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Dental Morphological Affinities Among Late Pleistocene and Recent Humans

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ABSTRACT This study uses analyses of Mean Measure of Divergence (MMD) to assess the affinities of ten populations representing early anatomically modern humans, Upper Paleolithic Europeans, recent modern humans, and Neandertals. The 18-trait MMD analysis demonstrates that, dentally, Neandertals are quite divergent from all modern humans. The results of cluster analyses based on MMD values suggest two major clusters: Neandertals and modern humans. The data also suggest two sub-clusters within the modern human cluster. One links Upper Paleolithic Europeans with recent North Africans and Europeans. The other links early anatomically modern humans with Late Pleistocene Africans and recent Sub-Saharan Africans. These results do not support a close relationship between Neandertals and any modern human groups sampled. They also tentatively suggest that, if the two populations were interbreeding, it is not reflected in their dental morphology. The results showing a close affinity between early anatomically modern humans and Sub-Saharan Africans are consistent with the Recent African Origin model for modern human origins.

INTRODUCTION

Over the past two decades research on modern human origins has focused on interpreting fossil remains within the framework of either of two competing models. These are the Multi-Regional Evolution model (MRE): modern humans evolved from archaic predecessors in many parts of the world (Wolpoff et al., 1984; Frayer et al., 1993) and the Recent African Origin model (RAO): modern humans have a single origin, from which they spread replacing existing "archaic" hominids in the rest of the world (Stringer et al., 1984; Cann, 1987; Stringer and Andrews, 1988). While most paleoanthropologists who study late Pleistocene human evolution no longer view these models as mutually exclusive and, therefore, accept some form of "out of Africa with admixture" hypothesis, most new research remains focused on testing either of the two more extreme models (Holliday, 1999; Kidder, 1999, Wolpoff et al., 1999).

Although early researchers gave considerable weight to certain morphological dental traits in classifying Neandertals and other hominids (Keith, 1924; 1925; Weidenreich, 1937), cranial and postcranial morphology and metrics have figured relatively more prominently in testing hypotheses for modern human origins (Stringer, 1992; Trinkaus, 1992; Holliday, 1997; Wolpoff et al., 1999). Studies that have emphasized the dentition have focused primarily on metric trends (Brace et al., 1987). Descriptive studies of dental morphology have dominated the literature on later Pleistocene hominid teeth (Genet-Varcin, 1966; 1972; Smith, 1976; Trinkaus, 1978; Tillier, 1979; Wolpoff, 1979; Tillier et al., 1989; Trinkaus et al., 1999) and systematic studies of tooth crown characteristics have only recently been brought to bear on the issue of modern human origins (Crummett, 1994; Stringer et al., 1997; Irish, 1998; Tyrell and Chamberlain, 1998).

Building on these studies that relied on samples of very recent modern humans and a single Neandertal sample (e.g., the one from Krapina), Bailey and Turner (1999) compared the dental morphology of three geographically distinct Neandertal samples to that of (geographically and temporally distinct) early anatomically modern humans (Qafzeh/Skūhl) and recent Europeans. The results of Mean Measure of Divergence analysis indicated that, dentally, all Neandertal groups are more similar to each other than they are to either modern human sample. The analysis also indicated that Neandertals from one region are no more similar to modern humans from the same region (in this case, Europe and Western Asia) than they are to other modern humans, as might be expected if they contributed significantly to later human evolution in these regions.

TABLE 1. Fossil and recent samples used in this study.

