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Original Article

Sex prediction according to digital analysis of the morphological characteristics of maxillary posterior teeth in a Pakistani population

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الملخص

أهداف البحث: قام الباحثون بفحص العديد من خصائص الأسنان لتحديد الاختلافات في شكل الأسنان بين الذكور والإناث في مجموعات سكانية مختلفة. ومع ذلك، لم يتم إجراء أي بحث للتأكد من إزدواج الشكل الجنسي وتطوير نموذج للتنبؤ بالجنس باستخدام نمط الأخاديد وعدد الحدبات ونمط الإطباق في أي مجموعة. وبذلك توصلت هذه الدراسة إلى الفروق الجنسية والقدرة على التنبؤ بالجنس بناء على هذه الخصائص للأسنان العلوية في المجتمع الباكستاني.

طرق البحث: تم اختيار 130 قالبا سنيا (65 ذكر و65 أنثى). تم التقاط صور رقمية للسطح الإطباقي للضاحك الأول والثاني والطاحن الأول العلوي باستخدام كاميرا رقمية. تم تسجيل عدد الحدبات، ونمط الأخاديد، والنمط الإطباقي لكل نوع من الأسنان. تم تحليل البيانات باستخدام اختبار "مربع كاي" وتحليل الانحدار اللوجستي.

النتائج: أظهر نمط الأخاديد والنمط الإطباقي للضاحك الأول والطاحن الأول العلوي تباينا جنسيا كبيرا. كما أظهر عدد الحدبات في الطاحن الأول العلوي فرقا كبيرا ذا دلالة إحصائية بين الذكور والإناث. بلغت دقة التنبؤ بالجنس للعينات التدريبية 76.7%، بينما كانت 70% للعينات الاختبارية.

الاستنتاجات: وجد تباين جنسي كبير في نمط الأخاديد والنمط الإطباقي للضاحك الأول والطاحن الأول العلوي، وكذلك في عدد الحدبات للطاحن الأول العلوي. أظهر نموذج التنبؤ دقة جيدة بنسبة 76.7%، وبالتالي يمكن استخدامه للتنبؤ بالجنس في المجتمع الباكستاني.

الكلمات المفتاحية: التباين الجنسي؛ التنبؤ بالجنس؛ عدد الحدبات؛ نمط الأخاديد؛ النمط الإطباقي؛ التصوير ثنائي الأبعاد

Abstract

Objective: Researchers have examined several dental characteristics to identify differences in tooth morphology between males and females in various populations. Nevertheless, no research has been undertaken to ascertain sexual dimorphism and develop a sex prediction model by using the groove pattern, cusp number and occlusal pattern in any population group. Therefore, this study accessed the sexual differences and the ability to predict sex according to these characteristics of maxillary teeth in the Pakistani community.

Method: A total of 130 dental casts were selected (65 each from males and females). Digital images of the occlusal surface of the maxillary first premolar, second premolar and first molar were captured with a Canon Powershot A2200 14.1 MP digital camera with 4× optical zoom. Cusp number, groove pattern and occlusal pattern were recorded for each tooth type. Data were analysed with chi-square tests and logistic regression analysis.

Results: The groove pattern and occlusal pattern of the maxillary first premolar and first molar showed significant sexual dimorphism ($p < 0.05$). The cusp number of the maxillary first molar also displayed a statistically

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significant difference between males and females ($p < 0.05$). The sex prediction accuracy was 76.7% for the training samples and 70% for the test samples.

Conclusion: We observed significant sexual dimorphism in the groove pattern and the occlusal pattern of the maxillary first premolar and maxillary first molar teeth, as well as the cusp number of the maxillary first molar teeth. The prediction model demonstrated good accuracy, at 76.7%, and hence can be used for sex prediction in the Pakistani population.

Keywords: 2D imaging; Cusp number; Groove pattern; Occlusal pattern; Sex prediction; Sexual dimorphism

Introduction

Tooth morphology is influenced by a combination of cultural, environmental and genetic factors. Dental features have been emphasised in relation to ethnic variations and geographical dispersion. Anomalies in one population may be a trait of another population,[1] thus aiding in identification of variations in morphological characteristics among populations.

