Original Article

Odontometric sex estimation from clinically extracted molar teeth in a North Indian population sample

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Abstract

Background: Different dental features have contributed significantly toward sex determination in the forensic anthropological contexts. Population-specific standards (discriminant functions or regression formulae) have been suggested for various population groups to identify the sex of an unknown individual from dental dimensions and other odontometric features. The main purpose of the present investigation was to examine the degree of sexual dimorphism exhibited by the human teeth of North Indians and identify importance as a forensic tool in sex determination. **Materials and Methods:** The linear and diagonal dimensions were recorded at both crown and cementoenamel junction levels of 58 upper and 72 lower molars of 130 Northwest Indian subjects (73 males and 57 females). The measurements were subjected to appropriate statistical analyses to estimate the sex estimation accuracy from lower and upper molars separately. **Results:** Univariate analyses revealed that molar teeth had greater dimensions in males than the females and the mesiodistal cervical diameter (MDCV) was found to be the most suitable variable for sex determination of the molars. The classification results were in agreement with the previously conducted studies. The index of sexual dimorphism (ISD) was calculated to be higher in lower molars than the upper molars, and the highest sex differences were observed for MDCV based on the ISD. The overall sex estimation accuracy obtained from multivariate discriminant function analysis and regression analysis of pooled data was 70.0% (74% males, 64.9% females) and 66.9% (78.1% males, 52.6% females), respectively. **Conclusions:** Odontometrics can play a significant role in establishing the biological identity of an unknown individual even from a single tooth in the absence of other sophisticated molecular or biochemical techniques used for this purpose.

Key words: Accuracy rates, discriminant function analysis, extracted teeth, forensic odontology, odontometrics, sex determination

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Introduction

Bones and teeth can serve as identity signatures of the unknown victims killed in mass disasters or some criminal activities. Teeth provide valuable information in the forensic situations where other physical and biological evidence becomes impractical to serve the purpose of identification.[1] Although the role of molecular means of identification such as DNA profiling has already surpassed many other forensic techniques, the anthropological techniques still have an advantage over the much-sophisticated techniques of DNA extraction, quantification, and individualization. Anthropological means of identification are comparatively quick and easy to apply, require no sophisticated instrumentations and expertise, and consume lesser time; however, they provide results with higher estimation errors. Skull and pelvis are considered as the most informative skeletal elements of the human body, providing up to 98% sex determination accuracies. Accuracies and accepted as a reliable proof of identity by courts of law in various civil or legal cases (Daubert' law). Human tooth can also serve as an alternate mean of identity; mostly, in cases of mass disasters, natural calamities (floods, tornados, earthquakes, tsunamis) terrorist massacres, etc., from where badly mutilated, decomposed, damaged, and commingled remains of multiple individuals are generally encountered.[2]

Teeth are resistant to biological, chemical, and physical degradations, and only attrition, taphonomic breakage, and demineralization can disturb the morphological integrity of human tooth. The greater postmortem longevity and capacity to resist taphonomic damages enable teeth to present themselves as one of the least challenged biological evidence recovered from the forensic contexts. Even a single tooth can provide enough information to help reconstruct the osteobiography of the victim.[3] Sex estimation is one of the most important attributes of biological identity to be established from both metric and nonmetric traits of unknown skeletal and dental remains, and it just halves the task of a forensic anthropologist engaged in their identification. Primarily, the relationship between tooth size and sexual dimorphism (as studied by anthropologists and odontologists) is based on the data collected from their linear dimensions, i.e., buccolingual (BL) and mesiodistal (MD) dimensions of the teeth. Recording the measurements of teeth tightly packed in the jaw sockets of the oral cavity and those having some structural anomalies poses a great difficulty in taking measurements to compromise the final results. Therefore, some additional measurement techniques have been devised to limit such restrictions and anomalies. Hillson *et al*.[4] mentioned that diagonal diameters of molars, between the contact points of the tooth crown, are least affected by periodontal problems than the MD or BL measurements.

It was felt to discuss many such discrepancies encountered in forensic dental research. First, the condition of teeth to be included in a particular study becomes a major factor to affect the research findings. Common dental anomalies such as attritions, crowding, presence of wears and caries (occlusal, cervical, or root), and few other dental anomalies may affect occlusal-crown surfaces of the teeth, which indirectly hampers the precision of measurements.[5] Second, uncertainty in dental landmarks (fixed or predefined) make it difficult to take precise dental dimensions to be used for forensic purposes. Measuring a tooth still in jaw sockets at its crown or cervical levels is a problematic one as observed by previous workers.[6] It is this reason that most research about sexual dimorphism in the human tooth is based on the mandibular canine index. Despite the fact that the ratio of two measurements (MD dimension of canines and intercanine arch width of canines) possess maximum degree of sexual dimorphism, its limitations for sex estimations have been discussed by Acharya and Mainali,[7] stressing that it is the measurements through index rather than actual canine dimensions which contribute for sex estimations. Another problematic concept is the case of reverse sexual dimorphism, where female teeth dimensions exhibit greater values than the male teeth.[8] To overcome these difficulties and limitations, and to improve dental applicability in sex determination, some alternate combinations of odontometric measurements were exercised and statistically analyzed to enhance the results of the present investigation.[4,9] The main objective of the present study was to demonstrate the medicolegal importance of permanent molars in determining sex from the standards derived from the contemporary sample collected from patients whose teeth were extracted due to some medical reasons. The present study was also aimed at calculating some accuracy functions (discriminant and regression) to estimate sex from odontometric measurements of any unknown tooth belonging to the present study population.

