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Permanent Maxillary Odontometrics for Sex Estimation Based on a 3-Dimensional Digital Method

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Statistical Analysis C
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Manuscript Preparation E
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Background: In the field of forensic medicine, sex estimation is a critical step in personal identification. Teeth are the hardest tissue and have high temperature resistance and corrosion resistance. In cases such as an airplane crash or the corpse of an unknown person, teeth often play a crucial role in identification. This study applied 3-dimensional technology to obtain odontometrics of permanent maxillary teeth and to examine the sexual dimorphism, finding suitable discriminant indicators to construct appropriate equations for sex estimation.

Material/Methods: A total of 204 participants (104 men and 100 women) from the Han population in Kashgar were included. Plaster models of their maxillary dentition were obtained to scan and measure through an accepted and commonly used 3-dimensional digital method. Descriptive statistics, *t* tests, and discriminant analyses were statistically analyzed using IBM SPSS 23.0 software.

Results: This study showed high intra- and interexaminer reliability (intraclass correlation coefficient >0.950). There were statistically significant sex-related differences ($P<0.05$), with male values generally being higher for buccolingual distance, mesiodistal distance, intercanine distance, crown area, crown module, crown index, and maxillary canine index. Compared with other measurements, mesiodistal distance and crown area indicator exhibited distinct sexual dimorphism. In addition, several appropriate equations were constructed through different discriminant analyses that could be used to estimate sex in our specific population.

Conclusions: Three-dimensional digital technology offers a promising method for odontometry. Combining mesiodistal distance and buccolingual distance of particular teeth or using maxillary canine index in discriminant functions are acceptable auxiliary tools for sex estimation in the forensic field.

Keywords: **Discriminant Analysis • Imaging, Three-Dimensional • Odontometry • Sex Differentiation**

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Background

Sex estimation is a crucial procedure for individual identification. The differences due to sexual dimorphism can be detected in tissue structure, shape, and size in the same population and are genetically based [1]. Identifying an individual's sex through gene detection is an effective method, but extracting nuclear DNA from degraded samples can be difficult, resulting in complicated procedures and high costs [2]. Compared with the organs of the human body, teeth are the hardest and long-lasting tissue, and they can resist damage due to bacterial degradation, high temperature, and erosion in terms of their physical and chemical properties. Even in massive disasters, teeth can withstand destruction and breakage [3]. Dental sexual dimorphism has been extensively studied in recent years, and a variety of crown diameters, related indices, equation algorithms, and measuring methods have been developed for sex estimation in different populations.

In 1957, Jensen et al [4] first reported measurement of teeth based on a US population. Other researchers subsequently discovered that odontometrics differ by region, race, and sex, and many studies estimated sex based on different dental measurements or combined indicators. Owsley and Webb [5] correctly distinguished the sex of Whites in the United States based on odontometrics, showing that the combinational algorithms for different teeth can be used for sex estimation. At present, the dental measurements and indicators used to estimate sex include mesiodistal distance (MD), buccolingual distance (BL), crown area (CA), crown module (CM), crown index (CI), and maxillary or mandibular canine index (MCI). Researchers from various countries have applied different odontometrics and established various sex prediction models to estimate sex [6-10], and most propose that the sex differences in tooth size and the sex prediction accuracy from indicators or equations differ by region and ethnic group, suggesting the need to establish reference data and prediction models for specific populations in specific regions.

The purpose of the current study was to obtain sex-related differences in odontometrics of the Han population in Kashgar using a 3-dimensional (3D) technique and to evaluate the probability of a male or female individual from odontometrics. This work applied an advanced dental measuring method to provide updated odontometric data for the population, verified the accuracy of existing indicators in sex detection, and used statistical discrimination analysis to calculate new functions that are applicable for estimating sex based on teeth in the Han population.

Material and Methods

Study Participants

Study participants were 18- to 25-year-old Han students from local universities and vocational technical colleges in Kashgar, China. The sample size was designed to detect a mean difference of 0.2 mm with a standard deviation of 0.50 mm at 80% power and α=0.05, with a 95% level of confidence. The calculated sample size was 196 participants (98 men and 98 women). To compensate for the expected 20% data loss, we recruited 236 participants.

Using a simple random sampling method (computer random number), 236 dental plaster models were selected from the dentition plaster model library of Han students in Kashgar established by our research group in a previous project. We selected 204 dental plaster models based on inclusion and exclusion criteria; 32 were eliminated. The selected participants were 21.60±1.59 years old on average and included 104 men and 100 women. This investigation was designed and conducted according to the guidelines of Strengthening the Reporting of Observational studies in Epidemiology (STROBE), and we applied the STROBE specification in this article [11].

Ethical Approval and Consent to Participate

This study was conducted with the approval of the Ethics Committee in the Xinjiang Medical University Affiliated First Hospital, in accordance with the standards of the Declaration of Helsinki and International Ethical Guidelines for Biomedical Research Involving Human Subjects. We obtained written informed consent from all participants.

Inclusion and Exclusion Criteria

Inclusion criteria required participants to be 18- to 25-year-old residents of Kashgar (≥3 years) and Han ethnicity (to at least their grandparents' generation) without any orthodontic treatment. Participants needed to have healthy gingival tissue and periodontium, individual normal occlusal dentition with the exception of the third molars, normal molar and canine relationships, normal overjet and overbite relationships (2-3 mm), and caries-free maxillary teeth.

The exclusion criteria included visible defects in the canine cusps, proximal-distal adjacent points, and labial/buccal/palatine surfaces of the maxillary teeth; damage to the dentition models during transportation or storage; moderate crowding (>4 mm) or visible spacing in the dentition; identification number mismatch between the dentition model and the corresponding participant; and incorrect, unclear, or missing recorded information.

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Definition of Measurement Indicators

The linear measurements taken were the mesiodistal and buccolingual distances of maxillary teeth and the maxillary intercanine distance. The mesiodistal distance of each tooth was obtained by measuring the maximum distance between the contact points on the mesial and distal surfaces of the crown [4]. Buccolingual distance was recorded as the greatest distance between the buccal and lingual surfaces of the crown [12]. Intercanine distance was measured between the tips of the maxillary canines [13].

The following indices were calculated from linear measurements taken in accordance with El Sheikhi and Bugaighis [14]. Crown index (CI) was calculated as (BL/MD)×100, and it gave an indication of the overall tooth shape. Crown area (CA) was calculated as MD×BL, and it indicated the overall tooth size. Crown module (CM) was equal to (BL+MD)/2, and it presented an overall picture of tooth size. Maxillary canine index (MCI) was equal to the canine MD divided by the maxillary intercanine distance. The percentage of sexual dimorphism was calculated as (M/F-1)×100, where M and F represented the mean dimensions of the male and female parameters, respectively. In general, 29 linear measurements were recorded, and from those measurements, 44 indices were computed in each dentition model.

Three-Dimensional Digitization Method

The 3D digital models were obtained by scanning the dental plaster models through the CAD/CAM system (Langcheng Company, China) with a dl-100 type scanner (accuracy up to ±10 μm). The documents were exported in STL format and imported into Geomagic 2015 reverse engineering software (Geomagic Company, USA) to recalibrate the models, create the coordinate systems, mark the points, and measure the indicators. Details can be found in a previous study [15]. Linear measurements are shown in **Figures 1 and 2**.

