

SEXUAL DIMORPHISM USING CRANIO-FACIAL MEASUREMENTS IN VINDHYA POPULATION: AN ANALYTICAL CROSS-SECTIONAL STUDY

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ABSTRACT

Background: Identification of unknown human remains is a fundamental aspect of forensic science, with sex determination being a critical initial step. Craniofacial measurements provide reliable and reproducible parameters for sex estimation, especially in cases where skeletal remains are the only available evidence. However, population-specific standards are essential due to regional variations. Limited data exist regarding craniofacial sexual dimorphism in the Vindhya population of India. **Aim:** To evaluate sexual dimorphism using cranial length, cranial circumference, and upper facial height in the Vindhya population and assess their accuracy in sex determination. **Materials and Methods:** This analytical cross-sectional study was conducted in the Department of Forensic Medicine and Toxicology at Shyam Shah Medical College, Rewa, over a period of 6 months. A total of 150 medico-legal autopsy cases (90 males and 60 females) aged 18–60 years were included. Cranial length, cranial circumference, and upper facial height were measured using standard anthropometric techniques. Measurements were recorded using a vernier caliper and measuring tape with an accuracy of 0.1 cm. Statistical analysis was performed using SPSS version 26.0. Mean and standard deviation were calculated, and Student's t-test was applied to compare sexes. Sensitivity, specificity, and overall accuracy were also determined. A p-value <0.05 was considered statistically significant. **Results:** All craniofacial parameters were significantly higher in males compared to females ($p < 0.001$). Mean cranial length was 18.72 ± 0.84 cm in males and 17.95 ± 0.76 cm in females. Mean cranial circumference was 54.96 ± 2.10 cm in males and 52.84 ± 1.88 cm in females, while upper facial height measured 6.92 ± 0.48 cm in males and 6.31 ± 0.44 cm in females. Cranial circumference demonstrated the highest sensitivity (80%), followed by upper facial height (77.8%) and cranial length (75.6%). All parameters showed an overall accuracy of approximately 76%. Derived cut-off values exhibited strong discriminatory ability with statistically significant differences between sexes ($p < 0.001$). **Conclusion:** Cranial length, cranial circumference, and upper facial height exhibit significant sexual dimorphism in the Vindhya population. These measurements are reliable, cost-effective, and practical tools for sex determination in forensic investigations. The establishment of region-specific standards enhances identification accuracy. Combining multiple craniofacial parameters may further improve predictive reliability.

INTRODUCTION

Identification of unknown human remains is one of the most crucial aspects of forensic medicine and anthropology. Among the primary parameters used in identification, determination of sex plays a pivotal role, as it significantly narrows down the pool of possible identities.^[1] In situations such as mass

disasters, criminal investigations, and decomposed bodies, skeletal remains often serve as the only source of identification. The skull, being one of the most durable structures of the human body, provides valuable morphological and metric information for sex determination.^[2]

Sexual dimorphism refers to the systematic differences in size and shape between males and

females of the same species. In humans, these differences are particularly evident in the skeletal system, including the skull and facial bones.^[3] The craniofacial region demonstrates distinct variations influenced by genetic, hormonal, and environmental factors. These differences are often quantifiable using anthropometric measurements, which form the basis of forensic identification techniques.^[4]

Cranial measurements such as cranial length and cranial circumference are widely used indicators of sexual dimorphism. Cranial length, measured from the glabella to the opisthocranium, reflects overall skull size and is typically greater in males due to their larger body size and robust skeletal features.^[5] Similarly, cranial circumference provides an estimate of skull volume and has been shown to exhibit significant sex-based differences.^[6]

Upper facial height, defined as the distance between the nasion and prosthion, is another important parameter in craniofacial analysis. This measurement reflects the vertical dimension of the mid-face and has been reported to vary significantly between males and females.^[7] These measurements are particularly useful because they can be obtained even in partially damaged skulls, making them valuable in forensic cases.

Several studies have demonstrated that craniofacial measurements vary across populations due to ethnic and geographical influences.^[8] Therefore, population-specific standards are essential for accurate sex determination. The Vindhya region of India, with its unique demographic and genetic characteristics, lacks sufficient anthropometric data related to craniofacial sexual dimorphism. Establishing such baseline data is crucial for improving the accuracy of forensic identification in this region.^[9]

In forensic practice, reliance on a single parameter may not always yield accurate results. Hence, the combined use of multiple craniofacial measurements enhances the reliability of sex determination. Metric methods, compared to morphological assessments, offer greater objectivity and reproducibility, reducing observer bias.^[10]

Despite advancements in molecular techniques such as DNA analysis, anthropometric methods remain indispensable due to their cost-effectiveness and applicability in resource-limited settings. Moreover, in cases where DNA is degraded or unavailable, skeletal measurements serve as the primary tool for identification.

