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ORIGINAL ARTICLE

Potential use of the cusp and crown areas of the maxillary posterior teeth measured with a two-dimensional stereomicroscope for sex determination

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Abstract

In this study, we aimed to compare the cusp and crown areas of the maxillary first premolar (PM1), second premolar (PM2), and first molar (M1) in males and females in the Malay population and to formulate sex prediction models. For this purpose, the maxillary posterior teeth of 176 dental cast samples (from 88 males and 88 females) were selected and transformed to two-dimensional digital models using 2D-Hirox KH-7700. Cusp and crown area measurements were obtained using Hirox software by tracing the outermost circumference of the tooth cusps. Statistical analysis included independent *t*-tests, logistic regression analysis, and receiver-operating characteristic (ROC) curves as well as determination of sensitivity and specificity; analysis was performed with SPSS version 26.0. The significance threshold was set at 0.05. All crown and cusp area measurements were significantly larger in males than in females ($p < 0.001$). The most sexually dimorphic tooth was the first maxillary molar (mean difference, 10.27 mm^2), and the most sexually dimorphic cusp was the mesiopalatal cusp (mean difference, 3.67 mm^2) of M1. The sex prediction model had a good accuracy, with 80% of selected cases correctly predicted. Hence, we conclude that the maxillary posterior teeth in the Malay population exhibit significant sexual dimorphism, and this information may be used for sex determination as adjuvants along with other procedures.

Keywords Cusp area · Crown area · Maxillary teeth · 2D · Sexual dimorphism

Introduction

Dental profiles include a group of distinct features associated with hard and soft tissues that aid in the estimation of the age, sex, and ethnicity of an individual. Dental profiling is usually based on postmortem dental features observed on plaster dental casts (dental casts), radiographs, and photographs [1]. Dental profiling for sex identification is of primary importance, as it reduces the search of antemortem dental records to half of the population.

Crown size measurements such as mesiodistal (MD), buccolingual (BL) [2, 3], and diagonal [4] diameters and circumference [5] have been used successfully to predict sex as adjuvant methods. A more advanced three-dimensional method has also been used to measure crown size, achieving a similar range of classification accuracy as that of conventional digital caliper methods [6, 7]. However, these 3D methods utilize fewer predictor variables than conventional methods.

Few researchers have used digital software to measure intracuspal variables for sex prediction. However, investigations of the cusp areas of the upper permanent molars [8] and of the upper first premolar using geometric morphometry and artificial intelligence [9] have yielded classification accuracy comparable with that of crown size methods.

Because tooth dimensions are under strong genetic control [10], population variations may be expected. Thus, the results from one population cannot be implemented in other populations. In the Malay community, studies have examined

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sexual dimorphism in crown size measurements of teeth [5, 11]. However, data on the cusp area of tooth surfaces needed to enable sex prediction in the Malay population are lacking; such data would provide options or alternatives regarding other crown size measurement methods. Thus, this study aimed to investigate the potential use of cusp and crown areas of the upper permanent posterior teeth (except the third molar) for sex prediction in the Malay population.

Materials and methods

Sample size calculation

The sample size was calculated using PS software version 3.1.6 (2018). The sample size for side difference evaluation was calculated based on the following parameters: power of 80%, alpha of 0.05, standard deviation (from previous publication) of 3.44 mm^2 [8], and mean difference of 1.5 mm^2. Thus, a minimum of 42 dental casts was needed for side difference evaluation. For sex prediction formulation, sample size was calculated according to the rule of thumb that each independent variable should be accompanied by 10 samples [12]. Because we had 11 variables, the minimum sample size was 110 dental casts (55 males and 55 females). Sixty-six samples (33 males and 33 females) were set aside as test samples for logistic regression analysis. Given the availability of data, 88 dental casts were used for comparison between males and females (Table 1). The dental casts were selected according to the inclusion and exclusion criteria. The inclusion criteria were as follows: Malay origin; age between 13 and 25 years; fully erupted healthy maxillary first premolar (PM1), maxillary second premolar (PM2), and maxillary first molar (M1); and a dental cast without any bubbles or distortion. The exclusion criteria were as follows: caries, fractured part of tooth structures, attrition, or restoration of the tooth occlusal surface.

