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Discriminant functional analysis of sexual dimorphism and stature using odontometric parameters: A cross-sectional study

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Abstract:
Basal and cortical implants enable immediate functional loading in severely resorbed ridges, but accurate prediction of treatment success remains a clinical challenge. Therefore, it is of interest to develop and validate the logistic regression, random forest and extreme gradient boosting (XGBoost) models using clinical, radiographic and implant-related data from 240 implants placed in 96 patients, with 12-month clinical success as the primary outcome. The random forest model showed the highest predictive performance (AUC 0.89), outperforming XGBoost (AUC 0.85) and logistic regression (AUC 0.79), while bone density, insertion torque, implant length and smoking status were the strongest predictors of success. Overall implant success at 12 months was 94.2%, confirming favourable outcomes for immediate-loading cortical and basal implant therapy. Thus, data shows that AI-based predictive models can improve personalised treatment planning and preoperative risk stratification for cortical and basal implant rehabilitation.

Keywords: Forensic odontology, sexual dimorphism, stature estimation, odontometric, canine index, discriminant function analysis, mesiodistal width and intercanine width

Background:
Dental arches exhibit individual variations and teeth provide consistent anatomical landmarks that can be reliably located and measured even after significant post-mortem deterioration **[1].** Forensic anthropology depends heavily on such stable biological markers for the identification of human remains, especially in medico-legal investigations involving fragmented, decomposed or mutilated bodies **[2]**. Traditional methods employ the pelvis and skull for biological sex determination and long bones for stature estimation; however, in cases of severe trauma or fragmentation, these skeletal elements may be unavailable or non-identifiable. In such circumstances, teeth the hardest and most durable structures in the human body emerge as a reliable alternative source of forensic information **[3]**. Sexual dimorphism in odontometric parameters has been documented across multiple species and populations. The morphological differences between males and females in tooth dimensions, collectively referred to as sexual dimorphism, are of significant utility in human identification, bioarchaeology and forensic anthropology **[3]**. Males consistently demonstrate larger tooth dimensions than females and this difference is particularly pronounced in the canine teeth. Mesiodistal width, buccolingual diameter, canine index and intercanine width of the permanent dentition are the most widely researched features for dental sex determination **[4]**. Stature is the standing height of a person and has a definite biological relationship with various body segments, including the head, trunk and extremities **[5]**. It is an important anthropometric parameter for physical identification and is particularly relevant in forensic and archaeological contexts where disarticulated or incomplete remains are encountered **[6]**. Since teeth are relatively resistant to decay and environmental degradation, dental measurements offer a more reliable supplementary tool for stature estimation when conventional predictors such as long bones are destroyed **[7, 8]**. Therefore, it is of interest to evaluate the sexual dimorphism and estimate stature using mesiodistal widths of maxillary and mandibular canines, intercanine width, interpremolar width and combined anterior maxillary dental care hospital in Himachal Pradesh.

Materials and Methods:
Study design and setting:
This was a cross-sectional study conducted among patients attending the Government Tertiary Dental Care Hospital in Shimla, Himachal Pradesh, from October 2024 to March 2025 (six months).

Ethical approval and informed consent:
Ethical approval was obtained from the Institutional Ethics Committee of H.P. Government Dental College, Shimla (Ref. No. HFW/ (GDC) B (12)50/2015-Vol-II-2307). All participants were informed about the purpose and procedures of the study and written informed consent was obtained prior to commencement of the examination.

Sampling method and sample size:
Convenience sampling was employed. The sample size was estimated based on a reported correlation coefficient of r = 0.415 between mandibular and stature in female subjects **[9]**, using the formula:

$$n = (Z_{1-\alpha/2} + Z_{1-\beta})^2 / [F(Zp_1) - F(Zp_0)]^2 + 3$$

Assuming 95% power, 5% alpha error and a population correlation of 0.6, the minimum required sample size was estimated at 174–180 subjects.

