ARE DENTAL INDEXES USEFUL IN SEX ASSESSMENT?

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ABSTRACT

This study describes sexual dimorphism in dental indexes derived from the permanent dentition. Three dental indices—'crown area,' 'crown module' and 'crown index'—were calculated from the buccolingual (BL) and mesiodistal (MD) measurements of 123 permanent dentitions (58 females and 65 males) belonging to young Nepalese adults (age-range 19–28 years). Sex differences in the dental indexes were assessed using univariate and multivariate statistics and compared to that of linear measurements reported previously on the same sample. Univariate sex dimorphism exhibited by crown area and crown module was similar to that of linear measurements whereas crown index displayed marked variation. The unusual results shown by the latter is explained as the result of it not being a representation of tooth size per se; rather, crown index is an expression of the *difference* between BL and MD dimensions and may be better suited as an indicator of tooth 'shape'. Stepwise discriminant analyses undertaken for the indices gave moderate to high accuracy rates in sexing (69.8–81.1%). However, this is lower to the classification accuracy reported for linear measurements. Therefore, it is concluded that dental indexes have no added utility in forensic sex assessment.
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Keywords: forensic odontology, sex determination, odontometrics, crown area, crown module, crown index

INTRODUCTION

Sex assessment from tooth measurements is a useful adjunct to identifying forensic and anthropological skeletal specimens. Sexual dimorphism in tooth size has been explored over the past half-century, with odontologists and anthropologists[1–3] focussing on the use of buccolingual (BL) and mesiodistal (MD) dimensions—termed linear measurements. Recently, some investigators have used diagonal measurements where tooth crowns were measured 'corner-to-corner'.[1,4] According to these authors, diagonal measurements allow measuring rotated, crowded and proximally restored teeth. The advantages notwithstanding, diagonal measurements have technical limitations.[4] Therefore, it is anticipated that linear measurements will continue to find favour in odontometric sex assessment owing to the relative ease with which they are obtained. While one recent study has revealed high levels of sexual dimorphism in linear measurements,[2] gender differences have not been consistent enough to warrant the use of linear tooth dimensions as the sole indicator of sex. Therefore, efforts to improve sex assessment outcomes from linear tooth dimensions are required. An option which could prove useful is the calculation of dental indexes. Dental indexes are derived from simple mathematical combinations of linear measurements. They include 'crown area,' 'crown module' and 'crown index' and are defined as follows:

Crown area—Crown area or tooth robustness is the product of BL and MD dimensions and derived for each tooth by multiplying the linear measurements (i.e. BL $\times$ MD).

Crown module—Crown module for each tooth is taken as the average of BL and MD dimensions, i.e. (BL + MD)/2.

Crown index—Crown index, on the other hand, is the ratio of the two linear measurements expressed as percentage, i.e. (BL/MD) $\times$ 100.

Dental indexes are shown to have evolutionary,[5] developmental[6] and clinical significance.[7] However, their use in forensic sex identification has not been explored fully. Townsend and Brown[8] presented statistical summaries for these indices in males and females, but did not comment on sexual dimorphism per se. Others limited their assessment of sex differences to crown index.[9,10] Introna *et al*.[11] undertook the solitary study that examined sex differences for all dental indexes, but restricted the assessment to maxillary deciduous molars. They did, however, perform discriminant analysis as an aid to sex identification. Garn *et al*.[12] have also undertaken discriminant analysis for tooth ratios of the permanent dentition. In fact, some believe that sex differences in dental indexes exceed those in linear dimensions and has the potential to improve sex differentiation when assessed by means of discriminant analysis.[9] Indeed, dental indices may serve as a measure of the 'whole' tooth crown, rendering them more amenable to sex assessment. The present study has, therefore, ventured to explore sexual dimorphism in dental indexes. In particular, the objectives of this study were to assess univariate and multivariate sex differences in dental indices derived from the BL and MD dimensions of the permanent dentition and determine their utility in sex assessment vis-à-vis linear measurements.

