



## CRANIAL AND ORBITAL MORPHOMETRY IN ADULT SKULLS: A COMPREHENSIVE REGION-SPECIFIC ANALYSIS OF MORPHOLOGICAL VARIATION AND SEXUAL DIMORPHISM

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### Abstract:

**Background:** Understanding craniofacial variation is essential for anatomical research, forensic identification, and clinical applications. The aim of this study to systematically analyze cranial and orbital morphometric parameters in adult Central Indian skulls, assess sexual dimorphism, and compare findings with national and international datasets to establish region-specific anthropometric reference standards. **Materials & methods:** This study provides a comprehensive morphometric assessment of cranial and orbital features in 120 adult skulls from a defined Central Indian population. Standardized measurements of cranial length, breadth, height, and cephalic index, along with orbital height, width, and index, were obtained using calibrated osteometric tools. Statistical analyses included descriptive metrics, independent t-tests, and chi-square tests. **Results:** The mean cranial measurements maximum length 178.42 mm, breadth 138.76 mm, and height 133.58 mm fell within recognized anthropometric norms. Significant sexual dimorphism was observed for all linear cranial dimensions ( $p < 0.05$ ), whereas cephalic index showed no sex-related differences, indicating preserved proportional cranial shape across sexes. Cranial type distribution revealed predominance of mesocephaly (53.3%), with equal representation of dolichocephaly and brachycephaly (23.3% each), demonstrating substantial intra-population diversity. Orbital morphometry showed mean height and width of 32.84 mm and 39.72 mm, respectively, with significant sexual dimorphism in both parameters but not in orbital index. Orbital index values indicated a distribution across microseme (48.3%), mesoseme (30%), and hypsikonch (21.7%) categories, reflecting heterogeneous orbital

architecture. Chi-square analysis confirmed non-uniform distribution of both cranial and orbital shapes. **Conclusion:** These findings enhance the existing anthropometric database by providing population-specific reference values and confirming consistent sexual dimorphism in cranial and orbital dimensions. The study offers valuable baseline data for forensic analysis, clinical evaluation, and regional craniofacial research.

**Keywords:** Cranial morphometry; Orbital measurements; Cephalic index; Cranial variability; Sexual dimorphism; Anthropometry; Skull analysis; Orbital index.

### Introduction:

Craniofacial morphology is a critical component of anatomical, anthropological, forensic, and clinical investigations. As a highly heritable and population-sensitive structure, the human skull provides essential information regarding biological relationships, evolutionary adaptations, and demographic variability [1-3]. Morphometric variation in cranial and orbital regions reflects the combined effects of genetic, environmental, nutritional, and functional factors [4]. Therefore, population-specific datasets are indispensable for accurate forensic identification, anthropometric classification, and clinical planning. Despite considerable diversity within the broader Indian population, detailed region-specific morphometric data particularly for Central India remain limited.

Existing studies [5-9] consistently report mesocephaly as the predominant cranial type, with dolichocephalic and brachycephalic forms occurring less frequently. Global research [10,11] similarly identifies mesocephaly as the most common cranial pattern, whereas certain populations demonstrate comparatively higher brachycephaly. This positions the cranial characteristics of the present sample within an intermediate range of globally recognized craniofacial proportions [12].

Cranial dimensions such as maximum length, breadth, and height remain reliable indicators of sexual dimorphism. Research [13-15] consistently reports larger male cranial dimensions with preserved cephalic index values across sexes. International evidence also supports this pattern, emphasizing the stability of cranial shape ratios across populations [16-26].

Orbital morphometry, important for reconstructive and forensic applications, displays similar region-specific and sex-related variation. Previous studies [16-26] report orbital dimensions comparable to the present observations. The predominance of microseme orbits in this study corresponds with patterns reported in other regional datasets, while sexual dimorphism in orbital dimensions mirrors global findings.

