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Univariate and multivariate sex dimorphism in the diverse age group of the South Indian dentition using the polyvinyl siloxane elastomeric impression material

Roshan Kumar Chaudhary[1,2*], Nagabhushana Doggalli[1] and Nuwadatta Subedi[3]

Abstract

Background: In the South Indian population, an odontometric analysis was performed with the older age group (18 to 60 years) and using the dimensionally stable polyvinyl siloxane elastomeric impression material (PVS) that can create minute detail replicas of tooth structure. Both measurements of buccolingual and mesiodistal dimensions of all permanent teeth (except third molars) were taken with a digital vernier calliper on 400 dental models as a reference sample and 80 dental models as a test sample, with the data from the reference samples subjected to an independent samples *t* test and stepwise logistic regression analysis.

Results: Independent samples *t* test divulged that canines were the most sexually dimorphic teeth followed by buccolingual dimensions of central and lateral incisors. All tooth variables were found greater in males, i.e. 56/56 (100%), whereas stepwise logistic regression analysis formula disclosed that the prediction accuracy in the age group of 18 to 39 years was 91%, 85% and 73% using the teeth from both the jaws, maxillary teeth and mandibular teeth respectively; similarly, in the age group of 40 to 60 years, it was 85%, 84% and 83% using teeth from both jaws, maxillary teeth and mandibular teeth respectively; finally, in the overall age group of 18 to 60 years, it was 83% and 75% using teeth from both jaws, maxillary teeth and mandibular teeth respectively. The mean percentage of sex dimorphism was found high in South Indian dentition compared with other populations.

Conclusions: Nonetheless, the accuracy of the results obtained can be considered moderate to high, and sexing can be achieved using regression formulas for each age group, which reflects demographic diversity.

Keywords: Sex determination, Odontometrics, Logistic regression analysis, Sexual dimorphism, Mesiodistal, Buccolingual, Polyvinyl siloxane

Background

Odontometric sex assessment is considered as a peculiar method and easiest processes of reconstructive postmortem dental profiling. Identification of the sufferer in situation like mass disaster is very tough and challenging, as there will be the demolition of soft tissues and all the bones may not get recovered from the scene like the pelvic fragmentation which is reported to be the most precise structural indicator. So, in situations like this, the skull bone and teeth can be a saviour and can provide material for forensic identification (Vodanoic et al. 2007). It has a high resistance to putrefaction and does not alter due to external influences, making it an outstanding forensic investigation study material (Astete 2009).

Many scholars (İşcan and Kedici 2003; Acharya and Mainali 2007; Prabhu and Acharya 2009; Rani et al. 2009; Acharya et al. 2011; Angadi et al. 2013) conducted odontometric

*Correspondence: samroshanchaudhary23@gmail.com
[1] Department of Forensic Odontology, JSS Dental College & Hospital, JSS Academy of Higher Education & Research, Mysore, Karnataka, India
Full list of author information is available at the end of the article

studies using dental casts fabricated from alginate impressions whereas an comprehensive search of the literature revealed that no research on the dimensions of teeth and their reliability in determining sex in older age groups using elastomeric impression materials have been conducted.. Since many regressive changes, such as tooth loss, occur in older age groups, only including the intact dentition of the younger adult age group cannot adequately reflect the age diversity of either population. In terms of dimensional stability and precision, elastomeric impression materials such as polyethers and polyvinyl siloxanes outperform alginate impression materials (Anusavice et al. 2012). The polyvinyl siloxane elastomeric impression material was used in the current study to obtain accurate measurements of tooth dimensions, as even a 1-mm difference in the dimension of the teeth will affect the accuracy of sexual dimorphism.

With the foregoing in mind, the aim of this study was to investigate univariate sex differences and develop stepwise logistic regression formulas that allow sex assessment in forensic reconciliation.

Methods

Source of data

A total of 240 South Indian patients, ranging in age from 18 to 60 years old, who came to the dental department for regular dental check-ups and minor tooth cleaning, including undergraduate, postgraduate students, and staff, were chosen at random and their written informed consent was obtained. The student, faculty, staff and the patient population originated from 5 of the 7 states of South India and were drawn from different ethnic groups, castes, and religious beliefs.

Sample selection and distribution

The teeth which were fairly intact with no pathosis and teeth with or without attrition were included in the sample so as to conduct study for overall population. Many regressive changes in tooth morphology, such as tooth wear, can be seen after the age of 20 years, but we believe that after the age of 40 years, the regressive changes become more severe, altering the teeth structure. It was difficult to find samples older than 40 years with relatively healthy teeth and no missing teeth, so patients who came in for minor teeth cleaning were chosen at random.

As a result, three age ranges were formed: 18–39 years ($n=100$ pairs of dental models), 40–60 years ($n=100$ pairs of dental models), and overall 18–60 years ($n=200$ pairs of dental models) (Table 1).

To determine the accuracy of the obtained logistic regression analysis formulas, a total of 40 pairs of dental models were used as a test sample for the overall age group 18 to 60 years, which was further subdivided into 20 pairs of dental models for 18 to 39 years and 20 pairs of dental models for 40 to 60 years (Table 1).

Table 1 Age groups and distribution of samples used for the study to derive the LRA formulas (reference sample)

Groups	Age (years)	Male	Female	Total
1	18 to 39	50	50	100
2	40 to 60	50	50	100
3	18 to 60	100	100	200
Age groups and distribution of samples used for the study to check the accuracy of LRA formulas (test sample)				
1	18 to 39	10	10	20
2	40 to 60	10	10	20
3	18 to 60	20	20	40

Methods

For the convenience of the patients, impressions were taken in the Department of Oral Medicine and Radiology; casts were made in the Department of Prosthodontics and Crown & Bridge, and measurements and examination of the study were performed in the Department of Forensic Odontology. After obtaining their written informed consent, a thorough case history was taken, and the pertinent information (name, age, sex, date of birth, serial number, address, and phone number) was registered in the research proforma.