A total of 176 dental casts (88 males and 88 females) were collected from the archive of the orthodontic and forensic departments after obtaining ethical approval from the Universiti Sains Malaysia Human Ethics Committee (USM/JEPeM/17100564). The age and sex of the patients were retrieved retrospectively from the patient's dental records. The dental casts were collected following the inclusion and exclusion criteria with simple stratified random sampling. Sex (male or female) was the stratum used in our study. The dental casts were assigned a unique number using a number generator (Calculator.net). This step was important to avoid any bias in the study. In this study, maxillary posterior teeth were selected for analysis because there is a risk of displacement of the mandible due to its anatomical structure. Hence, in such scenarios, identification is highly dependent on the maxillary teeth. Furthermore, anterior teeth are prone to early loss due to their anatomical position and root structure. Hence, in our study, the cusp and crown areas of the maxillary posterior teeth were analyzed to determine sexual dimorphism.

Transformation of the dental cast into 2D digital images

All dental casts were scanned using the autocalibrated system KH-7700 (Hirox, Japan) digital stereo photogrammetry, and 2D digital images were saved on a hard disk. The position of the dental casts was standardized with a bubble spirit level such that the occlusal plane of the teeth was always parallel to the desktop surface. Magnification was standardized at × 20. Light was adjusted such that a clear image with all visible groove patterns and cusp boundaries could be recorded. The magnification of the cast captured by the lens was autocalibrated regardless of the distance between the lens and the object.

2D measurement of the cusp area

From each image, the cusp and crown areas of the maxillary first premolar, second premolar, and first molar were recorded. Once the image was loaded on the software, the individual cusp area (in mm^2) of each tooth was measured

Table 1 Sample distribution with gender and age

Objective	Sample size	Age	Gender	Statistical analysis
Comparison of cusp and crown area in PM1, PM2 and M1 Left vs right side teeth	42 pairs	13–25	42 males 42 females	Paired *t*-test
Comparison of cusp and crown area in PM1, PM2 and M1 male vs female	88 samples	13–25	88 males 88 females	Independent *t*-test
Sex prediction formulation based on cusp and crown area of PM1, PM2, and M1	110 samples 66 test samples	13–25	55 males 55 females 33 males 33 females	Logistic regression

PM1 maxillary first premolar, *PM2* maxillary second premolar, *M1* maxillary first molar

by a Hirox KH-7700 device using Hirox software (Hirox, Japan) with a lens model (MXG-5040RZ) and a low-resolution adapter. First, the individual cusp area was measured by marking the tooth boundary and the grooves separating the four main cusps (Fig. 1).

The total crown area of an individual tooth was measured by tracing the maximum bulge area of the tooth crown. The total crown area outline for the molar tooth included any accessory cusps, such as the metaconule (extra cusp on the distal marginal ridge of the upper molar) and Carabelli's cusps. The software automatically detected the outline of the tooth, and the area (mm^2) of the enclosed region was calculated. The same procedure was repeated for all teeth. The images were saved with a resolution of 300 dots per inch (dpi) as.jpg (JPEG) files. The variables included in this study for the cusp area measurements were the buccal cusp of PM1 (PM1B), palatal cusp of PM1 (PM1P), buccal cusp of PM2 (PM2B), palatal cusp of PM2 (PM2P), mesiopalatal cusp of M1 (M1MP), mesiobuccal cusp of M1 (M1MB), distobuccal cusp of M1 (M1DB), and distopalatal cusp of M1 (M1DP). The variables for crown area measurements were the M1 crown area, PM1 crown area, and PM2 crown area.

Intrarater and interrater reliability

Intrarater reliability analysis was conducted on 14 casts with 11 variables at an interval of 2 weeks. Similarly, 14 casts were measured by two different examiners to assess interrater reliability.

Statistical analysis

Data were analyzed using SPSS version 26.0 (IBM, Armonk, NY, USA). The normality of the distribution was assessed using the Shapiro–Wilk test. Intrarater and interrater reliability analyses for the cusp and crown areas were conducted using the intraclass correlation coefficient (ICC). A paired *t*-test was performed on 42 male and 42 female dental casts to compare the cusp and crown areas between the left and right sides. Independent-sample *t*-tests were performed on 176 dental casts to compare the cusp and crown areas between males and females (88 dental casts each) to determine sexual dimorphism.