The present study aims to evaluate sexual dimorphism using cranial length, cranial circumference, and upper facial height in the Vindhya population. By generating region-specific data, this study seeks to contribute to the existing body of knowledge and enhance the applicability of craniofacial measurements in forensic investigations.

MATERIALS AND METHODS

Study Design: This study was designed as an **analytical cross-sectional study** aimed at assessing sexual dimorphism using craniofacial measurements.

Study Setting

The study was conducted in the **Department of Forensic Medicine and Toxicology, Shyam Shah Medical College, Rewa, Madhya Pradesh**, which caters to a large number of medico-legal autopsies from the Vindhya region.

Study Duration

The study was carried out over a period of **6 months**, following approval from the **Institutional Scientific and Ethical Committee**.

Sample Size

A total of **150 medico-legal autopsy cases** were included in the study.

Target Population

The study population comprised **deceased individuals aged 18–60 years** of both sexes from the Vindhya region, brought for medico-legal autopsy.

Inclusion Criteria

- Deceased individuals aged between 18–60 years
- Bodies brought for medico-legal autopsy
- Clearly identifiable sex
- Individuals belonging to the Vindhya region

Exclusion Criteria

- Decomposed bodies where sex could not be identified
- Mutilated bodies with damaged genital region
- Cases with extensive burns and heat fractures of the skull
- Bodies with visible skull fractures affecting measurements (except linear fractures)

Data Collection Procedure

After obtaining ethical clearance, relevant data including **age, sex, and address** of the deceased were recorded from autopsy records.

Craniofacial Measurements

All measurements were taken using standard anthropometric techniques during autopsy after reflecting the scalp using a **mastoid-to-mastoid incision**, ensuring minimal disfigurement.

Parameters Measured

1. **Cranial Length**
 - Measured from glabella to opisthocranium in the mid-sagittal plane
 - Glabella: most prominent point on the frontal bone
 - Opisthocranium: farthest posterior point on the skull
2. **Cranial Circumference**
 - Measured as the maximum circumference passing through
 - Glabella (anteriorly)
 - External occipital protuberance (posteriorly)
3. **Upper Facial Height**
 - Measured from nasion to prosthion
 - Nasion: junction of internasal and nasofrontal sutures

- Prosthion: point between upper central incisors
- Instruments Used**
- Vernier caliper (accuracy up to 0.1 cm) for linear measurements
 - Flexible measuring tape (accuracy up to 0.1 cm) for cranial circumference

Measurement Technique

- All measurements were taken twice to minimize intra-observer error
- The average of the two readings was recorded
- Measurements were recorded to the nearest 0.1 cm

Statistical Analysis

- Data was analyzed using statistical software SPSS version 26.0.
- Mean and standard deviation were calculated for each parameter
- Student's t-test was used to compare male and female measurements
- p-value <0.05 was considered statistically significant

Ethical Considerations

- Ethical approval was obtained from the Institutional Ethics Committee
- Consent was obtained from relatives of the deceased
- Confidentiality and anonymity of the data were maintained

RESULTS

A total of 150 medico-legal autopsy cases were included in the study, comprising 90 males (60%) and 60 females (40%). All individuals belonged to the Vindhya region and were aged between 18–60 years. Baseline Distribution

The majority of cases were in the 21–40 years age group (56%), followed by 41–60 years (30%) and 18–20 years (14%). There was no statistically significant difference in age distribution between males and females (p>0.05), indicating a comparable sample population.

Table 1: Comparison of Mean Craniofacial Measurements between Males and Females

Parameter	Males (n=90) Mean ± SD	Females (n=60) Mean ± SD	p-value
Cranial Length (cm)	18.72 ± 0.84	17.95 ± 0.76	<0.001*
Cranial Circumference (cm)	54.96 ± 2.10	52.84 ± 1.88	<0.001*
Upper Facial Height (cm)	6.92 ± 0.48	6.31 ± 0.44	<0.001*

All three craniofacial parameters were significantly higher in males compared to females.

- **Cranial length** was greater in males by approximately **0.77 cm**, which was statistically significant (p<0.001).
- **Cranial circumference** showed a mean difference of **2.12 cm**, indicating marked sexual dimorphism.
- **Upper facial height** was also significantly higher in males by **0.61 cm**.

These findings clearly demonstrate that craniofacial measurements can effectively differentiate between sexes in the Vindhya population.

Table 2: Distribution of Cranial Measurements Based on Cut-off Values

Parameter	Cut-off Value	Males Above Cut-off (%)	Females Above Cut-off (%)	p-value
Cranial Length	18.3 cm	68 (75.6%)	14 (23.3%)	<0.001*
Cranial Circumference	53.5 cm	72 (80.0%)	18 (30.0%)	<0.001*
Upper Facial Height	6.5 cm	70 (77.8%)	16 (26.7%)	<0.001*

Using derived cut-off values:

- **75.6% of males** had cranial length above 18.3 cm, compared to only **23.3% of females**, showing strong discriminatory ability.
- **Cranial circumference** above 53.5 cm was observed in **80% of males** but only **30% of females**, indicating high predictive value.
- **Upper facial height** above 6.5 cm was present in **77.8% of males** versus **26.7% of females**.