MATERIALS AND METHODS

The sample consisted of 123 dental casts from young Nepalese adults (58 females and 65 males) aged 19–28 years. Following verbal consent, impressions of the teeth were made using irreversible hydrocolloid material and casts poured in dental stone. MD and BL measurements of all teeth (excluding third molars) were obtained using a digital calliper[*] with calibration 0.01 mm. Dental indexes were calculated from BL and MD measurements of these teeth. The MD measurements were defined as the greatest dimension between the contact points on the approximate surfaces of the crown measured with the calliper beaks placed occlusally along the long axis of the tooth.[8] In cases where the teeth were rotated or malposed, measurements were taken between points on the approximate surfaces of the crown where it was considered that contact with adjacent teeth would have normally occurred. The BL measurements were defined as the greatest distance between the labial/buccal surface and the lingual surface of the tooth crown measured with the calliper held at right angles to the MD dimension.[8] A few tooth variables in some of the casts could not be measured due to impediments such as restorations, caries, excessive wear or casting defects. Consequently, dental index values were not always available for all teeth in the 123 dental casts. Univariate sex differences in the dental indexes were assessed using the independent samples *t*-test. Stepwise discriminant analyses were performed on 53 complete sets of dentitions belonging to 22 females and 31 males (the remaining 70 dental casts had at least one missing tooth variable and could not be included in the discriminant analysis since the analysis cannot take up incomplete data). Separate stepwise discriminant analyses were undertaken for crown area, crown module and crown index. All analyses were performed using the SPSS 10.0 software package.[†]

RESULTS

Univariate sex dimorphism

Tables 1–3 depict the descriptive statistics and *t*-values of crown area, module and index, respectively, for the measured teeth. For crown area (Table 1) and module (Table 2), canines showed the greatest sex dimorphism followed by the maxillary first molar, maxillary central incisor and mandibular second molar. Thirteen of the 28 tooth variables (a majority of which pertained to the maxilla) showed statistically significant sex differences ($p < 0.05$) for crown area and module. However, a different picture emerged for crown index (Table 3): the second molar and first premolar exhibited the greatest univariate sex difference while canines revealed none. Four crown index variables namely, tooth 37, 42, 46 and 47 showed greater mean values for females, the latter being statistically significant ($p < 0.05$).

Stepwise discriminant analyses

Table 4 illustrates the tooth variables for crown area, module and index that contributed to the stepwise discriminant analysis. Wilks' Lambda denotes how useful a given tooth variable is in the discriminant analysis and determines the order in which the variables entered the analysis; the Exact *F* Statistic determines how much variation exists between the sexes and the significance level of the variance.[13] Identical teeth entered the analysis undertaken for crown area and crown module. Only maxillary teeth contributed to the analysis performed for crown index, with no contribution what-so-ever of the canines. The cross-validated accuracy of the discriminant analyses in sex differentiation is presented in Table 5. The highest accuracy rate among the three dental indexes was obtained for crown module followed closely by crown area. Crown index exhibited lower classification accuracy.

DISCUSSION

Accurate sex assessment of skeletal remains has great importance in forensic and anthropological investigations. For optimal outcome, as many criteria as are available must be utilised.[14] Teeth are the strongest structures in the human body and are known to resist postmortem destruction. They are usually retained in skeletal specimens and, hence, can be used in sex differentiation.