Logistic regression was performed to construct the sex prediction model (176 samples). A total of 110 samples (55 males and 55 females) were selected to generate the formula, and 66 samples (33 males and 33 females) were selected as test samples. Binary logistic regression using the backward stepwise Wald method was performed to detect any statistically significant association of sex (male or female) with cusp or crown area variables to construct the sex prediction model. Using this method, 11 cusp and crown area variables were entered and then automatically removed one by one in each step based on the level of significance of the Wald statistics. The variables with $p < 0.25$ were retained in the final model [13]. The algorithm stopped once no more variable could be removed or entered. Finally, odds ratios were generated, and the corresponding 95% confidence interval was calculated for all significant variables. The significance threshold was set at 0.05.

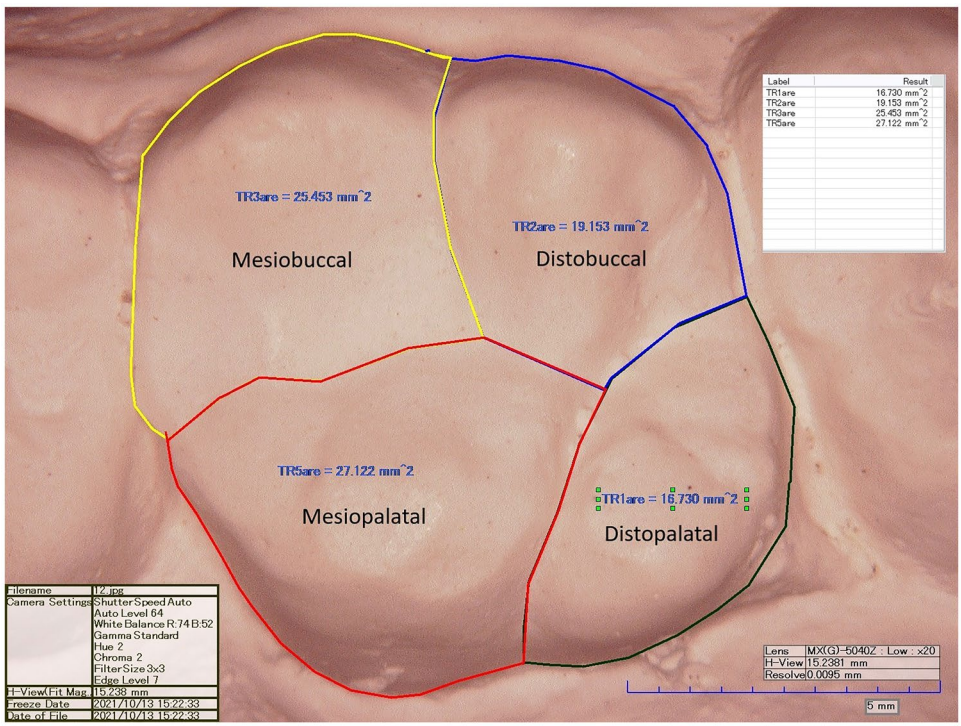

Fig. 1 Cusp outline marking for cusp and crown area measurement of maxillary molar using 2D Hirox

Table 2 Intrarater and interrater's reliability of cusp and crown area measurements

	Intraclass correlation (ICC)	95% confidence interval		*F* test with true value 0			
		Lower bound	Upper bound	Value	df1	df2	*p*
Intrarater	0.999	0.998	0.999	155.591	131	131	< 0.001*
Interrater	0.987	0.981	0.991	1456.833	109	109	< 0.001*

*Significance level as $p < 0.05$

Results

The intraclass correlation coefficient (ICC), which indicated intrarater reliability for cusp and crown area measurements using 2D Hirox microscopy, was 0.999; the ICC for interrater reliability for cusp and crown area measurement using 2D Hirox microscopy was 0.987, indicating excellent reproducibility (Table 2).

There was no statistically significant difference between the right- and left-side tooth samples of male subjects ($p > 0.05$) (Table 3) or female subjects ($p > 0.05$) (Table 4). Thus, either the left-side or right-side teeth could be used as a source of sample collection. The data were then collected from left-side teeth only. If any exclusion criterion was met for the left-side tooth, the corresponding right-side tooth was used.

There was a statistically significant difference in the cusp and crown areas of the maxillary first premolar, second premolar, and first molar between males and females, with males having larger areas than females (Table 5).

The logistic regression analysis using the backward stepwise Wald statistics method showed good accuracy, with 80% of selected cases and 71.2% of unselected cases correctly predicted (Table 6). The Hosmer and Lemeshow tests indicated a significance value of $p = 0.481$, which shows that the model adequately fits the data. The Nagelkerke R^2 value indicated that approximately 52.3% of the variation in the outcome variable was explained by the logistic regression model.