Data Analysis

Intraclass correlation coefficients (ICCs) were calculated by SPSSAU project (QingSi Technology Ltd, China) 2019 version 20.0 online application software (retrieved from http://www.spssau.com). The data were analyzed using IBM SPSS Statistics version 23.0 (IBM Corp., Armonk, NY, USA) with 5% ($P \leq 0.05$) confidence level to test for significance. Results are reported as mean±standard deviation. Independent samples *t* test was used to compare sex-based groups. General and stepwise discriminant analysis were utilized to determine discriminant score of functions established for sex estimation. Twenty 3D dental models were randomly selected for intra- and interobserver error calculations. The time interval between the first and second marked-point measurements was approximately 2 weeks.

Results

Intra- and Interexaminer Reliability

High intra- and interexaminer reliability was found by ICC analysis (ICC >0.950, **Table 1**), which confirmed that the results were reliable.

Descriptive Statistics and Comparison Between Sexes

Among the study participants, 104 (50.98%) were men and 100 (49.02%) were women. The mean values of crown dimensions and intercanine distance were significantly higher in men than in women, with the exception of buccolingual distances of center and lateral incisors for which the differences were not significant (**Table 2**).

The indices calculated from the measurements are show in **Table 3**. The mean values were higher in men than in women for CA, CM, and MCI, whereas CI was the opposite. CA, CM, and MCI of canine; CA and CM of the first premolar and the second molar; CA, CM, and CI of the second premolar and the first molar were significantly different between men and women.

Percentage of Sexual Dimorphism

With regard to sexual dimorphism in incisors, premolars, and the first molars, the results were MD >BL and CA >CM >CI. For canines, the results were MD >BL and CA >CM >MCI >CI. In the second molars, we found MD≈Bl and CA >CM >CI. Generally, the sexual dimorphism was evident for CA in maxillary teeth. In the comparison of crown dimensions, MD was higher than BL. Among crown indices, CA was the highest followed by CM, MCI, and CI. In a comparison of the sexual dimorphism of maxillary teeth parameters, canines, premolars, and the first molars were prominent (**Table 4**).

Discriminant Analysis

Discriminant function analysis was performed to predict sex. Mesiodistal distance, buccolingual distance, MCI, CA, CM, and CI were selected as predictor variables. $D=k+a_1x_1+a_2x_2+\ldots+a_nx_n$ was the discriminant function form, where D was the discriminant score, k was the y-intercept, a was the coefficient, x was the discriminant variable, and n was the number of discriminant variables.

The general discriminant analysis was carried out in crown dimensions (MD and BL) for sex estimation (**Table 5**), and the

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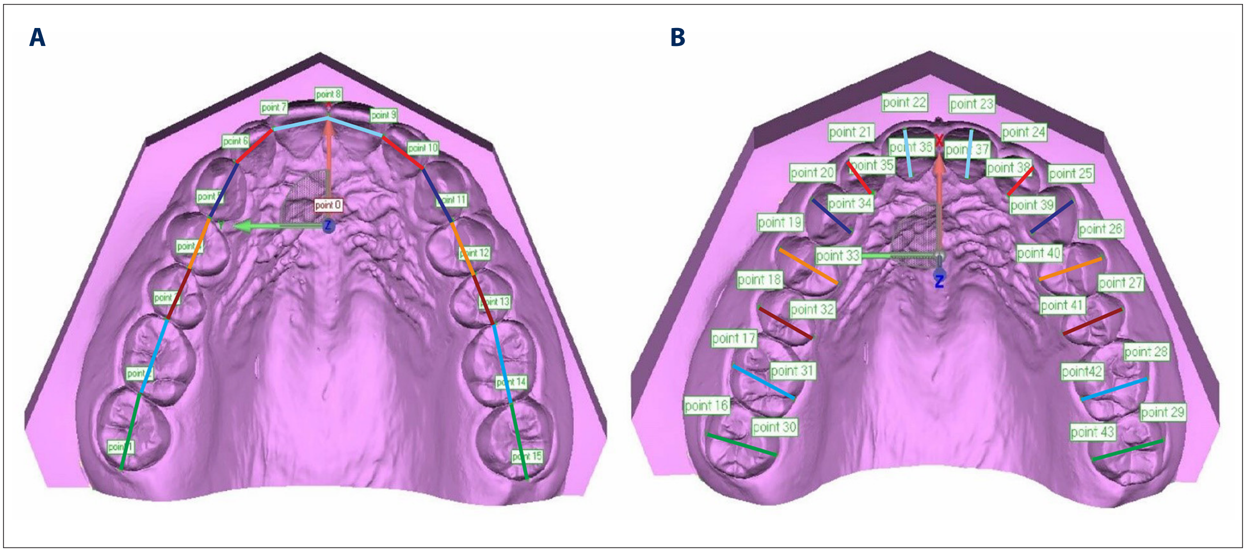

Figure 1. Measurements on mesiodistal distance (**A**) and buccolingual distance (**B**) of maxillary teeth on 3-dimensional digital dentition.

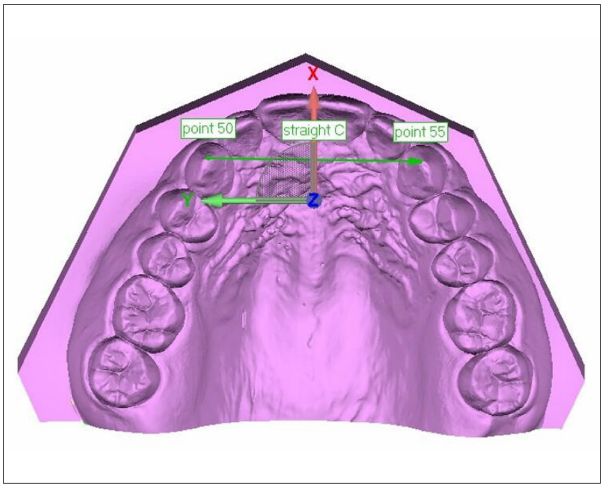

Figure 2. Maxillary canine cusp points and intercanine distance on 3-dimensional digital dentition.

accuracy rate can be seen in **Figure 3**. The highest overall accuracy was 67.6%, corresponding to the left first premolar and the first molar. The highest male accuracy was 67.3%, based on the left and the right first molars. The left first premolar provided the highest accuracy (72.0%) in distinguishing women.

The discriminant functions founded by indices for sex estimation are presented in **Table 6**, and the accuracy rate can be seen in **Figure 4**. Taking the MCI of the left canine into consideration, overall and female accuracy were up to 68.6% and 76.0%, respectively. While in males, accuracy was 69.2%, which corresponded to the CI of the right first molar.

The stepwise discriminant analysis is shown in **Table 7**. Crown dimensions, CA, and CM were selected as categorical variables, and all teeth of the corresponding variable were included in the homology equation. Crown dimension function was exploited to distinguish whether an individual was male or female with superior rates (69.2% in men, 72.0% in women, and 70.6% in overall), followed by the CA and CM functions (**Figure 5**).

