DOI: 10.21088/ijfmp.0974.3383.18125.4

Indian Journal of Forensic Medicine and Pathology
Volume 18, Number 1, January - March 2025

ORIGINAL ARTICLE

Sexual Dimorphism of Human Adult Skulls by Multivariate Analysis

Madhusudan R. Petkar[1], Vivek J. Dugad[2], Sandesh B. Datir[3], Jamebaseer M. Farooqui[4], Chandeep Singh Makhani[5], Rajendra S. Bangal[6], Kalidas D. Chavan[7],

HOW TO CITE THIS ARTICLE:

Madhusudan R. Petkar, Vivek J. Dugad, Sandesh B. Datir et. al, Sexual Dimorphism of Human Adult Skulls by Multivariate Analysis. Indian J Forensic Med Pathol. 2025; 18(1): 25-34.

ABSTRACT

Introduction: Sexual dimorphism in adult human skulls is critical in forensic anthropology and human identification. This study aims to assess the efficacy of multivariate analysis in estimating sex based on cranial measurements.

Methodology: A total of 108 adult skulls (58 male, 50 female) from a population in Maharashtra, India, were analyzed using 14 cranial parameters. Univariate and multivariate analyses were performed to compare the accuracy of sex determination. Descriptive statistics, identification points (IP), and demarking points (DP) were used to calculate ranges, means, and significance between male and female skulls. To improve accuracy, multivariate linear discriminant function analysis was used.

Results: The results showed an overall accuracy of 76.85%, with a classification accuracy of 84.48% for males and 68% for females. According to the study, males often had larger and more robust characteristics, while cranial measurements like cranial length, width, and height showed considerable sexual dimorphism.

Conclusion: The results reveal that multivariate analysis remarkably improves sex determination compared to univariate methods. It is crucial to use multiple

AUTHOR'S AFFILIATION:

[1] Professor, Department of Forensic Medicine and Toxicology, Dr. D.Y. Patil Medical College, Hospital and Research Centre, Dr. D. Y. Patil Vidyapeeth, Pimpri, Pune, Maharashtra, India.

[2] Associate Professor, Department of Pathology, Symbiosis Medical College for Women and Symbiosis University Hospital and Research Centre, Symbiosis International (Deemed University) Pune, Maharashtra, India.

[3] Professor, Department of Forensic Medicine and Toxicology, Symbiosis Medical College for Women and Symbiosis University Hospital and Research Centre, Symbiosis International University (Deemed University), Pune, Maharashtra, India.

[4] Professor, Department of Forensic Medicine and Toxicology, Dr. BalasahebVikhe Patil Rural Medical College of Pravara Institute of Medical Sciences, Loni, Ahmednagar 413736, Maharashtra, India.

[5] Professor and Head, Department of Forensic Medicine and Toxicology, Armed Forces Medical College, Pune, India.

[6] Registrar, Maharashtra University of Health Sciences, Nashik, Maharashtra, India.

[7] Dean, ESIC Medical College and Hospital, Chennai, Tamil Nadu, India.

CORRESPONDING AUTHOR:

Jamebaseer M. Farooqui, Professor, Department of Forensic Medicine and Toxicology, Dr. BalasahebVikhe Patil Rural Medical College of Pravara Institute of Medical Sciences, Loni, Ahmednagar 413736, Maharashtra, India.

E-mail: dr.jamebaseer@gmail.com

➤ **Received:** 12-02-2025 ➤ **Accepted:** 27-02-2025

parameters for sex determination and implement population-specific changes, which may improve accuracy even further. Overall, this study shows the importance of multivariate techniques in forensic identification, mainly when only skeletal remains are available for identification.

KEYWORDS

• Sexual dimorphism • Skulls • Multivariate analysis • Identification points • Demarking points • Discriminant function analysis • Sex determination