In the logistic regression analysis, the following five variables showed a significant association with the outcome (i.e., sex prediction): PM2P, PM2B, M1MP, M1DP, and PM2 (Table 7). The area under the receiver-operating characteristic (ROC) curve was 0.835 (Fig. 2). This shows that the model can accurately discriminate 83% of the cases, which is considered excellent.

Sensitivity and specificity analyses were conducted to determine the cutoff value based on the data entered, which was 0.520. The sensitivity at this cutoff value was 0.761, and the specificity was 0.239.

The sex prediction model was as follows:

$$\text{Sex} = \frac{\text{Exp}(\beta_0 + \beta_1 X_1 + \beta_2 X_2 \ldots .. \beta_5 X_5)}{1 + \text{Exp}(\beta_0 + \beta_1 X_1 + \beta_2 X_2 \ldots .. \beta_5 X_5)}$$

where Exp (exponential function) = 2.71828, β_0 (constant) = 17.39, $\beta_1 = -0.900$, $\beta_2 = -0.939$, $\beta_3 = -0.268$, $\beta_4 = -0.287$, and $\beta_5 = 0.826$, and the cusp area variables are specified as follows: X_1 = PM2P, X_2 = PM2B, X_3 = M1MP, X_4 = M1DP, and X_5 = PM2.

Thus, in the example case with the predictors in the formula having cusp and crown area values of PM2P = 19.09 mm^2, PM2B = 28.23 mm^2, M1MP = 35.36 mm^2, M1DP = 19.34 mm^2, and PM2 = 47.32 mm^2, the sex prediction model would be as follows:

Table 3 Cusp and crown area measurements (in mm^2) between the left- and right-side teeth of male samples

Pairs		Samples	Left side		Right side		Mean difference	95% CI		*t*	df	*p*
			Mean (mm^2)	SD	Mean (mm^2)	SD		Lower	Upper			
1	LPM1P–RPM1P	42	22.68	3.28	22.73	3.32	0.45	−0.30	0.21	−0.55	41	0.585
2	LPM1B–RPM1B	42	32.58	4.45	32.65	4.63	0.06	−0.38	0.25	−1.76	41	0.086
3	LPM2P–RPM2P	42	21.36	2.94	21.24	2.83	0.11	−0.19	0.41	0.78	41	0.436
4	LPM2B–RPM2B	42	30.32	4.43	30.13	4.61	0.18	−0.06	0.42	−0.16	41	0.100
5	LMMP–RMMP	42	29.81	3.88	29.49	4.03	0.31	−0.22	0.84	0.58	41	0.560
6	LMMB–RMMB	42	25.06	3.10	24.94	3.17	0.12	−0.26	0.50	−1.56	41	0.126
7	LMDB–RMDB	42	21.69	2.80	22.11	2.78	0.42	−0.90	0.06	−0.42	41	0.671
8	LMDP–RMDP	42	17.63	2.42	17.58	2.04	0.05	−0.21	0.33	1.57	41	0.123
9	LPM1–RPM1	42	55.23	7.55	55.43	7.41	0.19	−0.66	0.27	−1.66	41	0.103
10	LPM2–RPM2	42	51.73	7.01	51.53	7.01	0.20	−0.06	0.46	−0.95	41	0.347
11	LM1–RM1	42	92.14	7.27	92.12	7.33	0.01	−3.48	3.51	0.22	41	0.829

*Significance level as $p < 0.05$

Table 4 Cusp and crown area measurements (in mm^2) between the left- and right-side teeth of female samples

Pairs		Samples	Left side		Right side		Mean difference	*t*	df	*p*
			Mean (mm^2)	SD	Mean (mm^2)	SD				
1	LPM1P–RPM1P	42	20.98	1.92	21.12	1.81	0.25	−0.55	41	0.585
2	LPM1B–RPM1B	42	29.14	3.08	29.43	3.07	0.16	−1.76	41	0.086
3	LPM2P–RPM2P	42	20.63	3.19	20.39	2.47	0.31	0.78	41	0.436
4	LPM2B–RPM2B	42	26.82	3.19	27.23	3.02	0.24	−1.68	41	0.100
5	LM1MB–RM1MB	42	23.24	2.12	23.69	1.92	0.28	−1.56	41	0.671
6	LM1MP–RM1MP	42	27.28	2.90	27.11	2.52	0.30	0.58	41	0.560
7	LM1DB–RM1DB	42	20.71	1.79	20.83	1.97	0.26	−0.42	41	0.123
8	LM1DP–RM1DP	42	16.85	1.80	16.40	2.11	0.28	1.57	41	0.507
9	LPM1–RPM1	42	49.54	4.88	50.27	4.44	0.43	−1.66	41	0.103
10	LPM2–RPM2	42	47.03	5.27	47.54	5.01	0.53	−0.95	41	0.347
11	LM1–RM2	42	89.48	7.65	89.32	6.73	0.70	0.22	41	0.826

