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MORPHOMETRIC EVALUATION OF HARD PALATE IN SOUTH INDIAN SKULLS AND ITS FORENSIC SIGNIFICANCE: A CROSS-SECTIONAL OSTEOLOGICAL STUDY

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ABSTRACT

Background: Sex estimation is a fundamental component of forensic identification, particularly in cases involving fragmented or decomposed remains. The hard palate, due to its protected anatomical location and resistance to postmortem damage, serves as a reliable structure for osteometric analysis. However, population-specific data for South Indian skulls remain limited.

Materials and Methods: A cross-sectional osteological study was conducted on 132 adult human skulls of South Indian origin in the Department of Anatomy of a MVJ Medical College and Research Hospital, Hoskote, Bangalore, over a period of 6 months between November 2025 to May 2026. Palatal length, breadth, and height were measured using a digital vernier caliper, and the palatal index was calculated. Statistical analysis was performed using IBM SPSS Statistics version 20.0, including independent t-test, chi-square test, point–biserial correlation, and discriminant function analysis.

Results: All palatal dimensions were significantly greater in males than females ($p < 0.001$). Leptostaphyline type was most common (47.0%), with significant sex-based variation ($p = 0.041$). Palatal dimensions showed moderate positive correlation with male sex ($r = 0.35–0.42$). Discriminant function analysis demonstrated an overall classification accuracy of 78.8%.

Conclusion: Hard palate morphometry exhibits significant sexual dimorphism and provides a reliable adjunct for sex estimation in forensic contexts. Population-specific standards enhance its applicability, particularly in cases with limited skeletal remains.

Keywords: Hard palate; Sexual dimorphism; Forensic anthropology; Palatal index; Osteometry; South India.

INTRODUCTION

Establishing the biological profile of unknown human remains is a fundamental objective in forensic anthropology, particularly in scenarios involving mass disasters, criminal investigations, and unidentified skeletal remains.[1] Among the key parameters, sex estimation plays a pivotal role, as it significantly narrows the pool of potential identities and guides further identification processes.[2] While long bones and the pelvis are considered the most reliable indicators of sex, their availability is often compromised due to fragmentation, decomposition, or taphonomic damage. In such situations, craniofacial structures, especially the palate, serve as valuable alternative markers for forensic identification.[3,4]

The hard palate, formed by the palatine processes of the maxilla and the horizontal plates of the palatine bones, is a durable anatomical structure that resists postmortem degradation and environmental insults.[5] Its protected intraoral location often allows it to remain intact even when other skeletal elements are

severely damaged.[6]. Morphometric analysis of the hard palate—including dimensions such as palatal length, breadth, height, and indices—has been shown to exhibit sexual dimorphism, thereby aiding in sex determination with reasonable accuracy.[7,8]

In addition to sexual dimorphism, the morphology of the hard palate varies across populations due to genetic, environmental, and dietary influences.[7] These population-specific differences necessitate regionally derived osteometric standards for accurate forensic application. Studies conducted in various populations have demonstrated significant variability in palatal measurements, reinforcing the need for localized data.[7,8] However, there is a relative paucity of comprehensive osteological studies focusing on the hard palate in South Indian populations, limiting the applicability of existing standards in this demographic context.[9]

Furthermore, the hard palate has forensic significance beyond sex estimation. It plays a crucial role in personal identification through palatal rugae patterns (rugoscopy), which are unique to individuals and remain stable throughout life.[10] Additionally, palatal morphology can assist in ancestry estimation and may provide supportive evidence in reconstructive identification.[11]

Given these considerations, a detailed osteological analysis of the hard palate in South Indian skulls is warranted to establish baseline morphometric data and assess its utility in forensic identification. Such data would not only enhance the accuracy of sex determination in forensic casework but also contribute to the development of population-specific standards, thereby improving the reliability of anthropological assessments.

MATERIALS AND METHODS

Study Design and Setting

This cross-sectional osteological study was conducted in the Department of Anatomy of a MVJ Medical College and Research Hospital, Hoskote, Bangalore, over a period of 6 months between November 2025 to May 2026. The study involved detailed morphometric analysis of adult human skulls available in the departmental osteology museum and teaching collections. All procedures were carried out in accordance with institutional ethical standards for research involving human skeletal remains, and necessary permissions were obtained from the institutional review authority prior to commencement of the study.