Impressions of the maxillary and mandibular arches were taken using dentulous perforated impression trays and a modified two-stage putty wash technique with elastomeric impression material, i.e. polyvinyl siloxane (Ivoclar Vivadent VPS Impression Material) as per manufacturer's instructions.

After taking the impression, it was rinsed under slow running tap water until it was free of saliva and dirt, and then dried properly with the airway syringe. Since hydrogen gas would be released from the impression, the dental cast was poured about 1–2 h later to avoid any air bubbles (Ghose and Baghdady 1979).

Dental casts were made with type IV die stone (pearlstone; Asian chemicals) as per manufacturer's instructions, and air entrapment was reduced by using a vibrator with a high frequency and low amplitude.

The mesiodistal and buccolingual measurements of all 28 teeth were measured with a digital vernier calliper calibrated to 0.01 mm (Mitutoyo Corp., Kawasaki, Japan), leaving the third molars unmeasured. According to the previous authors, the MD and BL measurements were established (Acharya and Mainali 2007; Angadi et al. 2013). There were a total of 56 tooth variables measured (14 MD and 14 BL dimensions in the maxilla and mandible).

Each individual's dental model was coded with a numerical identification number (1–240) of ensure blindness to sex of the individuals. Ten sets of dental casts were obtained from the Department of Orthodontics' collection for self-training (single observer) purposes.

Statistical analysis

The values obtained were entered into the study proforma and again same data were entered to MS Excel spread sheet (Microsoft Office 2010, Microsoft Corp., and Redmond, USA). All statistical analyses were performed on the SPSS software program (SPSS Inc., Chicago, USA; now IBM Corp., Armonk, USA).

Descriptive statistical measures like mean and standard deviations were applied wherever necessary. Assessment of the potential univariate sexual dimorphism in the reference sample was done by applying the independent sample's *t* test.

A stepwise procedure was undertaken in order to select the best tooth variables for sex determination. As noted by Potter (Potter 1972), all tooth variables "may not necessarily be useful in discriminating between the sexes." Therefore, stepwise logistic regression analysis was performed on the reference sample in order to derive multiple regression formulas for both jaws and an individual jaw for all three age groups. To check the precision rates of sexing, accuracy of the test samples were compared with prediction accuracy of logistic regression analysis formulas.

Results

Univariate analysis (Table 2)

Independent sample *t* test performed for the equality of means showed sexual variability of all teeth (Table 2). Independent sample's *t* test analysis revealed that all tooth variables, i.e. 56 variables (100) % were bigger in males than in females. The canines, first premolars, central incisors, lateral incisors, first molars, second molars, and 2nd premolars chronologically showed the most sexually dimorphism, according to tooth-wise analyses determined from the average of all *t* values for mesiodistal and buccolingual dimension of each tooth (calculated from Table 2). The measurements of the maxillary teeth (average *t* value of 4.88) were significantly more sexually dimorphic than the dimensions of the mandibular teeth (average *t* value of 4.47). All teeth's buccolingual proportions (average *t* value of 5.19) were clearly more sexually dimorphic than their MD measurements (average *t* value of 4.19) (calculated from Table 2).

To express the magnitude of sexual dimorphism, the percentage of dimorphism can be described as "the percent to which the tooth size of males exceeds that of females." This was calculated as follows:

$$\left[\left(Xm/Xf\right) - 1\right] \times 100$$

where Xm = mean male tooth dimension

Xf = mean female tooth dimension (Acharya and Mainali 2007).

Table 3 summarises the percentage of dimorphism of maxillary and mandibular teeth.

The BL and MD dimensions of all four canines, as well as the BL and MD dimensions of the central incisor and lateral incisor, followed by the MD dimension of the maxillary right first premolar, were found to be sexually more dimorphic (Table 3).

Mean percentage of dimorphism

The percentage, by which the male dentition size as a whole exceeds that of females, is obtained by adding the percentage of dimorphism of each tooth which is divided by the number of teeth (Acharya and Mainali 2007). For maxillary teeth, the mean percentage of dimorphism was calculated as 5.51% of MD dimension and 8.38% of BL dimension, and for mandibular teeth, it was calculated as 5.34% of MD dimension and 7.24% of BL dimension. The MD and BL dimensions of the maxillary arch were found to be more sexually dimorphic than the MD and BL dimensions of the mandibular arch, indicating that the maxillary arch is more sexually dimorphic than the mandibular arch. Similarly, when the MD and BL percentages of dimorphism were combined, the maxillary arch (6.94%) was found to be more sexually dimorphic than the mandibular arch (6.29 percent) (calculated from Table 3)

Stepwise Logistic Regression Analysis (LRA)

The results of the stepwise LRA are depicted in Table 4.

a. Age group 18 to 39 years (Table 4)

For teeth in both jaws, maxillary teeth, and mandibular teeth, three LRA formulas were made. The tooth variables that contributed to the stepwise study, their respective coefficients, and the constant for each formula of teeth in both jaws, maxillary teeth, and mandibular teeth are all included (Table 4). MD 13, BL 13, MD 14, MD 21, BL 23, BL 24, BL 37, BL 44, and BL 45 were the tooth variables that contributed to the formula using teeth in both jaws; MD 11, MD 13, BL 13, MD 14, and BL 23 were the tooth variables that contributed to the formula using maxillary teeth; and BL 33 and BL 44 were the tooth variables that contributed to the formula using mandibular teeth (see Table 5). Most of the formula came from the canines and second premolars. BL dimensions were discovered to be the best predictors.

LRA formulas in equation form from Table 4.