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Table 1: *Descriptive statistics and t-values for crown area (BL×MD)*

Tooth Number[*]	Female				Male				t-Value[†]
	N	Mean	SD	CV	N	Mean	SD	CV	
11	56	61.16	7.31	11.95	62	65.12	8.04	12.35	-2.79[§]
12	57	43.18	6.35	14.70	63	44.90	7.37	16.42	-1.36
13	58	59.99	7.11	11.85	64	66.52	7.62	11.46	-4.88[‖]
14	58	64.57	7.54	11.68	65	66.83	7.14	10.68	-1.70
15	56	60.34	7.03	11.66	64	62.80	6.63	10.56	-1.98
16	57	115.70	10.21	8.83	62	123.14	12.02	9.76	-3.63[‖]
17	48	108.37	12.25	11.31	62	112.69	12.34	10.95	-1.83
21	57	61.07	7.01	11.47	65	65.13	7.92	12.17	-2.98[§]
22	57	43.29	6.46	14.92	62	45.03	6.82	15.15	-1.43
23	57	59.58	6.93	11.63	64	65.71	7.66	11.66	-4.60[‖]
24	57	65.03	7.46	11.48	64	67.14	6.25	9.31	-1.69
25	56	59.92	6.61	11.03	65	62.77	6.57	10.46	-2.38[‡]
26	57	115.30	9.83	8.52	63	120.91	10.91	9.03	-2.94[§]
27	47	106.71	10.58	9.91	56	112.87	12.46	11.04	-2.68[§]
31	56	32.17	3.96	12.31	62	33.24	3.85	11.58	-1.49
32	58	37.80	3.67	9.70	59	39.21	4.08	10.40	-1.97
33	58	48.57	5.05	10.39	64	54.74	5.98	10.93	-6.12[‖]
34	55	55.84	6.62	11.86	64	57.21	6.34	11.09	-1.15
35	56	59.45	6.45	10.85	63	60.48	5.55	9.17	-0.94
36	58	116.97	11.19	9.56	57	119.73	9.90	8.27	-1.40
37	48	105.01	12.30	11.71	62	111.71	12.55	11.23	-2.80[§]
41	54	32.44	3.60	11.09	59	33.45	3.68	11.00	-1.48
42	57	37.53	3.43	9.14	62	38.90	3.92	10.08	-2.02[‡]
43	58	48.25	5.02	10.40	65	54.64	6.09	11.14	-6.31[‖]
44	56	55.81	5.93	10.62	63	57.51	6.09	10.59	-1.54
45	51	58.78	6.50	11.06	62	60.09	5.49	9.13	-1.17
46	55	117.12	11.46	9.79	59	119.57	10.47	8.76	-1.19
47	48	105.83	11.88	11.23	63	110.83	11.63	10.49	-2.23[‡]

[*]FDI tooth notation
[†]Statistically significant at [‡]$p < 0.05$; [§]$p < 0.01$; [‖]$p < 0.001$ level

Table 2: *Descriptive statistics and t-values for crown module ((BL+MD)/2)*

Tooth Number[*]	Female				Male				*t*-Value[†]
	N	Mean	SD	CV	N	Mean	SD	CV	
11	56	7.84	0.47	5.93	62	8.09	0.50	6.16	-2.79[§]
12	57	6.57	0.48	7.35	63	6.69	0.56	8.40	-1.23
13	58	7.74	0.46	5.96	64	8.15	0.47	5.74	-4.91[‖]
14	58	8.11	0.47	5.82	65	8.26	0.44	5.34	-1.90
15	56	7.87	0.46	5.86	64	8.05	0.43	5.35	-2.13[‡]
16	57	10.76	0.48	4.44	62	11.10	0.54	4.85	-3.65[‖]
17	48	10.42	10.64	5.66	62	10.64	0.58	5.43	-1.93
21	57	7.83	0.45	5.71	65	8.09	0.50	6.13	-2.98[§]
22	57	6.57	0.51	7.72	62	6.70	0.51	7.65	-1.37
23	57	7.71	0.45	5.87	64	8.10	0.47	5.80	-4.62[‖]
24	57	8.13	0.47	5.73	64	8.28	0.39	4.70	-1.93
25	56	7.85	0.43	5.46	65	8.05	0.42	5.25	-2.55[‡]
26	57	10.74	0.46	4.30	63	11.00	0.50	4.52	-2.98[§]
27	47	10.35	0.52	5.00	56	10.66	0.59	5.51	-2.81[§]