All differences were statistically highly significant (p<0.001), confirming the reliability of these parameters for sex estimation

Table 3: Accuracy of Craniofacial Parameters in Sex Determination

Parameter	Sensitivity (%)	Specificity (%)	Overall Accuracy (%)
Cranial Length	75.6%	76.7%	76.0%
Cranial Circumference	80.0%	70.0%	76.0%
Upper Facial Height	77.8%	73.3%	76.0%

- **Cranial circumference** showed the highest sensitivity (**80%**), indicating better identification of males.
- **Cranial length** demonstrated balanced sensitivity and specificity (~76%), making it a reliable standalone parameter.
- **Upper facial height** also showed good accuracy (**76%**), supporting its utility.

Overall, all three parameters demonstrated **moderate to high accuracy (~76%)**, suggesting that combined use can further improve sex determination.

DISCUSSION

Sex determination remains a cornerstone in forensic identification, particularly in cases involving skeletal remains. The present study demonstrates significant sexual dimorphism in cranial length, cranial circumference, and upper facial height among the Vindhya population, supporting the applicability of craniofacial metrics in forensic practice.

The observed higher mean values of cranial length in males align with established anthropological evidence that male skulls are generally larger and more robust than female skulls. This difference is attributed to hormonal influences, particularly androgens, which promote bone growth and development during puberty. Similar findings have been reported in studies conducted across different populations, highlighting the consistency of cranial length as a reliable parameter for sex determination.^[12]

Cranial circumference emerged as the most discriminative parameter in the present study, with the highest sensitivity. This is consistent with previous research indicating that skull size and volume are significantly greater in males due to overall body size differences. Studies conducted in Indian populations have also demonstrated significant sex-based differences in cranial circumference, reinforcing its utility in forensic investigations.^[13]

Upper facial height also showed statistically significant differences between sexes. This measurement reflects the vertical dimension of the mid-face and is influenced by both genetic and environmental factors. The greater upper facial height observed in males may be related to increased maxillary and alveolar bone development. Previous studies have similarly reported that facial height measurements can effectively contribute to sex determination, particularly when combined with other cranial parameters.^[14]

The cut-off values derived in this study further enhance the practical applicability of these measurements. The high proportion of males exceeding the cut-off values compared to females indicates strong discriminatory power. These findings are consistent with earlier studies that have emphasized the importance of population-specific standards for improving accuracy.^[15]

The overall accuracy of approximately 76% for individual parameters suggests that while each measurement is useful, a combination of multiple parameters yields better results. This is supported by forensic anthropology literature, which recommends multivariate approaches for sex determination (15). Discriminant function analysis, although not performed in this study, could further improve classification accuracy.

The findings of this study are particularly relevant for the Vindhya region, where limited anthropometric data are available. Regional variations in craniofacial morphology have been well documented, emphasizing the need for localized standards. The present study contributes valuable baseline data that can be used in forensic casework within this population.

Despite the advantages of craniofacial measurements, certain limitations must be acknowledged. The study was conducted on autopsy cases, which may not fully represent the general population. Additionally, factors such as nutritional status, genetic diversity, and environmental influences were not assessed, which could affect craniofacial dimensions.

Nevertheless, the use of standardized measurement techniques and well-defined inclusion criteria strengthens the reliability of the findings. The study also highlights the practicality of using simple instruments such as vernier calipers and measuring tape, making these methods feasible even in resource-limited settings.

In comparison to advanced techniques such as DNA analysis, craniofacial measurements offer a cost-effective and rapid alternative for sex determination. While molecular methods provide higher accuracy, they are not always feasible due to cost and technical constraints. Therefore, anthropometric methods continue to play a vital role in forensic investigations.^[15]

Future research should focus on developing regression models and discriminant functions specific to the Vindhya population. Larger sample sizes and inclusion of additional craniofacial parameters could further enhance accuracy. Comparative studies across different regions would also help in understanding population variability.

CONCLUSION

The present study demonstrates that cranial length, cranial circumference, and upper facial height exhibit significant sexual dimorphism in the Vindhya population. Among these, cranial circumference showed the highest discriminatory power.

These findings confirm that craniofacial measurements are reliable, simple, and cost-effective tools for sex determination in forensic practice. The establishment of population-specific standards enhances the accuracy of identification and contributes to forensic anthropology databases.

Further studies incorporating larger samples and advanced statistical models are recommended to improve predictive accuracy and validate these findings.

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