Both jaws

Table 2 Descriptive statistics and *t* values of mesiodistal (MD) and buccolingual (BL) dimensions in South Indian dentition for overall age group 18 to 60 years

	Males (*n* = 100)		Females (*n* = 100)				
	Mean	**Std. deviation**	**Mean**	**Std. deviation**	**Differences between male and female (mean)**	***t* value**	***P***
MD11	8.3832	.60944	7.9014	.52157	0.4818	**6.006**	**.000**
BL11	6.5335	.80645	5.7847	.65617	0.7488	**7.202**	**.000**
MD12	6.5221	.56165	6.1100	.68552	0.4121	**4.650**	**.000**
BL12	5.7362	.80416	5.1503	.61442	0.5859	**5.789**	**.000**
MD13	7.3432	.52651	6.9362	.50665	0.407	**5.570**	**.000**
BL13	7.4367	.75290	6.4296	.71578	1.0071	**9.694**	**.000**
MD14	6.6486	.56516	6.1725	.62260	0.4761	**5.662**	**.000**
BL14	8.8876	.61289	8.2929	.81728	0.5947	**5.821**	**.000**
MD15	6.3680	.69342	6.1516	.63231	0.2164	**2.306**	**.022**
BL15	8.9065	.64914	8.5479	.57617	0.3586	**4.132**	**.000**
MD16	10.2090	.73040	9.7355	.80577	0.4735	**4.354**	**.000**
BL16	10.3883	.76932	9.9071	.59526	0.4812	**4.947**	**.000**
MD17	9.1894	.87384	8.8267	.76962	0.3627	**3.115**	**.002**
BL17	10.0633	.82028	9.6024	.69523	0.4609	**4.286**	**.000**
MD21	8.3379	.71402	7.8272	.64097	0.5107	**5.323**	**.000**
BL21	6.4598	.76783	5.9032	.89228	0.5566	**4.728**	**.000**
MD22	6.3211	.59350	6.0608	.70406	0.2603	**2.827**	**.005**
BL22	5.7485	.78773	5.1466	.61663	0.6019	**6.017**	**.000**
MD23	7.2575	.55737	6.7578	.55489	0.4997	**6.354**	**.000**
BL23	7.3578	.73698	6.3534	.84724	1.0044	**8.945**	**.000**
MD24	6.5965	.72507	6.2162	.66535	0.3803	**3.865**	**.000**
BL24	8.8855	.56735	8.3887	.79951	0.4968	**5.068**	**.000**
MD25	6.3738	.82123	6.1181	.88248	0.2557	**2.121**	**.035**
BL25	8.9364	.70055	8.6077	.71862	0.3287	**3.275**	**.001**
MD26	10.0126	.76920	9.5403	.64605	0.4723	**4.702**	**.000**
BL26	10.3792	1.06949	9.9379	.75658	0.4413	**3.369**	**.001**
MD27	8.8806	1.03540	8.4674	.87862	0.4132	**3.043**	**.003**
BL27	9.9969	.93203	9.5060	1.03392	0.4909	**3.527**	**.001**
MD31	5.3024	.46271	5.0201	.51011	0.2823	**4.099**	**.000**
BL31	5.2636	.70895	4.8261	.51230	0.4375	**5.002**	**.000**
MD32	5.7982	.47866	5.4761	.45751	0.3221	**4.864**	**.000**
BL32	5.4199	.74712	5.0600	.57592	0.3599	**3.815**	**.000**
MD33	6.5346	.47084	6.0600	.57697	0.4746	**6.373**	**.000**
BL33	6.6103	.72413	5.9129	.73846	0.6974	**6.743**	**.000**
MD34	6.6200	.51531	6.2501	.65562	0.3699	**4.436**	**.000**
BL34	7.5797	.61090	7.1184	.66217	0.4613	**5.120**	**.000**
MD35	6.8441	.75689	6.6268	.58293	0.2173	**2.275**	**.024**
BL35	8.0403	.76670	7.6653	.78911	0.375	**3.408**	**.001**
MD36	10.5601	.70043	10.1146	.78611	0.4455	**4.231**	**.000**
BL36	10.1429	.71224	9.6506	.72210	0.4923	**4.854**	**.000**
MD37	9.9533	.98228	9.4771	.86426	0.4762	**3.640**	**.000**
BL37	9.6103	.99895	9.1815	.85715	0.4288	**3.258**	**.001**
MD41	5.3503	.63997	5.0678	.69276	0.2825	**2.995**	**.003**
BL41	5.3591	.86993	4.9228	.45391	0.4363	**4.446**	**.000**
MD42	5.7614	.49928	5.5029	.47461	0.2585	**3.753**	**.000**
BL42	5.5243	.75137	5.0393	.53870	0.485	**5.246**	**.000**

Table 2 (continued)

	Males ($n=100$)		Females ($n=100$)				
	Mean	Std. deviation	Mean	Std. deviation	Differences between male and female (mean)	*t* value	*P*
MD43	6.4605	.51831	5.9541	.59276	0.5064	**6.431**	**.000**
BL43	6.5383	.78569	5.8546	.62984	0.6837	**6.790**	**.000**
MD44	6.6014	.55085	6.2688	.53745	0.3326	**4.322**	**.000**
BL44	7.5060	.52809	7.0393	.58832	0.4667	**5.903**	**.000**
MD45	6.8250	.68470	6.5433	.60787	0.2817	**3.077**	**.002**
BL45	8.0597	.76820	7.6734	.74524	0.3863	**3.609**	**.000**
MD46	10.4876	1.14288	10.1531	.64403	0.3345	**2.550**	**.012**
BL46	10.1155	.76669	9.6184	.72607	0.4971	**4.708**	**.000**
MD47	9.9150	.73722	9.4296	.78277	0.4854	**4.514**	**.000**
BL47	9.7473	.76115	9.2630	.69944	0.4843	**4.685**	**.000**

