Int J Legal Med (2011) 125:199–204
DOI 10.1007/s00414-010-0417-9

ORIGINAL ARTICLE

Odontometric sex assessment from logistic regression analysis

Ashith B. Acharya · Sudeendra Prabhu · Mahadevayya V. Muddapur

Received: 29 August 2009 / Accepted: 4 January 2010 / Published online: 27 January 2010

Abstract Odontometric sex assessment is considered a useful adjunct to more robust predictors such as pelvic and cranial bones, and discriminant function analysis (DA) has been widely applied in dental sex assessment. Logistic regression analysis (LRA) is considered a better alternative, although still untested in odontometric sex prediction. This study examines the use of LRA in dental sex assessment and compares its success to DA. Mesiodistal and buccolingual dimensions of all teeth, except third molars, were obtained on dental stone casts of 105 young adults (52 females, 53 males) using digital caliper. Application of LRA to teeth of both jaws combined and to maxillary and mandibular teeth separately yielded correct sex allocation rates ranging from 76% to 100%, which proved superior to sex assessment using DA (~52–71%). LRA enabled optimal sex prediction (100%) when all teeth in both the jaws were included. Results were not as accurate when only maxillary (76.2%) or mandibular (84.8%) teeth were used. To assess and compare the use of these multivariate techniques in practical forensic casework, >25% of tooth variables were randomly deleted. LRA still performed better (~91% sex allocation accuracy vs. 62.9% for DA), indicating that LRA may be superior in its ability to predict sex irrespective of the presence of complete or incomplete sets of dentitions and should be preferred in dental sex assessment. The 100% success rate of LRA in correctly assigning sex is also noteworthy considering that, in general, tooth measurements have yielded sub-optimal sex prediction levels. However, unambiguous sex assessment is possible only when the entire dentition is available and correct sex allocation levels decreases when teeth are missing.

Keywords Skeletal identification · Sex allocation · Tooth size · Discriminant function analysis

Electronic supplementary material The online version of this article (doi:10.1007/s00414-010-0417-9) contains supplementary material, which is available to authorized users.

A. B. Acharya (✉)
Department of Forensic Odontology,
S.D.M. College of Dental Sciences and Hospital,
Sattur,
580009 Dharwad, India
e-mail: ashithacharya@hotmail.com

S. Prabhu
Department of Oral Pathology,
S.D.M. College of Dental Sciences and Hospital,
Sattur,
580009 Dharwad, India

M. V. Muddapur
Karnatak University,
Pavate Nagar,
580004 Dharwad, India

Introduction

The dentition is routinely used in forensic investigation and its applications range from postmortem comparative identification to estimating age in children, juveniles, and adults [1–3]. Teeth are also useful in reconstructive identification and it is possible to obtain reasonable quantities of information concerning race, stature, and sex from them [4–6]. Sex assessment is an important step in building the biological profile of unidentified human remains, particularly since a correct result would automatically exclude about half the population in search operations. While DNA analysis can give irrefutable evidence concerning the sex of skeletal remains, it is relatively time-consuming and technique-intensive when compared to assessment of skeletal parameters. The pelvis and skull have produced

100% or near-100% success, respectively, in sex identification [7, 8]. Dental measurements of the permanent teeth are considered a useful adjunct in sex assessment [9] and their value is enhanced since teeth are highly resistant to postmortem destruction. Application of discriminant function analysis (DA) resulted in ~95% accuracy in odontometric sex identification [9, 10], further enhancing the dentition's role. However, these results are exceptions, for other studies have found that dental measurements predict sex with a precision ranging between 77% and 87% [11–14]. Because of such sub-optimal odontometric sex prediction, alternative tooth measurements and combinations have been attempted. Unfortunately, these have led to no major improvements in predictive accuracy [15, 16].

Albanese [17 and Albanese et al. 18] used logistic regression analysis (LRA) to determine sex from the hipbone and femur and obtained accuracy rates of up to 98.5%. Steyn and İşcan [19] recently suggested that it would be interesting to see whether results of LRA and DA are on par with respect to their accuracy. Central to both is the multivariate strategy of forming a composite of weighted independent variables [20]; what is different is the way in which it is accomplished.