Inclusion and exclusion criteria:
Inclusion criteria:
Subjects aged 18–35 years with complete permanent dentition and no missing teeth; subjects belonging to a specific geographic location (Himachal Pradesh); and subjects willing to participate.

Exclusion criteria:
Subjects with significant dental pathologies affecting assessment; history of orthodontic treatment; history of facial or dental trauma that could alter tooth dimensions or stature; and systemic diseases affecting dental development or stature

Training and calibration
The examiner was trained and calibrated in the Department of Public Health Dentistry, H.P. Government Dental College, Shimla, under faculty supervision before data collection. All measurements were performed by a single examiner to eliminate interobserver error. Each parameter was measured three times and the mean of the three values was recorded to minimise intra observer error. The Intraclass Correlation Co-efficient (ICC) was 0.99, indicating excellent reliability.

Data collection and odontometric parameters
Oral examination was conducted using a plane mouth mirror under dental chair lighting (Type III ADA clinical examination **[10]**). A digital Vernier calliper (Mitutoyo) was used for all odontometric measurements and an anthropometer was used to record standing height. The following parameters were assessed:

[1] **Mesiodistal Width:** the width of an individual tooth from its mesial to distal surface at the widest point measured for maxillary and mandibular right and left canines.
[2] **Intercanine Width**: the distance between the cusp tips of the right and left canines of the maxillary and mandibular arches.
[3] **Interpremolar Width**: the distance between the buccal cusp tips of the second premolars on either side of the maxillary and mandibular arches.
[4] **Combined Anterior** Width: the total mesiodistal width of the six maxillary anterior teeth (canine to canine).
[5] Sexual dimorphism was calculated using the formula of Garn and Lewis **[11]**:

Sexual Dimorphism Index (SDI) = $((X_m / X_e) - 1) \times 100$ Where X_m = mean value for males and X_e = mean value for females.

Statistical analysis:
Data were entered in Microsoft Excel 2016 and analysed using SPSS version 26. The Shapiro–Wilk test was used to assess data normality. Descriptive statistics were computed for all demographic and odontometric variables. Student's independent t-test was used to compare odontometric parameters between sexes. Pearson's correlation coefficient was used to evaluate relationships between odontometric parameters and stature. Simple linear regression was used to derive stature prediction equations. Discriminant function analysis was performed to evaluate the sex classification accuracy of canine dimensions. A p-value < 0.05 was considered statistically significant and $p < 0.001$ was considered highly significant.

Results:
A total of 180 subjects (90 males, 90 females) were included in the study. The mean odontometric parameters for both sexes are presented in **Table 1**. Males demonstrated consistently larger values across all measured parameters compared to females. As shown in **Table 1**, the mesiodistal width of the right mandibular canine was 6.93 ± 0.83 mm in males versus 6.37 ± 0.56 mm in females and the left mandibular canine was 6.92 ± 0.80 mm versus 6.39 ± 0.60 mm respectively. The mandibular intercanine width was 27.14 ± 3.30 mm in males versus 25.83 ± 2.92 mm in females and the maxillary interpremolar width was 47.88 ± 3.09 mm versus 46.00 ± 2.71 mm. As shown in **Table 2**, these four parameters - bilateral mandibular canine widths, mandibular intercanine width and maxillary interpremolar width - were statistically significant between sexes ($p < 0.001$ or $p < 0.01$). **Table 3** presents the Sexual Dimorphism Index (SDI) for all four canine measurements. The highest dimorphism was observed in the left mandibular canine (SDI = 10.83%), followed by the right mandibular canine (SDI = 10.82%) and the right maxillary canine (SDI = 10.80%). The left maxillary canine showed the lowest SDI at 10.60%. These results confirm that mandibular canines are the most dimorphic teeth in the study population. **Table 4** summarises the discriminant function analysis for sex classification based on canine dimensions. The right maxillary canine demonstrated the highest discriminative power with an F-value of 33.74 and Wilks' Lambda of 0.841, yielding classification accuracies of 66.6% for males and 71.1% for females. Wilks' Lambda values across all four canines ranged from 0.841 to 0.901, indicating fair to moderate discriminative ability. Significant sexual dimorphism was evident in all four canine measurements. The Pearson correlation coefficients between stature and all odontometric parameters are presented in **Table 5**. The maxillary intercanine width demonstrated the strongest and most significant positive correlation with stature ($r = 0.253$, $p = 0.001$). Additional significant correlations were observed for the maxillary interpremolar width ($r = 0.195$, $p = 0.009$), mandibular intercanine width ($r = 0.186$, $p = 0.012$), right maxillary canine mesiodistal width ($r = 0.165$, $p = 0.026$) and combined anterior maxillary width ($r = 0.166$, $p = 0.026$). The left