Table 3 Percentage of dimorphism of maxillary and mandibular teeth

Teeth	MD dimensions	BL dimensions
11	6.09	12.96
12	6.74	11.38
13	5.86	15.66
14	7.71	7.17
15	3.52	4.19
16	4.86	4.86
17	4.11	4.80
21	6.53	9.43
22	4.30	11.68
23	7.39	15.81
24	6.12	5.92
25	4.18	3.82
26	4.95	4.44
27	4.88	5.16
31	5.62	9.06
32	5.88	7.11
33	7.83	11.80
34	5.92	6.48
35	3.28	4.89
36	4.40	5.10
37	5.02	4.67
41	5.57	8.86
42	4.70	9.62
43	8.50	11.68
44	5.31	6.63
45	4.30	5.03
46	3.29	5.17
47	5.15	5.23

$$\begin{aligned} Ln\left[P/(1-P)\right] = -63.493 + [&(-5.997\times \mathrm{MD13}) \\ &+(3.896\times \mathrm{BL13}) + (4.748\times \mathrm{MD14}) \\ &+(2.175\times \mathrm{MD21}) + (1.965\times \mathrm{BL23}) \\ &+(2.124\times \mathrm{BL24}) + (1.366\times \mathrm{BL37}) \\ &+(3.589\times \mathrm{BL44}) + (-5.103\times \mathrm{BL45})] \end{aligned}$$

Maxillary teeth

$$\begin{aligned} Ln\left[P/(1-P)\right] = -31.700 + [&(1.397\times \mathrm{MD11}) \\ &+(-2.161\times \mathrm{MD13}) + (1.505\times \mathrm{BL13}) \\ &+(1.922\times \mathrm{MD14}) + (1.745\times \mathrm{BL23})] \end{aligned}$$

Mandibular teeth

$$Ln\left[P/(1-P)\right] = -20.187 + [(1.128\times \mathrm{BL33}) + (1.815\times \mathrm{BL44})]$$

where

Ln indicates = log-odd or logit of multiple regression equation

P indicates = probability, i.e. $P = 1\ /\ (1 + e^{-L})$, where e indicates exponential constant (2.718) and L indicates log-odd or logit of multiple regression equation.

To determine the sex, the tooth dimensions are multiplied by the respective coefficients (denoted as B in Table 5) and added to the constant. The individual is considered female if the value obtained is less than the sectioning point (0.5) given for the formula; the individual is considered male if the value obtained is greater than the sectioning point (0.5).

A value closer to 1 indicates a higher likelihood of a male case, while a value closer to 0 indicates a higher probability of a female case, similarly for all other LRA formulas.

b. Age group 40 to 60 years (Table 4)

The tooth variables that contributed to the formula using teeth in both jaws were BL 13, MD 15, BL 31, and

Table 4 Stepwise logistic regression analyses of teeth in both jaws and single jaw for age group 18 to 39 years, 40 to 60 years, and overall 18 to 60 years

Tooth variable		*B*	S.E.	Wald statistic	df	Sig.	Exp(*B*)
Age group 18 to 39 years (*N* = 100 pairs of dental cast)							
Both jaws	**MD13**	− 5.997	1.844	10.574	1	.001	.002
	BL13	3.896	1.196	10.605	1	.001	49.205
	MD14	4.748	1.349	12.389	1	.000	115.401
	MD21	2.175	.853	6.500	1	.011	8.798
	BL23	1.965	1.015	3.746	1	.053	7.132
	BL24	2.124	1.049	4.102	1	.043	8.366
	BL37	1.366	.559	5.973	1	.015	3.920
	BL44	3.589	1.464	6.012	1	.014	36.211
	BL45	− 5.103	1.369	13.897	1	.000	.006
	Constant	− 63.493	15.363	17.080	1	.000	.000
Maxillary teeth	**MD11**	1.397	.692	4.074	1	.044	4.043
	MD13	− 2.161	.896	5.816	1	.016	.115
	BL13	1.595	.611	6.819	1	.009	4.928
	MD14	1.922	.708	7.369	1	.007	6.836
	BL23	1.745	.602	8.402	1	.004	5.725
	Constant	− 31.700	7.608	17.363	1	.000	.000
Mandibular teeth	**BL33**	1.128	.346	10.652	1	.001	3.089
	BL44	1.815	.511	12.620	1	.000	6.139
	Constant	− 20.187	4.361	21.428	1	.000	.000
Age group 40 to 60 years (*N* = 100 pairs of dental cast)							
Both jaws	**BL13**	1.775	.485	13.395	1	.000	5.900
	MD15	− 2.044	.690	8.766	1	.003	.130
	BL31	2.390	.779	9.405	1	.002	10.915
	MD37	1.013	.448	5.105	1	.024	2.754
	Constant	− 21.804	5.164	17.829	1	.000	.000
Maxillary teeth	**MD12**	2.325	.873	7.098	1	.008	10.232
	BL13	2.774	.647	18.403	1	.000	16.018
	BL14	1.983	.830	5.707	1	.017	7.266
	MD15	− 2.365	.797	8.808	1	.003	.094
	BL16	1.855	.810	5.240	1	.022	6.391
	MD22	− 1.929	.885	4.744	1	.029	.145
	BL24	− 1.899	.982	3.738	1	.053	.150
	Constant	− 27.167	7.729	12.356	1	.000	.000
Mandibular teeth	**BL31**	2.509	.684	13.465	1	.000	12.286
	MD32	1.315	.579	5.153	1	.023	3.724
	MD35	− 1.505	.555	7.353	1	.007	.222
	BL35	1.032	.510	4.101	1	.043	2.807
	Constant	− 18.500	4.117	20.193	1	.000	.000
Overall age group 18 to 60 years (*N* = 200 pairs of dental cast)							
Both jaws	**MD11**	1.049	.363	8.349	1	.004	2.856
	BL13	1.279	.310	17.043	1	.000	3.591
	BL23	.878	.273	10.337	1	.001	2.407
	BL27	.389	.189	4.237	1	.040	1.476
	Constant	− 27.126	4.221	41.303	1	.000	.000