Study Sample calculation and Selection Criteria

The study sample comprised a total of 132 adult human skulls of South Indian origin. The sample size was calculated using the standard formula for estimation of a mean: $n=Z^2\sigma^2/d^2$, where n is the required sample size, Z is the standard normal deviate at 95% confidence level ($Z = 1.96$), σ is the standard deviation of the variable, and d is the permissible error. Based on previous morphometric data reported by Wahane et al., the standard deviation of palatal measurements was approximately 4.5 mm [8]. Considering a permissible error of 0.8 mm and a 95% confidence level, the calculated minimum sample size was approximately 121 skulls. To improve statistical robustness and compensate for potential exclusions due to damaged or incomplete specimens, a total of 132 skulls were included in the present study. Only well-preserved, fully ossified skulls with intact hard palates were included in the study. Skulls exhibiting damage, deformities, pathological lesions, congenital anomalies, or postmortem fractures involving the palate were excluded to avoid measurement bias. Where available, skulls with documented sex were included to facilitate assessment of sexual dimorphism; in cases where sex was not recorded, standard osteological criteria based on cranial features were used for sex estimation.

Preparation and Positioning of Specimens

Each skull was cleaned of debris and positioned in the anatomical (Frankfurt horizontal) plane on a stable surface to ensure uniformity during measurements. The hard palate was carefully inspected for integrity, and all measurements were performed under adequate lighting conditions to minimize observational errors. Each parameter was measured independently by the primary investigator, and a subset of specimens was re-measured after an interval of two weeks to assess intra-observer reliability.

Morphometric Parameters and Landmarks

The osteometric analysis of the hard palate was carried out using standard anthropometric landmarks.[8] The following parameters were recorded: Palatal length was measured as the linear distance from the orale (the anterior point on the alveolar margin between the central incisors) to the staphylion (the posterior point at the junction of the hard and soft palate in the midline). Palatal breadth was defined as the maximum transverse distance between the inner borders of the alveolar margins at the level of the first molars. Palatal height (depth) was measured as the perpendicular distance from the deepest point of the palatal vault to the plane defined by the alveolar margins. From these primary measurements, the palatal index was calculated using the formula: Palatal Index = (Palatal Breadth / Palatal Length) × 100.[8] Based on the palatal index, the palate was classified into leptostaphyline (narrow), mesostaphyline (intermediate), and brachystaphyline (broad) types, according to standard anthropological criteria.[8]

Instruments and Measurement Technique

All linear measurements were obtained using a digital vernier caliper with an accuracy of 0.01 mm. The caliper was calibrated prior to use, and each measurement was taken twice to ensure precision; the average of the two readings was considered for analysis. Care was taken to place the caliper tips precisely on defined anatomical landmarks to minimize inter-measurement variability (Figure 1 and 2).[10]

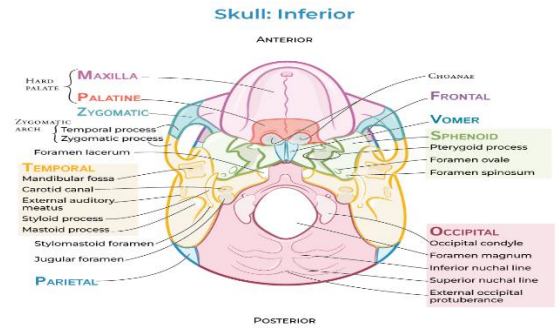

Figure 1: Anatomical Landmarks of the Hard Palate (Inferior View of Skull).

Orale – anterior midline point on the alveolar margin between central incisors; Staphylion – posterior midline point at the junction of hard and soft palate; Alveolar margins – lateral boundaries used for breadth measurement.

Figure 2: Measurement of Palatal Length, and Palatal Breadth.

Palatal length – linear distance from orale to staphylion measured using a digital vernier caliper. Palatal breadth – maximum transverse distance between inner borders of alveolar margins at the level of first molars. Palatal height – perpendicular distance from the deepest point of the palatal vault to the plane of the alveolar margins.

Assessment of Sexual Dimorphism

Sex-based differences in palatal dimensions were evaluated by comparing morphometric parameters between male and female skulls. Descriptive and inferential analyses were performed to determine the extent of sexual dimorphism and its statistical significance. Where sex was not pre-documented, classification was done using standard cranial morphological features, and such cases were analyzed cautiously.