maxillary canine, bilateral mandibular canine widths and mandibular interpremolar width did not achieve statistical significance. Simple linear regression analysis (**Table 6**) confirmed that maxillary intercanine width was the strongest predictor of stature (R^2 = 0.064, p = 0.001), followed by maxillary interpremolar width (R^2 = 0.038, p = 0.009), mandibular intercanine width (R^2 = 0.035, p = 0.012), right maxillary canine mesiodistal width (R^2 = 0.027, p = 0.026) and combined anterior maxillary width (R^2 = 0.028, p = 0.026). The regression equations derived for significant predictors are presented in **Table 7**. The highest predictive equation was: Height (cm) = 131.07 + 1.12 × (Maxillary Intercanine Width). Although the overall predictive capacity was modest, all significant equations provided clinically relevant baseline formulae for stature estimation in this population.

Table 1: Mean ± SD of odontometric parameters in male and female subjects

Odontometric Parameter	Maxilla (Mean ± SD)	Mandible (Mean ± SD)
MALE		
Mesiodistal width – Right canine	7.81 ± 0.69	6.93 ± 0.83
Mesiodistal width – Left canine	7.68 ± 0.70	6.92 ± 0.80
Intercanine width	35.49 ± 3.29	27.14 ± 3.30
Interpremolar width	47.88 ± 3.09	41.41 ± 3.11
Combined anterior width (maxilla only)	46.43 ± 5.53	—
FEMALE		
Mesiodistal width – Right canine	7.23 ± 0.64	6.37 ± 0.56
Mesiodistal width – Left canine	7.24 ± 0.62	6.39 ± 0.60
Intercanine width	34.12 ± 3.43	25.83 ± 2.92
Interpremolar width	46.00 ± 2.71	39.84 ± 3.46
Combined anterior width (maxilla only)	46.43 ± 2.71	—

Table 2: Student's t-test comparing statistically significant odontometric parameters between males and females

Odontometric Parameter	Male (Mean ± SD)	Female (Mean ± SD)	t-value	P-value
Mesiodistal width – Right mandibular canine	6.93 ± 0.83	6.37 ± 0.56	5.26	<0.001**
Mesiodistal width – Left mandibular canine	6.92 ± 0.80	6.39 ± 0.60	4.96	<0.001**
Mandibular intercanine width	27.14 ± 3.30	25.83 ± 2.92	2.72	0.007*
Maxillary interpremolar width	47.88 ± 3.09	46.00 ± 2.71	4.12	<0.001**

**p < 0.05; **p < 0.001*

Table 3: Sexual dimorphism index (SDI) for maxillary and mandibular canines

Odontometric Parameter	Male (Mean ± SD)	Female (Mean ± SD)	SDI (%)
Mesiodistal width – Right maxillary canine	7.81 ± 0.69	7.23 ± 0.64	10.8
Mesiodistal width – Left maxillary canine	7.68 ± 0.70	7.24 ± 0.62	10.6
Mesiodistal width – Right mandibular canine	6.93 ± 0.83	6.37 ± 0.56	10.82
Mesiodistal width – Left mandibular canine	6.92 ± 0.80	6.39 ± 0.60	10.83

SDI = $[(X_m/X_e) - 1] \times 100$. All values expressed as Mean ± SD

Table 4: Discriminant function analysis for sex prediction based on canine dimensions