Table 4 (continued)

Tooth variable		*B*	S.E.	Wald statistic	df	Sig.	Exp(*B*)
Maxillary teeth	**MD11**	1.049	.363	8.349	1	.004	2.856
	BL13	1.279	.310	17.043	1	.000	3.591
	BL23	.878	.273	10.337	1	.001	2.407
	BL27	.389	.189	4.237	1	.040	1.476
	Constant	− 27.126	4.221	41.303	1	.000	.000
Mandibular teeth	**BL33**	.593	.293	4.106	1	.043	1.810
	BL36	.508	.249	4.156	1	.041	1.662
	MD43	.996	.349	8.167	1	.004	2.708
	BL43	.562	.309	3.299	1	.069	1.754
	Constant	− 18.400	3.104	35.135	1	.000	.000

Table 5 Mean percentage dimorphism for different populations

Population group	Maxillary		Mandibular	
	MD	BL	MD	BL
South India (present study)	5.51	8.38	5.34	7.24
Native South America (Ticuna) (Harris and Nweeia 1980)	0.45	1.90	1.53	1.42
American Caucasoid (Garn et al. 1966)	4.01	6.11	4.31	5.20
South African Caucasoid (Kieser and Groeneveld 1989)	6.16	4.83	–	–
Australian Aborigine (Barrett et al. 1963)	3.57	4.02	3.74	3.88
Nepal (Acharya and Mainali 2007)	1.90	3.61	1.91	2.69
Turkey (İşcan and Kedici 2003)	–	7.31	–	7.26
India (Prabhu and Acharya 2009)	1.05	2.9	1.35	2.24

MD 37; the tooth variables that contributed to the formula using maxillary teeth were MD 12, BL 13, BL 14, MD 15, BL 16, MD 22, and BL 24; and the tooth variables that contributed to the formula using mandibular teeth were BL 31, MD 32, MD 35, and BL 35. Both BL and MD measurements contributed equally in the stepwise LRA in this age group (Table 4).

LRA formulas in equation form from Table 4.

Both jaws

$$Ln\left[P/(1-P)\right] = -21.804 + [(1.775 \times \mathrm{BL13}) + (-2.044 \times \mathrm{MD15}) + (2.390 \times \mathrm{BL31}) + (1.013 \times \mathrm{MD37})]$$

Maxillary teeth

$$Ln\left[P/(1-P)\right] = -27.167 + [(2.325 \times \mathrm{MD12}) + (2.774 \times \mathrm{BL13}) + (1.983 \times \mathrm{BL14}) + (-2.365 \times \mathrm{MD15}) + (1.855 \times \mathrm{BL16}) + (-1.929 \times \mathrm{MD22}) + (-1.899 \times \mathrm{BL24})]$$

Mandibular teeth

$$Ln\left[P/(1-P)\right] = -18.500 + [(2.509 \times \mathrm{BL31}) + (1.315 \times \mathrm{MD32}) + (-1.505 \times \mathrm{MD35}) + (1.032 \times \mathrm{BL35})]$$

iii. Age group 18 to 60 years (Table 4)

The tooth variables that contributed to the formula using teeth in both jaws were MD 11, BL 13, BL 23, and BL 27; MD 11, BL 13, BL 23, and BL 27 for maxillary teeth; and BL 33, BL 36, MD 43, and BL 43 for mandibular teeth (see Table 4). The canines were incorporated into the majority of the formula. BL dimensions were also discovered to be better predictors than MD dimensions.

LRA formulas in equation form from Table 4.

Both jaws

$$Ln[P/(1-P)] = -27.126 + [(1.049 \times \mathrm{MD11}) + (1.279 \times \mathrm{BL13}) + (0.878 \times \mathrm{BL23}) + (0.389 \times \mathrm{BL27})]$$

Maxillary teeth

$$Ln[P/(1-P)] = -27.126 + [(1.049 \times \mathrm{MD11}) + (1.279 \times \mathrm{BL13}) + (0.878 \times \mathrm{BL23}) + (0.389 \times \mathrm{BL27})]$$

Mandibular teeth

$$Ln[P/(1-P)] = -18.400 + [(0.593 \times \mathrm{BL33}) + (0.508 \times \mathrm{BL36}) + (0.996 \times \mathrm{MD43}) + (0.562 \times \mathrm{BL43})]$$

Altogether, 20 teeth (71.43%) out of 28 teeth contributed in overall stepwise LRA as represented in Zsigmondy/Palmer notation, i.e.

6 5 4 3 2 1	1 2 3 4 7
5 4 3	1 2 3 5 6 7

Example: Sex determination using formula for teeth in both jaws in age group 18 to 39 years

To determine the sex, tooth dimensions are multiplied with respective coefficients which was denoted as *B* in Table 5 and added to the constant.

$$Ln[P/(1-P)] = -63.493 + [(-5.997 \times \mathrm{MD13}) + (3.896 \times \mathrm{BL13}) + (4.748 \times \mathrm{MD14}) + (2.175 \times \mathrm{MD21}) + (1.965 \times \mathrm{BL23}) + (2.124 \times \mathrm{BL24}) + (1.366 \times \mathrm{BL37}) + (3.589 \times \mathrm{BL44}) + (-5.103 \times \mathrm{BL45})]$$

Let us consider MD13 = 6.81 mm; BL13 = 5.69 mm; MD14 = 6.61 mm; MD21 = 7.53 mm; BL23 = 5.69 mm; BL24 = 8.77 mm; BL37 = 9.40 mm; BL44 = 7.20 mm; and BL45 = 7.99 mm.