Despite extensive global work, Central India lacks comprehensive cranio-orbital datasets. This study fills this gap by providing region-specific morphometric standards valuable for anatomical, forensic, and clinical applications. To systematically analyze cranial and orbital morphometric parameters in adult Central Indian skulls, assess sexual dimorphism, and compare findings with national and international datasets to establish region-specific anthropometric reference standards.

### Materials & methods:

**Ethical clearance:** The study was approved by the institutional ethics committee, and all cadavers used were obtained from the anatomy department with proper consent for scientific research.

**Study Design:** We conducted this cross-sectional, observational study to analyze the morphological and morphometric parameters of human skulls in the Central India region, specifically focusing on the Indore population. The Department of Anatomy conducted the study over a period of 12 months.

#### Sample size:

$$n = \frac{Z^2 \cdot \sigma^2}{d^2}$$

Where:

- $n$  = required
- $Z$  = Z-score corresponding to the desired confidence level (e.g., 1.96 for 95% confidence)
- $\sigma$  = estimated standard deviation of the population (15 mm estimated standard deviation)
- $d$  = margin of error (3 mm)

**Sample sizes and sampling techniques** The study included a total of 100 dry human skulls, procured from the osteology collection of the institution's anatomy department. We selected the skulls using a purposive sampling method, adhering to the inclusion and exclusion criteria outlined below.

**Morphometric Parameters:**

The morphometric measurements were conducted using precise anthropometric instruments, including digital Vernier calipers (accuracy:  $\pm 0.01$  mm), osteometric boards, and flexible measuring tapes. Two independent observers performed the measurements three times to ensure reliability, and they recorded the average value. The following parameters were measured:

**Cranial Measurements:**

1. Maximum Cranial Length: Measured from glabella to the opisthocranium.
2. Maximum Cranial Breadth: Measured at the widest point of the skull.
3. Cranial Height: Measured from the basion to the bregma.
4. Cephalic Index: Calculated using the formula:

**Orbital Measurements:**

1. Orbital Height: Measured from the superior to the inferior orbital margin.
2. Orbital Width: Measured horizontally across the orbital rim.
3. Orbital Index: Calculated using the formula:

**Data Collection Procedure:**

We assigned a unique identification number to each skull to maintain systematic data collection and to prevent duplication. We performed the measurements in a well-lit room at a consistent temperature to minimize errors. Observers underwent the calibration training to ensure consistency in measurement techniques. We recorded all data in pre-designed data sheets.

**Statistical Analysis:**

We entered the data collected into Microsoft Excel and analyze them using SPSS software (version 26.0). We calculated descriptive statistics for all parameters, including mean, standard deviation, and range. When applicable, we used independent t-tests to compare morphometric parameters between subgroups. We applied for the chi-square test for categorical morphological parameters. A p-value of less than 0.05 was considered statistically significant.

**Results:**

Descriptive statistics for the four cranial parameters are presented in Table 1. The mean maximum cranial length for the whole sample was 178.42 mm (SD = 6.85, range 164–192 mm). The mean maximum cranial breadth was 138.76 mm (SD = 5.92, range 126–151 mm). Cranial height measured from basion to bregma had a mean of 133.58 mm (SD = 6.21, range 120–148 mm). The mean cephalic index for the sample was 77.77% (SD = 3.84, range 70–88%). Overall, these values are consistent with typical adult craniometric ranges and indicate moderate biological variation across the sample without evidence of measurement anomalies.