LRA is considered to be better than discriminant function models since the former is more flexible in its assumptions—it can handle both discrete and continuous variables, which need not be normally distributed, linearly related, or of equal variance within each group [21]. Furthermore, even when DA satisfies the assumptions required of it, logistic regression, comparatively, still performs well [21]; that is, the assumptions which DA must fulfill need not be met by LRA in order to optimize its prediction accuracy. Therefore, one would expect a 'natural' improvement in sex assessment using LRA. While LRA has been applied in other areas of forensic odontological investigations such as race prediction and age estimation [4, 22], its utility in sex prediction using teeth is unexplored. The present study has, therefore, ventured to evaluate the usefulness of LRA in odontometric sex prediction by comparing the outcome with that of DA.

Materials and methods

The sample comprised of dentitions from 105 individuals (52 females and 53 males), all young adults between 19 and 32 years of age. Most subjects ($n=102$) were 19–26 years old while the rest ($n=3$) ranged between 31 and 32 years of age. All subjects were either enrolled as students or employed as faculty in our institution and originated from this region. Following informed verbal consent, impressions of the teeth were made using alginate material and the casts poured in dental stone.

Mesiodistal (MD) and buccolingual (BL) dimensions of all teeth, except third molars, were measured on the casts using a digital caliper calibrated to 0.01 mm. The MD dimension was defined as the greatest distance between contact points on the approximate surfaces of the tooth crown and was measured with the caliper beaks placed occlusally along the long axis of the tooth [23]. In cases where teeth were rotated or misaligned, measurements were taken between points on the approximate surfaces of the crown where it was considered that contact with adjacent teeth would normally occur [23]. The BL measurement was defined as the greatest distance between the labial/buccal surface and the lingual surface of the tooth crown measured with the caliper held at right angles to the MD dimension [24].

Following measurement and data entry into an MS Excel spreadsheet, three discriminant and logistic regression analyses (one for teeth of both jaws, one each for the maxillary and mandibular teeth) were performed using SPSS 10.0 statistical program. The three analyses were undertaken with a view to compare prediction accuracy of teeth in both jaws taken together with teeth from a single jaw, as may be encountered in forensic contexts.

In both DA and LRA, coefficients and constants were derived and the variables multiplied with the respective coefficient and added to the constant. In DA, it results in a discriminant score, which is compared to the cut-off or sectioning point (the average of group centroids). A score less or more than the sectioning point would categorize the

Table 1 Cross-validated classification results of the discriminant (DA) and logistic regression analyses (LRA)

	Male		Female		Σ	
	n	%	*n*	%	*n*	%
DA						
Teeth in both jaws	31/53	58.5	29/52	55.8	60/105	57.1
Maxillary teeth	30/53	56.6	25/52	48.1	55/105	52.4
Mandibular teeth	38/53	71.7	36/52	69.2	74/105	70.5
LRA[a]						
Teeth in both jaws	53/53	100	52/52	100	105/105	100
Maxillary teeth	40/53	75.5	40/52	76.9	80/105	76.2
Mandibular teeth	46/53	86.8	43/52	82.7	89/105	84.8

[a] The consistency of regression coefficients were assessed using the Newton–Raphson test; consistency of the LRA coefficients based on all 56 tooth variables (teeth of both jaws taken together) could not be verified since the *P* values were either 0 or 1 owing to the 100% accuracy

case as female or male, respectively. In LRA, it results in a log-odd or logit. A predicted probability (P), which falls between 0 and 1, can be derived from the logit using the function $P = 1/(1 + e^{-L})$, where L is the logit of the multiple regression equation (i.e., $L = \beta_0 + \beta_1 X_1 + \beta_2 X_2 \ldots + \beta_n X_n$). The default cut-off in logistic regression is 0.5, so a case with a probability >0.5 would be categorized as male while P<0.5 would be considered female [20]. The closer the value is to 1, the greater the probability that the case is male, while a value closer to 0 indicates a greater probability of the case being female.