Statistical Analysis

The collected data were entered into Microsoft Excel and analyzed using IBM SPSS Statistics (version 20.0; IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean ± standard deviation, while categorical variables were presented as frequencies and percentages. The normality of data distribution was assessed using the Shapiro–Wilk test. As the majority of continuous variables followed a normal distribution, comparisons between male and female skulls were performed using the independent samples t-test. For variables not conforming to normal distribution, the Mann–Whitney U test was applied where appropriate. The association between categorical variables, including the distribution of palatal index types between sexes, was analyzed using the chi-square test. The relationship between palatal dimensions and sex was further evaluated using the point–biserial correlation coefficient (a special case of the Pearson correlation coefficient), given the dichotomous nature of the sex variable. To assess the predictive utility of palatal measurements for sex determination, discriminant function analysis was performed, and classification accuracy was calculated. Intra-observer reliability of measurements was evaluated using the intraclass correlation coefficient (ICC), demonstrating good measurement consistency. A p-value of <0.05 was considered statistically significant.

RESULTS

The study included 132 adult human skulls, of which 74 (56.1%) were male and 58 (43.9%) were female, demonstrating a slight male predominance typical of osteological collections. [Table 1]

Table 1: Sex-wise Distribution of Study Sample (n = 132)

Gender	Frequency (n)	%
Male	74	56.1
Female	58	43.9

Male skulls exhibited significantly higher mean values for all palatal dimensions compared to females. The mean palatal length was 49.8 ± 3.6 mm in males and 47.6 ± 3.2 mm in females, while palatal breadth measured 38.9 ± 2.9 mm in males versus 36.2 ± 2.6 mm in females. Similarly, palatal height was greater in males (12.8 ± 1.7 mm) than females (11.5 ± 1.5 mm). These differences were statistically highly significant (p <0.001), confirming marked sexual dimorphism. The bar chart further illustrates consistently higher mean values across all parameters in males, reinforcing these findings. [Table 2, Figure 3]

Table 2: Comparison of Palatal Dimensions between Male and Female Skulls

Parameter	Male (n=74)	Female (n=58)	p-value
	Mean ± SD		
Palatal Length (mm)	49.8 ± 3.6	47.6 ± 3.2	<0.001
Palatal Breadth (mm)	38.9 ± 2.9	36.2 ± 2.6	<0.001
Palatal Height (mm)	12.8 ± 1.7	11.5 ± 1.5	<0.001

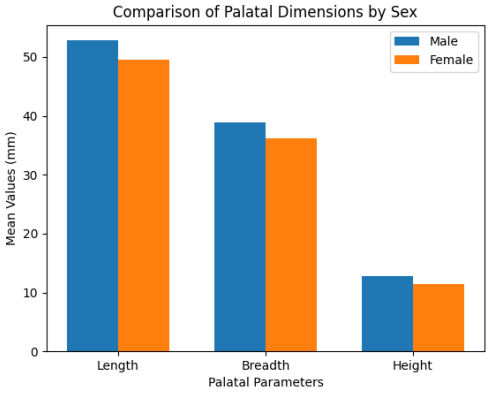

Figure 3: Comparison of mean palatal dimensions (length, breadth, height) between male and female skulls

Leptostaphyline type was the most prevalent palatal form (47.0%) in the overall sample. Males showed a higher proportion of brachystaphyline type (24.3%), whereas females demonstrated a greater frequency of mesostaphyline type (37.9%). The difference in distribution of palatal index types between sexes was statistically significant (p = 0.041), indicating sex-related variation in palatal morphology. [Table 3]

Table 3: Distribution of Palatal Index Types by Sex

Palatal Type	Male (n=74)	Female (n=58)	Total (n=132)	p-value
	Frequency (%)			
Leptostaphyline (<80)	34 (45.9%)	28 (48.3%)	62 (47.0%)	0.041
Mesostaphyline (80–85)	22 (29.8%)	22 (37.9%)	44 (33.3%)	
Brachystaphyline (>85)	18 (24.3%)	8 (13.8%)	26 (19.7%)	

In the combined sample, the mean palatal length was 49.4 ± 3.8 mm, palatal breadth was 37.7 ± 3.1 mm, and palatal height was 12.2 ± 1.8 mm. The palatal index ranged from 64.8 to 86.7, with a mean value of 73.3 ± 4.9, indicating moderate variability within the population. [Table 4]