Multiplying these dimensions with the respective coefficients and adding the constant, we obtained:

$$= -63.493 + [(-5.997 \times 6.81) + (3.896 \times 5.69) + (4.748 \times 6.61) + (2.175 \times 7.53) + (1.965 \times 5.69) + (2.124 \times 8.77) + (1.366 \times 9.40) + (3.589 \times 7.20) + (-5.103 \times 7.99)]$$

$$= -4.68574 \text{ which is logit value (L)}$$

Consider − 4.68574 as *L* value, then put the *L* value in exponential formula as Exp $^{(-L)}$, i.e. Exp $^{(-4.68574)}$. From this exponential formula, we will get the value as 108.3904516.

Again consider the obtained value as *Y*, and then put the *Y* value in probability formula as given below:

$$P = 1/(1+Y), \text{i.e.} 1/(1+108.3904516)$$

The final obtained value will be 0.009141566.

Since 0.0091 is lesser than the cutoff value 0.5, the individual is classified as female.

Accuracy of stepwise logistic regression analysis formulas

The results for accuracy of the stepwise LRA are depicted in Table 6.

Age group 18 to 39 years (Table 6)

When teeth from both jaws were used, the prediction accuracy of the stepwise logistic regression formulae obtained by their application on the reference sample that was used to construct the formulae revealed an overall accurate sex determination of 91% (Table 6). This was reduced to 85% when maxillary teeth were used and to 73% when mandibular teeth were used.

Table 6 shows the precision of the stepwise logistic regression formulae while using a test sample. The formulae for teeth in both jaws yielded an 80% right sex determination, which dropped to 70% for maxillary teeth and 65% for mandibular teeth.

Age group 40 to 60 years (Table 6)

When teeth from both jaws were used, the stepwise logistic regression formulae's prediction accuracy showed an overall accurate sex determination of 85 percent. Using maxillary teeth, this dropped to 84%, and using mandibular teeth, it dropped to 83% (Table 6).

Using the formulae for teeth in both jaws, a valid sex determination of 85% was made, which decreased to 75% using maxillary teeth and to 70% using mandibular teeth when using test sample (Table 6).

Age group 18 to 60 years (Table 6)

The stepwise LRA formulae's prediction accuracy was determined by applying them to the sample (reference sample) that was used to create the formulae, which revealed an overall correct sex determination of 83% using teeth in both jaws and maxillary teeth alone, and 74% using mandibular teeth (Table 6).

Similarly, using the test sample shown in Table 6, the formulae for teeth in both jaws and maxillary teeth alone yielded a right sex determination of 77.5%, which decreased to 75% when mandibular teeth were used.

Table 6 Prediction accuracy of stepwise LRA formulas using reference sample and test sample in different age groups

	Male		Female		Total	
	N	%	*N*	%	*N*	%
Accuracy on the sample of age group 18 to39 years used to develop model						
Teeth in both jaws	47/50	94	44/50	88	91/100	91
Maxillary teeth	44/50	88	41/50	82	85/100	85
Mandibular teeth	34/50	68	39/50	78	73/100	73
Accuracy on the sample of age group 40 to 60 years used to develop model						
Teeth in both jaws	43/50	86	42/50	84	85/100	85
Maxillary teeth	42/50	84	42/50	84	84/100	84
Mandibular teeth	39/50	78	44/50	88	83/100	83
Accuracy on the sample of overall age group 18 to 60 years used to develop model						
Teeth in Both jaws	84/100	84	82/100	82	166/200	83
Maxillary teeth	84/100	84	82/100	82	166/200	83
Mandibular teeth	76/100	76	74/100	74	150/200	74
Accuracy of LRA formula when applied on test sample of age group 18 to 60 years						
Teeth in both jaws	15/20	75	16/20	80	31/40	77.5
Maxillary teeth	15/20	75	16/20	80	31/40	77.5
Mandibular teeth	14/20	70	15/20	75	30/40	75

Due to the ability of teeth to withstand postmortem decay and fragmentation, the potential unavailability of other skeletal parameters, the ease and speed of obtaining tooth measurements, and the non-invasive nature of the process, the dentition can be used in forensic, anthropological, and archaeological cases, as shown by the results of this research.

Discussion

The present study's independent sample *t* test revealed that males outperformed females in 56 of 56 measured variables (100%) (Table 2). In contrast, the study by Angadi et al. in 2013 differs from the current study in that only 51/56 measured variables (91%) were greater in males, with the exception of five tooth variables, namely MD measurements of tooth 22, 25, 31, 35, and 45, which were greater in females (Angadi et al. 2013) Only a minority of the measured variables (46.4%) were greater in males, and reverse dimorphism was seen in the mesiodistal (MD) calculation of lower 2nd premolars, according to Acharya AB. and Mainali S. in a study in the Nepalese population in 2007 (Acharya and Mainali 2007). In a 2009 study by Prabhu S and Acharya AB, only 16/56 (28.6%) of the measured variables were greater in males, with reverse dimorphism seen in 10 tooth variables where female measurements were greater than males, including MD dimensions of tooth 15, 24, 25, 26, 34, 35, and 44 and BL dimensions of 32, 41, and 42 (Prabhu and Acharya 2009). In our study, no reverse sexual dimorphism was evident.

Even though large samples of Indian dentition were used in the previous research by Angadi et al. 2013 (Angadi et al. 2013), the authors found that only 91% of tooth dimensions were statistically greater in males, while 100% of tooth dimensions were found statistically greater in males in the current study. The proportion of greater dimension of male teeth herein is higher than in the Nepalese (46.4%) (another South Asian country) (Acharya and Mainali 2007), Tibetan (Sharma et al. 2009), and, additionally, West Asian sample such as Turkish (İşcan and Kedici 2003), Yemen Jew (Ghose and Baghdady 1979), and Iraq population (Ghose and Baghdady 1979).