Site	Fossils, Casts	Maximum Individuals	Maximum Scorable Teeth
Neandertals, Central Europe			
Krapina	casts	34	203
Neandertals, Western Europe			
Petit Puymoyen	fossils	5	12
Monsempron	fossils	4	11
Devil's Tower	casts	1	2
Arcy-sur-cure	casts	3	10
La Quina	casts	2	23
Spy	casts	2	32
Montgoudier	casts	1	3
Combe Grenal	casts	1	6
Châteaueneuf	casts	1	4
Marillac	casts	1	3
La Ferrassie	casts	3	4
Régourdou	casts	1	16
Neandertals, Near East			
Amud	fossils, casts	2	33
Tabūn	casts	5	30
Kebara	fossils, casts	1	17
Shanidar	casts	5	36
Early Anatomically Modern Humans			
Quafzeh	fossils, casts	8	116
Skhūl	fossils, casts	6	55
Upper Paleolithic, Western Europe			
Abri Blanchard	fossils	1	1
Abri Labatut	fossils	2	5
Isturitz	fossils	5	16
La Chaud	fossils	3	34
Fontéchevade	fossils	2	2
Grotte des Rois	fossils	3	44
Gruta da Caldierao	fossils	6	7
Galeria da Cisterna	fossils	2	9
Upper Paleolithic, Central Europe			
USSR	published[4]		
Late Pleistocene Africa			
Late Pleiscocene Africa	published[2]		
Recent Modern Humans			
Sub-Saharan Africans	published[1,2,3]	772	
North Africa	published[1,2,3]	545	
Northwest Europe	published[4]	162	
Poundbury	published[1,2,3]	131	

[1]Irish (1993), [2]Irish (1995), [3]Irish and Turner (1990), [4]Turner (1984). Upper Paleolithic Western Europe and Upper Paleolithic Central Europe samples were combined in the analysis. See text for explanation.

The primary objective of this study is to ascertain the dental relationships among fossil and recent human populations. This study differs from earlier ones by using a larger fossil sample (including Upper Paleolithic Europeans and early modern humans) and by using 18 tooth crown traits. MRE predicts that different geographic areas will show regional morphological differences that persist through time (Wolpoff, 1995:239). Therefore, as a test of MRE in Europe and Western Asia, I use Mean Measure of Divergence and cluster analyses to test the null hypothesis that Neandertal and AMH populations from one geographical region are (dentally) more similar to each other than either is to populations from other regions. The results of this study are discussed in terms of identifying a Neandertal dental morphological pattern and the significance it has for models of human origins.

MATERIALS and METHODS

MATERIALS

The samples include ten populations representing Neandertals and anatomically modern humans (AMH). The Neandertal, early AMH, and Upper Paleolithic Western European data were collected by me from both original fossils and high-definition casts that were produced and made available for study by Erik Trinkaus. The remaining data were taken from published sources (Table 1).

The Neandertal Sample

The Neandertal sample is divided into subsets based on their geographical sourcing. These subsets include Central European Neandertals, Western European Neandertals, and Near Eastern Neandertals (Table 1). Specimens included in the Central European subset are from the site of Krapina, Croatia. The 33 individuals used in this study are the result of Wolpoff's (1979) grouping of isolated and *in situ* teeth based on tooth morphology, wear and association, and also three composite individuals based on isolated teeth.

Data for specimens representing Western European Neandertals were collected from sites in France, Belgium and Spain. For some sites that consist largely of isolated teeth (e.g., Le Rois) composite individuals were created based on tooth status and morphology. Specimens representing Near East Neandertals are from Israel and Iraq.

The Modern Human Sample

The large modern human sample is divided into early AMH, Late Pleistocene African, Upper Paleolithic European and Recent human groups. The early AMH sample consists of individuals from sites of Qafzeh and Skhūl, Israel. The Upper Paleolithic European sample consists of data collected on fossils from sites in France and Portugal and published data on Upper Paleolithic fossils from Central Europe. The published data represent Late Pleistocene Africa, North African, Sub-Saharan Africa, England (Irish and Turner,1990; Irish, 1993; 1995) and Upper Paleolithic Northwest and Central Europe (Turner, 1984) (Tables 1, 2).

TABLE 2. Dental trait percentages and frequencies of ocurrence in samples used in this study.