*Significance level as $p < 0.05$

$$\text{Sex} = \frac{2.718((17.39 + (-0.900)(17.90) + (-0.939)(23.07) + (-0.268)(27.17) + (-0.287)(14.63) + (0.826)(40.97))}{1 + 2.718((17.39 + (-0.900)(17.90) + (-0.939)(23.07) + (-0.268)(27.17) + (-0.287)(14.63) + (0.826)(40.97))} = 0.665$$

The value determined using the sex prediction model was 0.665. The cutoff value (0.520) indicates that any value equal to or above 0.520 will lead to the prediction of female sex. Thus, in this example, the sex was predicted as female.

Discussion

With the advent of modern digital technologies in dentistry, scanned digital images can replace plaster dental casts, which have the disadvantages of consuming storage space

Table 5 Descriptive statistics and independent *t*-test for sexual dimorphism between males and females

Variables		Sample	Male		Female		95% CI		Mean diff	*t*	df	*p*	% diff
			Mean (mm^2)	SD	Mean (mm^2)	SD	Lower	Upper					
1	PM1P	88	23.34	3.06	21.15	2.44	1.36	3.00	2.18	5.23	165.91	< 0.001*	9.38
2	PM1B	88	33.65	4.52	30.03	3.55	2.41	4.83	3.62	5.91	164.81	< 0.001*	10.75
3	PM2P	88	22.01	2.64	19.94	2.21	1.34	2.79	2.07	5.64	174	< 0.001*	9.40
4	PM2B	88	30.90	3.79	27.75	4.65	1.88	4.41	3.15	4.92	167.14	< 0.001*	10.19
5	M1MP	88	30.12	3.26	26.45	2.97	2.74	4.60	3.67	7.79	174	< 0.001*	12.18
6	M1MB	88	25.70	2.82	22.90	2.28	2.02	3.55	2.78	7.19	166.62	< 0.001*	10.89
7	M1DB	88	22.63	2.42	20.25	2.23	1.68	3.07	2.38	6.76	174	< 0.001*	10.51
8	M1DP	88	18.09	2.17	16.46	2.07	0.99	2.25	1.62	5.07	174	< 0.001*	9.01
9	PM1	88	56.97	6.96	51.13	5.64	3.95	7.72	5.84	6.11	166.89	< 0.001*	10.25
10	PM2	88	52.77	5.92	47.39	5.08	3.73	7.01	5.37	6.45	174	< 0.001*	10.19
11	M1	88	97.23	8.40	86.95	7.65	7.88	12.67	10.27	8.47	174	< 0.001*	10.57

*Statistical significance was set as $p < 0.05$

Table 6 Classification accuracy of the logistic regression analysis based on selected and unselected cases

Observed		Predicted					
		Selected cases			Unselected cases		
		Sex		% correct	Sex		% correct
		Male	Female		Male	Female	
Gender	Male	42	13	76.4	24	9	72.7
	Female	9	46	83.6	10	23	69.7
Overall percentage				80.0			71.2

and potential damage when stored for a long period of time [14]. Digital images (e.g., clinical digital photographs) can be captured from plaster dental casts, which are available in most clinics and mortuaries. The digital images of dental casts have the advantages of ease of image creation, reduced storage costs, and the ability to study images using accessible software.

This study was conducted using a 2D Hirox KH-7700 digital stereomicroscope. A stereomicroscope has an accuracy of 0.1×10^{-6}, indicating that it is a legitimate and trustworthy tool for these measurements, and manual and digital sliding calipers have an accuracy of 0.01 mm [15]. This stereomicroscope produces a 1:1 true size of 2D digital images of tooth surfaces. In a mortuary/laboratory with no such facilities, a digital camera with a known size object/ruler would be able to produce similar digital images for cusp and crown area measurements that can be measured with free software. Thus, our prediction models and method may still be applicable.