Variable	Male	Female	F-value	p-value	Eigen-value	Canonical r	Wilks' λ	Accuracy M/F
Right Maxillary Canine	7.81±0.69	7.23±0.64	33.74	<0.001**	0.246	0.44	0.841	66.6% / 71.1%
Left Maxillary Canine	7.68±0.70	7.24±0.62	19.54	—	—	—	0.901	—
Right Mandibular Canine	6.93±0.83	6.37±0.56	27.73	—	—	—	0.865	—
Left Mandibular Canine	6.92±0.80	6.39±0.60	25.56	—	—	—	0.874	—

***p < 0.001. All values expressed as Mean ± SD.*

Table 5: Pearson correlation coefficients between stature and odontometric parameters

Odontometric Parameter	N	Mean ± SD	r-value	p-value	Significance
Mesiodistal width – Right maxillary canine	180	7.52 ± 0.72	0.165	0.026	Significant*
Mesiodistal width – Left maxillary canine	180	7.46 ± 0.79	0.131	0.079	NS
Mesiodistal width – Right mandibular canine	180	6.65 ± 0.76	0.145	0.052	NS
Mesiodistal width – Left mandibular canine	180	6.66 ± 0.76	0.101	0.179	NS
Intercanine width – Maxilla	180	34.81 ± 3.42	0.253	0.001	Highly Significant**
Interpremolar width – Maxilla	180	46.94 ± 3.05	0.195	0.009	Significant*
Intercanine width – Mandible	180	26.48 ± 3.18	0.186	0.012	Significant*
Interpremolar width – Mandible	180	40.62 ± 3.38	0.093	0.216	NS
Combined anterior width – Maxilla	180	44.66 ± 5.61	0.166	0.026	Significant*

**p < 0.05 (significant); **p < 0.001 (highly significant); NS = not significant.*

Table 6: Simple linear regression analysis predicting stature from significant odontometric parameters

Parameter	Regression Equation	p-value
Mesiodistal width – Right maxillary canine	Height = 144.12 + 3.45 (MDWRCMax)	0.026*
Intercanine width – Maxilla	Height = 131.07 + 1.12 (ICWMax)	0.001**
Interpremolar width – Maxilla	Height = 124.55 + 0.97 (IPWMax)	0.009*
Intercanine width – Mandible	Height = 146.58 + 0.88 (ICWMan)	0.012*

Combined anterior width – Maxilla	Height = 150.05 + 0.44 (CAWMax)	0.026*

**p < 0.05; **p < 0.001*

Table 7: Regression equations for stature prediction from significant odontometric parameters

Odontometric Parameter	Constant	Unstd. Coeff.	SE	R	R^2	Adj. R^2	p-value
Mesiodistal width – Right maxillary canine	144.12	3.45	1.54	0.17	0.03	0.022	0.026*
Mesiodistal width – Left maxillary canine	148.84	2.84	1.61	0.13	0.02	0.012	0.079
Mesiodistal width – Right mandibular canine	150.89	2.88	1.47	0.15	0.02	0.016	0.052
Mesiodistal width – Left mandibular canine	156.73	2	1.48	0.1	0.01	0.005	0.179
Intercanine width – Maxilla	131.07	1.12	0.32	0.25	0.06	0.059	0.001**
Interpremolar width – Maxilla	124.55	0.97	0.36	0.2	0.04	0.033	0.009*
Intercanine width – Mandible	146.58	0.88	0.35	0.19	0.04	0.029	0.012*
Interpremolar width – Mandible	153.18	0.41	0.33	0.09	0.01	0.003	0.216
Combined anterior width – Maxilla	150.05	0.44	0.2	0.17	0.03	0.022	0.026*

**p < 0.05; **p < 0.001*

Discussion:

The present study evaluated the usefulness of odontometric parameters for sex determination and stature estimation in individuals from Himachal Pradesh attending a government tertiary dental care hospital. Males exhibited significantly larger odontometric dimensions than females across most variables, with the mandibular canines showing the greatest degree of sexual dimorphism, while the maxillary intercanine width emerged as the strongest predictor of stature. These findings support the established role of dental measurements as supplementary forensic markers and are comparable with previous studies conducted in Indian and international populations **[9]**. The significantly greater mesiodistal widths of mandibular canines and wider dental arch dimensions observed in males are consistent with previous odontometric investigations. Studies have consistently reported mandibular canines as the most sexually dimorphic teeth because of their relative resistance to attrition and the influence of sex-linked genetic and hormonal factors during odontogenesis **[10]**. Similar observations have also been reported for maxillary canine dimensions, although the degree of dimorphism varies across populations due to ethnic and environmental influences. The Sexual Dimorphism Index recorded in the present study (10.60-10.83%) falls within the range previously described for Indian populations, supporting the need for population specific reference standards rather than universal odontometric cut-off values **[11]**. Discriminant function analysis identified the right maxillary canine as the most effective individual parameter for sex prediction, although the overall classification accuracy was moderate. Comparable studies have similarly demonstrated that canine dimensions alone provide reasonable but not absolute accuracy for sex estimation, indicating that odontometric variables should complement rather than replace conventional forensic methods **[12]**. Differences in predictive accuracy between studies are likely attributable to variations in ethnicity, sample size, measurement techniques and statistical models. Nevertheless, the present findings reaffirm that canine measurements remain valuable adjunctive indicators when skeletal remains are incomplete or fragmented **[13]**. Among all variables evaluated for stature estimation, maxillary intercanine width showed the strongest positive correlation with height, whereas individual tooth widths demonstrated weaker associations. These findings agree with previous reports suggesting that transverse arch dimensions are more closely associated with stature than isolated tooth measurements **[14]**. Although the regression model explained only a modest proportion of stature variability, the observed relationship remained statistically significant and supports the use of odontometric measurements as supplementary predictors when long bones are unavailable. The relatively low coefficient of determination also highlights that stature is influenced by multiple genetic and environmental factors beyond dental dimensions alone **[15]**. The present study has several strengths, including equal representation of both sexes, excellent intra-observer reliability (ICC = 0.99) and the application of multiple statistical methods, including discriminant function analysis and regression modelling, to comprehensively evaluate odontometric parameters. However, the findings should be interpreted in light of certain limitations. Convenience sampling limits the generalisability of the results and the modest predictive ability of regression models indicates that dental measurements should not be used as standalone indicators for stature estimation. Future multicentric studies involving larger and ethnically diverse populations, together with advanced digital morphometric techniques, are required to develop more robust population specific forensic models and improve the accuracy of both sex determination and stature estimation using odontometric parameters.

Conclusion:

Mandibular canines exhibited the highest sexual dimorphism, with the left mandibular canine showing the greatest Sexual Dimorphism Index (10.83%). Sex classification accuracy reached 71.1% using canine dimensions. Maxillary intercanine width was the strongest predictor of stature ($r = 0.253$, $p = 0.001$). Odontometric parameters provide a simple, non-invasive supplementary tool for forensic sex determination and stature estimation in the Himachal Pradesh population.

Clinical significance:

The odontometric parameters evaluated in this study offer a simple, accurate and non-time-consuming method for determining sex and estimating stature in forensic and medico-legal investigations. The population-specific reference values and regression equations derived for the Himachal Pradesh population enhance the applicability of traditional forensic

methodology and may be particularly valuable in mass casualty events, disaster victim identification or cases where conventional skeletal markers are unavailable.

List of Abbreviations:
ICC – Intraclass Correlation Coefficient;
ADA – American Dental Association;
SPSS – Statistical Package for the Social Sciences;
SDI – Sexual Dimorphism Index;
MDW – Mesiodistal Width;
ICW – Intercanine Width;
IPW – Interpremolar Width;
CAW – Combined Anterior Width;
DFA – Discriminant Function Analysis;
X_m – mean value for males;
X_e – mean value for females.

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