INTRODUCTION

Identification determines a person's identity by looking at specific physical traits, such as race, age, sex, height, and other distinguishing features.[1] Identification is crucial in various situations, such as verifying the identity of living individuals and recently deceased persons and determining the identity of decomposed, mutilated, or burned bodies where physical features may be unrecognizable. Even skeletal remains can provide vital information for identification. This process is necessary in criminal cases like assault, murder, rape, or cases involving the wrongful exchange of newborns, impersonation, or identity fraud. It is also essential in civil matters, such as marriage, inheritance, passport applications, insurance claims, disputes over gender, and cases involving missing persons. Accurate identification is crucial in resolving legal, social, and personal issues in all these situations.[1,2] Identification of dismembered and skeletal remains is a crucial aspect of medico-legal investigations, particularly in cases of mass disasters.[3,4] At times, when the dead body is intentionally dismembered and mutilated into multiple pieces to conceal the identity of the victim, the primary focus of the investigation is on establishing the biological profile of the deceased by estimating age, sex, stature, and ancestry.[5,6] One of the principal biological traits to be estimated from skeletal remains is the individual's sex.[7] Estimation of sex is based upon the sexual dimorphism exhibited by the human body.[8]

The researchers have been conducting studies on estimation of sex from various human bones worldwide, focusing on the long bones,[9-11] skull,[12-14] pelvis,[15-17] scapula,[18] clavicle,[19] sternum,[20-24] and hand and foot bones.[25]

Krogman, in his study, estimated sex with 100% accuracy when the whole skeleton was present, 98% from the pelvis and cranium, 95% with only the pelvis or pelvis and long bones, and 80-90% when only long bones or skull alone is brought for examination.[26] Later, Stewart stated a sexing accuracy of 90-95% from the whole skeleton, pelvis, or one hip bone and 80% accuracy from the skull alone.[27-28] Sex estimation in the human skull is generally based on size differences and robusticity.[7,29] The differences are population-specific and can be influenced by genetic, environmental, and social factors.[30-31]

In previous studies on Indian populations, Routal etal.[32] and Sayee *et al*.[33] utilized identification points (IP) and demarking points (DP) analysis, while Deshmukh and Devershi[34] used univariate analysis.

The present study was carried out with the objectives of studying sexual dimorphism in adult human skulls by identifying key traits that distinguish males from females, evaluating the effectiveness of different skull parameters for sex determination, develop a multivariate formula to predict sex based on cranial measurements, and compare the accuracy of multivariate and univariate analysis in identifying sexual differences.

METHODOLOGY

This study was a retrospective cross-sectional analysis conducted on adult human skulls of known sex which were retrieved from unknown dead bodies from the population of Maharashtra, available at the Department of Anatomy at a tertiary health care teaching hospital, after getting approval from the Institutional Ethics Committee. The study was carried out over 1 year, using a sample size of 108 skulls, including 58 male and 50 female specimens. Inclusion criteria involved skulls of known sex, intact and undamaged, from individuals aged 18 to 55 years who were residents of Maharashtra. In contrast, exclusion criteria ruled out fragmented, damaged, or deformed skulls and those of individuals outside the specified age range or from outside Maharashtra. Various instruments were used to measure skull parameters, including spreading calipers, sliding vernier calipers, measuring tape and a scientific weighing machine. The anatomical landmarks used for measurements included points such as the glabella, basion, asterion, and nasion. Key measurements taken included cranial length, cranial breadth, height, circumference, foramina magnum dimensions, and palatal and mastoid measurements.

Statistical methods were applied for data analysis to obtain ranges, means, standard deviations, and demarcating points for each parameter. The identification points were calculated based on the male and female skull parameter ranges, and 't' tests were performed to assess differences. Additionally, multivariate linear discriminant functional analysis, as proposed by Armitage[35], was conducted using a standard computer program (SPSS), which assigned coefficients to each measurement. A discriminant function analysis was used to classify skulls based on their measurements, with a sectioning point (Z0) used to determine sex. This method improved accuracy in classifying skulls and can be applied to various skeletal remains, including fragmented or burned skulls, allowing for sex determination based on specific measurements.

RESULTS

This study analyzed 108 adult human skulls 58 male and 50 female using multivariate analysis to examine sexual dimorphism. For every skull, 14 anthropometric parameters were measured. Descriptive statistics, such as the mean, standard deviation (SD), range, and estimated range (mean ± 3SD), were computed for each parameter in the initial part of the study. For every parameter, identification points (IP) and demarking points (DP) were created, and the proportion of skulls that these points accurately identified was calculated. Statistical comparisons were made using the t-test to assess significant differences between male and female skulls.