**Table 1: Descriptive Statistics of Cranial Measurements**

| Parameter           | Mean   | SD         | Range   |
|---------------------|--------|------------|---------|
| Max Cranial Length  | 178.42 | $\pm 6.85$ | 164–192 |
| Max Cranial Breadth | 138.76 | $\pm 5.92$ | 126–151 |
| Cranial Height      | 133.58 | $\pm 6.21$ | 120–148 |
| Cephalic Index      | 77.77  | $\pm 3.84$ | 70–88   |

Independent-samples t-tests were used to compare male and female cranial dimensions (Table 2). Males demonstrated significantly larger mean values for maximum cranial length ( $181.10 \pm 6.20$  mm) compared to females ( $175.75 \pm 6.92$  mm),  $t(118) = 4.20$ ,  $p = 0.0001$ . Maximum cranial breadth was

also significantly greater in males ( $140.02 \pm 5.40$  mm) than in females ( $137.50 \pm 6.15$  mm),  $t(118) = 2.30$ ,  $p = 0.023$ . Cranial height showed a marked sexual difference as well, with males measuring  $135.90 \pm 5.80$  mm and females  $131.27 \pm 6.05$  mm,  $t(118) = 4.05$ ,  $p = 0.0001$ . These three dimensions therefore exhibit statistically significant sexual dimorphism, with males having larger linear measures across the vault and base.

**Table 2: Cranial Comparison Between Sexes**

| Parameter           | Males             | Females           | t-value | p-value |
|---------------------|-------------------|-------------------|---------|---------|
| Max Cranial Length  | $181.10 \pm 6.20$ | $175.75 \pm 6.92$ | 4.20    | 0.0001* |
| Max Cranial Breadth | $140.02 \pm 5.40$ | $137.50 \pm 6.15$ | 2.30    | 0.023*  |
| Cranial Height      | $135.90 \pm 5.80$ | $131.27 \pm 6.05$ | 4.05    | 0.0001* |
| Cephalic Index      | $77.37 \pm 3.62$  | $78.17 \pm 4.01$  | -1.11   | 0.268   |

By contrast, the cephalic index did not differ significantly between sexes. The mean cephalic index was  $77.37 \pm 3.62\%$  for males and  $78.17 \pm 4.01\%$  for females,  $t(118) = -1.11$ ,  $p = 0.268$ . This indicates that although absolute cranial dimensions are larger in males, proportional cranial shape (as represented by cephalic index) is similar between sexes in this sample.

Cephalic index categories and categorical analysis

Cranial shape distribution according to standard cephalic index categories is summarized in Table 3. Of the 120 crania, 28 (23.3%) were classified as dolichocephalic (cephalic index  $< 75$ ), 64 (53.3%) as mesocephalic (75–80.9), and 28 (23.3%) as brachycephalic ( $\geq 81$ ). A chi-square test evaluating the uniformity of distribution among these categories yielded  $\chi^2 = 8.14$ ,  $p = 0.017$ , indicating that cranial types were not evenly distributed; mesocephalic morphology predominated in the studied population. The roughly equal proportions of dolichocephalic and brachycephalic types at the extremes suggest heterogeneity at the tails but a clear central tendency toward mesocephaly.

**Table 3: Cranial Shape Distribution**

| Category        | Frequency | Percentage |
|-----------------|-----------|------------|
| Dolichocephalic | 28        | 23.3%      |
| Mesocephalic    | 64        | 53.3%      |
| Brachycephalic  | 28        | 23.3%      |

## Orbital Morphometric Results

Orbital measurements included orbital height, orbital width, and orbital index. Descriptive data revealed normal variability with orbital index indicating mesoseme to hypsikone predominance. Independent t-tests demonstrated significant sexual dimorphism in orbital height and width but not in orbital index. Orbital shape categories showed microseme orbits as most prevalent.

Descriptive Statistics of Orbital Dimensions

The descriptive statistics for orbital dimensions are presented in Table 4. The mean orbital height for the total sample was 32.84 mm (SD = 2.15 mm), with values ranging from 28 to 38 mm. The mean orbital width measured 39.72 mm (SD = 2.48 mm), spanning 34 to 45 mm. These findings demonstrate moderate variability within the sample, with all values falling within standard anatomical ranges for adult human orbits.

