SEX DISCRIMINATION POTENTIAL OF PERMANENT MAXILLARY MOLAR CUSP DIAMETERS

P. J. Macaluso Jr.

Department of Anthropology, Binghamton University (SUNY), NY, USA.

ABSTRACT

The purpose of the present investigation was to assess the potential usefulness of permanent maxillary molar cusp diameters for sex discrimination of poorly preserved skeletal remains. Cusp diameters were measured from standardized occlusal view photographs in a sample of black South Africans consisting of 130 males and 105 females. Results demonstrated that all cusp dimensions for both first and second maxillary molars exhibited significant sexual dimorphism ($p < 0.001$). Univariate and multivariate discriminant function equations permitted low to moderate classification accuracy in discriminating sex (58.3%-73.6%). The allocation accuracies for cusp diameter measurements were as high as, and even surpassed, those observed for conventional crown length and breadth dimensions of the same teeth. The most accurate result (73.6%, with a sex bias of only 0.5%) was obtained when all cusp diameters from both maxillary molars were used concurrently. However, only slightly less accurate results (~70.0%) were achieved when selected dimensions from only one of the molars, or even a single cusp, were utilized. Although not as reliable at predicting sex as other skeletal elements in black South Africans, the derived odontometric standards can be used with highly fragmentary skeletal material, as well as immature remains in which crown formation of the maxillary molars is complete.

(J Forensic Odontostomatol 2010;28:1:22-31)

Keywords: sex determination; dentition; discriminant function analysis; South Africa

Running title: Sex discrimination from maxillary molar cusp diameters

INTRODUCTION

The determination of sex is central to the process of establishing a personal identification from human skeletal remains. Not only does accurate sex diagnosis effectively cut the number of possible matches in half, but also methods for estimating age-at-death and stature are often sex dependent. The most reliable results are obtained from morphological and metric analyses of the bony pelvis and skull.[1] Measurements of the long bones, particularly those of the femur and humerus, may also provide highly accurate sex assessments.[2]

It is often the case in forensic practice, however, that the only available criterion for discriminating sex is the measurement of the permanent dentition, given that teeth are more resistant to taphonomic degradation than osseous material.[3] As a result, odontometric standards to facilitate sex diagnosis have been developed for diverse population groups. The most commonly used dental measurements in forensic sex assessment studies have been mesiodistal and buccolingual crown diameters. For example, Acharya and Mainali[4] reported accuracy rates ranging from 62% to 83% for a Nepalese sample using combinations of crown length and breadth dimensions, while Ates et al.[5] obtained classification accuracies between 68% and 81% for similar measurements in a Turkish sample. More recently, Prabhu and Acharya[6] examined the dentition of an Indian sample and observed allocation accuracy results of 63% and 75% for the maxillary and mandibular teeth, respectively, using multivariate discriminant function analysis. Comparable sex classification percentages have also been achieved for a contemporary Turkish sample utilizing diagonal crown measurements, such as mesiobuccal-distolingual and distobuccal-mesiolingual diameters.[7] However, correct measurement of these dental dimensions may not be possible with highly fragmentary remains in which broken or incomplete tooth crowns are the only materials available for study.

Alternative approaches for measuring tooth size have also been devised, in which intra-coronal components, such as intercusp distances, cusp areas, and cusp diameters, are studied instead of the whole crown. In several recent investigations, cusp measurements of the permanent maxillary molars displayed levels of sexual dimorphism comparable to, and even greater than, those reported for conventional crown length and breadth dimensions.[8-10] These results suggest that metric analysis of intra-coronal dimensions may provide an alternative, yet effective, method of dental sex assessment. Therefore, the objective of the current study was to test the hypothesis that significant sexual dimorphism is present in permanent maxillary molar cusp diameters, for which reasonably accurate odontometric standards for discriminating the sex of poorly preserved skeletal remains can be produced.