The intra- and interrater reliability scores in our study were above 0.90. The mean difference in the first and second measurements (used to calculate intraobserver reliability) was 0.001 mm^2, and that for interrater reliability was 0.01 mm^2. This shows that the measurements are repeatable and accurate using 2D Hirox images. This high reliability might stem from the measurement method, which involved autocalibration using the Hirox software, which reduces the error chances compared to measurements performed manually or without autocalibration using 2D images.

Differences in the cusp and crown areas between the right- and left-side antimeric teeth were assessed. The results showed that the cusp and crown areas of the left- and right-side teeth were similar, with no statistically significant difference ($p > 0.05$). The results were consistent with those of a previous study conducted in the Malay population, which also showed that the left- and right-side antimere teeth had no significant difference in size according to MD and BL measurements [16]. In another study conducted on Australian twins and families, the estimates of genetic association for left–right-paired variables indicated that molar morphology has considerable bilateral integration [17]. Some studies have shown bilaterally symmetrical dimensions in some teeth and bilateral asymmetry in others [18–20]. These fluctuating results could be due to differences in methods, as the symmetry of the teeth was determined by the evaluation of only mesiodistal dimensions. However, morphogenesis is a complicated process regulated by morphogenetic activity, epigenetic information, growth factors, and environmental effects [21]. A multifactorial process may result in bilateral tooth dimensional asymmetry, but the level of difference might be different in different populations, resulting in statistically significant or nonsignificant results.

All cusp and crown area measurements were significantly larger in males than in females ($p < 0.001$). The M1 crown

Table 7 Logistic regression analysis of significant contributing independent variables with outcomes (predicted as females) in maxillary posterior teeth

Predictors	Regression coefficient (*B*)	Standard error	Wald	df	*p*	Odd ratio EXP(*B*)	95% CI for adjusted OR	
							Lower	Upper
PM2P	−0.900	0.437	4.239	1	0.040	0.407	0.173	0.958
PM2B	−0.939	0.471	3.974	1	0.046	0.391	0.155	0.984
M1MP	−0.268	0.093	8.284	1	0.004	0.765	0.637	0.918
M1DP	−0.287	0.122	5.539	1	0.019	0.751	0.591	0.953
PM2	0.826	0.437	3.571	1	0.059	2.283	0.970	5.375
Constant	17.390	3.575	23.658	1	*p<0.001*	35689091.50		

PM2P second premolar palatal cusp, *PM2B* second premolar buccal cusp, *M1MP* molar mesiopalatal cusp, *M1DP* molar distopalatal cusp, *PM2* second premolar crown, *OR* odd ratio, *CI* confidence interval. Male and female code in analyses