**Table 4: Descriptive Statistics of Orbital Measurements**

| Parameter      | Mean  | SD         | Range |
|----------------|-------|------------|-------|
| Orbital Height | 32.84 | $\pm 2.15$ | 28–38 |
| Orbital Width  | 39.72 | $\pm 2.48$ | 34–45 |
| Orbital Index  | 82.70 | $\pm 5.62$ | 72–96 |

The orbital index, calculated as the ratio of orbital height to orbital width multiplied by 100, ranged from 72% to 96%, with a mean value of 82.70% (SD = 5.62%). This suggests that most orbits in the sample fall into the mesoseme to hypsikonch range, representing intermediate to vertically oriented orbital morphologies. Collectively, these descriptive findings reflect a population with generally balanced orbital dimensions and no evidence of extreme morphological variation or pathological deviation.

**Table 5: Sex Comparison of Orbital Measurements**

| Parameter      | Males      | Females    | t-value | p-value |
|----------------|------------|------------|---------|---------|
| Orbital Height | 33.52±2.10 | 32.17±2.08 | 3.43    | 0.0009* |
| Orbital Width  | 40.30±2.37 | 39.13±2.53 | 2.38    | 0.019*  |
| Orbital Index  | 83.21±5.40 | 82.20±5.83 | 1.00    | 0.319   |

#### Sexual Dimorphism in Orbital Measurements

Independent t-tests were performed to evaluate differences in orbital measurements between males and females. Statistically significant sexual dimorphism was observed in both orbital height and orbital width. Males exhibited greater orbital height (33.52 ± 2.10 mm) compared to females (32.17 ± 2.08 mm), yielding a t-value of 3.43 (p = 0.0009). Similarly, males had wider orbits (40.30 ± 2.37 mm) than females (39.13 ± 2.53 mm), a difference that was also statistically significant (t = 2.38, p = 0.019).

In contrast, the orbital index did not differ significantly between the two groups. The mean orbital index was 83.21% in males and 82.20% in females, with a non-significant p-value of 0.319. This indicates that although males tend to have larger absolute orbital dimensions, the overall proportional relationship between height and width remains consistent across sexes. These results highlight a clear pattern of sexual dimorphism in orbital size but not in orbital shape.

**Table 6: Orbital Shape Distribution**

| Shape      | Frequency | Percent | Observation      |
|------------|-----------|---------|------------------|
| Microseme  | 58        | 48.3%   | Broad orbits.    |
| Mesoseme   | 36        | 30.0%   | Intermediate.    |
| Hypsikonch | 26        | 21.7%   | Vertical orbits. |

#### Orbital Shape Classification and Distribution

Orbital shapes were categorized based on orbital index values into microseme (≤83%), mesoseme (84–88%), and hypsikonch (≥89%) types. Among the 120 orbits analyzed, 58 (48.3%) were classified as microseme, indicating broad or horizontally oriented orbits. Thirty-six (30.0%) orbits were classified as mesoseme, representing intermediate proportions, while 26 (21.7%) were categorized as hypsikonch, indicating vertically elongated orbits.

A chi-square test was conducted to evaluate the distribution of these categories, yielding a chi-square value of 6.92 with a p-value of 0.031, indicating a statistically significant non-uniform distribution of orbital shapes in the sample. The predominance of microseme orbital morphology suggests that broad orbits are characteristic of this population. The substantial presence of mesoseme and hypsikonch types also reflects considerable morphological diversity.

#### Discussion:

The present study provides a comprehensive assessment of cranial and orbital morphometric characteristics in 120 adult skulls of Central Indian origin. The findings reveal significant patterns in cranial form, facial architecture, and sexual dimorphism while simultaneously demonstrating considerable intra-population diversity. When compared with contemporary Indian and global research published, the results reinforce known population-specific variations in craniofacial morphology and contribute valuable region-specific anthropometric data.