MATERIALS AND METHODS

The dental material used in this investigation was drawn from the Raymond A. Dart Collection of Human Skeletons, housed in the Department of Anatomical Sciences, University of the Witwatersrand, and the Pretoria Bone Collection, curated in the Department of Anatomy, School of Medicine, Faculty of Health Science, University of Pretoria. These documented skeletal series were derived primarily from donated and unclaimed cadavers of 20th century black (indigenous) and white (European) South Africans used for medical teaching and research.[11,12]

The permanent maxillary molars of 235 black South Africans of known sex (130 males, 105 females) were examined in the present investigation. The selected sample consisted of specimens simply labeled as 'black' or 'South African Negro', as well as identified individuals from the Zulu, Sotho, Tswana, Xhosa, and Swazi population groups, given that they constitute the majority of the indigenous remains in the two skeletal collections. For each group, roughly an equal number of males and females was selected. Although some degree of morphological variation has been observed between these ethnic groups, the subdivisions within the South African black population are disappearing.[13] Furthermore, in many forensic situations the local population is not known, and thus a model incorporating a variety of ethnic groups will be of more practical value. The age-at-death for the sample ranged between 12 and 78 years, with a mean age of 42.8 ± 13.9 years for males and 35.6 ± 13.4 years for females. The recorded dates of death for the sample ranged from 1927 to 2000.

This study examines the first and second maxillary molars. The third molar was not considered given that in many cases this tooth was absent due to agenesis, incomplete maturation, or antemortem/postmortem loss. In addition, the occlusal surface of the distal molar was often complicated by numerous accessory wrinkles and grooves, and thus cusp boundaries were not clearly discernible for a number of specimens in which the third molar was present. Tooth crowns in which the main fissures separating cusps were obscure, due either to dental restorations or marked occlusal wear, were excluded from the analysis. Only molars possessing all four principal cusps (protocone, paracone, metacone, hypocone) were utilized. This included teeth exhibiting hypocone expression consistent with grades 3.5-5 (moderate to very large cusp) according to the Arizona State University Dental Anthropology System.[14] Molars on the left side of the maxilla were examined unless one of these teeth was missing or damaged, in which case the antimere from the right side was utilized.

Cusp diameters were measured from standardized occlusal view photographs obtained for individual teeth using the macro setting of a digital camera (Nikon Coolpix S610). The camera was mounted on a tripod and a leveling device was used to ensure a consistent camera angle. Each tooth was oriented such that the buccal and, where possible, mesial and distal cervical enamel lines were perpendicular to the optical axis of the camera. The molar crown was positioned in the center of the image seen through the camera's LCD monitor to minimize parallax error. A millimeter scale, placed parallel to the tooth and in approximately the same horizontal plane as the occlusal surface, was included in each photograph for calibration. The computer-assisted image analysis software program ImageJ· was subsequently used to take measurements from the uploaded digital photographs.

On the occlusal view photographs, the diameter of each individual cusp was determined by measuring the diagonal distance from the central pit to the most distant point located along the outer margin of the crown corresponding to the relevant cusp (**Fig. 1.**). Following Yamada and colleagues,[10,15,16] the central pit or fovea located at the bottom of the central fossa was defined as the point of intersection of the primary occlusal fissures. Although the location of the central pit will be affected by the relative position of the cusps, it is a key feature of all maxillary molars that is readily identified on occlusal view photographs[15] and provides an appropriate

· Distributed freely by the National Institutes of Health, USA (http://rsbweb.nih.gov/ij/)

landmark for assessing the size of individual cusps.[10,16] It should be noted that cusp diameters do not necessarily cross over the cusp tips. Maximum mesiodistal and buccolingual crown diameters were also measured from the digital images. All measurements were rounded to the nearest tenth of a millimeter (0.1 mm).

