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

Jialin Liu*
Yanshi Liu*
Shupeng Ge
Yangyang Zhang
Xiaohe Wang
Lijuan Du
Huiyu He

* Jialin Liu and Yanshi Liu contributed equally to this work

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

Full-text PDF: https://www.medscimonit.com/abstract/index/idArt/933450
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/palatal 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.
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≤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+a₁x₁+a₂x₂+...+aₙxₙ 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
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 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

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
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 |  

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.
| 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 |       |       |
|       |           |       |            |           |         |       |       | 3.341 | 0.001 |
|       |           |       |            |           |         | 8.467 | 8.648 |       |       |
| 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 |       |       |
|       |           |       |            |           |         | 6.891 | 7.098 | 2.429 | 0.016 |
| 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 |       |       |
|       |           |       |            |           |         | 7.614 | 7.926 | 5.580 | <0.001|
| 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 |       |       |
|       |           |       |            |           |         | 9.314 | 9.626 | 4.410 | <0.001|
| 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 |       |       |
|       |           |       |            |           |         | 9.214 | 9.430 | 4.375 | <0.001|
| 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|       |       |
|       |           |       |            |           |         | 10.146| 10.617| 5.961 | <0.001|
| 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|       |       |
|       |           |       |            |           |         | 10.346| 10.671| 5.149 | 0.002 |
| 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 |       |       |
|       |           |       |            |           |         | 8.489 | 8.676 | 3.504 | 0.001 |
| 22    | BL        | Male  | 104        | 5.492     | 0.590   | 5.378 | 5.607 | 0.580 | 0.562 |
|       |           | Female| 100        | 5.449     | 0.668   | 5.356 | 5.542 |       |       |
|       |           |       |            |           |         | 8.240 | 8.411 |       |       |
odometric 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.

### 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   | 2.357   | 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                  | 6.846   |         |         |
| 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        | 10.523    | 0.503   | 10.430                 | 10.621  | 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.
### 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 | | | |
| | | | | CI | | | | |
| 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 | -1.703 | 0.090 |
| | | Male | 104 | 69.410 | 7.082 | 68.086 | 70.734 | 1.995 | 0.047 |
| | | Female | 100 | 70.876 | 5.433 | 69.398 | 72.354 | -1.703 | 0.090 |
| | | Male | 104 | 7.270 | 0.510 | 7.151 | 7.389 | 1.995 | 0.047 |
| | | Female | 100 | 7.113 | 0.471 | 7.019 | 7.206 | -1.703 | 0.090 |
| | | Male | 104 | 38.258 | 6.731 | 36.949 | 39.567 | 1.657 | 0.099 |
| | | Female | 100 | 36.924 | 4.602 | 36.011 | 37.838 | -1.703 | 0.090 |
| | | Male | 104 | 77.959 | 8.075 | 76.389 | 79.530 | -1.148 | 0.252 |
| | | Female | 100 | 79.144 | 6.623 | 77.830 | 80.459 | 1.724 | 0.086 |
| | | Male | 104 | 6.112 | 0.471 | 6.038 | 6.186 | 4.533 | <0.001 |
| | | Female | 100 | 6.220 | 0.512 | 6.120 | 6.320 | 1.995 | 0.047 |
| 12 | 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 | -0.686 | 0.493 |
| | | Male | 104 | 91.184 | 7.446 | 89.736 | 92.632 | 4.487 | <0.001 |
| | | Female | 100 | 91.898 | 6.623 | 90.427 | 93.370 | 3.728 | <0.001 |
| | | Male | 104 | 6.112 | 0.471 | 6.038 | 6.186 | 4.533 | <0.001 |
| | | Female | 100 | 6.220 | 0.512 | 6.120 | 6.320 | 1.724 | 0.086 |
| | | Male | 104 | 0.215 | 0.013 | 0.212 | 0.217 | 2.331 | 0.021 |
| | | Female | 100 | 0.210 | 0.013 | 0.208 | 0.213 | -2.096 | 0.037 |
| | | Male | 104 | 66.855 | 8.643 | 65.174 | 68.535 | 4.533 | <0.001 |
| | | Female | 100 | 61.815 | 7.195 | 60.388 | 63.243 | -0.658 | 0.511 |
| | | Male | 104 | 135.129 | 6.058 | 132.948 | 137.121 | 4.355 | <0.001 |
| | | Female | 100 | 135.943 | 10.995 | 134.765 | 137.311 | 3.896 | <0.001 |
| | | Male | 104 | 6.112 | 0.471 | 6.038 | 6.186 | 4.533 | <0.001 |
| | | Female | 100 | 6.220 | 0.512 | 6.120 | 6.320 | 1.724 | 0.086 |
| | | Male | 104 | 0.215 | 0.013 | 0.212 | 0.217 | 2.331 | 0.021 |
| | | Female | 100 | 0.210 | 0.013 | 0.208 | 0.213 | -2.096 | 0.037 |
| | | Male | 104 | 108.376 | 11.090 | 106.219 | 110.533 | 4.620 | <0.001 |
| | | Female | 100 | 101.834 | 9.069 | 100.035 | 103.634 | -2.300 | 0.022 |
| | | Male | 104 | 97.826 | 4.594 | 96.932 | 98.719 | 4.570 | <0.001 |
| | | Female | 100 | 99.262 | 4.315 | 98.406 | 100.118 | 4.570 | <0.001 |
| | | Male | 104 | 10.084 | 0.451 | 9.994 | 10.173 | 1.657 | 0.099 |
| | | Female | 100 | 9.814 | 0.421 | 9.613 | 10.015 | 1.724 | 0.086 |