31	56	5.67	0.36	6.27	62	5.77	0.33	5.77	-1.53
32	58	6.15	0.30	4.91	59	6.26	0.32	5.16	-1.94
33	58	6.97	0.37	5.26	64	7.40	0.41	5.53	-6.11[‖]
34	55	7.48	0.45	5.96	64	7.57	0.42	5.57	-1.21
35	56	7.74	0.42	5.41	63	7.82	0.36	4.58	-1.11
36	58	10.81	0.52	4.81	57	10.94	0.45	4.14	-1.43
37	48	10.23	0.60	5.86	62	10.56	0.59	5.57	-2.82[§]
41	54	5.70	0.32	5.70	59	5.79	0.32	5.45	-1.52
42	57	6.13	0.29	4.69	62	6.24	0.31	5.00	-1.98
43	58	6.95	0.37	5.28	65	7.40	0.42	5.64	-6.29[‖]
44	56	7.48	0.40	5.38	63	7.59	0.40	5.30	-1.60
45	51	7.70	0.43	5.56	62	7.79	0.35	4.54	-1.32
46	55	10.81	0.53	4.92	59	10.93	0.48	4.41	-1.21
47	48	10.28	0.57	5.58	63	10.52	0.55	5.21	-2.25[‡]

[*]FDI tooth notation
[†]Statistically significant at [‡]$p < 0.05$; [§]$p < 0.01$; [‖]$p < 0.001$ level

Table 3: *Descriptive statistics and t-values for crown index ((BL/MD)×100)*

Tooth Number[*]	Female				Male				*t*-Value[†]
	N	Mean	SD	CV	N	Mean	SD	CV	
11	56	84.02	6.85	8.15	62	84.42	7.09	8.40	-0.31
12	57	93.29	11.29	12.11	63	95.24	9.15	9.61	-1.04
13	58	103.56	6.91	6.67	64	105.31	7.02	6.66	-1.38
14	58	133.22	5.99	4.49	65	136.31	6.27	4.60	-2.78[§]
15	56	141.13	6.58	4.66	64	143.52	7.65	5.33	-1.82
16	57	107.92	5.02	4.65	62	109.30	4.74	4.34	-1.54
17	48	115.32	7.26	6.30	62	118.32	6.46	5.46	-2.30[‡]
21	57	84.77	6.29	7.42	65	84.99	6.74	7.93	-0.19
22	57	94.31	11.09	11.76	62	94.74	8.88	9.38	-0.24
23	57	104.15	7.02	6.74	64	105.37	7.04	6.68	-0.95
24	57	132.64	5.73	4.32	64	135.84	6.00	4.42	-2.99[§]
25	56	141.64	7.52	5.31	65	143.98	7.84	5.45	-1.67
26	57	108.09	4.78	4.42	63	110.33	4.57	4.15	-2.62[§]
27	47	114.85	6.58	5.73	56	119.74	7.24	6.04	-3.57[‖]
31	56	110.77	9.06	8.18	62	111.88	9.15	8.18	-0.66
32	58	105.98	9.17	8.65	59	106.33	8.33	7.83	-0.22
33	58	110.52	6.34	5.74	64	111.85	7.30	6.52	-1.07
34	55	112.84	7.08	6.27	64	115.41	5.81	5.04	-2.17[‡]
35	56	121.24	5.99	4.94	63	123.91	7.15	5.77	-2.20[‡]
36	58	97.24	4.50	4.63	57	97.34	4.90	5.04	-0.12
37[¶]	48	102.61	5.27	5.14	62	100.81	4.89	4.85	1.85
41	54	110.99	8.47	7.63	59	112.84	8.76	7.76	-1.14
42[¶]	57	107.01	9.34	8.73	62	106.65	9.07	8.50	0.21
43	58	111.43	6.06	5.44	65	112.75	7.29	6.46	-1.08
44	56	113.07	6.46	5.71	63	114.62	7.58	6.61	-1.19
45	51	122.24	5.45	4.46	62	124.33	7.79	6.27	-1.61
46[¶]	55	97.55	4.80	4.92	59	96.98	4.50	4.64	0.66
47[¶]	48	103.27	4.88	4.73	63	100.60	5.05	5.02	2.80[§]