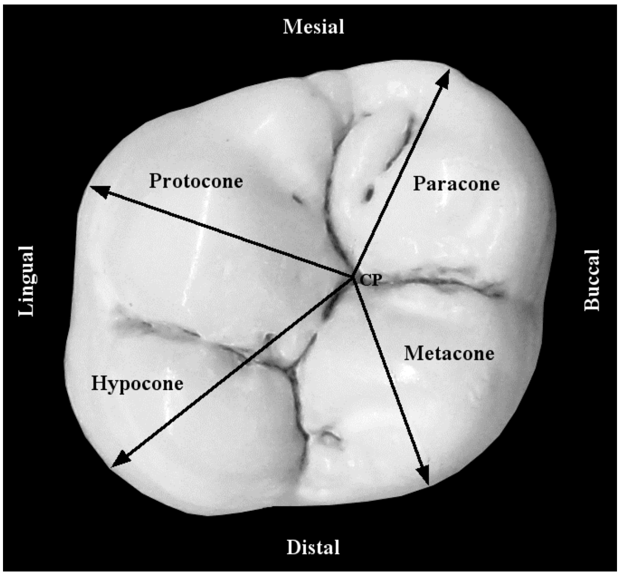

Fig. 1:. *Representative example of an occlusal view photograph of a permanent maxillary molar. Arrows illustrate cusp diameters, defined as the distance from the central pit (CP) to the most distant point on the crown margin (tip of arrow) of the corresponding cusp.*

An important consideration in this research is the repeatability of these rather small dental dimensions. Previous investigations have demonstrated that methods for measuring cuspal dimensions from digitized images have relatively low levels of measurement error both within and between observers.[9,15,17] In the present study, measurement precision was evaluated from double determinations in which the entire photogrammetric process (crown orientation, image capture, central pit identification and measurement) was repeated for 30 teeth selected at random from the original sample. There was no indication of systematic methodological errors between the two sets of values, based on paired *t*-tests ($p > 0.05$ for all dental dimensions). In addition, the relative technical error of measurement (rTEM), which quantifies the extent of random error,[18] ranged from 1.4% to 1.7% for the four cusp diameters. These results suggest that methodological errors were small and unlikely to bias the results.

Subsequent to data collection, the D'Agostino-Pearson omnibus test was conducted for all variables in order to determine whether or not the data were normally distributed.[19] Following this, general descriptive statistics and percentages of sexual dimorphism were calculated for all dental dimensions. Between-sex comparisons for each measurement were performed using the independent-sample *t*-test. The crown and cusp measurement data were then subjected to direct discriminant function analyses to develop a set of equations for determining sex. To address the differential preservation of forensic remains, various multivariate functions were generated for both maxillary molars taken together (M1 and M2) for more complete remains, as well as for each tooth separately (M1 or M2) for more fragmentary dentitions. Discriminant analysis was also performed on individual measurements (e.g., M1 paracone diameter) to obtain formulae for diagnosing sex from partial tooth crowns. The reliability of each of the derived discriminant functions was assessed using the leave-one-out classification procedure. This cross-validation technique classifies each individual of a sample by the functions derived for all specimens other than that specimen itself, and thus provides less biased classification estimates for the study sample. The advantage of employing the leave-one-out method over a split-sample (or holdout) method, particularly when relatively small datasets are concerned, is that the former procedure effectively uses all of the data for both developing a discriminant function and evaluating its performance, which increases the chance of generating an accurate classification model.[20]

RESULTS

The results of the D'Agostino-Pearson omnibus tests demonstrated that all measurements had a normal distribution ($K^2 < 1.05$, $p > 0.59$). The descriptive statistics of crown and cusp diameters for both maxillary molars are shown in **Table 1**. Mean values were significantly different between the sexes ($p < 0.001$), with male values exceeding those of females for all observed dimensions. The percentages of sexual dimorphism revealed that among cusp diameters the protocone and hypocone displayed the greatest dimorphism in both maxillary molars. In fact, protocone diameter was more dimorphic than mesiodistal and buccolingual dimensions in both the M1 and M2, as was hypocone diameter in the second molar.

Results of the direct discriminant function analyses for dimensions of the maxillary first molar are provided in **Table 2**. The highest cross-validated classification accuracy rate was observed for buccolingual breadth at 73.6% (F7). The addition of mesiodistal length to the equation (F1) did not increase the overall accuracy; however, it did provide a lower sex bias (or difference between male and female allocation rates). The combination of the two mesial cusp diameters (F2) yielded an overall sex prediction rate of 71.9%, as did the combination of lingual cusp diameters (F4). The most effective individual cusp diameter was the protocone (F8, 71.1%), followed by the hypocone (F11, 69.4%).