This work is licensed under Creative Common Attribution-NonCommercial-NoDerivatives 4.0 International (CC BY-NC-ND 4.0)
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        | 7.937     | 0.476    | 7.844                   | 8.029   | 3.388   | 0.001   |
|       |           | Female| 100        | 7.708     | 0.489    | 7.611                   | 7.805   |         |         |
| 21    | CA        | Male  | 104        | 49.280    | 6.277    | 47.485                  | 51.075  | -3.168  | 0.002   |
|       |           | Female| 100        | 48.344    | 5.716    | 46.776                  | 50.914  |         |         |
|       | CI        | Male  | 104        | 7.147     | 0.504    | 7.047                   | 7.247   | 1.323   | 0.187   |
|       |           | Female| 100        | 7.047     | 0.489    | 6.911                   | 7.183   |         |         |
| 22    | CA        | Male  | 104        | 37.251    | 4.886    | 35.632                  | 38.870  | 1.918   | 0.057   |
|       |           | Female| 100        | 36.281    | 4.378    | 34.833                  | 37.729  |         |         |
|       | CI        | Male  | 104        | 89.570    | 6.277    | 87.072                  | 92.067  | -3.168  | 0.002   |
|       |           | Female| 100        | 87.230    | 5.716    | 85.664                  | 88.796  |         |         |
|       | CM        | Male  | 104        | 6.133     | 0.397    | 5.950                   | 6.316   | 2.066   | 0.040   |
|       |           | Female| 100        | 6.055     | 0.358    | 5.938                   | 6.172   |         |         |
| 23    | CA        | Male  | 104        | 55.304    | 7.739    | 52.864                  | 57.743  | 3.143   | 0.002   |
|       |           | Female| 100        | 53.570    | 6.747    | 51.129                  | 55.931  |         |         |
|       | CI        | Male  | 104        | 89.570    | 6.277    | 87.072                  | 92.067  | -3.168  | 0.002   |
|       |           | Female| 100        | 87.230    | 5.716    | 85.664                  | 88.796  |         |         |
|       | CM        | Male  | 104        | 7.438     | 0.479    | 7.172                   | 7.713   | -2.555  | 0.011   |
|       |           | Female| 100        | 7.243     | 0.425    | 7.028                   | 7.458   |         |         |
| 24    | CA        | Male  | 104        | 67.104    | 8.281    | 64.651                  | 69.553  | 3.949   | <0.001  |
|       |           | Female| 100        | 65.790    | 7.739    | 63.339                  | 68.242  |         |         |
|       | CI        | Male  | 104        | 134.084   | 6.604    | 132.480                 | 135.691 | -2.584  | 0.010   |
|       |           | Female| 100        | 132.491   | 6.702    | 130.989                 | 133.992 |         |         |
|       | CM        | Male  | 104        | 8.266     | 0.510    | 7.246                   | 9.286   | 3.730   | <0.001  |
|       |           | Female| 100        | 8.018     | 0.435    | 7.932                   | 8.105   |         |         |
| 25    | CA        | Male  | 104        | 134.084   | 6.604    | 132.480                 | 135.691 | -2.584  | 0.010   |
|       |           | Female| 100        | 132.491   | 6.702    | 130.989                 | 133.992 |         |         |
|       | CI        | Male  | 104        | 134.084   | 6.604    | 132.480                 | 135.691 | -2.584  | 0.010   |
|       |           | Female| 100        | 132.491   | 6.702    | 130.989                 | 133.992 |         |         |
|       | 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   |         |         |
Table 3 continued. Comparison of crown indices between men and women.