[*]FDI tooth notation
[†]Statistically significant at [‡]$p < 0.05$; [§]$p < 0.01$; [‖]$p < 0.001$ level
[¶]Larger in females

Table 4: *Stepwise discriminant analysis of dental indexes*[*]

Variables Entered	Wilks' Lambda Statistic	Exact *F* Statistic	d.f.1	d.f.2	Sig.
Crown Area[†]					
Tooth 33	0.719	19.969	1	51	0.000
Tooth 34	0.594	17.075	2	50	0.000
Tooth 16	0.549	13.424	3	49	0.000
Tooth 36	0.505	11.754	4	48	0.000
Crown Module[†]					
Tooth 33	0.715	20.301	1	51	0.000
Tooth 34	0.596	16.956	2	50	0.000
Tooth 16	0.552	13.279	3	49	0.000
Tooth 36	0.507	11.677	4	48	0.000
Crown Index[†]					
Tooth 14	0.786	13.910	1	51	0.000
Tooth 26	0.713	10.081	2	50	0.000

F values are all significant at $p < 0.01$ level
[*]At each step, the variable that minimises the overall Wilks' Lambda is entered. Minimum partial F to enter is 3.84; maximum partial F to remove is 2.71
[†]All 28 variables (i.e. 28 teeth) were included in the analysis

Table 5: Classification results of the cross-validated discriminant analysis* for all 28 teeth

	Male		**Female**		**Total Average (%)**
Stepwise Discriminant Analyses	**N**	**%**	**N**	**%**	
Crown Area	24/31	77.4	18/22	81.8	79.2
Crown Module	25/31	80.6	18/22	81.8	81.1
Crown Index	21/31	67.7	16/22	72.7	69.8
Linear Measurements[2]	28/31	90.3	21/22	95.5	92.5

[*]Cross-validation (or jackknifing) is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

The dentition takes precedence particularly when preferred parameters such as the pelvis are unavailable and cranial and long bones fragmentary. However, since linear tooth measurements usually give moderate levels of accuracy in sex identification,[3,12] alternative means of assessing sex within the realm of linear measurements needs investigation. This study investigated whether univariate and multivariate sexual dimorphism in dental indexes derived from the permanent teeth offered a solution.

Univariate and multivariate sex differences in crown area and module

The results of univariate sex dimorphism for crown area and module (Tables 1 and 2) were largely consistent with those reported for linear measurements on the same sample,[2] where canines and molars showed the greatest sex difference. Also, more maxillary variables showed statistically significant sexual dimorphism ($p < 0.05$), reinforcing the observation that maxillary teeth have a greater tendency to be larger in males.[2]

Crown area and module of tooth 33 and 16 showed statistically significant univariate dimorphism (Tables 1 and 2) and also contributed to their respective stepwise discriminant analysis (Table 4). However, a number of teeth with significant univariate dimorphism did not enter the discriminant analysis. On the other hand, tooth 34 and 36 showed no significant univariate dimorphism for crown area and module yet, contributed to the stepwise discriminant analysis. These contradictions are the result of tooth correlations not being utilised in univariate statistical analysis such as the independent samples *t*-test, which compares the teeth individually between males and females.[15] Hence, some of the information useful for sex differentiation is unavailable in such analyses. On the other hand, multivariate analysis such as stepwise discriminant analysis takes into consideration tooth inter-relationships and the combined ability of a set of teeth to differentiate the sexes.[15] Hence, although a tooth may not show significant univariate sex differences, it could still contribute to sex identification on virtue of its potential to differentiate the sexes when used in combination with other teeth.