The cross-validated classification accuracies for functions derived from second molar dimensions are generally lower than those observed for the first molar (**Table 3**). The combination of the two lingual cusps (F15) provided the best overall result for the M2 with a sex prediction success rate of 71.9%, a value identical to that observed for M1 dimensions. Classification accuracies were reduced slightly for distal (F13, 69.8%) and mesial (F14, 69.4%) cusp combinations. Separate functions for protocone diameter (F19) and hypocone diameter (F22) yielded similar results, as both provided 70.2% accuracy in allocating sex.

The functions incorporating dimensions from both maxillary teeth did not generally provide increased sex classification accuracy rates over those achieved utilizing dimensions for only the first molar (**Table 4**). However, the function incorporating all cusp diameters from the M1 and M2 (F24) yielded the best overall accuracy rate observed in this study at 73.6%, with a minimal sex bias of only 0.5%.

DISCUSSION

In this study, digital photogrammetric methods were used to collect cusp diameter data for a black South African sample. All cusp measurements, for both the first and second maxillary molars, were highly sexually dimorphic in this group. These results are generally consistent with a previous investigation concerning sex dimorphism of maxillary molar cusp diameters in modern Japanese.[10] As with the Japanese, dimensions of the second molar displayed more dimorphism than the first molar in black South Africans. Likewise, in both studies the greatest percentage of sexual dimorphism was observed in hypocone diameter of the second molar. Additionally, hypocone diameter was the second most dimorphic cusp dimension of the M1 crown in Japanese and black South Africans. Although the abovementioned results are in general agreement, there are some notable differences between the Japanese study and the results of the current investigation. For example, in the present study protocone diameter displayed the highest percentage of sexual dimorphism among all first molar dimensions. In contrast, the diameter of the M1 protocone was the least dimorphic measurement in the Japanese sample.[10] Also, metacone diameter was the least dimorphic cusp for both the M1 and M2 in black South Africans, which was not the case in Japanese dentitions. The apparent difference in the pattern of sexual dimorphism between these two geographically disparate populations is likely due to a combination of environmental and genetic factors, given that dental sexual dimorphism is strongly influenced by sex-linked genes.[21, 22]

The results of the current research confirm the general trend in which molar teeth that develop later in ontogeny display greater sexual dimorphism compared to members of the same tooth class that develop earlier.[8,10,15,23] The results also support, for the most part, the ontogenetic hypothesis that sex differences tend to be more pronounced in later-formed, distal crown components of the maxillary and mandibular molars than in earlier-formed, mesial crown components.[8,10,15,24] However, sexual dimorphism was not always greater in the later-developed distal cusps of the first or second maxillary molars in black South Africans, a result consistent with previous findings based on molar cusp diameters in modern Japanese.[10] These latter observations, therefore, support the recent work of Guatelli-Steinberg et al.[22] which demonstrated that the timing of dental crown formation, and the related changes in sex hormone concentrations, has only a minor role in generating crown size sexual dimorphism.

Cusp diameter measurements of the maxillary first and second molars provide low to moderate sex discrimination, with overall classification accuracies for the derived discriminant functions ranging between 58.3% and 73.6%. These classification results are comparable to those reported in a prior study concerning sex allocation in black South Africans based on odontometric data. Specifically, Kieser and Groeneveld[25] achieved sex identification rates of 70.2% for males and 66.7% for females utilizing crown length and breadth diameters of the maxillary tooth row. In the current study, the sex classification percentages obtained for cusp diameters of the maxillary M1 and M2 were as high as, and even surpassed, those observed for conventional crown length and breadth dimensions of the same teeth. The most accurate allocation results for cusp diameter measurements were obtained when both maxillary molars were used concurrently. However, only slightly less accurate results were achieved when only one of the molars, or even a single cusp, was utilized.