Materials and Methods

The present study was conducted on 58 maxillary and 72 mandibular molar teeth collected from 57 male and 53 female North Indian patients who visited the Oral Health Centre of Government Medical College and Hospital, Sector-32, Chandigarh, India, for the extraction of their teeth for medical periodontal reasons. Well-informed written informed consent was taken from patients before collection and inclusion of their teeth in the present study data. The research study was approved by the Institutional Ethics Committee of the Panjab University, Chandigarh, vide letter no. PUIEC/2016/40/20//05 dated: August 18, 2016. Teeth having only intact anatomical crowns were included for measurements. Linear and diagonal dimensions of each tooth at both crown and cervical (cementoenamel junction) levels were measured with the help of a digital sliding caliper (Mitutoyo Digimatic Caliper) with calibration 0.01 mm and according to the technique given by Hillson *et al*.[4] [as diagrammatically represented in Figure 1]. All the recorded dimensions were subjected to statistical analyses. The brief description of measurements is given below.

- Crown and cervical MD measurements (mesiodistal cervical diameter [MDCV]): The distance between two parallel planes tangential to the most mesial and most distal points of the crown (MD) side and cervical region (MDCV)
- Crown and cervical BL measurements (buccolingual cervical diameter [BLCV]): The maximum distance between two parallel planes, one tangential to the most lingual point of the crown side and the other tangential to a point on the buccal crown side and cervical region
- Crown and cervical mesiolingual-distobuccal (MLDB) measurements (mesiolingual-distobuccal cervical diameter [MLDBCV]): It is defined as the maximum distance between the mesiolingual and distobuccal corners of the crown and cervical region
- Crown and cervical mesiobuccal-distolingual (MBDL) measurements (mesiobuccal-distolingual cervical diameter [MBDLCV]): Maximum distance from the mesiobuccal corner of the crown to the distolingual corner and cervical region.

The index of sexual dimorphism (ISD) was used as an indicator to describe the extent/degree of sexual differences between dimensions of male and female teeth, and it was calculated using a formula by Garn *et al*.[10] as given below:

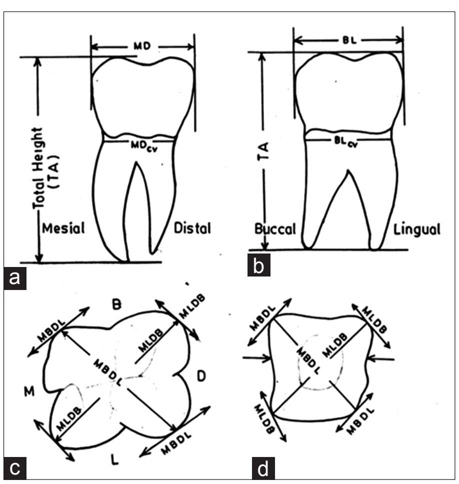

Figure 1: Diagrammatic representation of different odontometric measurements; (a) Lingual View measurements; (b) Buccal View Measurements; (c) Occlusal View measurements; (d) Cerivial level measurements (MD = Mesiodistal diameter of crown, BL = Buccolingual diameter of crown, MDCV = Mesiodistal diameter at cervical, BLCV = Buccolingual diameter at cervical (MLDB = Mesiolingual distobuccal of crown, MBDL = Mesiobuccal distolingual diameter of crown, MLDBCV = Mesiolingual-distobuccal diameter at cervical, MBDL = Mesiobuccal distolingual diameter at cervical)

$$\mathrm{ISD} = \left(\frac{X_m}{X_f}\right) - 1 \times 100$$

Where X_m = Male mean, X_f = Female mean and ISD = Index of sexual dimorphism.

The collected data were entered into the Microsoft Excel spreadsheet, and descriptive statistics were calculated using IBM SPSS Statistics Software (Version 21) (IBM Corp., Armonk, NY, 2012) and The univariate and multivariate discriminant and regression analyses were run using software, separately for upper and lower teeth, to assess the best variable/s to discriminate sex and their accuracy percentages. In multivariate function analyses (discriminant and regression), Function-I represents all the cervical measurements (MDCV, BLCV, MBDLCV, and MLDBCV), Function-II shows all the crown measurements (MD, BL, MBDL, and MLDB), Function-III represents all the linear measurements (MD, BL, MDCV, and BLCV), and Function-IV shows all the diagonal measurements (MBDL, MLDB, MBDLCV, and MLDBCV) in both maxillary and mandibular arches, and further statistical analyses were also carried out to satisfy the objectives of the present study.