Table 1: Univariate Analysis of each parameter of skull

Parameters	Sex	Mean	Standard Deviation	Range	Identification Point (IP)	Calculated range (Mean±3SD)	Demarking Point (DP)	Standard error
Weight (W) (grams)	Male	540.22	77.79	363-734	>631	306.84-773.61	>684.17	10.21
	Female	472.28	70.63	297-631	<363	260.40-684.17	<306.84	9.99
Maximum cranial length (MCL)(mm)	Male	172.79	6.03	157-185	>175	154.69-190.9	>189.37	0.79
	Female	164.42	8.32	144-175	<157	139.47-189.37	<154.70	1.17
Maximum cranial breadth (MCB) (mm)	Male	131.47	5.22	116-146	>140	115.81-147.12	>142.6	0.68
	Female	126.98	5.21	117-140	<116	111.36 -142.6	<115.81	0.73
Cranial height (CH) (mm)	Male	132.6	5.42	122-142	>138	116.34-148.87	>144.37	0.71
	Female	126.72	5.88	111-138	<122	109.07-144.37	<116.34	0.83
Maximum Cranial Circumference (MCC) (mm)	Male	496.91	14.32	470-550	>500	453.94-539.89	>524.45	1.88
	Female	476.08	16.12	442-500	<470	427.71-524.45	<453.94	2.28
Foramena Magnum Length (FML) (mm)	Male	34.34	2.89	26-41	>38	25.68-43.01	>40.36	0.37
	Female	33.64	2.24	29-38	<26	26.92-40.36	<25.68	0.31
Foramena Magnum Breadth (FMB) (mm)	Male	28.59	2.18	25-35	>32	22.06-35.12	>34.15	0.28
	Female	27.56	2.20	22-32	<25	20.97-34.15	<22.06	0.31
Palatal Length (PL) (mm)	Male	44.91	2.81	37-54	>53	36.48-53.35	>52.55	0.36
	Female	42.9	3.22	34-53	<37	33.25-52.55	<36.48	0.44
Palatal Breadth (PB) (mm)	Male	35.31	1.62	32-40	>40	30.44-40.18	>42.50	0.21
	Female	33.94	2.85	27-40	<32	25.38-42.50	<30.44	0.39

Parameters	Sex	Mean	Standard Deviation	Range	Identification Point (IP)	Calculated range (Mean±3SD)	Demarking Point (DP)	Standard error
Biasterionic Breadth (BAB)(mm)	Male	101.69	4.73	90-113	>105	87.50-115.87	>109.19	0.62
	Female	97.8	3.80	92-105	<90	86.41-109.19	<87.50	0.53
Nasion-bregma length (NBL) (mm)	Male	124.97	7.00	114-143	>137	103.98-145.95	>144.75	00
	Female	122.46	7.43	104-137	<114	100.17-144.75	<103.98	00
Bregma-Lambda length (BLL) (mm)	Male	125.72	9.13	108-164	>134	98.34-153.10	>144.65	1.19
	Female	118.92	8.58	90-134	<108	93.19-144.65	<98.34	1.21
Mastoid length (ML) (mm)	Male	29.36	2.98	23-36	>36	20.43-38.30	>39.07	0.39
	Female	26.6	4.16	21-36	<23	14.13-39.07	<20.43	0.58
Maximum bizygomatic diameter (MBZD) (mm)	Male	126.07	4.83	118-140	>131	111.58-140.56	>140.37	0.63
	Female	120.32	6.68	103-131	<118	100.27-140.37	<111.58	0.94

Table 1 shows the univariate analysis of various cranial parameters revealed sex specific mean and range differences. For male skulls, the mean weight was 540.22 grams, with a standard deviation of 77.79, while for females, the mean weight was 472.28 grams, with a standard deviation of 70.63. The maximum cranial length was also larger in males (mean 172.79 mm) compared to females (mean 164.42 mm). Other parameters like cranial height, maximum cranial circumference, and biasterionic breadth followed a similar trend, with males showing larger measurements than females. Notably, the mean palatal breadth for males was 35.31 mm, while females had a mean of 33.94 mm. Both sexes had similar values for foramina magnum length and breadth, but male skulls showed slightly higher measurements on average. Most parameters' calculated range (mean ± 3 standard deviations) indicated a broader span for males than females, suggesting greater variability in male cranial dimensions. The standard errors for all parameters were relatively small, reflecting the precision of the measurements.