	Labial Convexity UI1		Shovel UI1		Double Shovel UI1		*Tuberculum dentale* UI2		Mesial Ridge UC		Distal Acc. Ridge UC		Hypocone UM2		Cusp 5 UM1		Carabelli's Trait UM1	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
FOSSIL SAMPLES																		
Qafzeh/Skūhl	6	50.0	4	0.0	5	0.0	6	50.0	5	0.0	3	100.0	7	100.0	6	50.0	6	66.7
W. Europe Upper	3	0.0	3	66.7	3	0.0	1	0.0	1	0.0	1	100.0	4	100.0	5	60.0	4	50.0
Near East Neandertals	3	66.7	3	100.0	4	0.0	5	100.0	2	100.0	1	100.0	6	100.0	4	0.0	1	0.0
Central Europe	13	100.0	13	100.0	12	0.0	13	100.0	12	50.0	7	42.9	9	100.0	7	71.4	8	87.5
Western Europe Neandertals	6	83.3	6	100.0	4	0.0	6	50.0	4	50.0	3	66.7	8	100.0	4	75.0	5	80.0
PUBLISHED DATA																		
C. Europe Upper			6	16.7	6	16.7	3	66.7	3	0.0	3	33.3	5	60.0	6	0.0	7	57.1
Africa Late Pleistocene			22	59.1	20	0.0	18	38.9	18	22.2	7	71.4	27	92.6	14	28.6	13	46.2
Sub-Saharan Africa	425	55.5	413	28.1	437	1.1	454	61.2	586	18.1	483	71.8	772	99.0	618	32.8	683	51.2
North Africa	177	38.4	154	19.5	175	8.6	188	38.8	261	6.1	195	17.9	446	76.7	619	32.8	357	12.6
Northwest Europe	173	8.7	34	29.4	28	39.3	50	64.0	62	4.8	19	31.6	115	81.7	97	15.5	115	33.9
England			107	13.1	109	19.3	102	25.5	84	4.8	70	57.1	113	77.0	115	12.2	115	60.9
TRAIT PRESENCE	2-4		2-7		2-6		2-7		1-5		1-5		1-5		1-5		2-6	

	Parastyle UM3		Lingual Cusp No. LP2		Groove Pattern LM2		Cusp No. LM1		Cusp No LM2		Protostylid LM1		Cusp7 LM1		Anterior Fovea LM1		Peg/Red/ Absence UM3	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
FOSSIL SAMPLES																		
Qafzeh/Skūhl	7	14.3	3	66.7	5	40.0	7	0.0	7	33.6	7	0.0	7	0.0	2	50.0	5	20.0
W. Europe Upper	2	50.0	3	33.3	6	66.7	6	33.3	8	12.5	7	28.6	8	12.5			2	0.0
Near East Neandertals	1	0.0	4	100.0	4	75.0	5	0.0	6	33.3	6	0.0	7	14.3			4	50.0
Central Europe	8	12.5	14	85.7	14	78.6	10	40.0	12	0.0	14	0.0	12	58.3	12	91.7	6	0.0
Western Europe	5	0.0	10	70.0	11	100.0	13	53.8	14	0.0	15	20.0	15	26.7	10	90.0	5	0.0
PUBLISHED DATA																		
C. Europe Upper	1	0.0	4	25.0	6	16.7	7	0.0	5	80.0	7	14.3	8	0.0			4	0.0
Africa Late Pleistocene	34	0.0	39	0.0	15	93.3	27	59.3	30	30.0	33	6.1	21	28.6	28	3.6	39	0.0
Sub-Saharan Africa	550	2.0	530	68.5	617	52.4	561	16.6	585	24.1	556	21.0	598	38.5	418	67.5	708	5.4
North Africa	332	1.2	270	72.6	402	30.6	352	7.7	381	33.6	351	32.5	408	5.1	198	37.9	545	15.2
Northwest Europe	71	1.4	100	65.0	137	24.1	102	6.9	111	59.5	125	20.0	143	7.0			162	25.3
England	63	7.9	59	59.3	77	20.7	76	9.2	78	73.1	75	20.0	79	3.8			78	11.5
TRAIT PRESENCE	1-5		2-3		Y		1-5		4		1-8		1-5		2-5		P/R/A	

Upper Paleolithic Western European and Upper Paleolithic Central Europeans were combined into one sample in the analysis. W.Europe is Western Europe. C. Europe is Central Europe. Sources of data are given in Table 1. Empty cells indicate no data.