Results

A total number of four linear (MD, BL, MDCV, and BLCV) and four diagonal (MLDB, MBDL, MLDBCV, and MBDLCV) measurements, two each on cervical and crown surfaces of molar tooth, were included in the present study. The average age of males and females was found to be 49.8 and 48.9 years, respectively. Majority of the teeth were found to have some sort of carious lesions; however, the teeth having their coronal and cervical dimensions intact were included in the present study sample and the teeth with distorted dimensions were discarded from the study.

Descriptive

The summary of statistical descriptive (mean, standard deviation, and '*t*'-values) of various odontometric measurements has been presented in Table 1 (combinedly for both upper and lower molars) and shown in Figure 2a-c. Except BLCV, sexual differences can be noticed in all odontometric measurements and these differences were highly significant for the variables: BL, MD, and MDCV (P < 001). The mean values of molar dimensions were found comparatively higher in males than the females. Highest sex differences were observed for MDCV based on ISD, followed by MLDBCV and MLDB, whereas BLCV reflected smallest differences. Thus, odontometric measurements at cervical level are more sexually dimorphic than at crown level. Table 2 shows the descriptive calculated separately for upper and lower molars studied in the present investigation. The tooth size of males was found larger in both maxillary and mandibular arches. Significant

Table 1: Descriptive statistics for pooled odontometric variables (both upper and lower) considered in the present study

Variables	Male (*n*=73)			Female (*n*=57)			*t*	*P*	ISD
	Mean±SD	SEE	V	Mean±SD	SEE	V			
BL	10.45±0.85	0.10	0.73	10.04±0.83	0.11	0.69	2.75	0.01*	4.08
MD	10.34±0.94	0.11	0.88	9.82±1.07	0.14	1.15	2.91	0.004**	5.30
BLCV	9.56±1.20	0.14	1.43	9.27±1.09	0.14	1.20	1.42	0.16	3.13
MDCV	8.73±0.86	0.10	0.75	7.99±1.08	0.14	1.16	4.23	0.000**	9.26
MLDB	11.00±0.70	0.82	0.49	10.48±0.93	0.12	0.88	3.54	0.001**	4.96
MBDL	11.24±0.80	0.09	0.63	10.82±1.08	0.14	1.18	2.47	0.02*	3.88
MBDLCV	10.09±0.94	0.11	0.90	9.72±1.05	0.14	1.11	2.07	0.04*	3.81
MLDBCV	10.12±0.89	0.10	0.79	9.57±0.10	0.13	0.99	3.25	0.002**	5.75

**P*<0.05, ***P*<0.001, ISD: Index of sexual dimorphism, BL: Buccolingual (crown), MD: Mesiodistal (crown), BLCV: Buccolingual (cervical), MDCV: Mesiodistal (cervical), MLDB: Mesiolingual distobuccal (crown), MBDL: Mesiobuccal distolingual (crown), MBDLCV: Mesiobuccal distolingual (cervical), MLDBCV: Mesiolingual distobuccal (cervical), SD: Standard deviation, V: Variance, SEE: Standard error of estimates

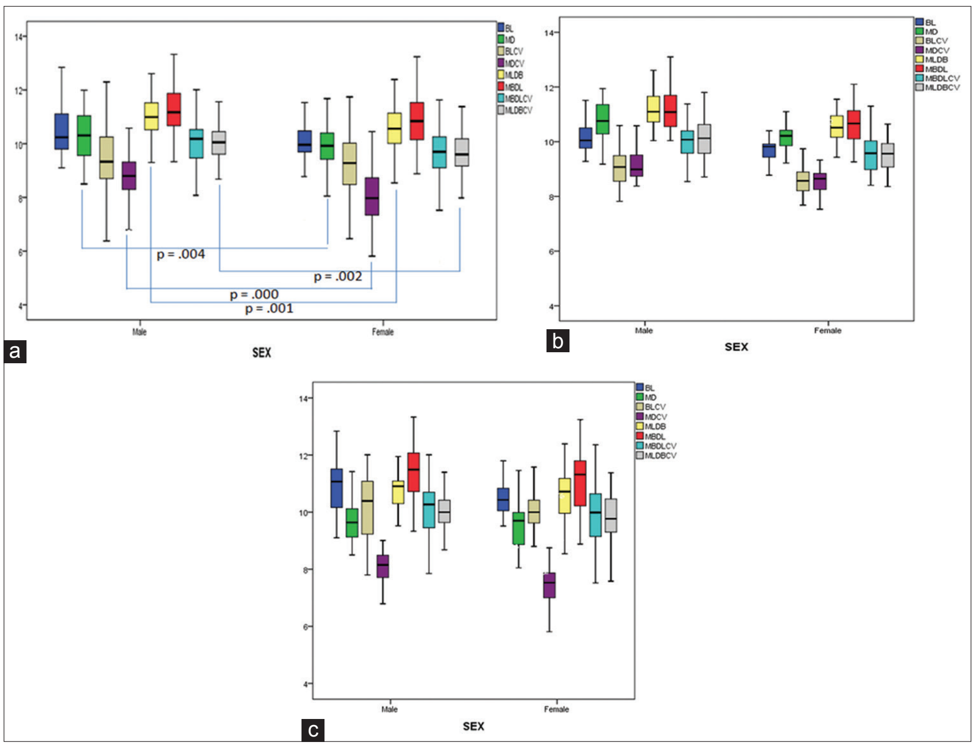

Figure 2: (a) Box plot graph for the pooled molar measurements (upper and lower combinedly). (b) Box plot graph between male and female molar measurements of lower molars only, (c) Box plot graph between male and female molar measurements of upper molars only