All MD and BL measurements of all canines in both maxillary and mandibular arches, i.e. eight canine measurements, were included in the most sexually dimorphic tooth variables in our research, which is close to previous studies by Ditch LE and Rose JC in 1972 (Ditch and Rose 1972), Townsend GC and Brown T in 1979 (Townsend 1979), Rao NG et al. in 1989 (Rao et al. 1989), Lund H and Mornstad H in 1999 (Lund and Mörnstad 1999), and Iscan MY and Kedici PS in 2003 (İşcan and Kedici 2003).

In this research, the BL dimension of maxillary and mandibular central and lateral incisors comes after canines in terms of sexual dimorphism, whereas Angadi et al. in 2013 (Angadi et al. 2013), Prabhu S and Acharya AB in 2009 (Prabhu and Acharya 2009), and Acharya AB and Mainali S in 2007 (Acharya and Mainali 2007) revealed that molars come after canines in terms of sexual dimorphism.

While quantifying the magnitude of sexual dimorphism using the "percentage dimorphism" and "mean percentage dimorphism," both buccolingual (BL) and mesiodistal (MD) dimensions of maxillary teeth in males were found to be greater when compared with females (from Table 3). This is higher for BL dimension of maxillary (8.38%) and almost similar for mandibular teeth (7.24%), compared with the values obtained in the study conducted on Turks (İşcan and Kedici 2003) (Table 5). They reported a mean percentage of dimorphism of 7.31% for BL dimension of maxillary teeth and of 7.26% for BL dimension of mandibular teeth (İşcan and Kedici 2003).

However, similar different studies on various populations have reported relatively medium and lower percentage of dimorphism. Native South American population (Harris and Nweeia 1980), Nepalese population (Acharya and Mainali 2007), and Indian population by Prabhu S and Acharya AB in 2009 (Prabhu and Acharya 2009) has shown the least sex dimorphism (Table 5). Almost medium mean percentage of dimorphism was observed in American Caucasoids (Kieser and Groeneveld 1989), South African Caucasoids (İşcan and Kedici 2003), and Australian aborigines (Barrett et al. 1964) populations (Table 5), whereas the mean percentage dimorphism were found to be high in South Indian population compared with other populations (Table 5) which highlights the importance of population specific study.

In a study conducted in Indian population of age group 18 to 32 years by Angadi et al. in 2013 (Angadi et al. 2013), only canines (other entered variables were contributing equally) and MD dimensions of the teeth contributed into most formulas, and maximum predictor values were contributed from mandibular arch (Angadi et al. 2013), which is in contrast to our study in which the canines and second premolars contributed into most of our formulas. Also, BL dimensions were found to be best predictors than MD dimensions, and only two variables were contributed for mandibular arch (BL33, BL44).

In another study conducted in Indian population of age group 19 to 32 years by Prabhu S and Acharya AB in 2009 (Prabhu and Acharya 2009), BL dimensions were found best predictors which is similar to the findings of our study.

The accuracy of stepwise logistic regression formulae of the present study shows that BL tooth dimensions collectively revealed more univariate sexual dimorphism than the MD measurements which also translate to their greater contribution to the stepwise LRA formulas. In fact, BL variables contributed recognisably more to all formulas, indicating that they are better suited for sex prediction in South Indians. This is in contrast to most studies, i.e. Potter R.H.Y. in 1972 (Yap Potter 1972), Acharya AB., Mainali S. in 2007 (Acharya and Mainali 2007), and Angadi et al. in 2013 (Angadi et al. 2013), wherein MD dimensions contributed more to sex determination. In contrast, Ditch and Rose reported a study in 1972 in which BL and MD variables contributed equally (Ditch and Rose 1972). BL variable are easier to measure and are "reliably taken"; hence, the tendency for BL dimensions contributing more to multivariate sex assessment may be very favourable in routine casework (İşcan and Kedici 2003). Also, a greater sexual dimorphism in BL dimension was reported by Garn et al. in 1966, and its wider use was recommended. In fact, the univariate analysis also shows BL dimensions as having a greater tendency for statistically significant sexual dimorphism. However, one drawback of taking BL measurements is that it may be compromised in case of cervical abrasion and the teeth may need to be properly cleaned to rid the cervical areas from calculus or other deposits (Acharya and Mainali 2007). In case of MD measurements, the difficulty in obtaining, considering the existence of proximal contact between teeth, becomes the major disadvantage. Also, if there is crowding in the anterior segment of the jaw and altered tooth alignment, the ease in obtaining MD measurement may be more undermined. Also, excessive attrition as it has been included in present study and interproximal wear facets can alter MD dimensions. So, MD dimensions were not found much contributing to the present study in sex determination even if all the MD dimensions were statistically larger in male compared with female (Table 3).

Even if all tooth variables in the present study showed statistically significant univariate dimorphism (Table 2), only 20 teeth (71.43%) except the maxillary right second molar, maxillary left second premolar and first molar, mandibular left first premolar, mandibular right central incisor, lateral incisor, first molar, and second molar contributed to the stepwise logistic regression analysis (calculated from Table 4).

As stated by Potter et al. in 1972 (Yap Potter 1972), univariate (independent *t* test) analysis compares the respective tooth measurements between males and females individually, whereas multivariate assesses the correlations among all tooth size variables which implies that sexual dimorphism is more accurately depicted when the male dentition is compared with female dentition in its entirety.

Even accuracy was not uniform between all the three age groups; moderate accuracy was obtained for age group 18 to 60 years. High accuracy was obtained for age group 18 to 39 years, a primary reason being that the teeth in this age group are relatively intact. This would give an indication of sex differences in a younger as well as older age group, in contrast to sex differences depicted in only for younger adult age group such as the one used previously such as Ditch LE and Rose JC in 1972 (Ditch and Rose 1972), Townsend GC and Brown T in 1979 (Townsend 1979), Rao NG et al. in 1989 (Rao et al. 1989), Lund H and Mornstad H in 1999 (Lund and Mörnstad 1999), Iscan MY and Kedici PS in 2003 (İşcan and Kedici 2003), Acharya AB and Mainali S in 2007 (Acharya and Mainali 2007), and Prabhu S and Acharya AB in 2009 (Prabhu and Acharya 2009).