Table 2: Univariate Analysis by Identification Point (IP)

Parameters	Percentage of skull sexed correctly by IP			P value
	Male	Feddmale	Overall	
W	12.06	08	10.19	<0.0001
MCL	32.75	14	24.07	<0.0001
MCB	3.45	0	1.85	<0.0001
CH	20.69	10	15.74	<0.0001
MCC	25.86	26	25.93	<0.0001
FML	5.17	0	2.78	>0.05
FMB	0	12	5.56	<0.01
PL	1.72	04	2.78	<0.0001
PB	06	14	10	<0.001
BAB	25.86	00	13.89	<0.0001
NBL	3.45	14	8.33	<0.01
BLL	10.34	02	6.48	<0.0001
ML	0	14	6.48	<0.0001
MBZD	13.79	32	22.22	<0.0001

As per Table 2, the univariate analysis by Identification Point (IP) revealed varying accuracy in sex determination based on different cranial parameters. For male skulls, the highest percentage of correct sexing was observed in maximum cranial length (MCL) at 32.75%, followed by weight (W) at 12.06% and biasterionic breadth (BAB) at 25.86%. For female skulls, the maximum bizygomatic diameter (MBZD) had the highest accuracy at 32%, while maximum cranial breadth (MCB) and mastoid length (ML) showed no correct sexing for females. Overall, parameters like MCL, W, BAB, and MCB demonstrated highly significant p-values (<0.0001), indicating their strong potential for sex determination. However, for foramina magnum length (FML) and mastoid length (ML), the accuracy was poor, with FML showing no correct sexing for females (p>0.05). Parameters such as palatal breadth (PB), foramina magnum breadth (FMB), and bregma-lambda length (BLL) also demonstrated statistically significant results (p<0.01). In contrast, others, like MBZD and NBL, had varying degrees of success based on the sex of the skull.

Table 3: Univariate Analysis by Demarking Point (DP)

Parameters	Percentage of skull sexed correctly by DP			P value
	Male	Female	Overall	
W	1.72	04	2.78	<0.0001
MCL	00	12	5.56	<0.0001
MCB	3.45	00	1.85	<0.0001
CH	00	04	2.78	<0.0001
MCC	3.45	12	7.41	<0.0001
FML	1.72	00	0.93	>0.05
FMB	1.72	02	1.85	<0.01
PL	1.72	04	2.78	<0.0001
PB	00	08	3.70	<0.001
BAB	5.17	00	2.78	<0.0001
NBL	00	00	00	<0.01
BLL	1.72	02	1.85	<0.0001
ML	00	00	00	<0.0001
MBZD	00	06	2.78	<0.0001

Table 3 depicts the univariate analysis by Demarking Point (DP), which showed varied success in skull sex determination across different cranial parameters. For male skulls, parameters like weight (W) and maximum cranial breadth (MCB) showed a low percentage of correct sexing (1.72% and 3.45%, respectively), while other parameters, such as maximum cranial length (MCL) and cranial height (CH), showed no correct sexing. The highest success rate for female skulls was seen in parameters like palatal breadth (PB) at 8% and maximum cranial circumference (MCC) at 12%. Overall, W, MCB, and BAB showed statistically significant results (p<0.0001), indicating their potential for sexing. In contrast, others like Nasion-bregma length (NBL) and mastoid length (ML) yielded no correct sexing (p<0.01). Some parameters, like foramina magnum breadth (FMB), palatal length (PL), and bregma-lambda length (BLL), showed moderate success with significant p-values (<0.01).

To further explore the degree of sexual dimorphism, multivariate linear discriminant function analysis was applied, where selected parameters were used to derive linear functions that could differentiate between male and female skulls. The analysis generated differential functional scores designated as Z for males (Zm) and females (Zf). A sectioning point, Z0, was calculated as the average of Zm and Zf, and this point was used to classify the sex of the skulls based on their respective Z scores. The accuracy of sex classification was then assessed by comparing the Z scores with Z0, and the percentage of correctly sexed skulls was determined.