sex differences were noticed in all the mandibular measurements ($P<0.001$), while only BL and MDCV showed significant size differences between males and females in the maxillary molars. Mandibular MDCV and MLDBCV exhibited maximum sexual dimorphism and maxillary MD and MLDB exhibited minimum sex differences as calculated from the degree of sexual dimorphism. The ISD was calculated to be higher in lower molars than the upper molars; thus, lower molars were comparatively more sexual dimorphic. The other descriptive can be analyzed and compared as described in Table 2 and depicted by box plots [Figure 2a-c].

Univariate analyses

The results of univariate discriminant function analysis (DFA) and regression analysis (run separately for upper and lower molars) have been presented in Tables 3 and 4, respectively. In DFA, the MDCV and BL were selected as the best univariate variables to identify sex of 67.2% (58.6% males and 75.9% females) and 63.8% (62.1% males and 65.5% females) upper molars, respectively. Similarly, MD diameter and MLDB dimensions of mandibular molars correctly estimated sex of 72.2% (68.2% males and 78.6% females) and 68.1% (75% males and 64.3% females) subjects, respectively. Thus, mandibular molars displayed comparatively higher accuracy rates of sex estimation. Likewise, in regression analysis, MLDB, MDCV, and BLCV were found to estimate sex of more than 66.7% lower molars and almost all upper molars could estimate sex of about 55% subjects, except MDCV and BL where accuracy rates were more than 63.8%.

Table 2: Descriptive statistics and index of sexual dimorphism for upper (n=58) and lower (n=72) molars

Variables	Dental arch	Males (n=73)			Females (n=57)			*P*	ISD
		Mean±SD	SEE	V	Mean±SD	SEE	V		
BL	Upper	10.86±0.93	0.17	0.87	10.42±0.82	0.15	0.66	0.057*	4.22
	Lower	10.17±0.68	0.10	0.46	9.65±0.66	0.12	0.43	0.002**	5.39
MD	Upper	9.71±0.82	0.15	0.68	9.55±1.18	0.22	1.39	0.532	1.68
	Lower	10.76±0.76	0.12	0.59	10.11±0.88	0.17	0.77	0.002**	6.43
BLCV	Upper	10.24±1.21	0.22	1.46	9.96±0.97	0.18	0.95	0.328	2.81
	Lower	9.11±0.96	0.14	0.92	8.56±0.69	0.13	0.48	0.007**	6.43
MDCV	Upper	8.17±0.76	0.14	0.57	7.59±1.00	0.19	1.00	0.017*	7.64
	Lower	9.10±0.73	0.11	0.53	8.40±1.01	0.19	1.03	0.003**	8.33
MLDB	Upper	10.79±0.63	0.12	0.40	10.54±0.93	0.17	0.86	0.239	2.37
	Lower	11.15±0.71	0.11	0.50	10.42±0.96	0.18	0.92	0.001**	7.01
MBDL	Upper	11.40±0.86	0.16	0.74	11.09±1.06	0.20	1.12	0.235	2.80
	Lower	11.14±0.74	0.11	0.55	10.54±1.06	0.20	1.13	0.012*	5.69
MBDLCV	Upper	10.21±1.20	0.22	1.44	9.95±1.03	0.19	1.05	0.383	2.61
	Lower	10.01±0.74	0.11	0.55	9.48±1.04	0.20	1.08	0.024*	5.59
MLDBCV	Upper	9.98±0.76	0.14	0.58	9.74±0.98	0.18	0.96	0.307	2.46
	Lower	10.22±0.96	0.14	0.92	9.41±1.00	0.19	1.01	0.001**	8.61

*P<0.05, **P<0.001, ISD: Index of sexual dimorphism, BL: Buccolingual (crown), MD: Mesiodistal (crown), BLCV: Buccolingual (cervical), MDCV: Mesiodistal (cervical), MLDB: Mesiolingual distobuccal (crown), MBDL: Mesiobuccal distolingual (crown), MBDLCV: Mesiobuccal distolingual (cervical), MLDBCV: Mesiolingual distobuccal (cervical), SD: Standard deviation, V: Variance, SEE: Standard error of estimates

Table 3: Univariate discriminant function analysis of upper molars (n=58) and lower molars (n=72) and their accuracy percentages (male (n)=73, female (n)=57)