In dental profiling, different characteristics of teeth are studied to estimate the age,[2] sex[3] and race[4] of human remains. Many studies have been conducted to determine sexual dimorphism in teeth through morphometric analysis using two dimensional and three dimensional techniques,[5–8] and have yielded promising results. Various populations have also been examined to study the prevalence of tooth morphological characteristics, which also differ by tooth type.[9–11] For instance, the maxillary first premolars (MxPm1), maxillary second premolars (MxPm2), and mandibular first premolars usually have two cusps, i.e., buccal and palatal (lingual in the mandibular premolar), whereas the mandibular second premolars usually have three cusps.[12] Similarly, maxillary molars usually have four cusps, whereas the mandibular molar teeth exhibit four, five or more cusps, with five being the most common number.[12] The buccal cusps of the maxillary molars are known as the mesiobuccal and the distobuccal cusps, whereas the palatal cusps are known as the mesiopalatal and distopalatal cusps. Sometimes a fifth cusp is present on the distal end of the tooth, known as the metaconule, which is between the distopalatal and distobuccal cusps.[13] Another trait that varies among populations is the groove pattern (GP). The most common GPs observed in premolars are U, H and Y. The GPs commonly observed in mandibular molars are +, x and Y.[1,14,15] However, only one study has observed the GP variance in maxillary molars, and reported them as H, branched H, U and μ type.[16]

Because tooth development involves multiple factors, the prevalence of cusp number (CN) and GP in teeth differs among populations. An accessory cusp in one population might be considered a dental trait in another population. Various populations have been studied to ascertain the frequency of GP, CN and occlusal pattern (OP) on different teeth.[9,15,17–19] The OP is a combination of the CN and the GP of a particular tooth. A limited number of studies have also demonstrated the importance of sexual dimorphism in study populations according to these characteristics.[17,19] The power of a sex prediction model with the GP, CN and OP of maxillary posterior teeth has yet to be tested. Additionally, limited research has assessed the prevalence, sexual dimorphism or sex prediction formulation of CN, GP and OP in the Pakistani community. Therefore, this study was conducted to investigate the prevalence, sexual dimorphism and sex prediction formulation according to CN, GP and OP in maxillary posterior teeth in the Pakistani population.

Materials and Methods

Sample selection

The study was conducted at the CMH Lahore Medical College & Institute of Dentistry in Lahore, Pakistan [614/ERC/CMH/LMC]. Plaster dental cast samples were collected from the dental school archive, according to the following inclusion and exclusion criteria. The inclusion criteria were participants of Pakistani origin; 13–25 years of age; with healthy and sound MxPm1, MxPm2 and maxillary first molar (MxM1) teeth, and teeth without any anomalies or defects that might obscure the occlusal surface morphology. The exclusion criteria were mandibular teeth, maxillary anterior teeth, and any teeth with restoration or caries. For sexual dimorphism, PS software version 3.1.6 (2018) was used for the sample size calculation with a 95% confidence interval, power = 0.80 and alpha = 0.05, with Y type GP in 91% of males and 68% of females,[20] and an equal sample size between males and females (M = 1). The minimum sample size required was 47 for each sex. For the sex prediction model, on the basis of the ratio of one independent variable to ten samples,[21] a minimum of 90 samples were required (given the nine variables in the study). A total of 130 dental casts were selected (65 each from males and females). Sixteen random samples (eight each form males and females) were selected for the intra- and inter-examiner study according to a sample size calculator,[22] with a power of 80%, a significance level of 0.05, $p0 = 0.6$ and $p1 = 0.9$.

Data collection

Images were captured for all plaster dental casts with a Canon Powershot A2200 14.1 MP digital camera with 4× optical zoom. All captured images were labelled and stored as jpeg. files. The images were loaded on a computer for data collection, so that the images could be zoomed in to provide a clear view of the cusp number and groove pattern. Three scoring types were used in this study:

1. CN scoring alone
2. GP scoring alone
3. OP scoring, in which the cusp number and groove pattern were observed together

CN scoring for the premolars and molars followed the Arizona State University scoring system (Table 1). However, different types of groove patterns not previously reported in the literature were observed on the premolars. These types were categorised as shown in Table 2 (Figure 1). The GP scoring for molars was adapted from Roy et al., 2019 (Table 2) (Figure 1).