METHODS

Data were collected using the standardized Arizona State University dental anthropology system (ASUDAS) (Turner et al., 1991) on all teeth that were not heavily worn. Where dentitions were relatively complete (i.e., teeth were *in situ* or were known to belong to one individual) only the antimere showing the highest degree of trait expression (the individual count method) (Turner and Scott, 1977) was used in the analysis.

Although data were collected using the complete set of ASUDAS tooth crown and root traits (where possible) only 18 traits were used in the analysis (Table 2). This allowed for the largest number of comparisons with published data. For each of these traits, the variation was dichotomized at the standard breakpoint according to the ASU scoring system (Table 2). Analysis consisted of assessment of biological affinity, cluster analysis, and trait frequency comparisons. The Mean Measure of Divergence (MMD) (Smith in Berry and Berry, 1967) was used for assessing biological affinity. This method provides a measure of phenetic similarity based on the entire suite of dental traits. The greater the value of the MMD, the less is the likelihood that two groups being compared are closely related. Divergence between two samples was considered significant at the 0.025 level of probability when the MMD is greater than twice the standard deviation (Sjøvold, 1973). Cluster analyses were based on dissimilarity matrices derived from MMD values. Both complete linkage and Ward's methods were used to generate dendrograms depicting phenetic relationships among samples.

RESULTS

Mean Measure of Divergence

The MMDs calculated between samples are presented in Table 3. MMDs that are statistically significant ($p<.025$) have asterisks. The MMDs between each modern human sample and each Neandertal sample are very high and significant. In contrast, the MMDs between Neandertal samples are neither high nor significant. The average MMDs between Neandertals (combined sample) and modern humans is 0.605 (Table 3). This is in marked contrast to the average MMD values among Neandertal samples (0.126) and among modern human samples (0.158) given in Table 3. This difference is even larger than the one found by Tyrell and Chamberlain (1998) based on genetic diversity coefficients.

TABLE 3. Mean Measure of Divergence (MMD) values between groups analyzed in this study.

Modern Humans		NWE	PBY	SSA	NAF	QSK	LPA	EUP		WEN	CEN	NEN	
Northwest Europe	(NWE)		0.104*	0.294*	0.098*	0.195*	0.356*	0.061		0.589*	0881*	0.465*	
Poundbury	(PBY)	0.104*		0.328*	0.103*	0.066	0.345*	0.006		1.010*	1.090*	0.707*	
Sub-Saharan Africa	(SSA)	0.294*	0.328*		0.244*	0.020	0.098*	0.150		0.286*	0.421*	0.324*	
Northern Africa	(NAF)	0.098*	0.103*	0.244*		0.194*	0.225*	0.070		0.680*	0.883*	0.646*	
Qafzeh/Skhūl	(QSK)	0.195*	0.066	0.020	0.194*		0.179*	0.019		0.481*	0.718*	0.388*	
Late Pleistocene Africa	(LPA)	0.356*	0.345*	0.098*	0.225*	0.179*		0.154*		0.396*	0.392*	0.521*	
European Upper Paleolithic	(EUP)	0.061	0.006	0.150	0.070	0.019	0.154*		AVG	0.482*	0.810*	0.530*	AVG
Average Modern Human MMDs		0.185	0.159	0.189	0.156	0.112	0.226	0.077	0.158	0.572	0.747	0.515	0.605
Neandertals													
Western Europe	(NEW)	0.589*	1.010*	0.286*	0.680*	0.481*	0.396*	0.482*			0.009	0.106	
Central Europe	(CEN)	0.881*	1.090*	0.421*	0.883*	0.718*	0.392*	0.810*		0.009		0.272	
Near East	(NEN)	0.465*	0.707*	0.324*	0.646*	0.388*	0.521*	0.530*		0.106	0.272		AVG
Average Neandertal MMDs										0.053	0.136	0.189	0.126

* indicates a statistically significant MMD. AVG is the average of MMD's, discussed above in the section, " Results." An empty cell indicates the result, had a sample been compared with itself.

