a previously published study (Kumar *et al*., [14], formal ethical approval was deemed not necessary and was waived by the Noida International Institute of Medical Sciences ethics committee. However, permission to use the original dataset was obtained from the primary investigators. In the original study, verbal informed consent was obtained from all participants, and confidentiality and anonymity were strictly maintained.

3. RESULTS

A total of 150 adult students were included in the study, with nearly an equal number of males (n=78) and females (n=72). The mean age of participants was 19.88 ± 1.21 years. The mean age of male participants was 20.0 ± 1.37 years, while that of females was 19.76 **±** 0.97 years, with no significant difference between the groups (p = 0.2153) (Table **1**).

The exploratory analysis (using a box plot) of the age, height, and weight of respondents, as presented in Figure **1**, indicates that the distributions of height and weight are nearly normal, while the distribution of age is slightly positively skewed.

The scattered diagram of height and weight presented in in Figure **2** indicates that in general both the measures are higher for male than their female counterparts.

Table **1** presents a comparative analysis of hand dimension measures between males and females. The

Table 1: Comparison of Hand Dimensions measures (Mean± Standard Deviation) Between Males and Females

Variables	Sex		p-value
	Male (n=78)	Female (n=72)	
Age in yrs	20.0±1.37	19.76±0.97	0.215
Height of Students in cm	172.46±6.99	158.82±6.14	<0.001
Weight of Students in kg	72.84±11.93	59.56±10.62	<0.001
Length of left Hand in cm	18.46±1.13	16.86±0.90	<0.001
Breadth of Left hand in cm	8.23±1.12	6.83±0.72	<0.001
Length of Right Hand in cm	18.46±1.19	16.77±1.45	<0.001
Breadth of Right Hand in cm	8.48±1.10	7.05±0.72	<0.001
Left Hand Index	44.65±5.85	40.20±5.99	<0.001
Right Hand Index	46.01±5.72	42.54±7.44	0.002

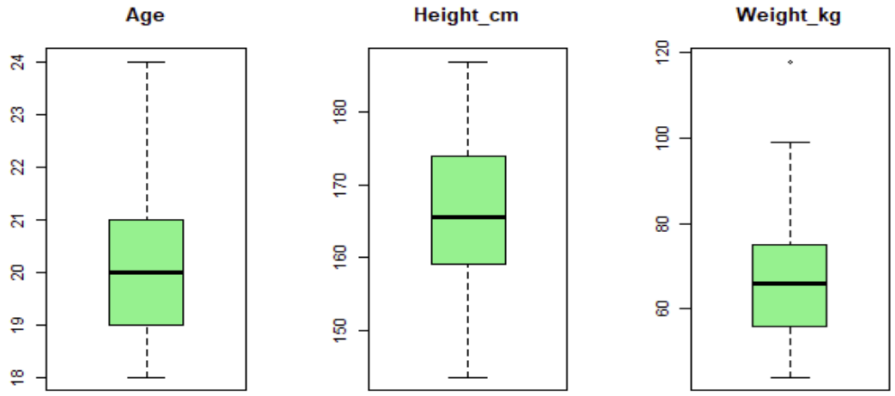

Figure 1: Box plot of age, height, and weight of respondents.

Figure 2: Scatter plot of height and weight by sex.

results indicate that all the measured hand dimensions were significantly greater in males than in females ($p < 0.001$), confirming sexual dimorphism. It also indicates that there is no significant bilateral asymmetry between right and left hands for both males and females.