Albanese [17] suggests four important methods to assess the fit of a logistic model to the data: (1) calculation of the allocation accuracy of the model applied to the sample used to develop the model; (2) a histogram of probabilities of the sample; (3) a goodness of fit statistic represented by the −2 log likelihood (−2LL); and (4) calculation of allocation accuracy for a hold-out sample not used to develop the model. As an alternative to the latter, cross-validation may be undertaken [25]. While the first three methods were used to gauge the fit of the logistic model to the odontometric data, cross-validated allocation accuracy was used to assess the usefulness of LRA relative to DA. While cross-validation in DA can be performed using the in-built leave-one-out command in the SPSS 10.0 statistical program, the same is not the case for LRA. The various logistic models obtained were, therefore, tested by the method suggested by Christensen [26] which, using weighted regression equations, estimates regression coefficients when the ith case ($n-1$) is deleted. The estimated regression coefficients are one additional step of the Newton–Raphson algorithm beyond those obtained by the logistic regression. If the estimated coefficients are close to the original LRA coefficients, a 'convergence', or unaltered allocation accuracy to that of the original results may be inferred.

Results

The accuracy of sex prediction of DA and LRA are depicted in Table 1. Entering all 56 tooth variables (i.e., 28 MD and 28 BL dimensions) yielded 57.1% and 100% success rates for DA and LRA, respectively. Accuracy levels from LRA fell when consideration is limited to only the maxillary or only mandibular teeth (Table 1).

Table 2 Goodness of fit statistic

	−2 Log likelihood
Teeth in both jaws	00.00
Maxillary teeth	97.91
Mandibular teeth	83.98

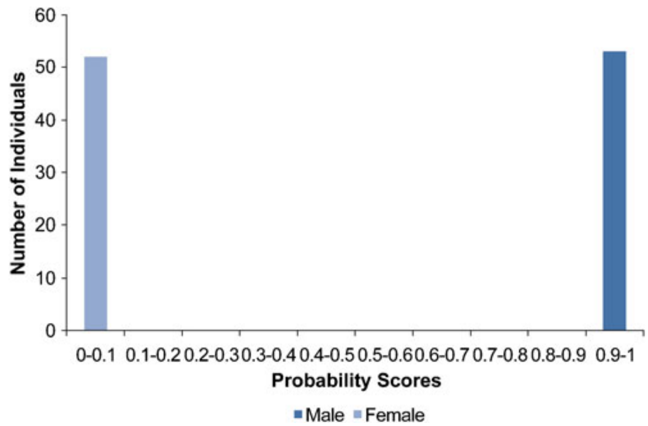

Fig. 1 Calculated probabilities for the sample using teeth from both jaws. Note the perfect fit, as denoted by the large columns near 0 and 1 with no probabilities in the mid-range

Table 2 shows the goodness of fit statistic, the −2LL. Lower the −2LL statistic, better the fit of the model to the data [17]. The −2LL for logistic regression model for teeth of both jaws is zero, indicating a perfect fit of the model to the odontometric data. The fit is better for the mandibular teeth compared to the maxillary dentition, although these are inferior to teeth from both jaws taken together.

Figures 1, 2, and 3 show the histogram of probabilities of the sample used to develop the logistic regression equations and depict the range of probability scores for the sexes. A greater number of probability scores near 0 and 1 for females and males, respectively, indicate ideal sex prediction. Indeed, sex is predicted optimally using teeth from both jaws, as denoted by the two large columns near 0 and 1 and virtually no probabilities in-between (Fig. 1). The power of sex prediction, however, is less using only maxillary or only mandibular teeth (Figs. 2 and 3).