Table 4: Overall Palatal Measurements in the Study Population

Parameter	Mean ± SD	Minimum	Maximum
Palatal Length (mm)	49.4 ± 3.8	44.2	56.1
Palatal Breadth (mm)	37.7 ± 3.1	31.5	45.2
Palatal Height (mm)	12.2 ± 1.8	9.2	16.5
Palatal Index	73.3 ± 4.9	64.8	86.7

A statistically significant positive correlation was observed between palatal dimensions and male sex. Palatal length demonstrated the strongest correlation (r = 0.42, p <0.001), followed by palatal breadth (r = 0.38, p <0.001) and palatal height (r = 0.35, p <0.001), indicating that larger palatal measurements are moderately associated with male skulls. [Table 5]

Table 5: Correlation between Palatal Dimensions and Sex (Point–Biserial Correlation)

Parameter	Correlation Coefficient (r)	p-value
Palatal Length	**0.42**	**<0.001**
Palatal Breadth	**0.38**	**<0.001**
Palatal Height	**0.35**	**<0.001**

Discriminant function analysis using palatal length, breadth, and height showed good predictive capability for sex estimation, with a Wilks' lambda of 0.68 and an eigenvalue of 0.47. The overall classification accuracy was 78.8%, with correct classification rates of 80.0% for males and 77.6% for females. The scatter plot demonstrates clustering of male skulls toward higher palatal dimensions with partial overlap with female values, supporting the moderate discriminatory ability of these parameters. [Table 6, and Figure 4]

Table 6: Discriminant Function Analysis for Sex Prediction

Parameter Included	Wilks' Lambda	Eigenvalue	Classification Accuracy
Length + Breadth + Height	0.68	0.47	78.80%
Sex Predicted	**Correctly Classified**		
Male	80.00%		
Female	77.60%		

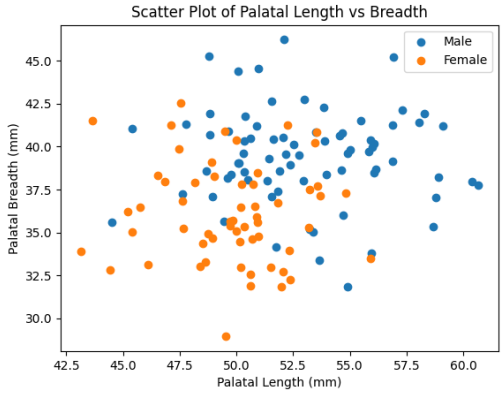

Figure 4: Scatter plot depicting relationship between palatal length and breadth by sex

DISCUSSION

The present study provides a comprehensive osteometric evaluation of the hard palate in a South Indian skeletal sample and demonstrates significant sexual dimorphism across all measured parameters, reinforcing its utility in forensic identification. The observed male predominance in the sample (56.1%) is consistent with typical osteological collections and does not introduce substantial bias in morphometric comparisons. The mean palatal dimensions obtained in this study (length: 49.4 ± 3.8 mm, breadth: 37.7 ± 3.1 mm, height: 12.2 ± 1.8 mm) fall within the range reported in Indian craniofacial studies by Kumar et al., Kaur et al., and Rao et al., thereby supporting the external validity of the dataset and its applicability to the regional population.[12,13,14]

A key finding of this study is the statistically significant increase in palatal length, breadth, and height in males compared to females ($p < 0.001$), indicating marked sexual dimorphism. These findings are in agreement with previous studies conducted in Indian populations, such as those by Patel et al., and Kumar et al., who also reported significantly larger palatal dimensions in males.[15,16] Similar trends have been documented internationally in review by Chiam et al., including study by Pallavi et al., suggesting that sexual dimorphism in palatal morphology is a consistent biological phenomenon across populations.[17,18] The underlying explanation for these differences lies in differential skeletal growth patterns influenced by sex hormones, particularly androgens, which promote greater craniofacial growth in males, resulting in increased bone size, robusticity, and palatal vault dimensions.[19]

The distribution of palatal index types further highlights sex-related morphological variation. In the present study, leptostaphyline palate was the most common type (47.0%), consistent with findings from Indian and Asian populations in studies by Kulkarni et al., and Khatiwada et al.[20,21] However, females demonstrated a higher prevalence of leptostaphyline (narrow) palates, while males showed a relatively greater proportion of brachystaphyline (broad) palates, with statistically significant differences ($p = 0.041$). Comparable observations have been reported regional Indian studies by Varalakshmi et al., and Gujar et al., suggesting that although absolute dimensions are larger in males, proportional relationships may differ, reflecting variations in craniofacial growth patterns and masticatory functional adaptations.[22,23] Environmental factors such as diet consistency and genetic influences may also contribute to these morphological differences.[19] [Table 7]