To identify the significant predictors of sex, logistic regression analysis of sex was done using different sets of predictor variables. Three models were fitted, considering various predictor variables. Table **2** presents the estimated values of the model parameters

Table 2: Logistic Regression Models for Predicting Sex

Models	Estimate	Standard Error	Odds Ratio (95% CI)	Z-value	p-value	AIC
Model 1						106.63
Age	-0.29250	0.19972	0.7464 (0.5046, 1.1040)	-1.465	0.143	
Height	-0.25911	0.04594	0.7717 (0.7053, 0.8445)	-5.641	0.000	
Weight	-0.05065	0.02436	0.9506 (0.9063, 0.9971	-2.079	0.037	
Constant	51.96527	8.79339		5.910	0.000	
Model 2						97.28
Age	-0.18500	0.22333	0.8311 (0.5365, 1.2875)	-0.828	0.407	
Height	-0.27882	0.05173	0.7567 (0.6837, 0.8374)	-5.390	0.000	
Weight	-0.04814	0.02695	0.9530 (0.9040, 1.0047)	-1.786	0.074	
LHI	-0.11871	0.07069	0.8881 (0.7732, 1.0200)	-1.679	0.093	
RHI	-0.10785	0.05410	0.8978 (0.8074, 0.9982)	-1.994	0.046	
Constant	62.70095	10.62026		5.904	0.000	
Model 3						95.988
Height	-0.28247	0.05212	0.7539 (0.6807, 0.8350)	-5.420	0.000	
Weight	-0.04761	0.02699	0.9535 (0.9044, 1.0053)	-1.764	0.077	
LHI	-0.11840	0.06905	0.8883 (0.7759, 1.0171)	-1.715	0.086	
RHI	-0.11434	0.05134	0.8920 (0.8066, 0.9864)	-2.227	0.025	
Constant	59.86315	9.96279		6.009	0.000	

and their standard errors, Z values, p-values, and AIC values.

Model 1 included age, height, and weight as predictor variables, while Model 2 added the left and right hand index as predictors of sex alongside height and weight. In both models, as expected, age was not significantly associated with sex. In Model 1, both height and weight demonstrated a significant association with sex. However, in Model 2, when the left and right hand indices were included, the association between the weight variable and sex became insignificant, suggesting that weight does not independently affect sex. Results from Model 2 also indicate that the left-hand index (LHI) is a significant predictor of sex ($p = 0.046$), while the right-hand index (RHI) is marginally associated with sex ($p < 0.10$). Between model 1 and model 2, model 2 is a better-fitted model compared to model 1, as indicated by the lower AIC value of model 2. Finally, Model 3 was fitted by excluding age, but including height, weight, LHI and RHI. Model 3 was found to be superior to other models (1 and 2) as indicated by the lowest AIC value (95.98) associated with Model 3. We therefore select Model 3 as the best-fitted model for predicting sex. According to model 3, right-hand index and height appear as the significant ($p <0.05$) predictors of sex, while weight and left-hand index are marginally associated ($p <0.10$) with sex.

The confusion matrix presented in Table **3** shows that all 78 male participants were correctly classified as male (true positives) and all 72 female participants were correctly classified as female (true negatives), with no misclassification errors. This indicates that the final logistic regression model achieved perfect sensitivity (100%) and specificity (100%) in this dataset. The overall accuracy was 92.3%, consistent

Table 3: Confusion Matrix Showing Correct Classification Rate of Sex Determination of Male and Female and the Area under Curve (AUC) of the Receiver Operating Curve (ROC) Results

	Predicted male	Predicted female	Accuracy	AUC (95% CI)
Actual male	78 (True positive)	0 (False Negative)	92.3	93.71 (89.78, 97.63)
Actual female	0 (False positive)	72 (True Negative)	92.3	93.71 (89.78, 97.63)

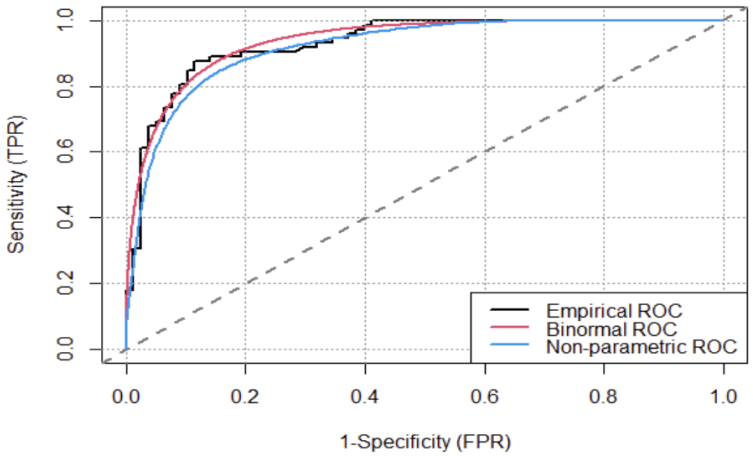

Figure 3: ROC curve.