Variables	Dental arch	WL	CFC	GC	SP	FCFC		Accuracy percentage		
						Male	Female	Male	Female	Total
BL	Upper	0.94	1.14 −12.16	0.26 −0.26	0	14.19 −77.79	13.16 −71.58	62.10	65.50	63.80
	Lower	0.87	1.49 −14.87	0.30 −0.48	−0.06	22.64 −115.87	21.48 −104.31	59.10	75.00	65.30
MD	Upper	0.99	0.98 −9.47	0.08 −0.08	0	9.38 −46.27	9.22 −44.70	51.70	48.30	50.00
	Lower	0.86	1.23 −12.96	0.31 −0.49	−0.07	16.38 −88.80	15.39 −78.48	68.20	78.60	72.20
BLCV	Upper	0.98	0.91 −9.19	0.13 −0.13	0	8.49 −44.15	8.25 −41.76	55.20	55.20	55.20
	Lower	0.91	1.16 −10.28	0.24 −0.38	−0.05	12.17 −56.09	11.44 −49.68	59.1	71.40	63.9
MDCV	Upper	0.90	1.13 −8.90	0.32 −0.32	0	10.41 −43.20	9.68 −37.43	58.60	75.90	67.20
	Lower	0.86	1.18 −10.39	0.32 −0.50	−0.07	12.60 −58.00	11.63 −49.52	75.0	64.30	68.10
MLDB	Upper	0.98	1.26 −13.44	0.16 −0.16	0	17.15 −93.18	16.75 −88.98	62.10	48.30	55.20
	Lower	0.84	1.23 −13.31	0.35 −0.55	−0.08	16.73 −93.99	15.64 −82.14	70.5	64.30	68.10
MBDL	Upper	0.99	0.98 −9.47	0.08 −0.08	0	12.27 −70.63	11.95 −66.94	58.6	44.8	51.70
	Lower	0.90	1.14 −12.40	0.27 −0.42	−0.06	14.40 −80.87	13.61 −72.41	56.8	60.70	58.3
MBDLCV	Upper	0.99	0.90 −9.03	0.12 −0.12	0.0	8.18 −42.47	7.98 −40.38	58.60	55.20	56.90
	Lower	0.92	1.15 −11.27	0.24 −0.37	−0.06	13.22 −66.87	12.52 −60.08	65.90	60.70	63.90
MLDBCV	Upper	0.98	1.14 −11.23	0.14 −0.14	0	12.95 65.27	12.64 62.23	51.70	58.60	55.20
	Lower	0.86	1.02 −10.14	0.32 −0.51	−0.07	10.697 −55.367	9.85 −47.05	65.90	64.30	65.30

SP: Sectioning point; calculated from the average of male and female group centroids

Table 4: Univariate logistic regression analysis of upper molars (*n*=58) and lower molars (*n*=72) and their accuracy percentages

Variables	Dental arch	*B*	SE	Wald	Significant	Exp	Accuracy percentage		
							Male	Female	Total
BL	Upper	−0.61	0.33	3.44	0.064	0.55	62.1	65.50	63.80
		6.45	3.49	3.42	0.065	634.68			
	Lower	−1.54	0.56	7.48	0.006	0.21	79.50	32.10	61.10
		14.84	5.57	7.09	0.008	2,775,384.68			
MD	Upper	−0.17	0.27	0.40	0.525	0.85	51.7	48.30	50.00
		1.63	2.57	0.40	0.527	5.09			
	Lower	−1.09	0.38	8.15	0.004	0.34	79.50	39.30	63.90
		10.96	3.99	7.55	0.006	57,719.65			
BLCV	Upper	−0.24	0.25	0.98	0.320	0.78	55.2	55.20	55.20
		2.47	2.52	0.96	0.330	11.82			
	Lower	−0.86	0.37	5.49	0.019	0.43	88.60	32.10	66.70
		7.10	3.22	4.88	0.027	1217.40			
MDCV	Upper	−0.77	0.34	5.09	0.024	0.46	58.6	75.90	67.20
		6.05	2.69	5.06	0.025	425.87			
	Lower	−1.17	0.42	7.77	0.005	0.311	90.90	28.60	66.70
		9.83	3.70	7.07	0.008	18,560.98			
MLDB	Upper	−0.41	0.35	1.40	0.247	0.66	62.1	48.30	55.20
		4.36	3.70	1.39	0.248	78.56			
	Lower	−1.43	0.46	9.79	0.000	0.24	81.80	50.00	69.40
		14.98	4.93	9.25	0.000	3,212,650.92			
MBDL	Upper	−0.34	0.28	1.43	0.233	0.71	58.6	44.80	51.70
		3.81	3.20	1.41	0.234	45.03			
	Lower	−0.888	0.356	6.21	0.010	0.41	79.50	35.70	62.50
		9.192	3.87	5.64	0.020	9814.76			
MBDLCV	Upper	−0.21	0.242	0.78	0.380	0.81	58.6	55.20	56.90
		2.16	2.46	0.77	0.380	8.64			
	Lower	−0.77	0.34	5.03	0.030	0.46	86.40	32.10	65.30
		7.05	3.35	4.44	0.040	1150.50			
MLDBCV	Upper	−0.30	0.31	1.06	0.302	0.73	51.7	58.60	55.20
		3.15	3.07	1.06	0.304	23.35			
	Lower	−1.14	0.40	8.13	0.004	0.320	81.80	39.30	65.30
		10.75	3.91	7.56	0.006	46,405.23			