Table 7: Comparative Analysis of Palatal Dimensions and Palatal Index Distribution across Previous Studies and the Present Study

Study	Palatal Length (mm)	Palatal Breadth (mm)	Palatal Height (mm)	L (%)	M (%)	B (%)
Gujar et al.[23]	47.10 ± 3.34	36.26 ± 2.55	NA	68	20	12
Varalakshmi et al.[22]	48.47 ± 4.66	36.00 ± 4.41	8.62 ± 2.76	66	18.5	15.5
Khatiwada et al.[21]	41.58 ± 3.48	40.63 ± 3.76	14.90 ± 2.04	10	4.5	84.5
Kulkarni et al.[20]	40.42 ± 5.70	40.42 ± 5.34	-	-	-	-
Pallavi et al.[18]	47.28 ± 1.55	36.01 ± 1.27	-	94.64	5.35	-
Kumar et al.[16]	46.30 ± 3.87	32.73 ± 2.66	11.27 ± 2.03	84	12	4
Rao et al.[14]	49.87 ± 3.54	34.42 ± 2.09	-	95	5	-
Kaur et al.[13]	46.16 ± 4.18	33.01 ± 2.67	11.06 ± 1.88	83	10	7
Kumar et al.[12]	45.95 ± 4.05	32.51 ± 2.83	10.93 ± 2.32	88	8	4
Present Study	49.4 ± 3.8	37.7 ± 3.1	12.2 ± 1.8	47	33.3	19.7

L = Leptostaphyline palate; M = Mesostaphyline palate and B = Brachystaphyline palate.

The correlation analysis in the present study demonstrated moderate positive associations between palatal dimensions and male sex, with palatal length showing the strongest correlation ($r = 0.42$). These findings are consistent with previous studies by Rao et al., and Meghatar et al., where palatal length has been identified as one of the most reliable indicators of sexual dimorphism.[24,25] The moderate strength of correlation indicates that while palatal measurements are useful, they should ideally be used in conjunction with other skeletal parameters for improved accuracy in sex estimation. This aligns with established forensic anthropology principles, which emphasize multifactorial approaches for biological profiling.[24,25]

Importantly, discriminant function analysis in this study yielded an overall classification accuracy of 78.8%, with comparable predictive rates for males (80.0%) and females (77.6%). These values are in close agreement with previously reported accuracies

by Ajanovic et al., and Uthman et al., ranging from 70% to 85% in craniofacial and palatal studies, indicating that the hard palate provides a reasonably reliable metric for sex determination.[26,27] Although slightly lower than the accuracy achieved using pelvic or long bone measurements, palatal analysis offers a valuable alternative in cases where more sexually dimorphic bones are unavailable or fragmented.[28] The partial overlap observed in scatter distribution further emphasizes that while discrimination is effective, it is not absolute, necessitating cautious interpretation in forensic scenarios.[29]

The forensic implications of the present study are substantial. The demonstrated sexual dimorphism and acceptable classification accuracy support the use of palatal measurements as a supplementary tool in forensic identification, particularly in mass disaster situations, fragmented remains, and advanced decomposition where conventional skeletal markers are compromised. Furthermore, the incorporation of palatal metrics into multivariate models can enhance the overall reliability of sex estimation protocols.[29]

Limitations

The present study is limited by its use of an osteological collection with partially documented demographic details, which may introduce selection bias. The sample represents a specific South Indian population, limiting generalizability to other ethnic groups. Additionally, only linear palatal measurements were analyzed; incorporation of three-dimensional imaging and larger multicentric samples could further enhance accuracy and forensic applicability.

CONCLUSION

The present study demonstrates significant sexual dimorphism in hard palatal dimensions among South Indian skulls, with males exhibiting consistently higher values for palatal length, breadth, and height. The palatal index distribution further revealed sex-related morphological variation. Moderate correlation with sex and an overall discriminant function accuracy of 78.8% highlight the reliability of palatal measurements in sex estimation. Although not a standalone definitive method, the hard palate serves as a valuable adjunct in forensic identification, particularly when more sexually dimorphic skeletal elements are unavailable. The findings emphasize the need for population-specific standards and support the integration of palatal morphometry into comprehensive forensic anthropological assessments.

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