Discussion

Estimating the sex in damaged bodies or from bones is important in forensics and anthropology identification. Teeth, as the hardest and most durable tissue, play a critical role. However, the standards for identification based on teeth vary among different populations [16,17], and data concerning sexual dimorphism in specific populations are still needed. Thus, we investigated the Han population, making identification possible through readily available dental measurements.

The electronic handheld digital caliper is conventionally used for tooth measurements due to its accuracy, practicality, portability, and low cost. However, it has some inherent drawbacks. It is only accurate to 0.01 mm, which is lower than 3D technology. In addition, samples are not convenient for storage and retrieval and may be easily damaged through direct contact by tools, affecting reuse. Continuously evolving technology enables multiple measurements obtained from 3D dental models, achieving great reliability, reproducibility and validity [18]. At the same time, the use of 3D techniques also facilitates research [19].

The current study estimated the sex of individuals from a Han population through odontometric data obtained with 3D technology. The Han underwent similar evolution, but no

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Table 1. The intra- and interexaminer reliability (n=20).

Teeth	Variables	Reliability	ICC
11	BL	Intra-examiner	0.969
		Inter-examiner	0.957
	MD	Intra-examiner	0.988
		Inter-examiner	0.984
12	BL	Intra-examiner	0.992
		Inter-examiner	0.989
	MD	Intra-examiner	0.989
		Inter-examiner	0.985
13	BL	Intra-examiner	0.994
		Inter-examiner	0.991
	MD	Intra-examiner	0.983
		Inter-examiner	0.980
14	BL	Intra-examiner	0.991
		Inter-examiner	0.990
	MD	Intra-examiner	0.985
		Inter-examiner	0.983
15	BL	Intra-examiner	0.989
		Inter-examiner	0.985
	MD	Intra-examiner	0.984
		Inter-examiner	0.981
16	BL	Intra-examiner	0.994
		Inter-examiner	0.991
	MD	Intra-examiner	0.990
		Inter-examiner	0.986
17	BL	Intra-examiner	0.995
		Inter-examiner	0.991
	MD	Intra-examiner	0.990
		Inter-examiner	0.987
21	BL	Intra-examiner	0.966
		Inter-examiner	0.958
	MD	Intra-examiner	0.987
		Inter-examiner	0.982
22	BL	Intra-examiner	0.993
		Inter-examiner	0.989
	MD	Intra-examiner	0.990
		Inter-examiner	0.986
23	BL	Intra-examiner	0.995
		Inter-examiner	0.991
	MD	Intra-examiner	0.984
		Inter-examiner	0.981
24	BL	Intra-examiner	0.992
		Inter-examiner	0.990
	MD	Intra-examiner	0.984
		Inter-examiner	0.981
25	BL	Intra-examiner	0.989
		Inter-examiner	0.986
	MD	Intra-examiner	0.983
		Inter-examiner	0.980
26	BL	Intra-examiner	0.993
		Inter-examiner	0.990
	MD	Intra-examiner	0.990
		Inter-examiner	0.987
27	BL	Intra-examiner	0.995
		Inter-examiner	0.992
	MD	Intra-examiner	0.989
		Inter-examiner	0.985
Maxillary inter-canine distance		Intra-examiner	0.999
		Inter-examiner	0.998

11 – the right central incisor; 12 – the right lateral incisor; 13 – the right canine; 14 – the right first premolar; 15 – the right second premolar; 16 – the right first molar; 17 – the right second molar; 21 – the left central incisor; 22 – the left lateral incisor; 23 – the left canine; 24 – the left first premolar; 25 – the left second premolar; 26 – the left first molar; 27 – the left second molar; BL – buccolingual distance; ICC – intraclass correlation coefficient; MD – mesiodistal distance.

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Table 2. Comparison of crown dimensions and intercanine distance in men and women.

Teeth	Variables	Group	Number (n)	Mean (mm)	SD (mm)	95% Confidence interval		t-value	p-value
						Lower	Upper		
11	BL	Male	104	5.942	0.690	5.808	6.076	0.508	0.612
		Female	100	5.898	0.546	5.790	6.006		
	MD	Male	104	8.558	0.467	8.467	8.648	3.341	0.001
		Female	100	8.327	0.518	8.224	8.430		
12	BL	Male	104	5.446	0.655	5.318	5.573	0.643	0.521
		Female	100	5.395	0.456	5.305	5.485		
	MD	Male	104	6.995	0.530	6.891	7.098	2.429	0.016
		Female	100	6.830	0.433	6.744	6.915		
13	BL	Male	104	7.151	0.656	7.023	7.278	2.710	0.007
		Female	100	6.914	0.592	6.796	7.031		
	MD	Male	104	7.846	0.414	7.766	7.926	5.580	<0.001
		Female	100	7.531	0.393	7.453	7.609		
14	BL	Male	104	9.514	0.677	9.382	9.645	3.700	<0.001
		Female	100	9.129	0.803	8.970	9.289		
	MD	Male	104	7.002	0.454	6.914	7.090	4.410	<0.001
		Female	100	6.760	0.321	6.696	6.824		
15	BL	Male	104	9.236	0.563	9.126	9.345	2.148	0.033
		Female	100	9.055	0.635	8.929	9.181		
	MD	Male	104	6.709	0.481	6.615	6.802	4.375	<0.001
		Female	100	6.453	0.345	6.385	6.522		
16	BL	Male	104	10.284	0.642	10.159	10.409	2.793	0.006
		Female	100	10.046	0.574	9.932	10.159		
	MD	Male	104	10.516	0.519	10.416	10.617	5.961	<0.001
		Female	100	10.122	0.418	10.039	10.205		
17	BL	Male	104	10.476	0.673	10.345	10.607	2.575	0.011
		Female	100	10.257	0.540	10.149	10.364		
	MD	Male	104	9.398	0.551	9.290	9.505	3.149	0.002
		Female	100	9.159	0.528	9.055	9.264		
21	BL	Male	104	5.954	0.615	5.832	6.076	0.637	0.525
		Female	100	5.897	0.651	5.771	6.024		
	MD	Male	104	8.583	0.482	8.489	8.676	3.504	0.001
		Female	100	8.340	0.506	8.240	8.441		
22	BL	Male	104	5.492	0.590	5.378	5.607	0.580	0.562
		Female	100	5.449	0.468	5.356	5.542		
	MD	Male	104	7.027	0.512	6.928	7.127	3.082	0.002
		Female	100	6.818	0.456	6.727	6.908		

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Table 2 continued. Comparison of crown dimensions and intercanine distance in men and women.