The regression and discriminant analyses performed on the variables of upper molars and lower molars separately showed that the percentage of assessing the two sexes was higher in lower molars in contrast to upper molars. In regression analysis, the MDCV (67.2%) for the upper molar and MLDB (69.4%) for the lower molar exhibited highest sexual dimorphism. From discriminant univariate analysis, the linear dimensions of both crown and cervical segments showed maximum classification percentage, i.e., MD (72.20%) for lower teeth and MDCV (67.2%) for upper teeth [Tables 3 and 4]. The MDCV was selected as the most sexually dimorphic discriminant variable (in pooled data of upper and lower molars), correctly classifying 66.2% subjects (74% males and 56.1% females) to their sex category. Similarly, 66.2% (78.1% males and 50.9% females) individuals were assigned correct sex from MDCV as the best selected univariate regression model. The least sexually dimorphic variable from DFA was BLCV, which could correctly classify sex of 50% subjects only. Likewise, BL and MD could identify the sex of only 56.9% teeth from the univariate regression analysis. All other variables showed classification rates in between the minimum and maximum values. Thus, we can say that both univariate DFA and univariate logistic regression analysis (LRA) of studied variables gave almost similar results in the pooled data as far as best classifying variable (MDCV) is concerned. Males exceeded in overall classification percentages for all the variables from regression analysis, whereas females exceeded the males for univariate DFA of BL, BLCV, and MLDBCV.

Multivariate analysis

The lower molars dimensions were selected in all the multivariate functions to discriminate the sex of subjects ranging from 68.1% (70.5% males, 64.3% females) to 75% (75% males, 75% females) whereas only cervical and linear dimensions of upper molars could estimate sex of 67.2% subjects. The upper crown and diagonal dimensions of studied molars did not contribute anything toward sex determination in multivariate DFA [Table 5]. The regression analysis results show that lower cervical dimensions classified sex to highest percentage of 72.2% (84.1% males, 53.6% females), and in case of upper molars, both cervical and linear dimensions classified sex of 67.2% molars. All

Table 5: Stepwise multivariate discriminant function analysis of upper and lower odontometric measurements (males=73; females=57)

Functions	Dental arch	Selected variables with WL	CFC	GC	SC	FCFC		Equations (DFA)	Accuracy percentage		
						Male	Female		Male	Female	Total
Function-I	Upper	MDCV 0.90	1.13 −8.90	0.32 −0.32	0	10.41 −43.20	9.68 −37.43	−8.90+1.13 (MDCV)	58.60	75.90	67.20
	Lower	MDCV 0.86 MLDBCV 0.81	0.70 0.61 −12.23	0.38 −0.60	−0.11	9.09 7.47 −80.24	8.41 6.87 −68.31	−12.23+0.70 (MDCV) +0.61 (MLDBCV)	75.00	75.00	75.00
Function-II	Lower	MLDB 0.84	1.23 −13.31	0.34 −0.55	−0.10	16.73 −93.99	15.67 −82.14	−13.31+1.23 (MLDB)	70.50	64.30	68.10
Function-III	Upper	BL 0.83 MDCV 0.90	0.80 0.94 −15.97	0.45 −0.45	0	16.33 13.02 −142.54	15.60 12.17 −128.17	−15.97+0.80 (BL) + 0.94 (MDCV)	69.00	65.50	67.20
	Lower	MDCV 0.86	1.18 −10.39	0.32 −0.50	−0.09	12.60 −58.001	11.63 −49.524	−10.39+1.18 (MDCV)	750.0	64.30	70.80
Function-IV	Lower	MLDB 0.84	1.23 −13.31	0.34 −0.55	−0.11	16.73 −93.99	15.67 −82.14	−13.31+1.23 (MLDB)	70.50	64.30	68.10

the functions accurately classified more than 65% subjects to their original sex category from multivariate regression analysis [Table 6]. Thus, we can conclude that upper molars dimensions (cervical and linear) could identify sex of 67.2% subjects from both multivariate analyses, i.e., DFA and LRA. The lower molar dimensions were found comparatively more accurate and reliable enough for sex determination of any unknown molar tooth from equations derived in the present study. The multivariate analysis of pooled data (without discriminating between lower and upper molars) was also run for both discriminant and regression analyses. MDCV, BL, BLCV, and MLDB were selected as the most sexually dimorphic variables. Linear dimensions have been selected more frequently than diagonal dimensions in more than half functions; thus, former gave better classification rates than the later. The results of multivariate discrimination function of both upper and lower molars metrics revealed that the equations so-formulated identified sex of more than 70% individuals. In the case of regression analysis, the function using all linear and diagonal measurements assigned the sex to the highest percentage of subjects (i.e., 69.4% subjects).