It should also be mentioned that the current research formed part of a larger study that also evaluated the degree of sexual dimorphism present in basal cusp areas of the maxillary molars and the utility of these measurements in diagnosing sex. Univariate and multivariate discriminant function analyses incorporating cusp area measurements for the same South African sample yielded similar allocation accuracies, ranging from 59.6% to 74.0% (Macaluso, In press [ref 31]). As in the current study, mesial and lingual cusp combinations for the M1 and M2 provided some of the highest sex prediction accuracy rates. These results are unsurprising given that both investigations utilized datasets which represent measures of cusp size for the same set of teeth. However, cusp diameters demonstrated higher levels of accuracy for functions derived from maxillary second molar dimensions in comparison to those obtained utilizing cusp area data. An additional benefit of using cusp diameters, over cusp areas, is that these dimensions do not require access to specialized equipment or computer programs. Although the cusp diameter measurements used in this study were derived from digital photographs, equivalent odontometric data can be obtained using conventional measuring techniques, such as sliding calipers.[10,16] Therefore, digital photogrammetric methods are not required to make use of the sex discriminatory capacity of maxillary molars cusp diameters, which is not the case for basal cusp areas.

The classification accuracies obtained for cusp diameter measurements of the permanent maxillary first and second molars are lower than those observed in previous, non-dental, sex allocation studies of black South Africans.[13,26-29] Therefore, it is recommended that the derived discriminant functions be used as an adjunct to more reliable sex discriminating methods when additional skeletal elements are available for examination. Nonetheless, the odontometric formulae derived in the current investigation are of interest to forensic scientists given that tooth crowns are often preserved, even in situations where the recovered skeletal remains are incomplete or badly damaged, such as dismemberments, cremations, and mass disasters.

In addition, a number of previously established odontometric approaches require a complete maxillary and/or mandibular dentition or at least some portion of the anterior tooth row, such as the canines. However, in many instances the dentition is too fragmented by perimortem (e.g., trauma, burning) and/or postmortem (e.g., weathering, soil acidity) factors to allow for the measurement of each tooth in either dental arcade. Likewise, the anterior teeth may not be available for examination. The odontometric standards developed in this study that employ dimensions of the multi-rooted maxillary molars, therefore, may be of particular value given that these teeth are less frequently lost postmortem than the anterior teeth, which possess only a single root.[30] Furthermore, various antemortem and taphonomic processes can differentially affect the dentition thus rendering conventional mesiodistal and buccolingual crown dimensions useless, yet allowing individual cusp diameters to be accurately measured. For example, a particular postmortem insult may fracture the enamel along the buccal aspect of a molar crown, given its greater exposure to the external environment, while leaving the lingual portion of the tooth unaffected. Therefore, the utility of the odontometric formulae developed in this study is enhanced by the fact that they may be used with even partial tooth crowns.

Additionally, the sex discriminating standards developed in this study can be used with both adult and immature specimens since the crowns of the permanent dentition develop at an early age and, once formed, remain unchanged during the growth process. Therefore, cusp diameter measurements may provide a useful indication as to the sex of a subadult individual in which the secondary sex features of the skeleton are not yet defined. This is important given that the inability to diagnose the sex of juvenile skeletal material with satisfactory accuracy continues to be an important limitation to forensic identification. However, in view of the metric variation that exists between human populations, caution is warranted when attempting to apply the odontometric standards derived in this study to an individual from a different population.

CONCLUSION

The present study demonstrated that the level of sexual dimorphism in the cusp diameters of the permanent maxillary molars in black South Africans was sufficiently large to determine sex with an accuracy of 58.3%–73.6%, utilizing univariate and multivariate discriminant function analyses. These allocation accuracy rates are lower than those obtained for other skeletal elements in black South Africans, and thus the derived formulae should only be used as an adjunct to more reliable sex discriminating methods if additional remains are preserved. However, the odontometric standards developed in this study have particular value in situations where the recovered skeletal material is highly fragmentary due to perimortem and/or postmortem insults. In these cases, cusp diameter measurements of the maxillary first and second molars can be used to diagnose the sex of complete or partial tooth crowns, even when conventional mesiodistal and buccolingual crown dimensions cannot be accurately recorded. Furthermore, the derived classification models may provide a useful indication as to the sex of immature remains in which the secondary sexual features of the skeleton are not fully expressed.

ACKNOWLEDGMENTS

The author would like to thank the Department of Anatomical Sciences, University of the Witwatersrand for permission to study the Raymond A. Dart Collection of Human Skeletons, and Mr. Brendon Billings for his generosity and help during data collection. The author also wishes to express his gratitude to Professor Maryna Steyn for granting access to the Pretoria Bone Collection, housed in the Department of Anatomy, School of Medicine, Faculty of Health Sciences, University of Pretoria and Mr. Marius Loots and Dr. Ericka L'Abbe of the same department for their hospitality and assistance with the skeletal material in their care.