| Teeth | Variables | Group | Number | 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)       | -2.649  | 0.009  |
| 26    | 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)        | 0.019   | 0.985  |
| 26    | CM        | Male  | 104    | 10.476   | 0.559   | (10.368, 10.585)         | 0.096   | 0.995  |
|       |           | Female| 100    | 10.157   | 0.440   | (10.069, 10.244)         | 0.096   | 0.995  |
| 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)         | -0.019  | 0.995  |
| 27    | CI        | Male  | 104    | 109.944  | 7.140   | (108.555, 111.332)       | -0.019  | 0.995  |
|       |           | Female| 100    | 109.961  | 5.860   | (108.799, 111.124)       | -0.019  | 0.995  |
| 27    | 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)           | 3.096   | 0.002  |

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   | BL    | MD    | CA    | CI    | CM    | MCI   |
|---------|-------|-------|-------|-------|-------|-------|
| 11      | 0.749 | 2.769 | 3.551 | -2.068| 1.931 |       |
| 12      | 0.938 | 2.416 | 3.612 | -1.499| 1.764 |       |
| 13      | 3.433 | 4.187 | 7.821 | -0.777| 3.826 | 2.031 |
| 14      | 3.690 | 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.
Table 5. General discriminant analysis in crown dimensions for sex estimation.

| Teeth          | Function          | Discriminant function | Wilks' Lambda | p-value | Accuracy (%) | Cutting point* |
|----------------|-------------------|-----------------------|---------------|---------|--------------|----------------|
| 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         | <0.001  | 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         | <0.001  | 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 Sheikh 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.
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.

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.

Indexed in: [Current Contents/Clinical Medicine] [SCI Expanded] [ISI Alerting System] [ISI Journals Master List] [Index Medicus/MEDLINE] [EMBASE/Excerpta Medica] [Chemical Abstracts/CAS]

Liu J. et al: Permanent maxillary odontometrics for sex estimation © Med Sci Monit, 2021; 27: e933450

This work is licensed under Creative Common Attribution-NonCommercial-NoDerivatives 4.0 International (CC BY-NC-ND 4.0)
## Table 6. Discriminant functions in indices for sex estimation.