Teeth	Variables	Group	Number (n)	Mean (mm)	SD (mm)	95% Confidence interval		t-value	p-value
						Lower	Upper		
23	BL	Male	104	7.028	0.656	6.900	7.155	2.710	0.007
		Female	100	6.791	0.592	6.673	6.908		
	MD	Male	104	7.848	0.427	7.765	7.931	5.615	<0.001
		Female	100	7.527	0.387	7.450	7.604		
24	BL	Male	104	9.465	0.633	9.342	9.588	2.557	0.011
		Female	100	9.251	0.556	9.141	9.362		
	MD	Male	104	7.067	0.465	6.977	7.158	4.654	<0.001
		Female	100	6.785	0.397	6.707	6.864		
25	BL	Male	104	9.228	0.549	9.121	9.335	2.358	0.019
		Female	100	9.042	0.576	8.928	9.157		
	MD	Male	104	6.721	0.430	6.638	6.805	4.516	<0.001
		Female	100	6.467	0.373	6.393	6.541		
26	BL	Male	104	10.424	0.697	10.289	10.560	2.736	0.007
		Female	100	10.189	0.522	10.086	10.293		
	MD	Male	104	10.528	0.503	10.430	10.626	5.856	<0.001
		Female	100	10.124	0.480	10.029	10.219		
27	BL	Male	104	10.386	0.716	10.247	10.525	2.473	0.014
		Female	100	10.152	0.629	10.027	10.277		
	MD	Male	104	9.457	0.499	9.360	9.554	3.014	0.003
		Female	100	9.242	0.517	9.140	9.345		
Maxillary inter-canine distance		Male	104	36.649	2.037	36.253	37.045	2.686	0.008
		Female	100	35.888	2.006	35.490	36.286		

11 – the right central incisor; 12 – the right lateral incisor; 13 – the right canine; 14 – the right first premolar; 15 – the right second premolar; 16 – the right first molar; 17 – the right second molar; 21 – the left central incisor; 22 – the left lateral incisor; 23 – the left canine; 24 – the left first premolar; 25 – the left second premolar; 26 – the left first molar; 27 – the left second molar; BL – buccolingual distance; MD – mesiodistal distance; SD – standard deviation.

odontometric data had been collected until our study. The maxilla is a fixed bone that is not easy to dissociate. In our investigation, we used maxillary odontometrics to simulate scenarios in which only a skull with the maxilla is available, establishing an equation algorithm for sex estimation. Our data present the crown dimensions, intercanine distance, and the calculated indices in maxillary teeth of 18- to 25-year-old individuals of the Han population in Kashgar. As tooth wear is minimal in this age group, odontometric information could be maximized. Furthermore, discriminant functions were established for the local population.

The Reliability of Examiners

In other fields of forensic science, complex comparisons between different evaluators are necessary [20]. The current study obtained high intra- and interexaminer reliability, which provides a credible guarantee for subsequent measurement results. On one hand, the high degree of consistency in the formulation of a complex judgment reflects that the forensic dental professionals have well-established and shared understanding and knowledge. On the other hand, the controllability and repeatability of 3D software should not be ignored.

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Table 3. Comparison of crown indices between men and women.

Teeth	Variables	Group	Number (n)	Mean (mm)	SD (mm)	95% Confidence interval		t-value	p-value
						Lower	Upper		
11	CA	Male	104	51.022	7.863	49.493	52.552	1.682	0.094
		Female	100	49.273	6.942	47.895	50.650		
	CI	Male	104	69.410	6.808	68.086	70.734	-1.703	0.090
		Female	100	70.876	5.433	69.798	71.954		
	CM	Male	104	7.250	0.510	7.151	7.349	1.995	0.047
		Female	100	7.113	0.471	7.019	7.206		
12	CA	Male	104	38.258	6.731	36.949	39.567	1.657	0.099
		Female	100	36.924	4.602	36.011	37.838		
	CI	Male	104	77.959	8.075	76.389	79.530	-1.148	0.252
		Female	100	79.144	6.623	77.830	80.459		
	CM	Male	104	6.220	0.512	6.120	6.320	1.724	0.086
		Female	100	6.112	0.373	6.038	6.186		
13	CA	Male	104	56.232	7.047	54.862	57.603	4.365	<0.001
		Female	100	52.154	6.258	50.912	53.395		
	CI	Male	104	91.184	7.446	89.736	92.632	-0.686	0.493
		Female	100	91.898	7.415	90.427	93.370		
	CM	Male	104	7.498	0.463	7.408	7.588	4.487	<0.001
		Female	100	7.222	0.414	7.140	7.304		
	MCI	Male	104	0.215	0.013	0.212	0.217	2.331	0.021
		Female	100	0.210	0.013	0.208	0.213		
14	CA	Male	104	66.855	8.643	65.174	68.535	4.533	<0.001
		Female	100	61.815	7.195	60.388	63.243		
	CI	Male	104	135.129	6.058	132.948	137.121	-0.658	0.511
		Female	100	135.943	10.995	134.765	137.311		
	CM	Male	104	8.258	0.536	8.153	8.362	4.355	<0.001
		Female	100	7.945	0.488	7.848	8.042		
15	CA	Male	104	62.142	7.569	60.670	63.614	3.728	<0.001
		Female	100	58.529	6.233	57.292	59.766		
	CI	Male	104	137.948	7.368	136.515	139.381	-2.096	0.037
		Female	100	140.516	9.980	138.535	142.496		
	CM	Male	104	7.972	0.478	7.879	8.065	3.454	0.001
		Female	100	7.754	0.421	7.671	7.838		
16	CA	Male	104	108.376	11.090	106.219	110.533	4.620	<0.001
		Female	100	101.834	9.069	100.035	103.634		
	CI	Male	104	97.826	4.594	96.932	98.719	-2.300	0.022
		Female	100	99.262	4.315	98.406	100.118		
	CM	Male	104	10.400	0.533	10.297	10.504	4.570	<0.001
		Female	100	10.084	0.451	9.994	10.173		

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Table 3 continued. Comparison of crown indices between men and women.

Teeth	Variables	Group	Number (n)	Mean (mm)	SD (mm)	95% Confidence interval		t-value	p-value
						Lower	Upper		
17	CA	Male	104	98.524	9.531	96.671	100.378	3.304	0.001
		Female	100	94.135	9.435	92.263	96.007		
	CI	Male	104	111.785	8.965	110.041	113.528	-0.321	0.748
		Female	100	112.108	4.879	111.140	113.076		
	CM	Male	104	9.937	0.476	9.844	10.029	3.388	0.001
		Female	100	9.708	0.489	9.611	9.805		
21	CA	Male	104	50.785	7.739	49.280	52.290	0.876	0.382
		Female	100	49.846	7.571	48.344	51.348		
	CI	Male	104	68.705	6.277	67.485	69.926	-3.168	0.002
		Female	100	71.384	5.776	70.238	72.530		
	CM	Male	104	7.240	0.500	7.143	7.337	1.323	0.187
		Female	100	7.147	0.504	7.047	7.247		
22	CA	Male	104	38.734	6.070	37.553	39.914	1.918	0.057
		Female	100	37.251	4.886	36.281	38.220		
	CI	Male	104	78.288	7.603	76.809	79.766	-1.801	0.073
		Female	100	80.053	6.312	78.801	81.306		
	CM	Male	104	6.260	0.472	6.168	6.351	2.066	0.040
		Female	100	6.133	0.397	6.055	6.212		
23	CA	Male	104	55.304	7.277	53.889	56.720	3.143	0.002
		Female	100	52.269	6.509	50.977	53.560		
	CI	Male	104	89.570	7.113	88.187	90.954	-2.555	0.011
		Female	100	92.114	7.107	90.704	93.524		
	CM	Male	104	7.438	0.479	7.345	7.531	4.404	<0.001
		Female	100	7.159	0.425	7.074	7.243		
	MCI	Male	104	0.215	0.013	0.212	0.217	2.453	0.015
		Female	100	0.210	0.013	0.208	0.213		
24	CA	Male	104	67.104	8.281	65.493	68.714	3.949	<0.001
		Female	100	62.918	6.747	61.579	64.256		
	CI	Male	104	134.084	6.604	132.799	135.368	-2.584	0.010
		Female	100	136.491	6.702	135.161	137.820		
	CM	Male	104	8.266	0.510	8.167	8.365	3.730	<0.001
		Female	100	8.018	0.435	7.932	8.105		
25	CA	Male	104	62.178	7.068	60.804	63.553	3.820	<0.001
		Female	100	58.585	6.328	57.330	59.841		
	CI	Male	104	137.516	7.139	136.127	138.904	-2.287	0.023
		Female	100	140.033	8.542	138.338	141.728		
	CM	Male	104	7.975	0.446	7.888	8.061	3.637	<0.001
		Female	100	7.755	0.417	7.672	7.837		