Address for Correspondence
Department of Anthropology,
Binghamton University (SUNY),
PO Box 6000,
Binghamton,
NY 13902-6000, USA;
e-mail: p.james.macaluso@hotmail.com
tele: 607-777-2737;
fax: 607-777-2477;

Table 1: *Descriptive statistics, t-values, and percentages of sexual dimorphism for maxillary molar crown dimensions*

Variables †	Males (n = 130)			Females (n = 105)			Sex Dimorphism	
	Mean	SD	Range	Mean	SD	Range	t-values*	%‡
M1								
MD diameter	11.09	0.57	9.5-12.6	10.63	0.53	9.4-12.4	6.380	4.33
BL diameter	11.50	0.59	10.1-13.4	10.89	0.52	9.6-12.3	8.370	5.60
Pr diameter	6.56	0.38	5.6-7.6	6.18	0.40	5.1-7.5	7.510	6.15
Pa diameter	5.59	0.34	4.8-6.8	5.34	0.27	4.6-6.0	6.290	4.68
Me diameter	5.52	0.32	4.6-6.4	5.36	0.32	4.7-6.3	3.900	2.99
Hy diameter	7.23	0.44	6.0-8.5	6.89	0.43	5.8-8.0	5.950	4.93
M2								
MD diameter	10.94	0.76	9.3-12.6	10.38	0.57	9.1-12.0	6.530	5.39
BL diameter	11.70	0.71	10.0-13.5	11.18	0.61	9.6-12.6	6.970	4.65
Pr diameter	6.73	0.47	5.6-8.3	6.31	0.43	5.3-7.4	7.110	6.66
Pa diameter	5.85	0.44	5.0-7.1	5.58	0.40	4.7-6.7	4.650	4.84
Me diameter	5.25	0.38	4.2-6.1	5.09	0.43	4.3-5.9	3.460	3.14
Hy diameter	7.10	0.56	5.3-8.3	6.56	0.54	5.0-8.0	7.450	8.23

† MD: mesiodistal; BL: buccolingual; Pr: protocone; Pa: paracone; Me: metacone: Hy: hypocone.
‡ Sexual dimorphism % = [male mean/female mean-1] x 100.
*All significant at $p < 0.001$.

Table 2: *Discriminant functions for determining sex from crown dimensions of the maxillary first molar*

Function number	Discriminant function †	Sectioning point	Male accuracy	Female accuracy	Overall accuracy
F1: crown diameters	y = (0.570)(MD) + (1.427)(BL) - 22.223	-0.061	72.3%	75.2%	73.6%
F2: mesial cusps	y = (1.847)(Pr) + (1.565)(Pa) - 20.378	-0.059	68.5%	76.2%	71.9%
F3: distal cusps	y = (0.407)(Me) + (2.108)(Hy) - 17.132	-0.042	68.5%	69.5%	68.9%
F4: lingual cusps	y = (02.154)(Pr) + (0.527)(Hy) - 17.484	-0.054	70.8%	73.3%	71.9%
F5: buccal cusps	y = (2.815)(Pa) + (0.753)(Me) - 19.529	-0.045	64.6%	71.4%	67.7%
F6: mesiodistal	y = (1.802)(MD) - 19.619	-0.045	60.0%	67.6%	63.4%
F7: buccolingual	y = (1.790)(BL) - 20.099	-0.058	76.2%	70.5%	73.6%
F8: protocone	y = (2.585)(Pr) - 16.515	-0.053	72.3%	69.5%	71.1%
F9: paracone	y = (3.217)(Pa) - 17.629	-0.044	68.5%	66.7%	67.7%
F10: metacone	y = (3.113)(Me) - 16.962	-0.027	58.3%	61.0%	58.3%
F11: hypocone	y = (2.291)(Hy) - 16.208	-0.042	68.5%	70.5%	69.4%

†Abbreviations are the same as in Table 1.