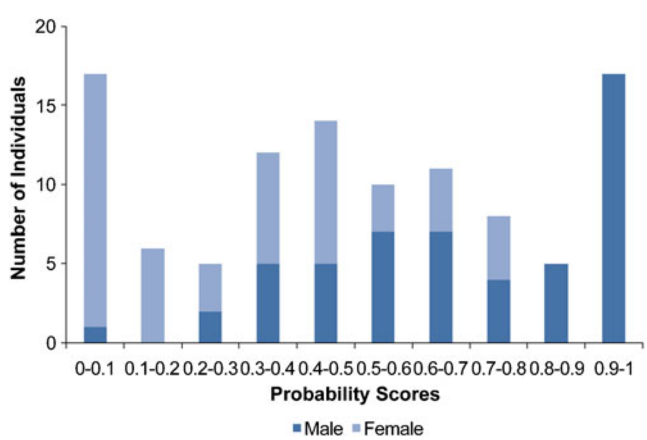

Fig. 2 Calculated probabilities for the sample using maxillary teeth. Although the greatest number of probabilities for females and males are close to 0 and 1, respectively, a large number of probabilities are observed across the mid-range

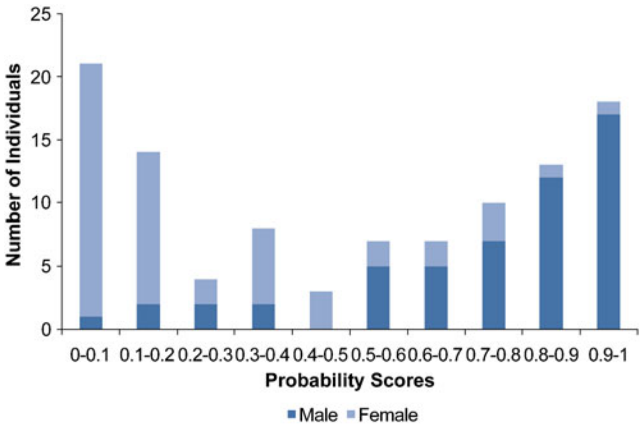

Fig. 3 Calculated probabilities for the sample using mandibular teeth. Fewer probabilities are seen in the mid-range when compared to maxilla, indicating better degrees of prediction and allocation than maxilla

The coefficients for the logistic regression equation derived for teeth of both jaws, and for maxillary and mandibular teeth separately are presented in Supplementary Table S1. Considering LRA's superior sex allocation (Table 1), coefficients for DA are not included in Table S1.

Discussion

Proper sex assessment of skeletal remains has important ramifications in forensic and bioarchaeological investigation. It has been suggested that, for optimal sex prediction, as many criteria as are available should be utilized [27, 28]. Since teeth are one of the strongest tissues in the human body and are known to resist postmortem insults, they assume importance when preferred predictors such as the pelvis or long bones are destroyed or fragmented. However, sex prediction from tooth measurements using DA has most often produced only moderate levels of accuracy [11–14], relegating such measurements to a mere 'adjunct' in sex assessment. Moreover, some believe that DA can be problematic since "it does not allow for direct prediction of group membership for the dependent variable" (page 785 in [25]). Indeed, in DA coefficients are chosen so that the distance between the group means or 'centroids' is maximized [20]. In other words, coefficients are chosen which push the group centroids as far apart as possible; that is, to maximally discriminate between the sexes [20] rather than allocate an individual to a sex.

Albanese [17] believed that LRA is a powerful, albeit underused, statistical approach for predicting a binary dependent variable such as sex. In addition to the advantages of logistic regression stated in the introduction, a major benefit over DA is that the probability of sex allocation is calculated. Hence, not only is the overall success of allocation derived (Table 1), but also the probability of each case belonging to a particular sex (Figs. 1, 2, and 3). The histograms indicate a remarkable capacity for sex assessment when all tooth variables are entered in the analysis, for the probability for all males being categorized as male is 1 (100%) and that for females is 0 (which is analogous to 100% probability derived for males), indicating a perfect fit. Using maxillary teeth only, sex was predicted correctly with a probability of ≥80% in ~42% of cases (Fig. 2) and increased to 58% of cases using only mandibular teeth (Fig. 3). Overall, correct sex allocation was just over 76% for maxillary tooth variables and almost 85% for mandibular teeth (Table 1, Figs. 2 and 3). This was better than sex classification using DA (Table 1).