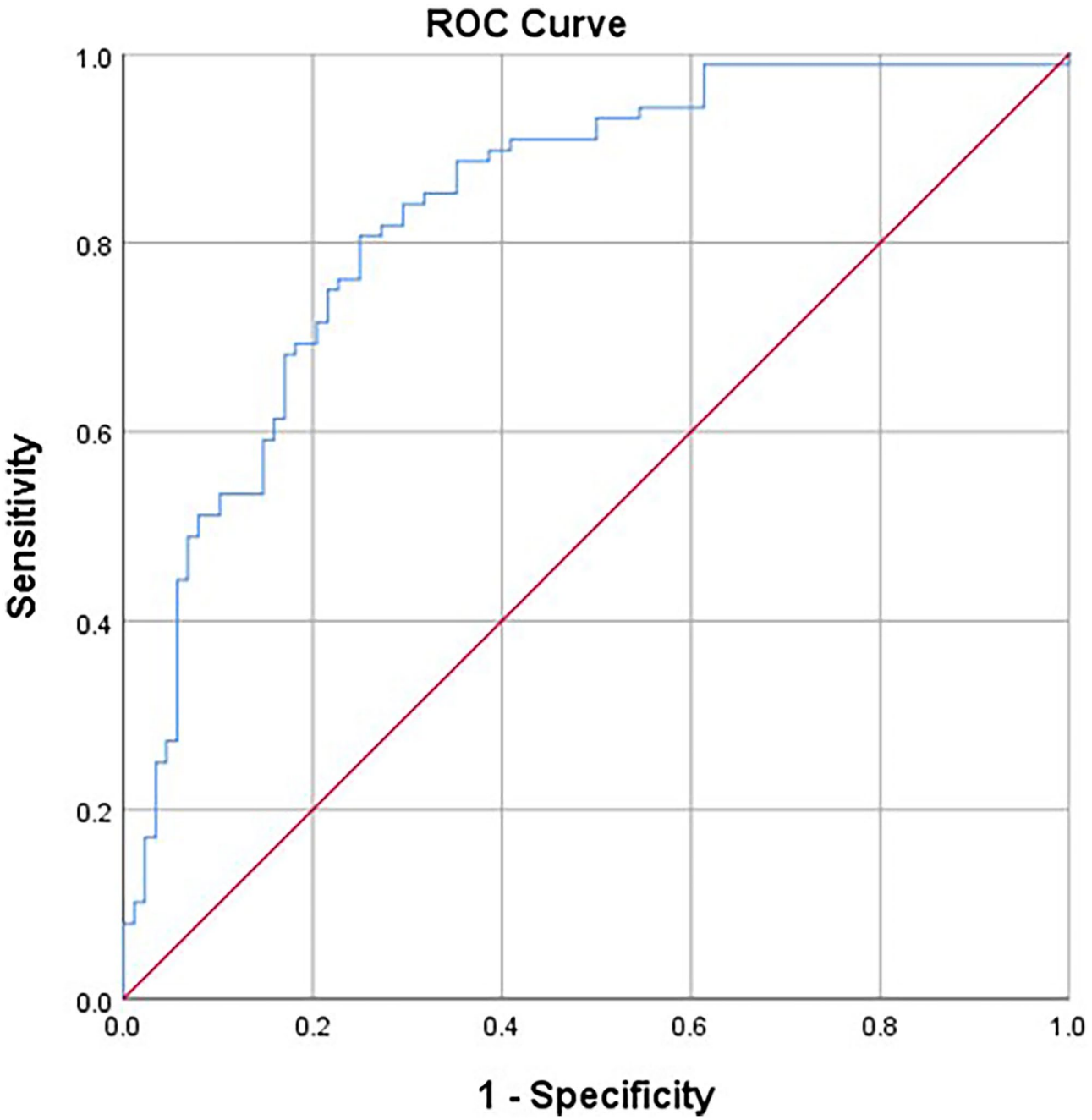

Fig. 2 Receiver operating characteristic (ROC) curve (area under the ROC curve = 0.835, standard error = 0.031, 95% confidence interval = 0.775–0.894, and cutoff value = 0.520)

area was the most sexually dimorphic, followed by the PM1 and PM2 crown areas. In terms of individual cusp area, the M1MP cusp area exhibited the highest sexual dimorphism (12.18%), followed by the M1MB cusp area (10.89%), M1DB cusp area (10.51%), and M1DP cusp area (9.01%). Thus, the mesial cusps had greater sexual dimorphism than the distal cusps. Similarly, the buccal cusp areas of both PM1 and PM2 were more sexually dimorphic than the palatal cusps of the corresponding teeth. Similar to our findings, Macaluso [22] also reported greater sex differences in the mesial cusps of the first maxillary molar than in the distal cusps of the same tooth in a Black South African population. In the Japanese population, one of the mesial cusps of M1 (M1MB) showed higher sexual dimorphism than the M1DB and M1DP cusps [23]. This is partially consistent with our findings, in which both mesial cusps showed higher sexual dimorphism than the distal cusps. Some studies, however, reported that mandibular molars had greater

sexual dimorphism values in talonid (the distal portion of a molar) dimensions than in trigonid (anterior portion of a molar) dimensions, indicating that sex differences are more pronounced in the later-developed crown units [24–26].

Cusp development is largely influenced by genes and environmental factors [27, 28]. Genes of X chromosomes regulate enamel deposition, and the cell division associated with the creation of the enamel dentin bond and enamel deposition is controlled by Y chromosome genes. X chromosome genes expedite enamel deposition, and in females, genes of both X chromosomes are active in amelogenesis, whereas Y chromosome genes play a role in enamel and dentin deposition [29]. Because the Y chromosome causes slower maturation in males, the longer crown growth duration may result in larger crown dimensions due to a longer period of enamel and dentin deposition [30]. This might explain why male teeth have larger cusp areas and larger crown areas.