| Teeth | Function        | Discriminant function | Wilks’ Lambda | p-value | Accuracy (%) | Male | Female | Overall | Cutting point* |
|-------|-----------------|-----------------------|---------------|---------|--------------|------|--------|---------|---------------|
| 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    | -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   |
| 14    | Crown area      | -8.082+0.126CA        | 0.908         | <0.001  | 63.5         | 68.0 | 65.7   | -0.006  |
|       | Crown module    | -15.785+1.948CM       | 0.914         | <0.001  | 53.8         | 68.0 | 60.8   | -0.007  |
|       | 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    | -17.485+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+7.527MCI     | 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   |

*Cutting point values indicate the threshold for sex estimation.*
Table 6 continued. Discriminant functions in indices for sex estimation.

| Teeth | Function | Discriminant function | Wilks' Lambda | p-value | Accuracy (%) | Cutting point* |
|-------|----------|------------------------|---------------|---------|--------------|---------------|
| 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 48.0 52.0 | 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+0.153Cl       | 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.
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.

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

| Teeth             | Function          | Discriminant function                                                      | Wilks’ Lambda | p-value  | Accuracy (%) | Cutting point |
|-------------------|-------------------|----------------------------------------------------------------------------|---------------|----------|--------------|---------------|
| Crown dimensions  |                   | -20.461+0.838x(BL13)-1.219x(BL21)+1.122x(MD13)+1.275x(MD16)               | 0.758         | <0.001   | 69.2         | 72.0          | 70.6          | -0.011        |
| Crown area        |                   | -8.521+0.342x(CA13)-0.083x(CA21)-0.24x(CA23)+0.066x(CA26)                | 0.788         | <0.001   | 63.5         | 68.0          | 65.7          | -0.010        |
| Crown module      |                   | -18.094+2.107x(CM13)+1.359x(CM16)-1.578x(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 – mesiolingual distance of the right canine; MD16 – mesiolingual 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.

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

We acknowledge the contributions of the Department of Prosthodontics in the First Affiliated Hospital of Xinjiang Medical University for providing facilities for the study. Our thanks go to all the participants of the study for their valuable co-operation.

References:

1. Jankowska A, Janiszewska-Olszowska I, Grocholewicz K. Nasal morphol- ogy and its correlation to craniofacial morphology in lateral cephalometric analysis. Int J Environ Res Public Health. 2021;18(6):3064.
2. Quiney D, Carle G, Alunni V, Quatrehomme G. Difficulties of sex determin- ization from forensic bone degraded DNA: A comparison of three methods. Sci Justice. 2011;51(3):253-60.
3. Bozkurt MH, Karalog J, Saw and teeth segmentation on the panoramic X-ray images for dental human identification. J Digit Imaging. 2020;33(6):1410-27.
4. Jensen E, Kai-jen YP, Moorrees CF, Thomsen SO. Mesiodistal crown diam- eters of the deciduous and permanent teeth in individuals. J Dent Res. 1957;36(1):39-47.
5. Osley DW, Webb RS. Misclassification probability of dental discrimination functions for sex determination. J Forensic Sci. 1983;28(1):181-85.
6. Kiran CS, Ramaswamy P, Swathi E, et al. Discriminant canine index – a nov- el approach in sex determination. Ann Stomatol (Roma). 2019;6(2):43-46.
7. Silva AM, Pereira ML, Gouveia S, et al. A new approach to sex estimation using the mandibular canine index. Med Sci Law. 2016;56(1):7-12.
8. Phulari R, Rathore R, Talegaon T, Jarlawa P. Comparative assessment of maxillary canine index and maxillary first molar dimensions for sex deter- mination in forensic odontology. J Forensic Dent Sci. 2017;9(2):110.
9. Couto D, Gallassi N, Gomes SL, et al. Brazilian’s dental anthropometry: hu- man identification. J Forensic Dent Sci. 2019;11(2):73-77.
10. Erelwieny NM, Ismail M, Zaghioui HS, et al. Palatoscopy and odontomet- rics’ potential role in sex determination among an adult Egyptian popula- tion sample: A pilot study. Homo. 2020;71(1):19-28.
11. Vandenbroucke JP, von Elm E, Altman DG, et al. Strengthening the Reporting of Observational Studies in Epidemiology (STROBE): Explanation and elab- oration. Int J Surg. 2014;12(12):1500-24.
12. Gann SM, Lewis AB, Kerewsky RS. Buccolingual size asymmetry and its de- velopmental meaning. Angle Orthod. 1967;37(3):186-93.
13. Atreyaa A, Shrestha R, Tuladhar LR, et al. Sex predictability by using man- dibular canine index. J Nepal Health Res Counc. 2020;17(4):501-5.
14. El Sheikh I, Bugajigis I. Sex discrimination by odontometrics in Libyan subjects. J Egypt J Forensic Sci. 2016;6:157-64.
15. Liu J, Liu Y, Wang J, et al. Dental measurements based on a three-dimen- sional digital technique: A comparative study on reliability and validity. Arch Oral Biol. 2021;124:105059.
16. Shawesheh AM. Mesiodistal and faciolingual diameters of the permanent teeth in a Jordanian population. Arch Oral Biol. 2017;73:253-58.
17. Romero A, Ramirez-Rozzi FV, Perez-Perez A. Dental size variability in Central African Pygmy hunter-gatherers and Bantu-speaking farmers. Am J Phys Anthropol. 2018;166(3):671-81.
18. Soto-Álvarez C, Fonseca GM, Viciano J, et al. Reliability, reproducibility and validity of the conventional buccolingual and mesiodistal measurements on 3D dental digital models obtained from intra-oral 3D scanner. Arch Oral Biol. 2020;109:104575.
19. Chiu A, Chen Y, Hayashi J, Sadr A. Accuracy of CAD/CAM digital impressions with different intraoral scanner parameters. Sensors. Basel. 2020;20(4):1157.
20. Russo M, Boccal M, Sabadin V, Aprile A. The medicolegal assessment of aesthetic damage. A correlation analysis between experts and an opera- tive proposal. Leg Med (Tokyo). 2019;40:47-53.
21. Pereira C, Bernardo M, Pestana D, et al. Contribution of teeth in human fo- rensic identification – discriminant function sexing odontometrical tech- niques in Portuguese population. J Forensic Leg Med. 2010;17(2):105-10.
22. Thapar R, Angadi PV, Hallikerimath S, Kale AD. Sex assessment using odont- ometry and cranial anthropometry: Evaluation in an Indian sample. Forensic Sci Med Pathol. 2012;8(2):94-100.
23. Al-Gunaid T, Yamaki M, Saito I. Mesiodistal tooth width and tooth size dis- crepancies of Yemeni Arabs: A pilot study. J Orthod Sci. 2012;1(2):40-45.
24. Peckmann TR, Logar C, Garrido-Vara SE, et al. Sex determination using the mesio-distal dimension of permanent maxillary incisors and canines in a modern Chilean population. Sci Justice. 2016;56(2):84-89.