***Table 3:** Discriminant functions for determining sex from crown dimensions of the maxillary second molar*

Function number	Discriminant function †	Sectioning point	Male accuracy	Female accuracy	Overall accuracy
F12: crown diameters	y = (0.727)(MD) + (0.988)(BL) - 19.147	-0.054	67.7%	71.4%	69.4%
F13: mesial cusps	y = (1.836)(Pr) + (0.776)(Pa) - 16.465	-0.053	68.5%	70.5%	69.4%
F14: distal cusps	y = (0.111)(Me) + (1.774)(Hy) - 12.733	-0.052	70.0%	69.5%	69.8%
F15: lingual cusps	y = (1.036)(Pr) + (1.109)(Hy) - 14.382	-0.055	71.5%	72.4%	71.9%
F16: buccal cusps	y = (1.817)(Pa) + (1.170)(Me) - 16.469	-0.036	58.5%	61.9%	60.0%
F17: mesiodistal	y = (1.463)(MD) - 15.642	-0.044	62.3%	70.5%	66.0%
F18: buccolingual	y = (1.504)(BL) - 17.318	-0.049	70.0%	65.7%	68.1%
F19: protocone	y = (2.199)(Pr) - 14.391	-0.050	67.7%	73.3%	70.2%
F20: paracone	y = (2.343)(Pa) - 13.421	-0.033	56.2%	71.4%	63.0%
F21: metacone	y = (2.766)(Me) - 14.327	-0.024	63.1%	55.2%	59.6%
F22: hypocone	y = (1.806)(Hy) - 12.382	-0.052	70.0%	70.5%	70.2%

†Abbreviations are the same as in Table 1.

***Table 4:** Discriminant functions for determining sex from crown dimensions of the maxillary first and second molar*

Function number	Discriminant function†	Sectioning point	Male accuracy	Female accuracy	Overall accuracy
F23: crowns diameters	y = (0.284)(MD M1) + (1.188)(BL M1) +	-0.062	70.0%	76.2%	72.8%
	(0.373)(MD M2) + (0.158)(BL M2) - 22.238				
F24: all cusps	y = (0.937)(Pr M1) + (1.151)(Pa M1) +	-0.068	73.8%	73.3%	73.6%
	(-0.094)(Me M1) + (-0.009)(Hy M1) +				
	(-0.171)(Pr M2) + (0.554)(Pa M2) +				
	(-0.583)(Me M2) + (1.205)(Hy M2) - 19.015				
F25: lingual cusps	y = (1.468)(Pr M1) + (-0.113)(Hy M1) +	-0.061	70.0%	69.5%	69.8%
	(0.253)(Pr M2) + (0.958)(Hy M2) - 16.799				
F26: buccal cusps	y = (2.361)(Pa M1) + (0.494)(Me M1) +	-0.046	63.8%	67.6%	65.5%
	(0.451)(Pa M2) + (0.366)(Me M2) - 20.112				

†Abbreviations are the same as in Table 1.