If modern humans evolved through the process of local evolution in Europe and the Near East we would predict phenetic analyses to show that Neandertals are (dentally) more similar to AMH from the same geographic region than they are to AMH and Neandertals from other geographic regions. Contrary to this prediction MMD values indicate that Neandertals are much more similar to each other than they are to any modern human population. Moreover, the modern population that is dentally most similar (although still quite divergent) to Neandertals is Sub-Saharan Africans (not Recent or Upper Paleolithic Europeans). This finding is in agreement with findings by Stringer et al (1997) and Tyrell and Chamberlain (1998) based on cladistic analyses and genetic distance coefficients, respectively.

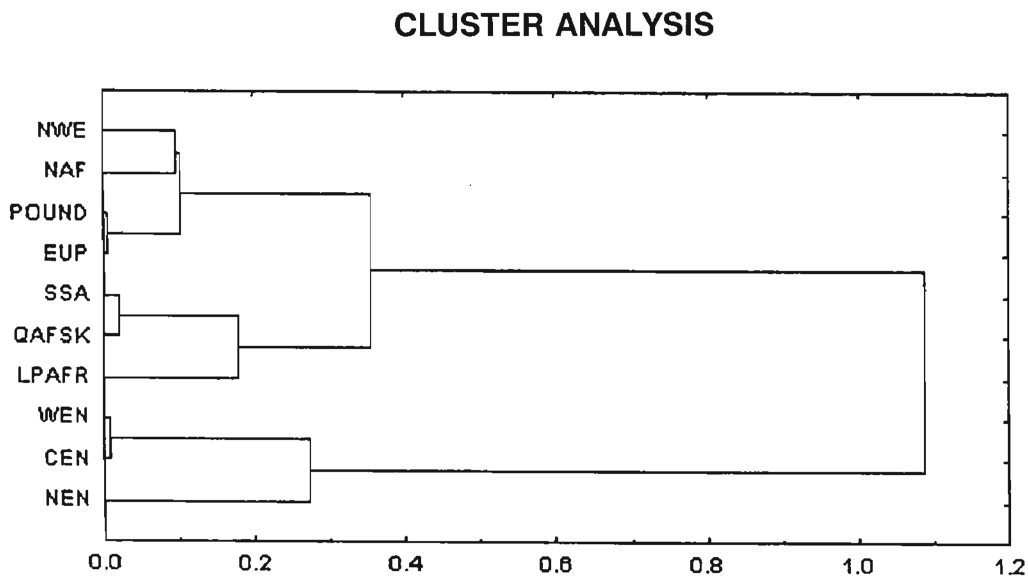

Fig. 1 Complete linkage method cluster dendrogram of MMD values of ten modern and Neandertal samples. Abbreviations given in Table 2.