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Table 3 continued. Comparison of crown indices between men and women.

Teeth	Variables	Group	Number (n)	Mean (mm)	SD (mm)	95% Confidence interval		t-value	p-value
						Lower	Upper		
26	CA	Male	104	109.999	11.681	107.728	112.271	4.626	<0.001
		Female	100	103.291	8.892	101.527	105.055		
	CI	Male	104	99.015	4.548	98.131	99.900	-2.649	0.009
		Female	100	100.734	4.719	99.797	101.670		
	CM	Male	104	10.476	0.559	10.368	10.585	4.549	<0.001
		Female	100	10.157	0.440	10.069	10.244		
27	CA	Male	104	98.378	10.253	96.384	100.372	3.084	0.002
		Female	100	94.017	9.930	92.047	95.987		
	CI	Male	104	109.944	7.140	108.555	111.332	-0.019	0.985
		Female	100	109.961	5.860	108.799	111.124		
	CM	Male	104	9.921	0.522	9.820	10.023	3.096	0.002
		Female	100	9.697	0.511	9.596	9.799		

11 – the right central incisor; 12 – the right lateral incisor; 13 – the right canine; 14 – the right first premolar; 15 – the right second premolar; 16 – the right first molar; 17 – the right second molar; 21 – the left central incisor; 22 – the left lateral incisor; 23 – the left canine; 24 – the left first premolar; 25 – the left second premolar; 26 – the left first molar; 27 – the left second molar; CA – crown area; CI – crown index; CM – crown module; MCI – maxillary canine index; SD – standard deviation.

Table 4. Percentage sexual dimorphism of maxillary teeth parameters.

Teeth	Parameter sexual dimorphism (%)					
	BL	MD	CA	CI	CM	MCI
11	0.749	2.769	3.551	-2.068	1.931	
12	0.938	2.416	3.612	-1.498	1.764	
13	3.433	4.187	7.821	-0.777	3.826	2.031
14	3.580	4.210	8.152	-0.598	3.942	
15	1.991	3.960	6.173	-1.828	2.810	
16	2.374	3.896	6.424	-1.447	3.138	
17	2.141	2.599	4.662	-0.288	2.357	
21	0.960	2.907	3.753	-1.884	1.300	
22	0.796	3.071	3.981	-2.205	2.060	
23	3.495	4.264	5.808	-2.762	3.899	2.084
24	2.311	4.155	6.653	-1.764	3.091	
25	2.055	3.934	6.132	-1.798	2.839	
26	2.309	3.987	6.495	-1.706	3.145	
27	2.302	2.320	4.638	-0.016	2.311	

11 – the right central incisor; 12 – the right lateral incisor; 13 – the right canine; 14 – the right first premolar; 15 – the right second premolar; 16 – the right first molar; 17 – the right second molar; 21 – the left central incisor; 22 – the left lateral incisor; 23 – the left canine; 24 – the left first premolar; 25 – the left second premolar; 26 – the left first molar; 27 – the left second molar; BL – buccolingual distance; CA – crown area; CI – crown index; CM – crown module; MCI – maxillary canine index; MD – mesiodistal distance.

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Table 5. General discriminant analysis in crown dimensions for sex estimation.

Teeth	Function	Discriminant function	Wilks' Lambda	p-value	Accuracy (%)			Cutting point*
					Male	Female	Overall	
11	Crown dimensions	-15.435-0.812BL+2.397MD	0.937	0.001	61.5	60.0	60.8	-0.005
12	Crown dimensions	-13.183-0.427BL+2.242MD	0.970	0.048	53.8	52.0	52.9	-0.003
13	Crown dimensions	-19.218+0.1BL+2.407MD	0.866	<0.001	65.4	64.0	64.7	-0.008
14	Crown dimensions	-17.470+0.496BL+1.866MD	0.906	<0.001	55.8	68.0	61.8	-0.006
15	Crown dimensions	-15.124-0.133BL+2.482MD	0.914	<0.001	57.7	68.0	62.7	-0.006
16	Crown dimensions	-20.407-0.557BL+2.525MD	0.842	<0.001	67.3	64.0	65.7	-0.009
17	Crown dimensions	-20.185+0.734BL+1.355MD	0.944	0.003	59.6	64.0	61.8	-0.005
21	Crown dimensions	-12.993-1.310BL+2.452MD	0.899	<0.001	61.5	64.0	62.7	-0.007
22	Crown dimensions	-12.388-0.642BL+2.296MD	0.951	0.006	55.8	64.0	59.8	-0.005
23	Crown dimensions	-18.764-0.082BL+2.514MD	0.865	<0.001	59.6	56.0	57.8	-0.008
24	Crown dimensions	-14.488-0.447BL+2.695MD	0.900	<0.001	63.5	72.0	67.6	-0.007
25	Crown dimensions	-15.641-0.177BL+2.617MD	0.908	<0.001	61.5	68.0	64.7	-0.007
26	Crown dimensions	-19.480-0.486BL+2.371MD	0.848	<0.001	67.3	68.0	67.6	-0.009
27	Crown dimensions	-19.577+0.579BL+1.458MD	0.952	0.007	61.5	64.0	62.7	-0.004

11 – the right central incisor; 12 – the right lateral incisor; 13 – the right canine; 14 – the right first premolar; 15 – the right second premolar; 16 – the right first molar; 17 – the right second molar; 21 – the left central incisor; 22 – the left lateral incisor; 23 – the left canine; 24 – the left first premolar; 25 – the left second premolar; 26 – the left first molar; 27 – the left second molar; BL – buccolingual distance; MD – mesiodistal distance. * A discriminant score less than the cutting point indicates a woman.