Statistical analysis

SPSS software version 28.0 (IBM, Armonk, NY, USA) was used for data analysis. Intra- and inter-examiner study error was analysed on 16 random samples with Cohen's kappa. Descriptive statistics was used to assess the frequencies. A chi-square test was performed to compare male and female samples to assess sexual dimorphism. A logistic regression analysis was conducted with the backward Wald approach to determine the association between sex and non-metric occlusal variables. Of the 130 samples, 70% were selected as training samples, and 30% were selected as test samples. The training samples were used by the software to generate a prediction model or formula. Then the software used the test samples to run the analysis to verify the accuracy of the model. Sensitivity and specificity analyses were run to detect the cut-off value.

Results

Reliability analysis (Cohen's kappa)

Excellent intra- and inter-examiner reliability were observed. All variables had an intra-examiner reliability score of 1.00, whereas the inter-examiner reliability score ranged from 0.998 to 1.00.

Sexual dimorphism (chi-square test)

The GP and OP of MxPm1 and MxM1, as well as the CN of MxM1, demonstrated significant differences between

Table 1: Scoring of cusp number.

Tooth	Score	Cusp number
Premolar teeth	2	One buccal and two palatal cusps
	3	One buccal, one mesiopalatal and one distopalatal cusp
Molar teeth	4	Mesiopalatal, distopalatal, mesiobuccal and distobuccal cusps
	5	Metaconule (a conule between the distopalatal and mesiopalatal cusps of maxillary molar teeth) on the distal side

Table 2: Scoring of groove pattern.

Groove pattern	Description
Premolar	
X	No mesiopalatal, distopalatal, mesiobuccal and distobuccal triangular grooves fully developed
H	Well-developed mesiopalatal, distopalatal, mesiobuccal and distobuccal triangular grooves
U	Underdeveloped distopalatal and mesiopalatal triangular grooves
μ	Underdeveloped distopalatal or mesiopalatal triangular grooves
Molar	
H	Distopalatal and mesiobuccal grooves connected by the transverse groove crossing the oblique ridge
Branched H (BH)	Distopalatal, and mesiobuccal grooves with multiple attachments of supplementary grooves
μ	Any underdeveloped palatal or buccal segments of the distopalatal or mesiobuccal grooves

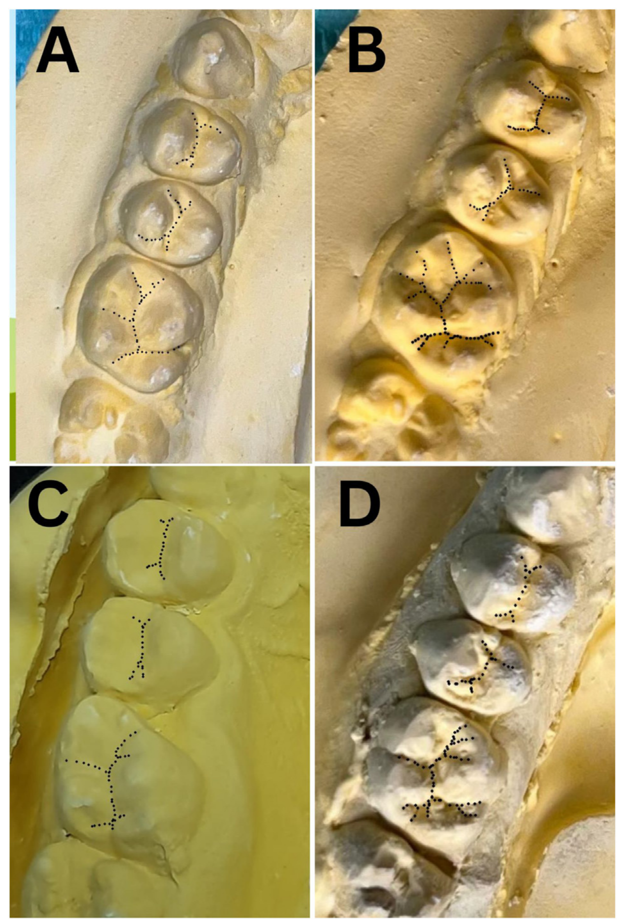

Figure 1: Types of groove patterns observed on maxillary posterior teeth. A) MxM1 = H, MxPm1 = μ, MxPm2 = U, B) MxM1 = BH, MxPm1 = H, MxPm2 = μ, C) MxM1 = μ, MxPm1 = X, MxPm2 = X, D) MxM1 = BH, MxPm1 = X, MxPm2 = μ.

sexes. However, no significant difference was observed in the CN of premolars or the GP and OP of MxPm2 (Tables 3 and 4).