Univariate and multivariate sex dimorphism in crown index

The results for crown index differ from crown area and module reported in this study as well as those for linear measurements reported previously for the same sample:[2]

Foremost, the crown index of canines makes no contribution to sex dimorphism (Tables 3 and 4). This is a unique finding, considering that canines have shown the greatest univariate sex differences, and also contributed to discriminant analysis of other dental indices (Tables 1, 2 and 4). Canines have also displayed significant univariate and multivariate sex differences in linear[2,3] and diagonal measurements.[1,4]

Additionally, fewer teeth showed significant univariate dimorphism for the crown index (Table 3). Among these, premolars did not show significant statistical differences for crown area or module. Moreover, four variables - tooth 37, 42, 46 and 47 - showed greater mean values for females, of which the latter was statistically significant. It is interesting to note that crown index values reported by Townsend and Brown[8] had similar deviations where, females had larger means for the mandibular canines and first molars. However, in terms of linear measurements per se, both these teeth were significantly larger in males, with mandibular canines showing the greatest univariate sex dimorphism.[8] Crown index values for mandibular canine and first molar were also greater in females in a North American sample, the differences being statistically significant.[9] In a compilation of crown index data of posterior teeth for six West-Asian populations, 35% of the tooth variables were found to be larger in females.[10] These high levels of reverse dimorphism are seldom reflected in linear dimensions. Furthermore, sex classification accuracy of the discriminant analysis undertaken for crown index was recognisably lower to those performed for crown area and module (Table 5).

Crown index, therefore, presents a picture of univariate and multivariate sex dimorphism different to crown area, crown module and linear measurements. The contrasting result brings into question its validity as a measure of tooth size. According to Kondo and Townsend,[5] crown index "indicates the relative size of mesiodistal and buccolingual diameters," i.e. it expresses one linear measurement in terms of the other. While male linear dimensions are generally larger than females' in absolute terms, this may not be true when they are taken as a relative measure. Indeed, some consider crown index to be independent of the absolute values of linear dimensions.[10] We believe that, being a measure of the ratio of BL to MD dimensions expressed as percentage, the crown index value for any given tooth is affected by the *difference* between linear dimensions. The greater mean values in females or, for that matter, larger male values, merely imply proportionally greater differences between BL and MD dimensions for the respective sex and, unlike crown area or module, are not the result of greater tooth dimensions. Therefore, crown index does not quantify male tooth size vis-à-vis female tooth size as crown area, crown module and linear measurements do. Consequently, it reveals sex differences different to what one would 'normally' anticipate. Indeed, some consider crown index to be a representation of tooth shape rather than tooth size[9,16] and tooth shape is considered to be a more relevant measure of population variations and not sex differences.[17]

Utility of dental indices in sex differentiation

Introna *et al*.[11] reported 80% accuracy in sexing from discriminant analysis of dental indexes of maxillary deciduous molars. In the present study, classification accuracy of the stepwise discriminant analyses ranged between 69.8–81.1% (Table 5). This is lower to the 92.5% classification accuracy reported for linear measurements on the same sample[2] (comparison in Table 5). The sex classification accuracy of tooth ratios was also found to be lower to those of linear measurements in another study.[12] Moreover, calculating dental indices requires additional time and necessitates that both BL and MD dimensions are measurable for any given tooth - a requirement which may not always be fulfilled in forensic scenarios. Therefore, dental indexes are neither ideal nor provide information that can be used as a substitute for linear measurements and should probably be disregarded as a tool in odontometric sex assessment.

CONCLUSION

The present study has described sexual dimorphism in dental indexes derived from the permanent dentition using univariate statistics and stepwise discriminant analyses. While crown area and crown module showed univariate sex dimorphism similar to that of linear measurements, crown index depicted a marked variation. Stepwise discriminant analyses undertaken for the three dental indices produced sex assessment accuracy levels lower to that of linear measurements reported previoulsy. Hence, dental indexes do not provide additional information for sex differentiation. Linear measurements afford better sex discrimination and investigators examining sex differences in the teeth may confine themselves to analysing BL and MD dimensions per se.

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