Table 4: Comparison of Present Study with Past for Sex Predictions from Hand Dimension and its Accuracy Rate

First Author	Year	Ref.	#Participants	Features	Accuracy Rate
Case D T	2007	[9]	259 (136M, 123F)	Phalange features	85.70%
Amayeh G	2008	[20]	40 (20M, 20F)	MPEG-7 Hand shape features	98.00%
Kanchan T	2009	[7]	500 (230M, 270F)	Hand breadth	90.00%
Khanpetch	2012	[21]	196 (118M, 78F)	Metacarpal features	89.80%
Jee,S	2015	[22]	321 (167M, 154F)	Palm length, hand breadth and hand thickness.	90.00%
Rahman	2023	[23]	150(78 M, 72 F)	Determination of Gender using Discriminant Analysis	87%
Present study	2025		150(78M,72 F)	sex determination using Logistic regression	93%

with the ROC analysis (AUC = 0.9371), reflecting excellent discriminative ability.

The ROC curve presented in Figure **3** demonstrates the discriminatory performance of the logistic regression model for sex classification. The area under the curve (AUC) was 0.9371, which falls within the "excellent" range (>0.90). This indicates that the model has a very high probability of correctly distinguishing between male and female participants based on the selected predictors. An AUC close to 1.0 reflects strong sensitivity and specificity, meaning the model consistently achieved high true-positive rates (correctly identifying males) while maintaining low false-positive rates (incorrectly classifying females as males). These results suggest that the selected predictors, particularly right hand index (RHI) and height, are highly reliable for sex determination in this study population.

Table **4** shows a comparison of the accuracy rate of prediction of the present study with some previous studies. It was observed that 93 % accuracy has been observed in the prediction of sex using logistic regression, which is the highest accuracy in comparison to previous studies, except by Amayeh *et al*. [20]. The accuracy of the model is presented by the ROC curve in Figure **3**.

4. DISCUSSION

Sex determination is a critical component of forensic science, physical anthropology, and biometric authentication. When the remains of a dead body are severely damaged or decomposed, determining sex becomes challenging as genitalia may not be available.

Sex determination turns out to be the earliest precedence in the process of identification of a person [24]. The human hand is the most used portion of the physique which can be used to determine stature [25]. This study aimed to assess the accuracy of logistic regression in determining sex from hand dimensions among adult medical students of a medical college. The results clearly demonstrated that hand dimensions exhibit significant sexual dimorphism, with males having consistently larger hand length, breadth, and palm length compared to females. Among these, hand breadth emerged as the strongest individual predictor

of sex, aligning with prior studies conducted in diverse Indian populations [18, 19, 26].

Varu *et al*. [24] mentioned in their paper that estimation using hand dimensions revealed that hand breadth shows significant but small bilateral asymmetry, while hand length was found to be insignificant. Furthermore, they reported that all hand measurements were, on average, larger in males than in females. The study by Rongpi & Mondal [17] demonstrated that male hands are significantly larger compared to their female counterparts, thus showing sexual dimorphism based on hand length (HL).