Logistic regression analysis

The correlations between the variables and sex were assessed with binary logistic regression to create a predictive model for predicting sex. A confidence interval of 95% was determined. The Hosmer−Lemeshow significance was 0.946, thus demonstrating that the model fit the data sufficiently. The accuracy of classification in the training samples was 82.2% for males and 71.1% for females. In contrast, the accuracy rate was 85% for correctly predicting males and 55% for correctly predicting females in the test samples. Overall, the classification accuracy rate was in an acceptable range (76.7% of the training samples and 70% of the test samples) (Table 5).

The variables CNMxM1, MxPm1GP (1), MxPm1GP (2), MxPm1GP (3) and MxPm1GP (4) were selected by the system for the prediction model (Table 6). The variables CNMxM1 and MxPm1GP (1) showed a significant association with the outcome (predicted as female).

The model exhibited a precise discrimination rate of 77.7% on average (Figure 2). Sensitivity and specificity analyses were conducted by using the input data to determine the cutoff value (0.316).

The sex prediction model generated from logistic regression analysis for the Pakistani population was as follows:

Table 3: Sexual dimorphism in cusp number and groove pattern.

	N	Male N (%)	Female N (%)	*p*-value
Cusp number				
MxPm1	130			
2		65 (50)	65 (50)	–
3		–	–	
MxPm2	130			
2		65 (50)	65 (50)	–
3		–	–	
MxM1	130			
4		51 (78.5)	64 (98.5)	<0.001*
5		14 (21.5)	1 (1.5)	
Groove pattern				
MxPm1	130			
U		21 (32.3)	10 (15.4)	<0.001*
X		14 (21.5)	44 (67.7)	
μ		8 (12.3)	4 (6.2)	
H		22 (33.8)	7 (10.8)	
MxPm2	130			
U		24 (36.9)	29 (44.6)	0.093
X		23 (35.4)	29 (44.6)	
μ		5 (7.7)	3 (4.6)	
H		13 (20)	4 (6.2)	
MxM1	130			
H		30 (46.2)	28 (43.1)	0.002*
BH		35 (53.8)	20 (40)	
μ		–	11 (16.9)	

MxPm1: maxillary first premolar; MxPm2: maxillary second premolar; MxM1: maxillary first molar; chi-squared test applied; $*p < 0.05$.

$$\text{Sex} = \frac{\text{EXP}\begin{bmatrix} -1.18 + CNMxM1(1)(-2.59) + MxPm1GP(1)(2.61) \\ +MxPm1GP(2)(0.08) + MxPm1GP(3)(0.70) \end{bmatrix}}{1 + \text{EXP}\begin{bmatrix} -1.18 + CNMxM1(1)(-2.59) + MxPm1GP(1)(2.61) \\ +MxPm1GP(2)(0.08) + MxPm1GP(3)(0.70) \end{bmatrix}}$$

On the basis of this model, sex can be predicted by using 0.316 as a cut-off value; any value greater than or equal to this value is classified as female.

Discussion

This study was conducted to evaluate the sex determination potential of tooth morphological characteristics. A Canon Powershot A2200 14.1 MP digital camera with 4× optical zoom was used to capture images of the occlusal tooth surfaces. This method allowed the GP of molar teeth, including any branched groove patterns, to be observed, and enabled the images to be examined in zoomed in view without any distortion. Posterior teeth were selected in this study, because they are multicusped teeth, thus showing variations in CN and GP. Moreover, the variables selected for this study are easily accessible in all dental hospitals and clinics, given that patient dental records are primarily in the form of plaster dental casts, dental photographs and, more recently, 3D scans.

Anterior teeth were not used in this study, because they are usually altered even if all teeth are sound and healthy for aesthetic purposes.[23] Moreover, the anterior teeth are singe cusped and have incisal edges instead of the occlusal surface, and hence cannot be used for the OP record.

Anthropological research places great importance on the analysis of dental morphological characteristics, which provides valuable data regarding evolutionary links among species, as well as diversity and variations within populations. Non-metric traits, such as form, GP, CN and the existence or lack of a cusp, can indicate morphological differences among ethnic groups and species.[24,25] To distinguish abnormalities within a particular population from a distinguishing feature of another population, analysis of the morphological traits of teeth in all populations is crucial.

