D. W. Owsley,[1] *Ph.D. and R. S. Webb,*[2] *M.A.*

Misclassification Probability of Dental Discrimination Functions for Sex Determination

REFERENCE: Owsley, D. W. and Webb, R. S., **"Misclassification Probability of Dental Discriminant Functions for Sex Determination,"** *Journal of Forensic Sciences,* JFSCA, Vol. 28, No. 1, Jan. 1983, pp. 181-185.

ABSTRACT: Misclassification probability of dental discriminant functions for sexing American whites was evaluated using three verification procedures. These validation techniques involved sample resubstitution, jackknife classification, and use of a holdout sample. Resulting discriminant score distributions yielded correct classifications ranging between 65 and 81% depending upon the particular tooth combinations selected. Dental discriminant functions are applicable to forensic science cases if used with caution.

KEYWORDS: odontology, dentition, human identification, sexing discriminant functions, misclassification

Sexual dimorphism in tooth size has led to the development of dental discriminant functions for sex determination [*1-6*]. Basic to their application to samples of forensic science or archaeological interest is the question of discriminatory effectiveness. The probability of misclassification has often been estimated through a process of resubstitution [*7*]. Samples used to compute discriminant formulas were reused in estimating error rates. Error rates of 15% or less have been reported using resubstitution [*3,4,8*]. Simulation studies, however, find this technique to be misleading, yielding a biased estimate that reduces the probability of misclassification [*7*]. Using the same data to define and test effectiveness of a function ensures favorable bias toward correct classification. The error is especially acute when samples used to develop the functions are small, a common occurrence with archaeological samples.

Other validation procedures have also been used. For example, Ditch and Rose [*3*] applied a holdout method for estimating the probability of misclassification. A separate sample not included in developing the functions was evaluated to estimate error probabilities. Their test series was limited in size. Males, who showed a higher percentage of misclassification on the various functions, were represented by a small holdout sample ($n = 6$).

Scott and Parham applied a jackknife procedure for estimating discriminatory effectiveness [*6*]. In jackknife validation, each individual is sequentially omitted from computation of the discriminant function without contributing to group means or the pooled within groups variance-covariance matrix [*9*]. Subsequent identification of individual cases on corresponding functions reduces bias [*10*]. The effectiveness of Scott and Parham's best function was 88.2% correct classification as determined by jackknife testing [*6*].

Presented at the 34th Annual Meeting of the American Academy of Forensic Sciences, Orlando, FL, 8-11 Feb. 1982. Received for publication 22 March 1982; accepted for publication 13 May 1982.

[1]Assistant professor, Department of Geography and Anthropology, Louisiana State University, Baton Rouge, LA.

[2]Graduate student, Department of Anthropology, University of Tennessee, Knoxville, TN.

This study reports the probability of misclassification for dental discriminant functions derived for a sample of American whites. Three validation procedures were applied. The overall objective was to assess the practicality of using dental discriminants for sex determination in forensic science case studies.

Materials and Methods

Mesiodistal (MD) and buccolingual (BL) diameters of 14 right permanent teeth, excepting third molars, were measured on dental casts of American white students of the University of Tennessee, Knoxville (male = 86; female = 90). Measurements were taken to 0.1 mm using Helios Dial calipers with needle tips. Sixty of these cases (males = 30, females = 30) lacked a complete set of measurements because of agensis, pathology, or orthodontic alteration. This subset was withheld from formula calculations, providing a special test for the various functions developed using the larger reference sample.

Data were analyzed using the stepwise jackknife discriminant function program BMDP7M [*9*]. Separate and combined formulas were developed for buccolingual and mesiodistal measurements of the maxillary (Max.) and mandibular (Mand.) dentition (Table 1). For each initial formula, a second formula with fewer variables was determined by including only variables having significant F ratios at the 0.05 level when entering the discriminatory sequence. For instance, buccolingual measurements of mandibular teeth I_1 through M_2 (seven variables) were entered into the discriminant function and rates of correct classification were ascertained. Because dental measurements are highly correlated and since not all dimensions present a marked sex difference, fewer teeth frequently describe the difference between males and females. In this example, two measurements proved statistically significant, canine and second premolar buccolingual measurements (Table 1). A second formula based on this variable subset was then evaluated. This limiting procedure determines the smallest variable subset with possible discriminatory utility. Formulas based on the least possible number of measurements represent a realistic approach when considering forensic science applications. Teeth may become lost, especially single rooted anterior teeth, and not located during skeletal recovery. Loss excludes use of any formula based on missing teeth. Thus, testing formulas relying on few dimensions are a practical necessity.

Three techniques were used to estimate misclassification rates: (1) resubstitution, (2) jackknife, and (3) holdout. Resubstitution and jackknife classification results are available for all formulas presented in Table 1. Both methods are based upon the reference sample. Statistically, however, the jackknife procedure best defines accuracy of resulting discriminant formulas. Validation testing using the holdout sample was possible with formulas requiring fewer variables.