Crown Dimensions and Sexual Dimorphism

The mesiodistal distance was significant in estimating an individual's sex based on maxillary teeth, with measurements from men generally being greater than those from women, a finding that agreed with earlier studies [14,21-24]. The reason may be that the greater thickness of enamel in men due to long period of amelogenesis compared with women and the Y chromosome producing slower male maturation [25]. MD values in our sample were found to be smaller than those of Brazilians [26], Africans [27], and Malaysian Tamils [28]; equivalent to those of Indians [29] and Japanese [27]; and larger than those of Greeks [30] and Whites [27]. In our study, the percentage of sexual dimorphism for MD ranged from 2.32% to 4.26%. The results of the anterior teeth were closest to those from the Indian study [29]. Sexual dimorphism of the premolars was similar to that found for Africans [27]. The first molar sexual dimorphism matched that of Americans [31] and the second molar was equivalent to Brazilians [26].

Buccolingual distance of maxillary teeth other than incisors showed sex differences. Men's values were greater than women's, and the observations were roughly consistent with previous reports [14,28,31-33], whereas some results were contrary to Babu et al [34] and Dash et al [35]. In comparison with measured values from Turks [36], Nepalese [37], Indians [38], and Brazilians [39], the BL distances of anterior teeth and molars in our sample were smaller, but premolars were larger. Our results for the sexual dimorphism percentage ranged from 0.75% to 3.58%, which was smaller than the other populations above. Previous studies have suggested that the reason could be evolution, which results in overlapping sex-based measurements, as well as environmental, cultural, and genetic factors [40].

In this research, MD had a higher sexual dimorphism percentage than BL distance, which accorded with previous reports that MD is better than BL for sex estimation. For a certain tooth, Garn et al [12], El Sheikhi and Bugaighis [14], and Eboh et al [41] reported that BL distance is more dimorphic than MD. Other researchers, such as Acharya [42], indicated that sex estimation had higher accuracy when MD and BL distances were used simultaneously. Thus, crown dimensions can serve as simple and reliable parameters for sex estimation from teeth. Furthermore, MD and BL distance can be used to obtain other indicators that are used by forensic experts as auxiliary means to estimate sex in catastrophes.

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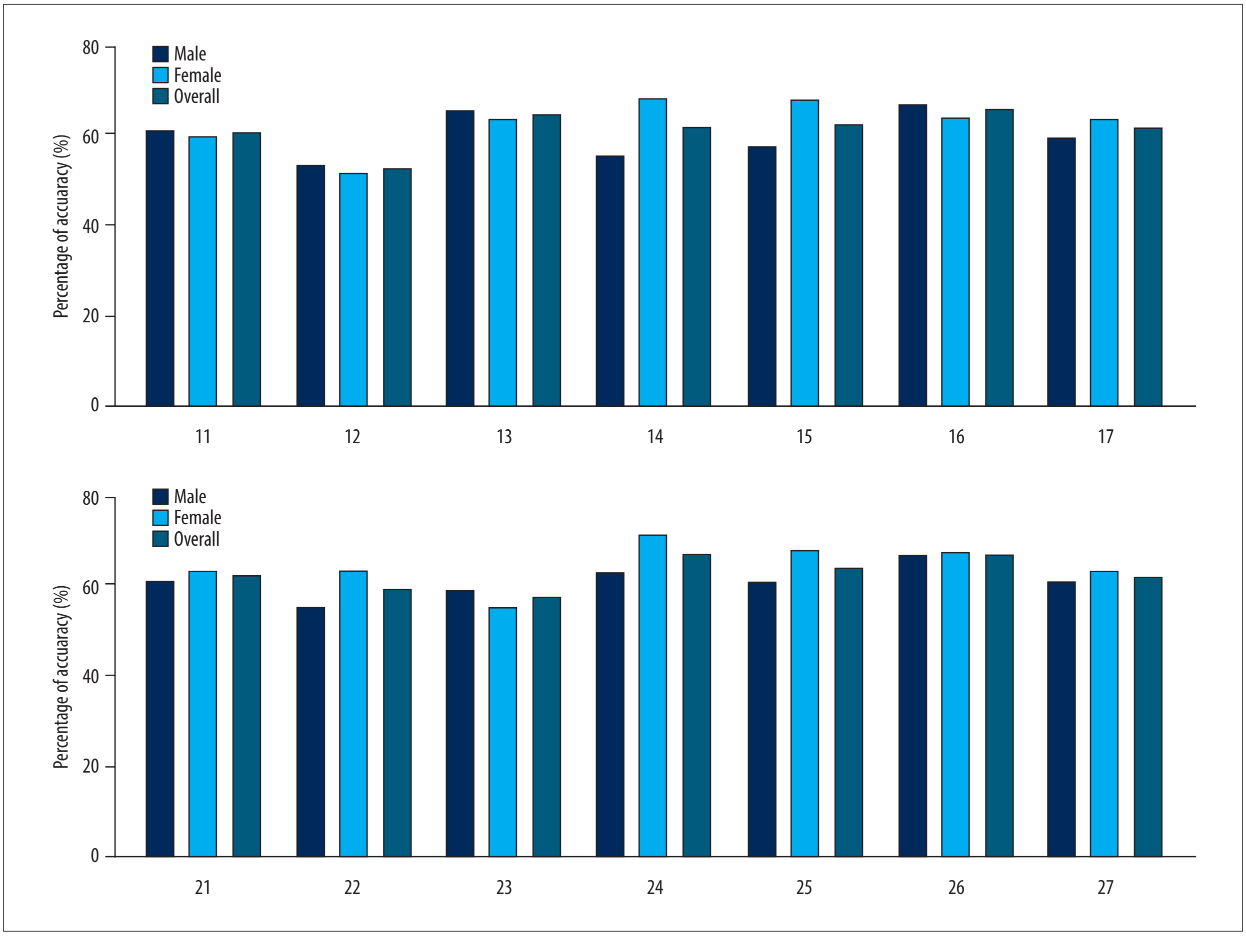

Figure 3. Comparison of the sex estimation accuracy through crown dimensions. 11– the right central incisor; 12 – the right lateral incisor; 13 – the right canine; 14 – the right first premolar; 15 – the right second premolar; 16 – the right first molar; 17 – the right second molar; 21 – the left central incisor; 22 – the left lateral incisor; 23 – the left canine; 24 – the left first premolar; 25 – the left second premolar; 26 – the left first molar; 27 – the left second molar.

Crown Indices and Sexual Dimorphism

CA, CM, and CI were selected as crown indices and were calculated from linear odontometrics. In comparison with Brazilians [39], CA, CM, and CI values of the anterior teeth were smaller in both men and women in our sample. For posterior teeth, the results for CM of the first premolars and CI of the premolars were larger. In addition, the CA of premolars, CI of molars, and CM of the second premolars and molars were similar in these 2 populations.

Among these indices, CA presented the strongest sexual dimorphism. In comparison with Brazilians [39], except for the first premolars, the sexual dimorphism of the rest teeth was less, manifesting as a smaller tooth size overall. Regarding CI, center incisors, canines, and the first premolars showed apparent differences in tooth shape between these 2 populations. Moreover, the results on CM demonstrated significant differences between male and female, especially in premolars and the first molars.