Discussion

Estimation of age, sex, racial affinity, and traumatic signatures from human skeletal remains is an important attribute of biological profile and is possible from human dentition. Both primary and permanent dentition of primates including humans exhibit certain degree of sexual dimorphism in dental features.[11] Most forensic dental experts have focused their research on assessing the extent of sexual dimorphism in human dental features, not only through odontometric analysis but also using different physical, biochemical, and molecular techniques.[12] Numerous odontometric studies have reported significant variations in tooth dimensions of individuals of two sexes among different population groups, and such variations have been used for forensic identification purposes.[13] However, these variations are population specific, showing secular and spatial variations. Hence, there arises a need for renewal and formulation of newer standards of odontometrics for different population groups. Second, most of the previous studies are based on measurements taken either on dental casts or on the teeth *in situ* in the oral cavity. Very few studies used odontometric dimensions of loose teeth collected from archeological collections for forensic or bioarcheological purposes. The present study was planned to estimate sexual dimorphism in molar metrics of Northwest Indian subjects whose teeth were extracted by a dentist for certain medical reasons and the "discarded to be" teeth were collected by one of the authors for estimating degree of sexual dimorphism in them.

The present study odontometric results show distinct sex differences in molar diameters measured at different anatomical levels of the tooth [Table 1]. Bishara *et al*.[14] were first to report sexual dimorphism molar dimensions in a mixed population sample. Various studies have examined such variations associated with the metric dimensions of molars between males and females of different populations of the world, thus signifying the importance of odontometrics as one of the important aspects of identification in forensic odontology. Such variations among the diverse populations have been attributed to some genetic, environmental, geographical, and nutritional factors which are known to affect tooth size.[15]

Of the eight variables considered in this study, four variables produced statistically significant ($P < 0.05$ or $P < 0.001$) results. All the variables from lower molars were found

Table 6: Multivariate logistic regression analysis of upper and lower odontometric measurements (males=73; females=57)

Functions	Dental arch	*B*	SE	Wald	Significant	Exp (B)	Equation	Accuracy percentage		
								Male	Female	Total
Function-I	Upper	MDCV −0.77 6.05	0.34 2.70	5.09 5.06	0.024 0.025	0.46 425.87	6.05-0.77 (MDCV)	58.6	75.9	67.20
	Lower	MDCV −0.93 MLDBCV −0.86 16.50	0.44 0.41 5.04	4.43 4.8310.74	0.035 0.028 0.001	0.396 0.408 14,700,973.314	16.50-0.93 (MDCV) - 0.86 (MLDBCV)	84.1	53.6	72.20
Function-II	Lower	MLDB −1.43 14.98	0.46 4.93	9.79 9.26	0.002 0.002	0.24 3,212,650.92	14.98-1.43 (MLDB)	81.80	50.0	69.40
Function-III	Upper	BL −0.75 MDCV −0.88 14.90	0.36 0.35 5.29	4.41 6.10 7.96	0.036 0.014 0.005	0.47 0.42 2,966,843.60	14.90-0.75 (BL) - 0.88 (MDCV)	69.00	65.50	67.20
	Lower	BL −1.14 MDCV −0.91 18.96	0.59 0.44 6.33	3.72 4.27 8.99	0.054 0.039 0.003	0.32 0.40 170,764,901.30	18.96-1.14 (BL) - 0.91 (MDCV)	84.10	35.70	65.30
Function-IV	Lower	MLDB −1.43 14.98	0.46 4.93	9.79 9.25	0.002 0.002	0.24 3,212,650.919	14.98-1.43 (MLDB)	81.8	50.0	69.40

Function-I: All cervical measurements, Function-II: All crown measurements, Function-III: All linear measurements, Function-IV: All diagonal measurement

statistically significant, and among the upper molars, no other variable was found statistically significant, except for MDCV. MDCV from both upper and lower arch was found statistically significant [Table 2]. All the variables examined, except BLCV, showed differences in the two sexes which are statistically significant. Among the eight variables considered in this investigation, the MDCV had the highest rate of accuracy and therefore highly significant. In linear measurements, MDCV, MD, and BL were the most sexually dimorphic variables. Similarly, in diagonal measurements, MLDB, MLDBCV, and MBDL depicted statistically significant differences between the two sexes ($P < 0.05$). Sufficient data are available in the literature for crown dimensions, but cervical dimensions have not been studied up to that extent. Zorba *et al*.[16] reported an order of linear measurements according to their significance in determining sex as BLCV, BL, MDCV, and MD in the Greek population. Although a study by Acharya and Mainali[17] stated that MD dimension was more reliable to determine sex than BL, they have further suggested that better results in dental sex assessment may be achieved using both MD and BL dimensions simultaneously. The greater sex discriminatory ability of MD could be related to the upper and lower arch dimensions that anteroposterior jaw measurements were statistically larger in males and the arch size influences the tooth size, implying that larger jaws in males affected comparably to larger MD dimension.[18] The results obtained in this study found that mean values of all the variables were larger in males (dimensions) than in females, and these findings were in agreement with the most previous studies on odontometric sex estimations in different populations.[19,20]

In addition to traditional linear measurements used for estimating sexual dimorphism in odontometrics, the diagonal measurements have been found equally useful for sex determination of teeth samples. The MBDL and MLDB crown diagonal diameters of molars were chosen as the best sex estimators in Turkish and Greek population when analyzed statistically.[21,22] It has been observed in this study that MDCV is highly significant for sex estimations, followed by MLDB, MLDBCV, MD, and BL.