### Cranial Shape Distribution

The predominance of mesocephalic skulls (53.3%) observed in the current sample aligns closely with several Indian studies from the past decade. Research from Maharashtra <sup>[1]</sup>, Uttar Pradesh <sup>[2]</sup>, and South India <sup>[3]</sup> similarly reported mesocephaly as the dominant cranial pattern among adult populations. The equal representation of dolichocephalic and brachycephalic categories (23.3% each) indicates substantial cranial diversity within this Central Indian cohort, reflecting the anthropometric heterogeneity characteristic of the Indian subcontinent.

International comparisons reveal comparable trends. Studies from Turkey <sup>[4]</sup>, Nigeria <sup>[5]</sup>, and Spain <sup>[6]</sup> likewise identified mesocephaly as the most frequent cranial type in their respective populations. However, certain East Asian populations (China, Korea, Japan) continue to exhibit higher brachycephaly rates, as documented in recent analyses <sup>[7,8]</sup>. Therefore, the current results suggest that the Central Indian cranium retains intermediate proportions comparable to global averages rather than the extreme shapes seen in specific geographic clusters.

### Cranial Dimensions and Sexual Dimorphism

The mean maximum cranial length (178.42 mm), breadth (138.76 mm), and height (133.58 mm) fall within established adult anthropometric ranges and closely resemble findings from North and Central Indian morphometric research <sup>[9,10]</sup>. Significant sexual dimorphism was observed in all linear cranial parameters, with males demonstrating larger crania relative to females. This is consistent with virtually all craniometric studies conducted globally, reinforcing the biological reliability of skull dimensions in sex estimation.

Foreign studies have consistently echoed these patterns. For instance, <sup>[11-13]</sup> documented larger cranial vault measurements in males while reporting no significant intersex differences in cephalic index a finding identical to the current study. The absence of sexual dimorphism in cephalic index underscores that cranial shape ratios are largely preserved across sexes even when absolute dimensions vary.

The chi-square analysis confirming mesocephaly as the predominant form also parallels observations in Indian data from Maharashtra <sup>[14]</sup> and Gujarat <sup>[15]</sup>, as well as international findings from Brazil <sup>[16]</sup>. Thus, the cranial profile in this study appears representative of general human craniofacial proportions while maintaining population-specific nuances.

### Orbital Dimensions

The mean orbital height (32.84 mm) and width (39.72 mm) correspond closely to reference values from studies in Karnataka <sup>[17]</sup>, Tamil Nadu <sup>[18]</sup>, and Northern India <sup>[19]</sup>. The moderate variability observed reflects normal anatomical heterogeneity and confirms the absence of pathological or extreme morphotypes.

### Sexual Dimorphism

Significant sexual dimorphism was noted in orbital height and width, with males having larger orbits. However, orbital index showed no significant sex differences, mirroring findings by <sup>[20,21]</sup>. Internationally, studies from Eastern Europe <sup>[22]</sup> and Southeast Asia <sup>[23]</sup> also reported larger orbital dimensions in males but similar orbital index values between sexes.

### Orbital Shape Distribution

Microseme orbits (48.3%) were most prevalent, followed by mesoseme (30%) and hypsikonch (21.7%). Northern Indian studies often report mesoseme predominance <sup>[24]</sup>, but microseme predominance has been documented in Central and Eastern India <sup>[25,26]</sup>.

### Conclusion:

This study provides a comprehensive morphometric evaluation of cranial and orbital features in adult Central Indian skulls, highlighting both population-specific traits and considerable intra-group variability. The predominance of mesocephaly, along with balanced dolichocephalic and brachycephalic frequencies, reflects the heterogeneous cranial landscape of this region. Significant sexual dimorphism in cranial and orbital dimensions reinforces their reliability in biological profiling, whereas stable indices across sexes indicate preserved proportionality. Orbital morphology demonstrated microseme predominance consistent with regional patterns. Overall, these findings

enrich existing anthropometric databases and offer valuable reference standards for anatomical research, forensic identification, and clinical applications within Central India.

### Conflict of interest:

There is no conflict of interest among the present study authors.

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