REFERENCES

1. Krogman WM, Íşcan MY. *The human skeleton in forensic medicine*. Springfield: Charles C. Thomas, 1986.
2. France DL. Observational and metric analysis of sex in the skeleton. In: Reichs KJ. Ed. Forensic Osteology: *Advances in the Identification of Human Remains*, *2nd Edition*. Springfield, IL: Charles C. Thomas, 1998;163-86.
3. Kieser JA. *Human Adult Odontometrics*. Cambridge: Cambridge University Press, 1990.
4. Acharya AB, Mainali S. Sex discrimination potential of buccolingual and mesiodistal tooth dimensions. *J Forensic Sci* 2008;53:790-92
5. Ateş M, Karaman F, Işcan MY, Erdem TL. Sexual differences in Turkish dentition. *Leg Med* 2006;8:288-92.
6. Prabhu S, Acharya AB. Odontometric sex assessment in Indians. *Forensic Sci Int* 2009;192:129.e1-29.e5.
7. Karaman F. Use of diagonal teeth measurements in predicting gender in a Turkish population. *J Forensic Sci* 2006;51:630-35.
8. Takahashi M, Kondo S, Townsend GC, Kanazawa E. Variability in cusp size of human maxillary molars, with particular reference to the hypocone. *Arch Oral Biol* 2007;52:1146-54.
9. Kondo S, Townsend GC. Associations between Carabelli trait and cusp areas in human permanent maxillary first molars. *Am J Phys Anthropol* 2006;129:196-203.
10. Kondo S, Townsend GC, Yamada H. Sexual dimorphism of cusp dimensions in human maxillary molars. *Am J Phys Anthropol* 2005;128:870-77.
11. Dayal MR, Kegley ADT, Štrkalj G, Bidmos MA, Kuykendall KL. The history and composition of the Raymond A. Dart Collection of Human Skeletons at the University of the Witwatersrand, Johannesburg, South Africa. *Am J Phys Anthropol* 2009;140:324-35.
12. L'Abbe EN, Loots M, Meiring JH. The Pretoria Bone Collection: A modern South African skeletal sample. *HOMO-J Comp Hum Biol* 2005;56:197-205.
13. Franklin D, Higgins PO, Oxnard CE, Dadour I. Discriminant function sexing of the mandible of Indigenous South Africans. *Forensic Sci Int* 2008;179:84.e1-84.e5.
14. Turner CG, Nichol CR, Scott GR. Scoring procedures for key morphological traits of the permanent dentition: the Arizona State University Dental Anthropology System. In: Kelley MA, Larson CS. Eds. *Advances in Dental Anthropology*. New York: Wiley-Liss, 1991;13-31.
15. Yamada H, Brown T. Contours of maxillary molars studied in Australian Aborigines. *Am J Phys Anthropol* 1988;76:399-407.
16. Kondo S, Yamada H. Cusp size variability of the maxillary molariform teeth. *Anthropol Sci* 2003;111:255-63.
17. Bailey SE, Pilbrow VC, Wood BA. Interobserver error involved in independent attempts to measure cusp base areas of *Pan* M^1s. *J Anat* 2004;205:323-31.
18. Harris EF, Smith RN. Accounting for measurement error: a critical but often overlooked process. *Arch Oral Biol* 2009;54:S107-S17.
19. Zar JH. *Biostatistical Analysis*. 4th edn. Upper Saddle River, New Jersey: Prentice Hall, 1999.
20. Johnson RA, Wichern DW. *Applied Multivariate Statistical Analysis*. 5th edn. Upper Saddle River, New Jersey: Prentice Hall, 2002.
21. Alvesalo L. Sex chromosomes and human growth: a dental approach. *Hum Genet* 1997;101:1-5.
22. Guatelli-Steinberg G, Sciulli PW, Betsinger TK. Dental crown size and sex hormone concentrations: another look at the development of sexual dimorphism. *Am J Phys Anthropol* 2008;137:324-33.
23. Gingerich PD. Size variability of the teeth in living mammals and the diagnosis of closely related sympatric fossil species. *J Paleontol* 1974;48:895-903.
24. Kondo S, Townsend GC. Sexual dimorphism in crown units of mandibular deciduous and permanent molars in Australian Aborigines. *HOMO-J Comp Hum Biol* 2004;55:53-64.
25. Kieser JA, Groeneveld HT. The unreliability of sex allocation based on human odontometric data. *J Forensic Odontostomat* 1989;7:1-12.
26. Steyn M, Íşcan MY. Osteometric variation in the humerus: sexual dimorphism in South Africans. *Forensic Sci Int* 1999;106:77-85.
27. Asala SA, Bidmos MA, Dayal MR. Discriminant function sexing of fragmentary femur of South African blacks. *Forensic Sci Int* 2004;145:25-29.

28. Patriquin ML, Steyn M, Loth SR. Metric analysis of sex differences in South African black and white pelves. *Forensic Sci Int* 2005;147:119-27.
29. Dayal MR, Spocter MA, Bidmos MA. An assessment of sex using the skull of black South Africans by discriminant function analysis. *HOMO-J Comp Hum Biol* 2008;59:209-21.
30. Schimdt CW. Forensic dental anthropology: issues and guidelines. In: Irish JD, Nelson GC. Eds. *Technique and Application in Dental Anthropology*. Cambridge: Cambridge University Press, 2008;266-92.
31. Macaluao P.J Investigation on the utility of permanent maxillary molar cusp areas for sex estimation. *Forensic Sci Med Pathol.*