As for the prediction of sex from hand dimensions and its accuracy is concerned, sex determination has been carried out using multivariable logistic regression model. The multivariable logistic regression model developed in this study achieved an overall classification accuracy of 93%, with a high area under the ROC curve (AUC = 0.937**)**. This indicates excellent discriminatory power in predicting biological sex from simple anthropometric measurements. These results are consistent with those from other studies that used logistic models or machine learning methods and reported similar or less accuracies [7, 17, 22]. Our finding that right hand index is a significant predictor of sex is consistent with the findings of previous studies. A study conducted by Case and Ross [9] investigated the utility of length measurements of the hands and feet to estimate sex based on a sample consisting of white females (n=123) and males (n=136) from the Terry Collection. Discriminant function analysis was used by them to classify individuals by sex and they reported that right hand outperformed both the left hand and foot producing correct classification rates exceeding 80%. Another study conducted by Kanchan and Rastogi [7] reported that 90% accuracy rate in sex determination using hand dimensions based on 500 samples. A similar study was conducted by Jee *et al*. [22] based on 321 measurements (167 Male, and 154 female) using logistic regression and it was reported that maximum hand circumference showed the highest accuracy of 88.6% for predicting sex for males and 89.6% for females. Recently Rahman *et al*. [23] studied sex determination using discriminant analysis and reported 87 % accuracy. A similar study was conducted on sex determination by Varu *et al*. (2016) based on 200 samples (100 males, 100 females) and reported an accuracy of 82% [19, 22, 23].

In the present study, the right hand index (RHI) was identified as a more significant predictor of sex compared to the left hand index (LHI). One possible explanation is that hand dominance and functional asymmetry may contribute to subtle differences in hand proportions. In this study, almost all the individuals were right-handed, the dominant hand often experiences greater mechanical loading, muscular development, and bone remodelling, which may accentuate sex-based dimorphism more clearly in the right hand. Previous anthropometric studies have also reported minor bilateral differences, with the dominant hand showing stronger discriminatory power in sex estimation [7, 22].

The present study achieved an AUC of 0.937, indicating excellent discriminatory power for sex prediction using logistic regression. This performance is notably higher than that reported by Kanchan & Rastogi [7], who achieved approximately 0.90 accuracy using hand breadth in North and South Indian populations, and Jee *et al*. [22], who reported classification accuracies of ~88–90% among Koreans using palm length, breadth, and thickness. Similarly, Rahman *et al*. [23] reported an overall accuracy of 87% using discriminant analysis of hand dimensions in an Indian population, which is substantially lower than our findings. Only Amayeh *et al*. [20], who employed MPEG-7 hand shape features, reported a higher accuracy (~98%), though their study was based on a much smaller sample size (n=40). Collectively, this comparison highlights that our logistic regression model, particularly incorporating RHI and height, demonstrates superior predictive accuracy relative to most existing anthropometric studies, thereby reinforcing its potential utility in forensic applications.

The strengths of this study include its standardized data collection, balanced sex ratio, and use of validated statistical techniques. Importantly, the study provides valuable sex estimation data for a relatively homogeneous population of young Indian adults, which can serve as a reference in medico-legal and forensic settings. Moreover, the findings emphasize the practical applicability of logistic regression in forensic anthropology due to its ease of interpretation and implementation. Unlike more complex machine learning methods, logistic regression allows for direct insight into the influence of individual variables on the predicted outcome, making it suitable for routine forensic practice.

While the study produced promising results, several limitations must be acknowledged. The study sample consisted solely of medical students from a single

region in India, limiting the generalizability of the findings to broader or more diverse populations. The study was restricted to young adults (18–24 years), so the model's accuracy may vary in older age groups or pediatric populations. As medical students often share similar educational and socio-economic backgrounds, the hand dimensions observed may not reflect national averages. Future studies should aim to validate the findings in larger, multi-center cohorts representing different ethnic and geographic groups in India.

5. CONCLUSIONS

This study confirms that hand dimensions, particularly the left-hand index, is highly effective in predicting sex among young Indian adults. The logistic regression model demonstrated excellent classification performance and could serve as a simple, cost-effective tool in forensic identification, especially when only partial remains are available. With further validation, this approach can be adopted in routine forensic practice to assist in sex estimation when skeletal evidence is incomplete.

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CONFLICT OF INTEREST

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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