The aforementioned analyses were based on complete sets of dentitions, which are seldom recovered in postmortem skeletal remains. To gauge the utility of LRA in jaws with missing teeth, a set of 15 tooth variables were randomly deleted from the data. The deleted variables constituted just over 25% of the entire dentition and were as follows: BL of 14, 15, 17, 24, 25, 26, and 33 and MD of 15, 17, 23, 24, 26, 27, 37, and 45. DA and LRA were performed for the remainder of 41 variables, the cross-validated classification

Table 3 Cross-validated classification results of the incomplete dentition[a] using discriminant analysis (DA) and logistic regression analysis (LRA)

	Male		Female		Total	
	n	%	*n*	%	*n*	%
DA						
Teeth in both jaws	35/53	66.0	31/52	59.6	66/105	62.9
Maxillary teeth	34/53	64.2	31/52	59.6	65/105	61.9
Mandibular teeth	37/53	69.8	34/52	65.4	71/105	67.6
LRA						
Teeth in both jaws	49/53	92.5	46/52	88.5	95/105	90.5
Maxillary teeth	39/53	73.6	36/52	69.2	75/105	71.4
Mandibular teeth	47/53	88.7	43/52	82.7	90/105	85.7

[a] Forty-one tooth variables were retained in both jaws (16 in maxilla and 25 in mandible)

accuracy of which is depicted in Table 3. Once again, LRA gives better success; indeed, the accuracy of LRA is one-and-half times more than DA and is relatively high at over 90%. This suggests that LRA gives high accuracy even when over one-quarter of the entire dentition is missing or unavailable for obtaining measurements.

A practical issue that is seldom addressed in most odontometric sex assessment studies is that of the influence of age on tooth dimensions. The present study and a number of previous works (e.g., [10, 14]) have evaluated dentitions of young adults, a primary 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 special food and the approximate surfaces could show signs of wear, which in turn may give altered dental measurements and impact sex assessment outcomes. It would therefore be interesting to test the use of LRA in odontometric sex differences in samples that include subjects from diverse age groups. This would give an indication of sex differences in a 'normal' population, in contrast to sex differences depicted in 'ideal' populations such as the one used here and previously [10, 14]. Also, considering that levels of dental sexual dimorphism are shown to vary from population-to-population, the results obtained here using LRA may not necessarily be observed in other ethnic groups; hence, it must be applied in conjunction with DA in additional populations for verification of its possible superiority.

Conclusion

The study has revealed that LRA may be better than DA for odontometric sex prediction. In fact, a perfect fit of the logistic regression model to the odontometric data was derived using the entire dentition, although there was a tendency for allocation accuracy to reduce when maxillary/mandibular teeth were assessed separately and when teeth are missing. Nevertheless, high sex prediction is possible by applying LRA even when more than one-fourth of tooth variables are unavailable for assessment. Overall, the results show that the dentition, when used as a unit and through the application of flexible multivariate statistics such as LRA, has potential for use as the sole indicator of sex.

Acknowledgments The authors (ABA and SP) wish to thank the students and faculty who consented to provide their dental casts for this study. We express our gratitude to Prof. C. Bhasker Rao, Director, and Prof. Srinath L. Thakur, Principal, S.D.M. College of Dental Sciences and Hospital, for their continued support and encouragement to research in forensic odontology. The authors also thank Dr. Punnya V. Angadi for assistance in impression-making and cast preparation and are grateful to the anonymous reviewers whose comments and suggestions considerably enhanced the content of this paper.