The stepwise logistic regression formulae produced comparatively less accurate sex prediction in the test sample than in the reference sample but was found more accurate compare to the previous Indian study conducted by Angadi et al. in 2013 (Angadi et al. 2013).

This is unsurprising because there is bound to be some bias in the determination accuracy of the stepwise logistic regression formulae when applied to the same sample that was used to construct the formulae ($n=200$ pairs of dental cast); the very aim of using a test sample ($n=20$ pairs of dental cast for age groups 18 to 39 years, 40 to 60 years, and $n=40$ pairs of dental cast for 18 to 60 years) was to eliminate bias. Our findings indicate that the stepwise logistic regression equations for the three age groups described here may predict sex in forensic casework less accurately than predicted, but with higher accuracy than a previous Indian study (Angadi et al. 2013) with a larger sample size and younger age group (Angadi et al. 2013).

The sample sizes used by Acharya AB. and Prabhu S. et al. in 2011 (Acharya et al. 2011) and Prabhu S and Acharya AB in 2009 (Prabhu and Acharya 2009) were smaller (i.e. $n=105$) and could not represent the entire population of India, given that India has the world's second largest population and is made up of people of various ethnic groups. As a result, the accuracy provided by those studies may not be appropriate for use in forensic scenarios.

Since no studies of using dimensionally stable PVS elastomeric impression materials that can provide more accurate impressions and precise measurements of teeth dimensions than alginate impressions have been found, our current research employs it in the hopes of achieving high accuracy.

The impact of age on tooth measurements is a realistic question that is rarely discussed in most odontometric sex assessment studies. Many reports, including those by Ditch LE and Rose JC in 1972 (Ditch and Rose 1972), Townsend GC and Brown T in 1979 (Townsend 1979), Rao NG et al. in 1989 (Rao et al. 1989), Lund H and Mornstad H in 1999 (Lund and Mörnstad 1999), Iscan MY and Kedici PS in 2003 (İşcan and Kedici 2003), Acharya AB and Mainali S in 2007 (Acharya and Mainali 2007), and Prabhu S and Acharya AB in 2009 (Potter 1972), have evaluated the dentitions of young adults, a main reason being that teeth in this age group are relatively intact. With time, in older age groups, the MD dimension can be influenced by advanced consumption of food and the approximate surfaces could show signs of tooth wear, which in turn may give altered dental measurements and impact sex assessment outcomes.

This study did not include interobserver variability, which is a significant limitation. The precision of the current study demonstrates that the formulas are much more appropriate for determining sex in a wide range of age groups in the South Indian population.

Conclusions

This research used polyvinyl siloxane impression material to examine gender dimorphism in the dentition of a South Indian population of various ages. South Indians have a higher magnitude of overall univariate dimorphism (100%) than the rest of the population. The largest and most robust univariate dimorphism was found in all canines, corroborating the findings of many previous studies. In the current population, the maxillary teeth and buccolingual dimensions were more sexually dimorphic. Using the teeth in both jaws and maxillary teeth alone, LRA can predict sex with a 91% accuracy rate for the age group 18 to 39 years, an 83% accuracy rate for the overall age group 18 to 60 years, and a 74% accuracy rate using mandibular teeth formulas. Because of the use of dimensionally stable PVS elastomeric impression content and population specificity, the findings can be classified as moderate to high in terms of accuracy. Since mixed prediction accuracy was achieved, the inclusion of age diversity reflects the entire population rather than just the younger adults with intact dentition. This is comparable to the near-perfect accuracy in sex assessment using pelvic and skull bones, despite the fact that the classification accuracy of most functions ranged from 74 to 91%. As a result, sexing based on tooth measurements has always been regarded as a supplement rather than a primary choice.

Abbreviations

PVS: Polyvinyl siloxane; MD: Mesiodistal; BL: Buccolingual.

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Authors' contributions

Dr. RK Chaudhary has made major contributions to the concept, design of the work, acquisition and analysis, and interpretation of sample's data regarding the dimensions of teeth along with the manuscript preparation. Dr. ND revised the concept, design of work, and interpretation of data along with the revision of manuscript prepared. Dr. NS has a major role in the analysis and interpretation of data along with the manuscript revision. All authors read and approved the final manuscript.

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Availability of data and materials

Impressions of maxillary and mandibular arches were taken using polyvinyl siloxane elastomeric impression material after obtaining written informed consent in the Department of Oral Medicine and Radiology, JSS Dental College and Hospital, JSS Academy of Higher Education & Research, Mysore, Karnataka, India.

Declarations

Ethics approval and consent to participate

Approval from ethical committee (No: JSS/DCH/IEC/2017-18/01) of JSS Academy of Higher Education and Research, Mysore, Karnataka, was obtained, and the study was conducted in accordance with the ethical standards.
A total of 240 South Indian patients, ranging in age from 18 to 60 years old, which came to the dental department for regular dental check-ups and minor tooth cleaning, including undergraduate, postgraduate students, and staff, were chosen at random and their written informed consent was obtained.

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

Author details

[1]Department of Forensic Odontology, JSS Dental College & Hospital, JSS Academy of Higher Education & Research, Mysore, Karnataka, India. [2] Research Coordinator and Lecturer of Forensic Odontology, Madan Bhandari Academy of Health Sciences, Hetauda, Nepal. [3]Department of Forensic Medicine & Toxicology, Gandaki Medical College, Pokhara, Nepal.

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