Results and Discussion

Results indicate a level of accuracy ranging between 69 and 81.5% by resubstitution and 65 to 80.6% by jackknife (Table 1). Resubstitution and jackknife differences vary by as much as 10%, although the discrepancy is often minor. The average difference based on comparison of both sets of formulas is 3%, with resubstitution evaluations being less conservative. Further discussion focuses upon the more reliable jackknife test results.

Functions based on mandibular teeth perform better than those based on the maxillary dentition. This observation applies to both mesiodistal and buccolingual measurements, whether treated separately or in combination. The complete formula based on 14 buccolingual and mesiodistal maxillary measurements indicated correct classification of 65% of the sample. The corresponding value for mandibular measurements was 74.1%. Our results provide no evidence for systematically better discrimination by functions based on mesiodistal diameters than for buccolingual, although this has been noted by Garn et al [*8*].

TABLE 1—*Validation results for dental discriminant functions.*

Measurements	Teeth	Reference Sample		Number of Variables	Resubstitution Classification (% Correct)			Jackknifed Classification (% Correct)			Test Samples		Test Sample Classification (% Correct)		
		Males	Females		Males	Females	Total	Males	Females	Total	Males	Females	Males	Females	Total
Max. BL	I^1-M^2	50	50	7	72.0	68.0	70.0	66.0	64.0	65.0	...	...	...	...	...
Max. BL	M^1, M^2	50	50	2	74.0	66.0	70.0	74.0	64.0	69.0	25	21	72.0	47.6	60.9
Max. MD	I^1-M^2	50	50	7	68.0	72.0	70.0	66.0	72.0	69.0	...	...	...	...	...
Max. MD	C, M^2	50	50	2	68.0	70.0	69.0	68.0	68.0	68.0	22	20	77.3	45.0	61.1
Mand. BL	I_1-M_2	51	57	7	74.5	77.2	75.9	68.6	75.4	72.2	...	...	...	...	...
Mand. BL	C, P_2	51	57	2	74.5	80.7	77.8	72.5	80.7	76.9	28	24	67.2	69.3	68.5
Mand. MD	I_1-M_2	51	57	7	74.5	80.7	77.8	68.6	75.4	72.2	...	...	...	...	...
Mand. MD	I_1, C, M_1	51	57	3	70.6	78.9	75.0	66.7	78.9	73.1	27	25	77.8	68.0	70.9
Max. BL, MD	I^1-M^2	50	50	14	74.0	76.0	75.0	64.0	66.0	65.0	...	...	...	...	...
Max. BL, MD	MD C, BL M_2	50	50	2	72.0	78.0	75.0	72.0	76.0	74.0	27	22	70.4	59.1	65.3
Mand. BL, MD	I_1-M_2	51	57	14	78.4	78.9	78.7	72.5	75.4	74.1	...	...	...	...	...
Mand. BL, MD	BL C, BL P_1 MD M_1	51	57	3	78.4	84.2	81.5	78.4	82.5	80.6	20	19	80.0	78.9	79.5
Max., Mand. BL, MD	Max. MD C, BL C BL M^2; Mand. BL C	45	47	4	77.8	78.7	78.3	73.3	78.7	76.1	27	22	63.0	68.2	65.3

Improved results were derived using variable subsets containing two to four variables. Our best formula correctly classified 80.6% of the reference sample. This formula was based on three mandibular measurements involving the canine (BL), first premolar (BL), and first molar (MD). The measurements most consistently emphasized in abbreviated formulas were canine dimensions. Canine measurements are predominant in discriminant functions developed by others [*3,6,11*]. This tendency reflects relatively greater sexual dimorphism and greater discriminatory value of canines as compared with other teeth [*1,5,12-16*].

Holdout results were less than jackknife on all formulas. The canine, first premolar, and first molar function experienced the least reduction in accuracy, with a drop of only 1%. On other formulas misclassification rates increased dramatically, especially for females. The holdout sample was comprised of individuals with missing observations. Factors documented as responsible for missing teeth included agenesis and extraction because of crowding. Both factors have an effect on tooth size [*17*], and thus also affect dental discriminant scores.

Discriminant score distributions for American whites display considerable overlap. The estimated efficiency of our formulas approximate those of Corruccini and Henderson [*2*] and Potter [*5*], but are not as high as reported for formulas derived from archaeological samples of American Indians [*3,4,6*]. Perhaps population differences are indicated in the magnitude of sexual dimorphism.

Crown measurements do not allow sex determination at the level of accuracy achieved by conventional indicators [*18,19*]. Nevertheless, a positive view with regard to potential forensic science applications should be taken. The method has certain advantages. Dependence on the dentition is beneficial when preservation is poor. The more durable dentition may allow sex identification even though osseus criteria are damaged or destroyed. Also, dental discriminant sexing techniques are applicable to older children. Measurements needed are obtained from the permanent dentition, which begins alveolar eruption at age six. If appropriate measurements can be obtained, sex can be determined. The lack of accurate criteria for sexing subadults is a major problem in skeletal biology research. Dental discriminant sexing helps alleviate this difficulty.