References

1. Cruz-Landeira A, Linares-Argote J, Martínez-Rodríguez M, Rodríguez-Calvo MS, Otero XL, Concheiro L (2009) Dental age estimation in Spanish and Venezuelan children. Comparison of Demirjian and Chaillet's scores. Int J Legal Med. doi:10.1007/s00414-009-0380-5
2. Zeng DL, Wu ZL, Cui MY (2009) Chronological age estimation of third molar mineralization of Han in southern China. Int J Leg Med. doi:10.1007/s00414-009-0379-y
3. Acharya AB, Vimi S (2009) Effectiveness of Bang and Ramm's formulae in age assessment of Indians from dentin translucency length. Int J Leg Med 123(5):483–488
4. Edgar HJH (2005) Prediction of race using characteristics of dental morphology. J Forensic Sci 50(2):269–273
5. Kalia S, Shetty SK, Patil K, Mahima VG (2008) Stature estimation using odontometry and skull anthropometry. Indian J Dent Res 19(2):150–154
6. Prabhu S, Acharya AB (2009) Odontometric sex assessment in Indians. Forensic Sci Int 192:129.e1–129.e5
7. Luo Y-C (1995) Sex determination from the pubis by discriminant function analysis. Forensic Sci Int 74:89–98
8. Williams BA, Rogers TL (2006) Evaluating the accuracy and precision of cranial morphological traits for sex determination. J Forensic Sci 51(4):729–735
9. Ditch LE, Rose JC (1972) A multivariate dental sexing technique. Am J Phys Anthropol 37:61–64
10. Acharya AB, Mainali S (2007) Univariate sex dimorphism in the Nepalese dentition and the use of discriminant functions in gender assessment. Forensic Sci Int 173:47–56
11. Potter RHY (1972) Univariate versus multivariate differences in tooth size according to sex. J Dent Res 51:716–722
12. Garn SM, Cole PE, Wainwright RL, Guire KE (1977) Sex discriminatory effectiveness using combinations of permanent teeth. J Dent Res 56:697
13. Potter RHY, Alcazaren AB, Herbosa FM, Tomaneng J (1981) Dimensional characteristics of the Filipino dentition. Am J Phys Anthropol 55:33–42
14. İşcan MY, Kedici SP (2003) Sexual variation in buccolingual dimensions in Turkish dentition. Forensic Sci Int 137:160–164
15. Karaman F (2006) Use of diagonal teeth measurements in predicting gender in a Turkish population. J Forensic Sci 51:630–635
16. Acharya AB, Mainali S (2008) Are dental indexes useful in sex identification? J Forensic Odontostomatol 26(2):53–59
17. Albanese J (2003) A metric method for sex determination using the hip bone and the femur. J Forensic Sci 48(2):263–273
18. Albanese J, Eklics G, Tuck A (2008) A metric method for sex determination using the proximal femur and fragmentary hipbone. J Forensic Sci 53(6):1283–1288
19. Steyn M, İşcan MY (2008) Metric sex determination from the pelvis in modern Greeks. Forensic Sci Int 179(1):86.e1–86.e6
20. Spicer J (2004) Making sense of multivariate data analysis: an intuitive approach. Sage, Thousand Oaks
21. Norusis MJ (1990) SPSS advanced statistics student guide. SPSS, Chicago, cited in: Albanese J (2003) A metric method for sex determination using the hip bone and the femur. J Forensic Sci 48(2):268
22. Knell B, Ruhstaller P, Prieels F, Schmeling A (2009) Dental age diagnostics by means of radiographical evaluation of the growth stages of lower wisdom teeth. Int J Leg Med 123(5):465–469

23. Moorrees CFA, Thomsen SØ, Jensen E, Yen PK-J (1957) Mesiodistal crown diameters of the deciduous and permanent teeth in individuals. J Dent Res 36(1):39–47
24. Townsend GC, Brown T (1979) Tooth size characteristics of Australian aborigines. Occas Pap Hum Biol 1:17–38
25. Torwalt CRRM, Hoppa RD (2005) A test of sex determination from measurements of chest radiographs. J Forensic Sci 50(4):785–790
26. Christensen R (1997) Log-linear models and logistic regression. Springer, New York
27. Genovés S (1963) Sex determination in earlier man. In: Brothwell D, Higgs E (eds) Science in archaeology. Thames and Hudson, London, pp 353–2, cited in: Ditch LE, Rose JC (1972) A multivariate dental sexing technique. Am J Phys Anthropol 37:61
28. Krogman WM, Iscan MY (1986) The human skeleton in forensic medicine. CC Thomas, Springfield, cited in: Albanese J (2003) A metric method for sex determination using the hip bone and the femur. J Forensic Sci 48(2):272