Table 4: Multivariate Analysis

	Male	Female	Overall
Percentage of skull sexed correctly	84.48%	68%	76.85%

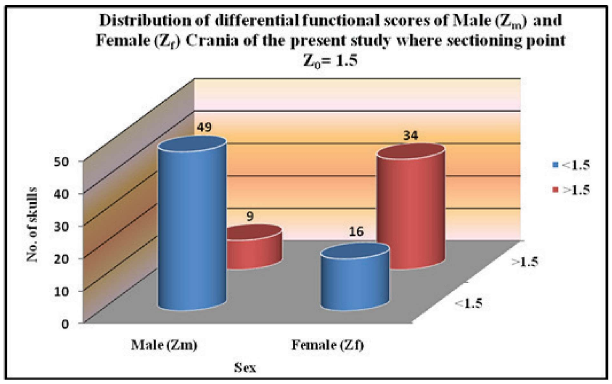

Figure 1: Distribution of differential functional scores of Male and Female skulls

Figure 1 shows that 49 out of 58 male skulls scored on the male side of Z0, and 34 out of 50 female skulls scored on the female side of Z0. Thus, 83 out of 108 skulls were sexed correctly. So, the percentage of skulls sexed correctly for males was 84.48%, and for females, it was 68%. The overall percentage was 76.85%, as depicted in **table 4.**

DISCUSSION

The present study analyzed a total of 108 adult skulls, consisting of 58 male and 50 female specimens, across 14 parameters. Statistical analyses, including the calculation of mean, standard deviation (SD), range, identification points (IP), demarking point (DP) revealed significant findings for many of the parameters measured. A comparison of the results with previous studies shows a general consistency with earlier findings, with some variations that can be attributed to differences in the populations studied.

In terms of skull weight, the mean value in the present study for males was 540.22 grams (range 363–734 grams, SD = 77.79), and for females, it was 472.28 grams (range 297–631 grams, SD = 70.63). These results are comparable to the findings of Deshmukh[34,] who reported mean values of 526 grams for males and 494 grams for females.Similarly, maximum cranial length in the present study showed a mean of 172.79 mm for males and 164.42 mm for females, which aligns closely with the results of Deshmukh[34] and Hong Weisong[36], both of whom found similar measurements. The present study also corroborated previous findings by Keen[37], who reported slightly lower values but within a similar range. For cranial breadth, the mean values in this study were 131.47 mm for males and 126.98 mm for females, which are consistent with those of Keen[37] and Deshmukh[34] who observed comparable dimensions.Cranial height in the present study was 136.60 mm for males and 126.72 mm for females, which is in agreement with the findings of Steyn[38,] Hong Weisong[36], Hanihara[39], and Deshmukh[34]. Notably, the study by Steyn[38] also demonstrated statistically significant sex differences in cranial height, similar to the present study. Furthermore, the maximum cranial circumference was found to be 496.91 mm for males and 476.08 mm for females, consistent with previous studies, including those by Keen[37] and Deshmukh[34,] which reported similar findings.

Foramina magnum length, showed a mean of 34.34 mm for males and 33.64 mm for females, which is consistent with Deshmukh[34] and Hong Weisong[36,] who reported similar dimensions for their respective populations. However, the statistical significance observed in the current study ($p > 0.05$) differs from the findings of Keen[37,] who found a slightly greater difference between sexes. Likewise, foramina magnum breadth in this study (28.59 mm for males, 27.56 mm for females) is consistent with the measurements found by Deshmukh[34] and Hong Weisong[36,] although statistical significance was reported in the present study.

Palatal length, showed a mean of 44.91 mm for males and 42.9 mm for females, which shows a close similarity to the findings of Deshmukh[34] and Hong Weisong[36,] although the current study found a statistically significant difference between sexes. In contrast, palatal breadth in the present study (35.31 mm for males, 33.94 mm for females) aligns well with previous studies by Deshmukh[34] and Hong Weisong[36,] although statistical significance was observed in the current study, unlike in the studies by Hong Weisong[36].

Biasterionic breadth was also measured in the present study, with values of 101.69 mm for males and 97.8 mm for females, which correspond to the findings of Deshmukh[34] and Hong Weisong.[36] A significant sex difference was observed in the present study, in line with findings by Hong Weisong[36], who also reported significant differences between male and female skulls in their sample. The nasion bregma length was 124.97 mm for males and 122.46 mm for females, and although no significant sex differences were found by Deshmukh[34], the present study revealed a statistically significant difference.

The bregma-lambda length in the present study showed a mean of 125.72 mm for males and 118.92 mm for females, which is similar to the findings of Deshmukh[34], Keen[37] and Hong Weisong[36], all of whom reported comparable values. Finally, mastoid length in the present study (29.36 mm for males, 26.6 mm for females) was consistent with the results from studies by Keen[37] and Hong Weisong[36], all of which found similar measurements and statistical significance. Similarly, maximum bizygomatic diameter was measured at 126.07 mm for males and 120.32 mm for females in the present study, reflecting the findings of previous workers such as Keen[37] and Deshmukh[34], who reported comparable data.