Maxillary Canine Index and Sexual Dimorphism

Several studies have been conducted to establish canine dimorphism, especially the mandibular canines, which have the highest degree of dimorphism [43-45]. However, our research was limited to maxillary dentition. There were sexual differences in both canine mesiodistal distance and intercanine distance, in keeping with Gupta et al [46]. In our results, sexual dimorphism of the MCI was 2.03% and 2.08% for the right and the left, respectively, in contrast to Phulari et al [47], who found -28.13% on average. Consequently, the accuracy of using the same index to classify the sex of an individual was different. Differences in the results between our study and previous studies may be attributable to racial, ethnic, regional, and genetic elements that affect dental measurements, as well as the different methods employed.

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Table 6. Discriminant functions in indices for sex estimation.

Teeth	Function	Discriminant function	Wilks' Lambda	p-value	Accuracy (%)			Cutting point*
					Male	Female	Overall	
11	Crown area	-6.755+0.135CA	0.986	0.094	48.1	56.0	52.0	-0.002
	Crown module	-14.613+2.035CM	0.981	0.047	53.8	56.0	54.9	-0.002
	Crown index	-11.361+0.162CI	0.986	0.092	48.1	64.0	55.9	0.003
12	Crown area	-6.499+0.173CA	0.987	0.101	48.1	60.0	53.9	-0.002
	Crown module	-13.724+2.225CM	0.986	0.088	50.0	60.0	54.9	-0.002
	Crown index	-10.615+0.135CI	0.994	0.254	53.8	52.0	52.9	0.002
13	Crown area	-8.128+0.150CA	0.914	<0.001	61.5	68.0	64.7	-0.011
	Crown module	-16.746+2.274CM	0.909	<0.001	63.5	68.0	65.7	-0.006
	Crown index	-12.318+0.135CI	0.998	0.493	53.8	56.0	54.9	0.001
	Maxillary canine index	-16.240+76.447MCI	0.974	0.021	51.9	64.0	57.8	-0.003
14	Crown area	-8.082+0.126CA	0.908	<0.001	53.8	68.0	60.8	-0.007
	Crown module	-15.785+1.948CM	0.914	<0.001	53.8	68.0	60.8	-0.006
	Crown index	-15.351+0.113CI	0.998	0.511	50.0	44.0	47.1	0.001
15	Crown area	-8.691+0.144CA	0.936	<0.001	57.7	64.0	60.8	-0.005
	Crown module	-17.458+2.220CM	0.944	0.001	59.6	64.0	61.8	-0.005
	Crown index	-15.916+0.114CI	0.979	0.037	50.0	52.0	51.0	0.003
16	Crown area	-10.362+0.099CA	0.905	<0.001	55.8	64.0	59.8	-0.007
	Crown module	-20.724+2.023CM	0.906	<0.001	57.7	64.0	60.8	-0.006
	Crown index	-22.096+0.224CI	0.974	0.022	69.2	60.0	64.7	0.003
17	Crown area	-10.162+0.105CA	0.949	0.001	57.7	68.0	62.7	-0.004
	Crown module	-20.372+2.074CM	0.946	0.001	59.6	68.0	63.7	-0.004
	Crown index	-15.428+0.138CI	0.999	0.751	53.8	60.0	56.9	0.001
21	Crown area	-6.572+0.131CA	0.996	0.382	48.1	56.0	52.0	-0.002
	Crown module	-14.341+1.993CM	0.991	0.187	46.2	56.0	51.0	-0.002
	Crown index	-11.598+0.166CI	0.953	0.002	51.9	60.0	55.9	0.004
22	Crown area	-6.883+0.181CA	0.982	0.057	50.0	56.0	52.9	-0.003
	Crown module	-14.192+2.290CM	0.979	0.040	51.9	56.0	53.9	-0.003
	Crown index	-11.307+0.143CI	0.984	0.073	51.9	48.0	50.0	0.003
23	Crown area	-7.786+0.145CA	0.954	0.002	53.8	72.0	62.7	-0.005
	Crown module	-16.095+2.204CM	0.913	<0.001	59.6	68.0	63.7	-0.006
	Crown index	-12.773+0.141CI	0.969	0.011	61.5	58.0	59.8	0.004
	Maxillary canine index	-16.677+78.527MCI	0.971	0.015	61.5	76.0	68.6	-0.003
24	Crown area	-8.595+0.132CA	0.928	<0.001	55.8	60.0	57.8	-0.005
	Crown module	-17.164+2.107CM	0.936	<0.001	55.8	60.0	57.8	-0.005
	Crown index	-20.333+0.150CI	0.968	0.010	51.9	52.0	52.0	0.004

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Table 6 continued. Discriminant functions in indices for sex estimation.

Teeth	Function	Discriminant function	Wilks' Lambda	p-value	Accuracy (%)			Cutting point*
					Male	Female	Overall	
25	Crown area	-8.997+0.149CA	0.933	<0.001	57.7	64.0	60.8	-0.006
	Crown module	-18.205+2.314CM	0.939	<0.001	55.8	64.0	59.8	-0.005
	Crown index	-17.656+0.127CI	0.975	0.023	53.8	36.0	45.1	0.003
26	Crown area	-10.253+0.096CA	0.905	<0.001	59.6	68.0	63.7	-0.007
	Crown module	-20.483+1.985CM	0.908	<0.001	61.5	68.0	64.7	-0.006
	Crown index	-21.555+0.216CI	0.966	0.009	57.7	64.0	60.8	0.004
27	Crown area	-9.532+0.099CA	0.955	0.002	55.8	64.0	59.8	-0.004
	Crown module	-18.990+1.936CM	0.955	0.002	57.7	64.0	60.8	-0.004
	Crown index	-16.802+0.153CI	1.000	0.985	55.8	48.0	52.0	0.000

11 – the right central incisor; 12 – the right lateral incisor; 13 – the right canine; 14 – the right first premolar; 15 – the right second premolar; 16 – the right first molar; 17 – the right second molar; 21 – the left central incisor; 22 – the left lateral incisor; 23 – the left canine; 24 – the left first premolar; 25 – the left second premolar; 26 – the left first molar; 27 – the left second molar; CA – crown area; CI – crown index; CM – crown module; MCI – maxillary canine index. * A discriminant score less than the cutting point for CA, CM, and MCI indicates a woman. A discriminant score less than the cutting point for CI indicates a man.