Sexual differences in tooth size may be due to dimorphic differences in body sizes of two sexes existing in almost every human population.[16] The sex estimation accuracy for each variable (calculated from index of dimorphism) mentioned in the present study was calculated using the formula generated by Garn *et al*.[10] The percentage sexual dimorphism (based on ID) was maximum for MDCV (9.26%), followed by MLDBCV (5.74%), MD (5.29%), MLDB (4.96%), and BLCV (3.12%). Rai *et al*.[23] used intraoral and cast measurements of BL width and noticed gender dimorphism in 8.95% (right) and 8.4% (left) intraorally and 8.8% (right) and 8.3% teeth casts. Recently, Peckmann *et al*.[24] calculated the percentage of sexual dimorphism in an Afro-American sample using molar metrics and found a degree of sexual dimorphism ranging from 1.55% to 10.52% in mandibular (MBDL, crown) and maxillary (MBDL, cervical) variables, concluding that maxillary molars are more sexually dimorphic than the mandibular molars.

The potential of both LRA and DFA has been tested as a statistical tool to predict sex, age, and race in different populations in some previous odontometric studies.[25,26] The data collected from dental casts of all teeth, except for the third molar, were subjected to LRA and simultaneously compared with the results of DFA by Acharya *et al*.[25] for an Indian population. The higher percentage of classification was obtained from LRA (76%–100%) while ~52%–71% subjects were correctly classified using DFA only. Similar comparisons were made in the present investigation also. In univariate DFA and LRA analyses, each variable was subjected to analysis and it was found that the majority of the variables showed statistically significant differences in two sexes and were found reliable enough to discriminate between two sexes. From the univariate as well as multivariate analyses, MDCV was selected as the best sex predicting variable in this study. Among crown measurements, MLDB was assigned as the best predictor. Likewise, the LRA results were compared with DFA and satisfying results have been obtained from both the analyses. LRA yielded ~65%–70% classification rates from multivariate analysis and the accuracy levels from the univariate analysis varied between ~55% and 67%.

Discriminant function estimates the accuracy of variables and their contribution in sex determination. Almost all the variables included in the DFA presented statistically significant differences between males and females. Four different functions were generated from grouping of different dimensions selected in multivariate DFA to predict the sex of unknown molars. Most of the functions from upper and lower arches selected cervical and linear to suggest corresponding sex estimation equations from multivariate analyses.

Therefore, it can be said that selected variables (MDCV and BL) are more sexually dimorphic than the other molar dimensions. In Functions II and IV, the variable MLDB presented a statistically significant difference between the two sexes only for the lower arch. No upper variable was selected in any of the DFA or LRA multivariate analyses. An analysis of odontometric data in a Malay population indicated that though BL was reported to be more sexual dimorphic, MD still performed better in terms of their classification rates.[27] A study by Acharya and Mainali[7] estimated higher accuracy rate for MD dimensions (77.4%–83%) in sex identification than the BL measurements (62.3%–64.2%) and the present study results are consistent with these findings. Zorba *et al*.[22] reported that maxillary molars are more sexually dimorphic than most of the lower diagonal diameters. The sexual dimorphism in human dentition is a distinctly observed phenomenon. The odontometric analyses based on metric measurements have demonstrated the sexual dimorphism possessed by different human tooth, though canines have been positioned on topmost level, being as the most sexually dimorphic tooth among all other permanent teeth.[28,29]

Conclusions

The present study results suggest that molars dimensions, both linear and diagonal, can be used for sex determination in medicolegal matters. Males have larger crown and cervical tooth dimensions than the females. Likewise, the overall accuracy rate of correct classification was found higher for the males. Different multivariate functions generated from LRA and DFA analyses were analyzed carefully, and it was concluded that MDCV is highly sexually dimorphic as compared to other tooth dimension. It was also the best predictor of sex when multivariate functions from cervical and linear measurements were taken into consideration. The MLDB dimensions of crown and cervical were found the most frequently selected variable for correct sex estimation in different statistical analyses applied in the present study. The results of both discriminant and regression analyses were almost alike to some extent. However, an improvement in sexing accuracies can be anticipated by increasing the sample size and incorporating more population groups to generate a larger database of odontometrics and provide more reliable sex estimates.

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Conflicts of interest

There are no conflicts of interest.

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