The purpose of this study was to examine and evaluate the occlusal morphological differences in teeth between males and females in the Pakistani population. Morphogenesis is a multifaceted phenomenon regulated by an interplay of morphogenetic activity, epigenetic information, growth

Table 4: Sexual dimorphism in occlusal pattern.

Variables	Samples (n)	Male n (%)	Female n (%)	*p*-value
MxPm1	130			
2U		21 (32.3)	10 (15.4)	
2X		14 (21.5)	44 (67.7)	
2µ		8 (12.3)	4 (6.2)	<0.001*
2H		22 (33.8)	7 (10.8)	
MxPm2	130			
2U		24 (36.9)	29 (44.6)	
2X		23 (35.4)	29 (44.6)	
2µ		5 (7.7)	3 (4.6)	0.093
2H		13 (20)	4 (6.2)	
MxM1	130			
4H		29 (44.6)	28 (43.1)	
4BH		28 (43.1)	25 (38.5)	<0.001
4µ		–	11 (8.5)	
5BH		8 (12.3)	11 (8.5)	

MxPm1: maxillary first premolar; MxPm2: maxillary second premolar; MxM1: maxillary first molar; chi-square test applied; *$p < 0.05$.

Table 5: Sex prediction classification accuracy with logistic regression.

Observed sex	Training samples	Test samples
Male	82.2%	85%
Female	71.1%	55%
	76.7% (overall percentage)	70% (overall percentage)

factors and environmental influences. The GP and OP of MxPm1 and MxM1 differed significantly between males and females. The samples in our analysis showed a constant occurrence of bicuspid MxPm1 and MxPm2 in both males and females. This cusp number is the prevailing characteristic of maxillary premolars, possibly because a thorough examination of the existing research revealed a greater focus on investigating the number of cusps in mandibular premolars (which typically contain two or three cusps) than in maxillary premolars.

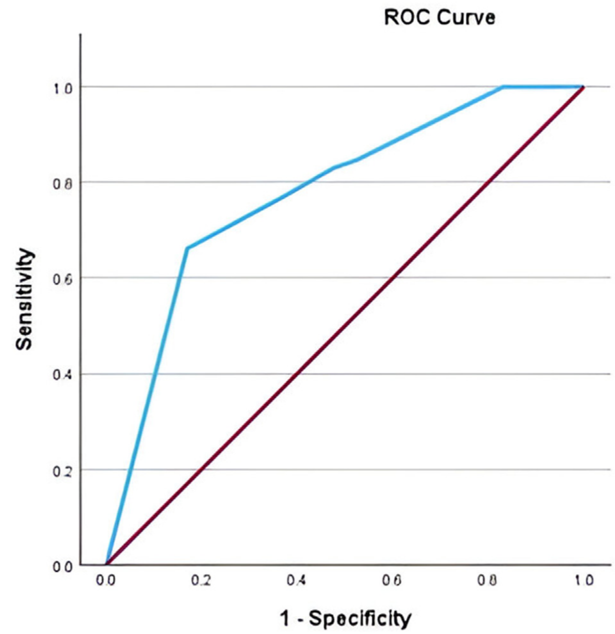

Figure 2: Area under the ROC curve = 0.777, 95% CI = 0.7697–0.857, S.E. = 0.041, cut-off value = 0.316.

Our study indicated that a high percentage of MxM1 in both males (78.5%) and females (98.5%) had four cusps. In a prior investigation of MxM1 among Southern Chinese individuals, males showed the highest occurrence of five cusps (39%), whereas females showed the highest occurrence of four cusps (39%).[21] In contrast, a study performed in the population of Libya has demonstrated a greater prevalence of five cusps (64%) than four cusps (35.6%).[22] In MxPm1, the most common GP observed was H-type for males (33.8%) and X-type for females (67.7%). In the case of MxPm2, the most frequent GPs were U in males, accounting for 36.91% of cases, and U and X-type in females, accounting for 44.6% of cases each. The most prevalent molar GP was H, accounting for 43.1% in females, whereas BH was most common in males (53.8%). However, in a study conducted by Roy et al.,[9] BH was the predominant GP (60%), and was followed by H-type GP (37.5%). The BH variant of GP occurs when multiple

Table 6: Logistic regression analysis.