On a variety of cranial parameters, the current study supports the findings of many studies, such as Keen[37], Deshmukh[34], Hong Weisong[36], and others, with recurring trends concerning sex differences in skull morphology. It is crucial to contextualize anthropometric data within the framework of particular study groups and environmental influences because variations in certain parameters, like palatal breadth and foramina magnum dimensions, may be due to racial or population-specific factors.

The multivariate analysis conducted in the present study on 14 cranial parameters demonstrated a sexing accuracy of 84.48% for males and 68% for females, with an overall accuracy of 76.85%. These results are comparable to those of previous studies, although the accuracy reported in the present study is somewhat lower than the highest values found in the literature. For instance, Hong Weisong[36] achieved an impressive accuracy rate of 96.7%, one of the highest reported values. Similarly, studies by Giles and Elliot[40] and Hanihara[39] found accuracies of 85.5% and 89.7%, respectively. On the other hand, the present study's accuracy is similar to the findings of Deshmukh[34], who reported an accuracy of 87.84%, and Steyn[38] with 86% accuracy. This demonstrates that the results of the current study align with worldwide patterns in the use of multivariate techniques to determine the sex of the individual from the skull. The higher sexing accuracy of the current study for males (84.48%) compared to females (68%) is an important point of comparison. This gender discrepancy in accuracy is consistent with previous research showing that males are often more accurate at sexing than females. Male skulls exhibit a greater degree of sexual dimorphism than female skulls, which explains this trend. Males tend to have more pronounced cranial features, such as greater cranial breadth and robusticity, which may make sex determination easier for male skulls, while female skulls tend to exhibit more subtle differences.[34,38] When comparing the multivariate analysis results to those from univariate analysis, the present study shows that multivariate analysis significantly outperforms univariate methods. This improvement is consistent with the findings of Hong Weisong[36] and Deshmukh[34], who observed that multivariate techniques provided more accurate sex estimation by considering multiple cranial parameters simultaneously instead of relying on a single variable or set of variables. Multivariate analysis considers the intricacy of sexual dimorphism in the skull by employing an extensive range of cranial measures, producing more robust and dependable outcomes.[34,36] Hong Weisong's[36] higher accuracy rates, which included a 96.7% correct sexing rate, could be explained by variations in population or sample size and potentially more advanced approaches. Perhaps more accurate identification was possible because Hong's study concentrated on a group with well-known features. However, the current study offers a more comprehensive, generalized method, similar to that of Giles and Elliot[40] and Hanihara[39], which may explain the somewhat lower accuracy in comparison.

In summary, the current study shows promising results in determining sex by multivariate analysis, but it also emphasizes the variation among various populations and approaches. Although multivariate analysis is very effective, factors like sample population, methodological variations, and racial or ethnic characteristics can all affect the accuracy of cranial sex estimation, as indicated by the slight differences between the current study and those of Hong Weisong[36,] Deshmukh[34,] and others. The results of this study, however, demonstrate the value of multivariate analysis as a crucial instrument in forensic anthropology, providing a notable increase in overall accuracy over conventional univariate approaches.

CONCLUSION

The results of the current study, which used 14 cranial parameters to analyze 108 adult skulls, were in line with earlier studies on sex variations in cranial morphology. Although there were slight differences in several measures, these might be due to population-specific variables. The study found a sex determination accuracy of 84.48% for males and 68% for females, yielding an overall accuracy of 76.85%. The greater accuracy for male skulls reflects the common trend of more pronounced sexual dimorphism in males.

The study also confirmed that multivariate analysis outperforms univariate methods in sex determination. Multivariate analysis provides more accurate results by considering multiple cranial measurements, as it accounts for the complexity of sexual dimorphism. Overall, the study supports multivariate analysis in forensic anthropology while acknowledging that factors like population and methodology can influence accuracy.

LIMITATIONS

Our study sample size was comparatively smaller, which may restrict the applicability of the data to other populations, especially those with diverse geographic or cultural backgrounds. Furthermore, even though we have used standardized tools for measurements, anatomical variability, and human error may have affected the data's accuracy. We also discovered that male skulls had a better sex determination accuracy than female skulls, which is a typical pattern that restricts the method's use in groups with less noticeable sexual dimorphism.