25. Phulari RGS, Rathore R, Talegaon T, Jarlawa P. Comparative assessment of maxillary canine index and maxillary first molar dimensions for sex deter- mination in forensic odontology. J Forensic Dent Sci. 2017;9(2):110.
26. Martins-Filho I. [Relationship between gender and tooth measures: A Brazilians study (thesis).] São Paulo (Brazil): Universidade de São Paulo, Faculdade de Odontologia; 2013 [In Portuguese].
27. Fernandes TM, Sathler R, Natalicio GL, et al. Comparison of mesiodistal tooth widths in Caucasian, African and Japanese individuals with Brazilian ancestry and normal occlusion. Dental Press J Orthod. 2013;18(3):130-35.
28. Khamis MF, Taylor JA, Malik SN, Townsend GC. Odontometric sex vari- ation in Malaysians with application to sex prediction. Forensic Sci Int. 2014;234:181-83.
29. Angadi PV, Hemani S, Prabhu S, Acharya AB. Analyses of odontometric sexual dimorphism and sex assessment accuracy on a large sample. J Forensic Leg Med. 2013;20(6):673-77.
30. Mitsea AG, Moraitis K, Leon G, et al. Sex determination by tooth size in a sample of Greek population. Homo. 2014;65(1):322-29.
31. Bishara SE, Jakobsen JR, Abdallah EM, Fernandez GA. Comparisons of me- siodistal and buccolingual crown dimensions of the permanent teeth in three populations from Egypt, Mexico, and the United States. Am J Orthod Dentofacial Orthop. 1989;95(6):416-22.
32. Suazo GI, Cantin LM, Lopez FB, et al. Sexual dimorphism in mesiodis- tal and buccolingual tooth dimensions in Chilean people. Int J Morphol. 2008;26:609-14.
33. Castillo L, Castro AM, Lerma C, et al. [Mesiodistal and buccolingual dental diameters in a group of mixed ethnicity population in Cali, Colombia.] Rev Estomatol 2011;29(19):16-22 [in Spanish].
34. Babu SS, Nair SS, Gopakumar D, et al. Linear odontometric analysis of per- manent dentition as a forensic aid: A retrospective study. J Clin Diagn Res. 2016;10(5):C24-28.
35. Dash KC, Panda A, Behura SS, et al. Employing dimensional disparity of teeth to establish the gender in Odisha population: A dimorphic study. J Int Soc Prev Community Dent. 2018;8(2):174-78.
36. Iscan MY, Kedicis P. Sexual variation in bucco-lingual dimensions in Turkish dentition. Forensic Sci Int. 2003;137(2-3):160-64.
37. Acharya AB, Mainaili S. Univariate sex dimorphism in the Nepalese denti- tion and the use of discriminant functions in gender assessment. Forensic Sci Int. 2007;173(1):47-56.
38. Thapar R, Angadi PV, Hallikerimath S, Kale AD. Sex assessment using odont- ometry and cranial anthropometry: Evaluation in an Indian sample. Forensic Sci Med Pathol. 2012;8(2):94-100.
39. Martins FL, Lopez-Capp TT, Biazevic MG, Michel-Crosato E. Sexual dimor- phism using odontometric indexes: Analysis of three statistical techniques. J Forensic Leg Med. 2016;44:37-42.
40. Dempsey PJ, Townsend GC. Genetic and environmental contributions to variation in human tooth size. Heredity (Edinb). 2001;86(Pt 6):685-93.
41. Eobh DEO. Odontometric sex discrimination in young Urhobo adults of South-South Nigeria. Anat Cell Biol. 2019;52(3):269-77.

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.
42. Acharya AB, Mainali S. Sex discrimination potential of buccolingual and mesiodistal tooth dimensions. J Forensic Sci. 2008;53(4):790-92
43. Rao NG, Rao NN, Pai ML, Kotian MS. Mandibular canine index – a clue for establishing sex identity. Forensic Sci Int. 1989;42(3):249-54
44. Iqbal R, Zhang S, Mi C. Reliability of mandibular canine and mandibular canine index in sex determination: A study using Uyghur population. J Forensic Leg Med. 2015;33:9-11
45. Gandhi N, Jain S, Kahlon H, et al. Significance of mandibular canine index in sexual dimorphism and aid in personal identification in forensic odontology. J Forensic Dent Sci. 2017;9(2):56-60
46. Gupta S, Chandra A, Gupta OP, et al. Establishment of sexual dimorphism in North Indian population by odontometric study of permanent maxillary canine. J Forensic Res. 2014;5(2):1000224
47. Phulari R, Rathore R, Talegaon T, Jariwala P. Comparative assessment of maxillary canine index and maxillary first molar dimensions for sex determination in forensic odontology. J Forensic Dent Sci. 2017;9(2):110