Conclusions

This research has examined dental discriminant formulas as objective methods for sexing American whites. Attention was given to validation results as determined through techniques termed resubstitution, jackknife, and holdout. The evaluation attempts to establish guidelines leading to the formulation of discriminants based on known sex skeletal samples. Our findings include the following:

1. Various techniques are available for ascertaining formula effectiveness.
2. Specific combinations of variables, such as mandibular measurements and, in particular, canine measurements, provide best results.
3. The level of accuracy is approximately 80%.
4. Application of formulas to individuals displaying antemortem tooth loss decreases the level of accuracy.

Acknowledgments

The authors are indebted to the University of Tennessee Computing Center for providing computer time and to Dr. Richard L. Jantz for assistance with research design.

References

[*1*] Anderson, D. L. and Thompson, G. W., "Interrelationships and Sex Differences of Dental and Skeletal Measurements," *Journal of Dental Research*, Vol. 52, No. 3, May-June 1973, pp. 431-438.

[2] Corruccini, R. S. and Henderson, A. M., "Odontometric Discriminant Function," *Journal of Dental Research*, Vol. 55, No. 4, Aug. 1976, p. 713.
[3] Ditch, L. E. and Rose, J. C., "A Multivariate Dental Sexing Technique," *American Journal of Physical Anthropology*, Vol. 37, No. 1, July 1972, pp. 61-64.
[4] Owsley, D. W., "A Demographic Analysis of Skeletons from the Larson Site (39WW2) Walworth County, South Dakota," Master's thesis, University of Tennessee, Knoxville, 1975.
[5] Potter, R. H. Y., "Univariate Versus Multivariate Differences in Tooth Size According to Sex," *Journal of Dental Research*, Vol. 51, No. 3, May-June 1972, p. 716.
[6] Scott, G. T. and Parham, K. R., "Multivariate Dental Sexing: Discrimination of the Sexes Within an East Tennessee Mississippian Skeletal Sample," *Tennessee Anthropologist*, Vol. 4, No. 2, Nov. 1979, pp. 189-198.
[7] Lachenbruch, P. A. and Mickey, M. R., "Estimation of Error Rates in Discriminant Analysis," *Technometrics*, Vol. 10, No. 1, Feb. 1968, pp. 1-11.
[8] Garn, S. M., Cole, P. E., Wainwright, R. L., and Guire, K. E., "Sex Discrimination Effectiveness Using Combinations of Permanent Teeth," *Journal of Dental Research*, Vol. 56, No. 6, June 1977, p. 697.
[9] Jenrich, R. and Sampson, P., "P7M Stepwise Discriminant Analysis," *BMDP-77 Biomedical Computer Programs*, W. Dixon and M. Brown, Eds., University of California Press, Berkeley, 1977, pp. 711-733.
[10] Gray, H. L. and Schucany, W. R., *The Generalized Jackknife Statistic*, Marcel Dekker, New York, 1972.
[11] Breitburg, E., "A Multivariate Dental Sexing Technique for East Tennessee Mississippian Populations," unpublished manuscript on file, McClung Museum, University of Tennessee, Knoxville, no date.
[12] Garn, S. M., Brace, C. L., and Cole, P. E., "Use of Crown Areas in Odontometric Analyses," *Journal of Dental Research*, Vol. 56, No. 7, July 1977, p. 876.
[13] Garn, S. M., Cole, P. E., and Van Alstine, W. L., "Sex Discriminatory Effectiveness Using Combinations of Root Lengths and Crown Diameters," *American Journal of Physical Anthropology*, Vol. 50, No. 1, Jan. 1979, pp. 115-118.
[14] Perzigian, A. J., "The Dentition of the Indian Knoll Skeletal Population: Odontometrics and Cusp Number," *American Journal of Physical Anthropology*, Vol. 44, No. 1, Jan. 1976, pp. 113-122.
[15] Rosenzweig, K. A. and Smith, P., "Dental Variability in Isolates," *Journal of Dental Research*, Vol. 50, No. 1, Jan.-Feb. 1971, pp. 155-160.
[16] Wolpoff, M. H., "Some Aspects of the Evolution of Early Hominid Sexual Dimorphism," *Current Anthropology*, Vol. 17, No. 1, Dec. 1976, pp. 579-596.
[17] Garn, S. M., Lewis, A. B., and Kerewsky, R. S., "Third Molar Agenesis and Size Reduction of the Remaining Teeth," *Nature*, Vol. 200, No. 4905, Nov. 1963, pp. 488-489.
[18] Giles, E. and Elliot, O., "Sex Determination by Discriminant Function Analysis of Crania," *American Journal of Physical Anthropology*, Vol. 21, No. 1, March 1963, pp. 53-68.
[19] Phenice, T. W., "A Newly Developed Visual Method of Sexing the Os Pubis," *American Journal of Physical Anthropology*, Vol. 30, No. 2, March 1969, pp. 297-302.

Address request for reprints or additional information to
Douglas W. Owsley
Department of Geography and Anthropology
Louisiana State University
Baton Rouge, LA 70803