RECOMMENDATIONS

Future studies should include a larger sample size and a range of populations representing different age groups, ethnic backgrounds, and geographical areas. This would lessen population bias, increase the generalizability of the results, and give a more complete understanding of sexual dimorphism across a variety of populations. Furthermore, because sexual dimorphism is population-specific, methods that are tailored to the unique traits of various groups may improve the accuracy of sex detection even further.

REFERENCES

1. Reddy K.S.N., Murty O.P. *The Essentials of Forensic Medicine and Toxicology*. 33rd ed. New Delhi: Jaypee Brothers Medical Publishers (P) Ltd; 2014. p. 57.
2. Biswas G. *Review of Forensic Medicine and Toxicology*. 2nd ed. New Delhi: Jaypee Brothers Medical Publishers (P) Ltd; 2012. p. 45.
3. Burns K.R. *Forensic Anthropology Training Manual*. 2nd ed. Upper Saddle River: Prentice-Hall; 2007.
4. Cattaneo C. Forensic anthropology: development of a classical discipline in the new millennium. *Forensic Sci Int*. 2007; 165: 185-93.
5. Chandrakanth H.V., Kanchan T., Krishan K., Arun M., Pramod Kumar G.N. Estimation of age from human sternum: an autopsy study on a sample from South India. *Int J Legal Med*. 2012; 126(6): 863-8.
6. Krishan K., Kanchan T., Ghosh A., Menezes R.G. Forensic anthropological casework-essential methodological considerations in stature estimation. *J Forensic Nurs*. 2012; 8: 45-50.
7. Tracy LR. Determining the sex of human remains through cranial morphology. *J Forensic Sci*. 2005; 50: 493-500.
8. Krishan K., Kanchan T., Passi N., DiMaggio J. Heel-Ball (HB) index-sexual dimorphism of a new index from foot dimensions? *J Forensic Sci*. 2012; 57: 172-5.
9. Charisi D., Eliopoulos C., Vanna V., Koilias C.G., Manolis S.K. Sexual dimorphism of the arm bones in a modern Greek population. *J Forensic Sci*. 2011; 56: 10-8.
10. Srivastava R., Saini V., Rai R.K., Pandey S., Tripathi S.K. A study of sexual dimorphism in the femur among North Indians. *J Forensic Sci*. 2012; 57: c19-23.
11. Robinson M.S., Bidmos M.A. An assessment of the accuracy of discriminant function equations for sex determination of the femur and tibia from a South African population. *Forensic Sci Int*. 2011; 206: 212. e1-5.