Sex prediction formulation involves the evaluation of whether certain variables can lead to accurate sex prediction. Previous studies have used logistic regression analysis and discriminant analysis for this purpose [3, 7, 31–33]. In our study, data were analyzed using logistic regression analysis. Studies that conducted both types of analyses have observed higher classification accuracies with logistic regression analysis [8, 34]. In our study, the classification accuracy rates were 76.4% for males and 83.6% for females in the selected cases. The overall classification accuracy rate in our study was 80% (Table 6), which is in accordance with a previous study conducted in the Malay population with a classification accuracy of 77.9% based on linear (MD and BL) tooth measurements with a stepwise discriminant function [11]. Khamis et al. [11] reported that the MD and BL dimensions of maxillary posterior teeth showed sexual dimorphism of 0.4–3.6%, whereas in our study, sexual dimorphism in maxillary teeth ranged from 9.01 to 10.89%. Tooth dimensions in Khamis et al. [11] were more sexually dimorphic in maxillary molars (MD16:1.4, MD17:2.3, BL16: 3.2, and BL17:3.0) than in premolars (MD14:1.0, MD15:1.1, BL14: 2.9, and BL15:1.7). This is similar to our findings, as the crown area of maxillary M1 was more sexually dimorphic (10.57%) than the crown areas of PM1 (10.25%) and PM2 (10.19%).

Multivariate analysis results of crown size measurements in other populations were comparable to our results [22, 31, 34, 35]. This falls within the suggested minimum accuracy rate of 75–80% for a reliable application method for sex identification in forensics [8, 36, 37]. Our results were also comparable to (and better than) those of more advanced 3D methods in several comparisons. Oliva et al. [9] reported 80% classification accuracy using geometric morphometric and neural network analyses of the occlusal surface of the upper first premolar. Yong et al. [38] reported an average classification accuracy of less than 70% in both indigenous Australians and individuals of European descent using geometric morphometric analysis of upper and lower premolars. Paknahad et al. [7] found accuracy rates of 77–84%, and a lower percentage of accuracy (47.8%) was noted in Issrani et al. [6] using 3D cone-beam computed tomography. These comparisons suggest that regardless of the 3D method, the average classification accuracy was comparable with our findings.

The logistic regression analysis in this study was validated by an area under the ROC curve of 0.835, indicating that the acquired classification rates were good [39]. For both the selected and unselected cases, females were more accurately classified than males, which may suggest higher tooth feature stability in females than in males [32].

The highest sex prediction accuracy has been reported using deoxyribonucleic acid (DNA) multiplex PCR (100%) [40], the pelvic bone (98–100%) [41], and the skull (97%) [42]. However, there might be situations in which the pelvic bone, skull, and DNA are deteriorated because of postmortem changes such that they cannot be practically used for sex determination. In such scenarios, teeth may be a helpful tool for sex identification because teeth are robust to postmortem changes [43] and intense heat [44]. The resistant nature of teeth renders them available for most forensic odontology investigations. Most of previous studies have utilized complete mandibular or maxillary dentitions or included some of the anterior teeth [7, 31, 34, 35], which may be difficult to obtain in many forensic situations where remnant teeth may not allow the measurement of each tooth. In addition, anterior teeth are difficult to obtain, as they might already be aesthetically modified or lost early because they are single-rooted teeth. In our study, maxillary teeth were used, which have higher chances of being available for forensic investigations because the mandible bone might be separated from the human remains.

In conclusion, the cusp and crown areas of the maxillary posterior teeth in the Malay population were symmetrical, and Malay males had larger cusp and crown areas than females. The cusp and crown areas of maxillary posterior teeth generated an accuracy rate of 80% correct classification, which falls within acceptable limits as an adjuvant method for sex prediction. However, this finding focused on one main population in Malaysia. Further studies should be conducted with a larger sample size based on the three ethnic groups in Malaysia.

Key points

1. To establish an additional reliable method for predicting sex using tooth variables, this study measured the cusp areas of posterior teeth. These anatomical variables have rarely been used for dental sex prediction.

2. The area of each cusp was measured digitally.
3. The results confirmed that the cusp areas of the maxillary posterior teeth in this population were sexually dimorphic, and the constructed sex prediction model was as useful as tooth sizes for complementing sex prediction models.
4. 3D cusp area measurement methods do not necessarily yield higher classification accuracy than the 2D digital cusp area measurement method.

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Data availability The data are available upon request from the authors.

Declarations

Ethical approval Ethical clearance was obtained from the USM Ethics Committee (USM/JEPeM/17100564) prior to dental cast recruitment. The submitted manuscript has not been published before, it is not under consideration for publication anywhere else and its publication has been approved by all co-authors.

Conflict of interest The authors declare no competing interests.

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