Predictors	Regression coefficient (B)	S.E.	Wald	df	Sig.	Odds ratio EXP (B)	95% CI for adjusted OR	
							Lower	Upper
CNMxM1 (1)	−2.59	1.14	5.10	1	0.02	0.07	0.008	0.70
MxPm1GP			20.12	3	<0.01			
MxPm1GP (1)	2.61	0.69	14.25	1	<0.01	13.70	3.52	53.33
MxPm1GP (2)	0.08	0.99	0.008	1	0.93	1.09	0.15	7.69
MxPm1GP (3)	0.70	0.77	0.84	1	0.35	2.02	0.44	9.18
Constant	−1.18	0.57	4.31	1	0.03	0.30		

S.E: standard error, df: degree of freedom, Wald: Wald statistic, CI: confidence interval, OR: odds ratio, MxPm1GP: groove pattern of maxillary first premolar, CNMxM1: cusp number of maxillary first molar.

disparate supplementary grooves manifest alongside the distopalatal and mesiobuccal grooves. The most common OP in MxPm1 was 2H in males (33.8%) and 2X in females (67.7%). For MxPm2, males showed the highest frequency of 2U (36.91%), whereas females showed the highest frequency of 2X and 2U (44.6% each). In molars, the most common OP was 4BH in males (43.1%) and 5BH in females (43.1%). The variation in CN, GP and OP in various populations indicates the influence of genetic, epigenetic and environmental factors on tooth morphology during tooth development, thus resulting in variation among populations.

GP formation starts during the initial bell stage of tooth development. Development is influenced by many growth factors that promote the emergence of the enamel organ, which is responsible primarily for the deposition of enamel and dentin.[26] This mechanism is further controlled by specific genes. In the cap stage of tooth development, enamel knot signalling centres control the number of cusps formed during the initial and morphogenetic phases. The presence of multiple elements simultaneously influences tooth morphology, thus leading to distinct variations specific to each individual. Because of variations in the rates of change across regional and ethnic groups, the prevalence of these alterations may differ among populations and races, thus indicating a genetic influence.[27,28]

A classification accuracy below 60% is considered poor, whereas a value above 75% is considered acceptable for forensic investigations. In our investigation, the sex prediction accuracy was approximately 76.7%. Male prediction was more accurate (82.2%) than female prediction (71.1%) in the training samples. Nevertheless, the prediction accuracy for the test samples was 70%, which is considered good. An extensive literature review identified only one study evaluating tooth morphological traits for sex prediction, and reported a classification accuracy of 61% when the logistic regression was run on the cusp numbers of the mandibular premolars and maxillary second molar.[29] Multiple studies have been conducted to achieve sex prediction in various populations according to tooth measurements determined with 2D imaging, 3D imaging, geometric morphometric analysis and artificial neural networks, and have yielded varying results.[5,30−33] However, because of cost and availability, most hospitals and dental clinics remain limited to 2D dental records and the plaster dental casts. In such scenarios, our prediction model could easily be applied. Moreover, to our knowledge, this study is the first to use GP, CN and OP scores together as independent variables to establish their correlation with the categorical characteristic of sex, which can be easily observed from readily available dental records. We established a sex prediction model on the basis of this analysis, which achieved the recommended minimum accuracy of 75−80% for tools used for forensic sex determination[34,35] and thus may be used for sex determination along with other procedures in forensic investigations. This method might facilitate further investigation of sexual dimorphism by using non-metric dental characteristics in situations in which the data are insufficient.

Conclusion

This study investigated the significance of non-metric dental traits in evaluating sexual dimorphism and sex prediction formulation in the Pakistani population. The GP and OP of MxPm1 and MxM1 showed significant sexual dimorphism. Moreover, the CN of MxM1 also showed significant sex differences. The sex prediction accuracy was acceptable, at 77.7%. Therefore, the model could be applied for sex prediction in the Pakistani population. Further studies should be conducted to access the morphological traits for sexual dimorphism and sex prediction modulation in different populations, to assess the diversity of these traits and their effects on sex prediction models.

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Conflict of interest

The authors have no conflict of interest to declare.

Ethical approval

Ethical approval was granted by the ethics committee of CMH Lahore Medical College & Institute of Dentistry, Lahore, Pakistan [614/ERC/CMH/LMC].

Authors contributions

SR conceived and designed the study. All authors conducted research, and collected, organised, analysed and interpreted data. EZ and ARC provided research materials. SR and SA wrote the initial and final drafts of the article. SS, EZ and ARC critically revised the article and provided logistic support. All authors have critically reviewed and approved the final draft and are responsible for the content and similarity index of the manuscript.

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