12. Raghavendra Babu Y.P., Kanchan T., Attiku Y., Dixit P.N., Kotian M.S. Sex estimation from foramen magnum dimensions in an Indian population. *J Forensic Leg Med*. 2012; 19: 162-7.
13. Gonzalez R.A. Determination of sex from juvenile crania by means of discriminant function analysis. *J Forensic Sci*. 2012; 57: 24-34.
14. Spradley M.K., Jantz R.L. Sex estimation in forensic anthropology: Skull versus postcranial elements. *J Forensic Sci*. 2011; 56: 289-96.
15. Biwasaka H., Aoki Y., Sato K., Tanijiri T., Fujita S., Dewa K., *et al*. Analyses of sexual dimorphism of reconstructed pelvic computed tomography images of contemporary Japanese using curvature of the greater sciatic notch, pubic arch and greater pelvis. *Forensic Sci Int*. 2012; 219: 288. e1-8.
16. Steyn M., Becker P.J., L'Abbé E.N., Scholtz Y., Myburgh J. An assessment of the repeatability of pubic and ischial measurements. *Forensic Sci Int*. 2012; 214: 210. e1-4.
17. Nagesh K.R., Kanchan T., Bastia B.K. Sexual dimorphism of acetabulum-pubis index in South-Indian population. *Leg Med (Tokyo)*. 2007; 9: 305-8.
18. Frutos L.R. Determination of sex from the clavicle and scapula in a Guatemalan contemporary rural indigenous population. *Am J Forensic Med Pathol*. 2002; 23: 284-8.
19. Papaioannou V.A., Kranioti E.F., Joveneaux P., Nathena D., Michalodimitrakis M. Sexual dimorphism of the scapula and the clavicle in a contemporary Greek population: applications in forensic identification. *Forensic Sci Int*. 2012;217(1-3):231.e1-7.
20. Hunnargi S.A., Menezes R.G., Kanchan T., Lobo S.W., Binu V.S., Uysal S., *et al*. Sexual dimorphism of the human sternum in a Maharashtrian population of India: a morphometric analysis. *Leg Med (Tokyo)*. 2007; 10(1): 6-10.
21. Hunnargi S.A., Menezes R.G., Kanchan T., Lobo S.W., Uysal S., Herekar N.G., *et al*. Sternal index: is it a reliable indicator of sex in the Maharashtrian population of India? *J Forensic Leg Med*. 2009; 16(2): 56-8.
22. Franklin D., Flavel A., Kuliukas A., Cardini A., Marks M.K., Oxnard C., *et al*. Estimation of sex from sternal measurements in a Western Australian population. *Forensic Sci Int*. 2012; 217: 230. e1-5.
23. Bongiovanni R., Spradley M.K. Estimating sex of the human skeleton based on metrics of the sternum. *Forensic Sci Int*. 2012;219:290.e1-7.
24. Ramadan S.U., Türkmen N., Dolgun N.A., Gökharman D., Menezes R.G., Kacar M., *et al*. Sex determination from measurements of the sternum and fourth rib using multislice computed tomography of the chest. *Forensic Sci Int*. 2012; 197(1e3): 120. e1-5.
25. Case D.T., Ross A.H. Sex determination from hand and foot bone lengths. *J Forensic Sci*. 2007; 52(2): 264-70.
26. Krogman W.M., Iscan M.Y. *The Human Skeleton in Forensic Medicine*. 2nd ed. Springfield, Illinois: Charles Thomas Publisher; 1986. pp. 189-243.
27. Stewart T.D. Medico-legal aspects of the skeleton I. Age, sex, race, and stature. *Am J Phys Anthropol*. 1948; 6: 315-21.
28. Stewart T.D. What the bones tell. *FBI Law Enforcement Bull*. 1951; 20(2-5): 19.
29. Gapert R., Black S., Last J. Sex determination from the foramen magnum: discriminant function analysis in an eighteenth and nineteenth century British sample. *Int J Leg Med*. 2009; 123: 25-33.
30. Hamilton M.E. Sexual dimorphism in skeletal samples. In: Hall R.L., editor. *Sexual Dimorphism in Homo Sapiens: A Question of Size*. New York: Praeger Publishers; 1982. pp. 107-63.
31. Rösing F.W., Graw M., Marré B., Ritz-Timme S., Rothschild M.A., Rötzscher K., *et al*. Recommendations for the forensic diagnosis of sex and age from skeletons. *Homo*. 2007; 58: 75-89.
32. Routal R.R., Pal G.P., Bhagawat S.S., Tamankar B.P. Metrical studies with sexual dimorphism in foramen magnum of human crania. *J Anat Soc India*. 1984; 33: 85-9.
33. Sayee R., Janakiram S., Thomas I.M. Foramen magnum measurements of Crania from Karnataka. *J Anat Soc India*. 1987; 36: 87-9.
34. Deshmukh A.G., Devershi D.B. Comparison of cranial sex determination by univariate and multivariate analysis. *J Anat Soc India*. 2006; 55: 48-51.
35. Armitage P. *Statistical methods in medical research*. Oxford: Blackwell; 1971. pp. 332-5.
36. Hong-Wei Song, Zi Qing Lin, Jing Tao Jia. Sex diagnosis of Chinese skulls using multiple

stepwise discriminant functional analysis. *Forensic Sci Int*. 1992; 54: 135-40.

37. Keen J.A. Sex differences in skull. *APJA*. 1950; 8(1): 65-79.

38. Steyn M., Işcan M.Y. Sexual dimorphism in the crania and mandibles of South African whites. *Forensic Sci Int*. 1998 Nov 30; 98(1-2): 9-16. doi: 10.1016/s0379-0738(98)00120-0. PMID: 10036755.

39. Hanihara K. Sex diagnosis of Japanese skulls and scapulae by means of discriminant functions. *J Anth Soc Nippan*. 1959; 67(722): 21-7.

40. Giles E., Elliot O. Sex determination by discriminant function analysis of crania. *Am J Phys Anthropol*. 1963 Mar; 21(1): 53-68. doi: 10.1002/ajpa.1330210108. PMID: 13947858.