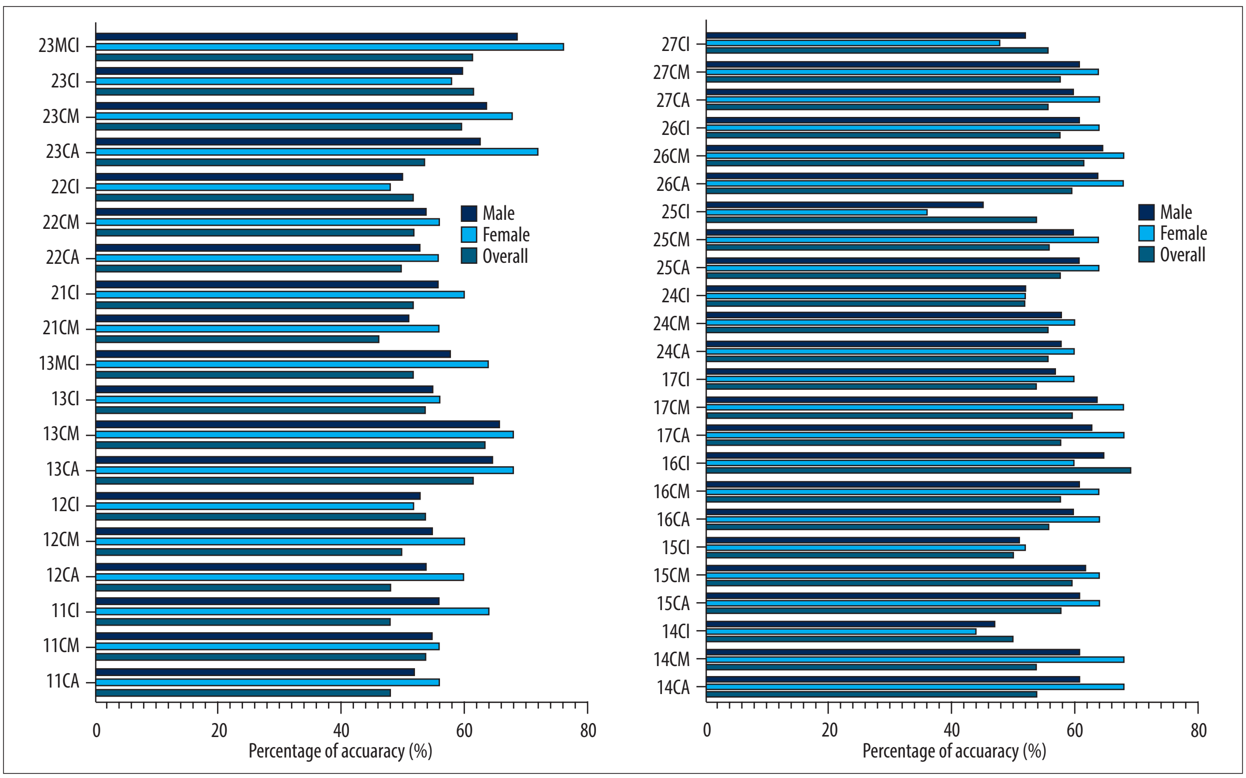

Figure 4. Comparison of the sex estimation accuracy through crown indices. 11 – the right central incisor; 12 – the right lateral incisor; 13 – the right canine; 21 – the left central incisor; 22 – the left lateral incisor; 23 – the left canine; 14 – the right first premolar; 15 – the right second premolar; 16 – the right first molar; 17 – the right second molar; 24 – the left first premolar; 25 – the left second premolar; 26 – the left first molar; 27 – the left second molar; CA – crown area; CI – crown index; CM – crown module; MCI – maxillary canine index.

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Table 7. Stepwise discriminant analysis for sex estimation from maxillary teeth.

Teeth	Function	Discriminant function	Wilks' Lambda	p-value	Accuracy (%)			Cutting point*
					Male	Female	Overall	
All	Crown dimensions	-20.461+0.838 ×(BL13)-1.219×(BL21)+1.122 ×(MD13)+1.275×(MD16)	0.758	<0.001	69.2	72.0	70.6	-0.011
All	Crown area	-8.521+0.342×(CA13)-0.083 ×(CA21)-0.24×(CA23)+0.066×(CA26)	0.788	<0.001	63.5	68.0	65.7	-0.010
All	Crown module	-18.094+2.107×(CM13) +1.359×(CM16)-1.578×(CM21)	0.841	<0.001	63.5	64.0	63.7	-0.009

BL13 – buccolingual distance of the right canine; BL21 – buccolingual distance of the left central incisor; CA13 – crown area of the right canine; CA21 – crown area of the left central incisor; CA23 – crown area of the left canine; CA26 – crown area of the left first molar; CM13 – crown module of the right canine; CM16 – crown module of the right first molar; CM21 – crown module of the left central incisor; MD13 – mesiodistal distance of the right canine; MD16 – mesiodistal distance of the right first molar. * A discriminant score less than sectioning point indicates a woman.

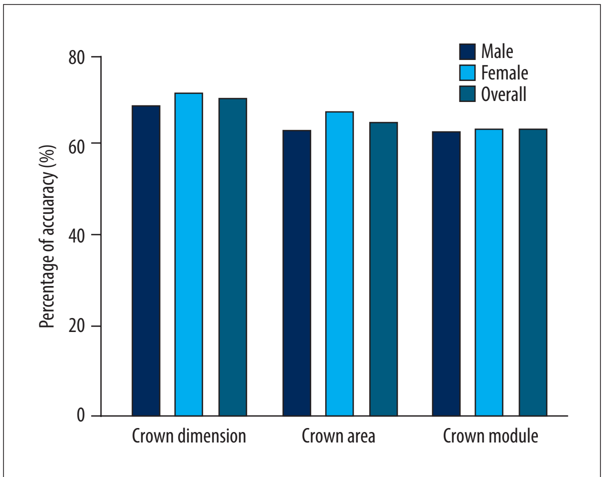

Figure 5. Comparison of the sex estimation accuracy by stepwise discriminant equations.

Discriminant Function

We united MD and BL dimensions in our equation, with the prediction rates ranging from 52% to 72%. When the indices were applied to create functions separately, the accuracy ranged from as low as 36% up to 76%. With all the maxillary teeth included in the classified indicators, stepwise discriminant analysis for sex determination was performed to establish functions, improving the holistic accuracy with a limit of 63.5-72%. The discriminant function on crown dimensions displayed a more acceptable and stable accuracy of 69.2-72%, in men and women and overall.

Limitations and Expectations

There are some limitations in this study. First, this study only estimated the sex of individuals in a Han population by linear dental measurements and only as an auxiliary sex estimation method. Second, we used only maxillary odontometrics to simulate scenarios in which only a skull with the maxilla is available. In the future, we will conduct comprehensive studies on the mandibular odontometrics and the overall indexes. Third, we only used good dentitions and high-quality models, which limited further applications. Special circumstances such as prostheses, conservative treatments, malpositions, wear, and so forth could yield different results.

Conclusions

We are the first to present a study on odontometrics of all permanent maxillary teeth by using a 3D technique for sex estimation of the Han population in Kashgar. Crown dimensions, maxillary intercanine distance, and crown indices exhibited descriptive statistics and sexual dimorphism. For possible future studies estimating sex through permanent maxillary teeth measurements in our population, we suggest combining BL and MD distances with the left first premolar and the left first molar for relatively high accuracy that can be used to aid sex estimation. Compared with other indices, the function established by the left canine index had a higher accuracy and could serve as an auxiliary method for estimating sex. The stepwise discriminant function on crown dimensions including BL13, BL21, MD13, and MD16 can be used for sex estimation with more acceptable and stable accuracy.

In this study, 3D digital technology offered a promising method for odontometry and a starting point for the application in the forensic field. However, differences between populations, the variability based on the time when a sample is found, and the influence of the environment must be taken into consideration. Thus, the data derived from 3D measurements in this study are not generalizable.

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Declaration of Figures Authenticity

All figures submitted have been created by the authors who confirm that the images are original with no duplication and have not been previously published in whole or in part.

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