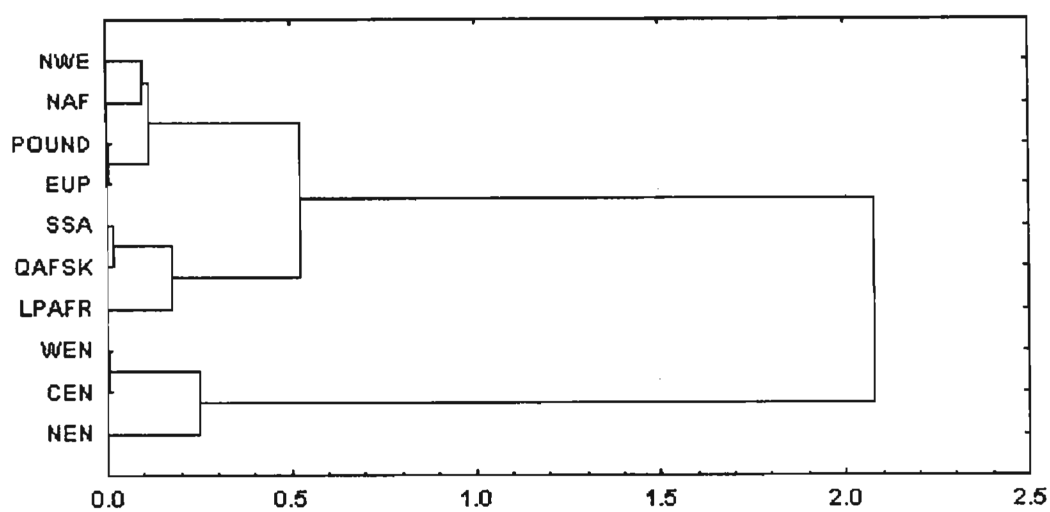

Fig. 2. Wards method cluster dendrogram of MMD values between ten modern human and Neandertal samples. Abbreviations given in Table 2.

Both cluster analyses resulted in identical dendrograms (Figures 1 and 2). Both suggest that Neandertals and modern humans fall into two distinct clusters, with modern human samples (regardless of their geographic or temporal sourcing) clustering with each other to the exclusion of Neandertals. Within the modern human cluster other sub-clusters are apparent. One links Upper Paleolithic Europeans with Recent Europeans and North Africans. The other links the early AMH (Qafzeh/Skhūl) sample with Recent Sub-Saharan Africans and (more distantly) Late Pleistocene Africans.

TRAIT FREQUENCY ANALYSIS

Both MMD and cluster analyses suggest that the Neandertal dental pattern is unique. A close inspection of trait frequencies can provide clues about which traits contribute to the distinctiveness of Neandertal teeth. Of the traits listed in Table 4, unusual incisor morphology that combines strong shoveling, labial convexity, and tubercle development is the most noteworthy of Neandertal dental traits. Neandertals show an average frequency of 100.0% for shoveling, 90.9% for labial convexity, and 87.5% for *tuberculum dentale*. Interestingly, what the frequencies in Table 4 do not show is that Neandertals also exhibit some of the highest expressions of these traits. For example, scores for labial convexity expression are often higher than the highest grade (grade 4) on the ASUDAS scale (Bailey, personal observation).

When compared to world averages for trait frequencies (Table 4) Neandertals are at the extreme ends of the modern range for many traits (incisor shoveling, mandibular first molar cusp 7, absence of 4-cusped mandibular second molars, absence of maxillary incisor double shoveling). They are even outside the range of variation for some traits (mesial ridge, Carabelli's cusp, M^1 cusp 5, M^2 Y-groove). This pattern is not found in any recent or fossil population studied. Moreover, with the exception of double shoveling absence and Carabelli's cusp presence, Neandertals exhibit a pattern opposite that seen in living Europeans, who are characterized by trait absence more than trait presence (Mayhall and Saunders, 1986; Scott and Turner, 1997).

TABLE 4. Neandertal combined trait frequencies compared to world ranges in trait frequencies in modern humans.

Trait (tooth) presence	Low Frequency Groups	High Frequency Groups	World Range	Neandertal Frequency
Shoveling (I^1) 3+	Western Eurasia, Sub-Saharan Africa, Sahul-Pacific	North and East Asia, Americas	0.0%-91.0%	80.0%
Double Shoveling (I^1) 2+	Western Eurasia, Sub-Saharan Africa, Sahul-Pacific, Sunda-Pacific	Americas	0.0%-70.5%	0.0%
Mesial Ridge (C') 1+	Western Eurasia, Americas, Sahul-Pacific, Sunda-Pacific	Sub-Saharan Africa	0.0%-35.0%	55.6%
Hypocone Absence (M^1)	Sub-Saharan Africa. Australia, New Guinea	Europe, India, Northeast Siberia, American Arctic	3.3%-30.6%	0.0%
Carabelli's Cusp (M^1) 3+	North Asia, Americas, Jomon, Ainu	Western Europe	1.9%-36.0%	55.8%
Cusp 5 (M^1) 1+	Western Eurasia, Americas	Sub-Saharan-Africa, Sahul Pacific	10.4%-62.5%	72.7%
Cusp Number (M_2) 4	San, Americas	Western Eurasia	4.4%-84.4%	11.1%
Y Groove (M_2) Y	Western Eurasia, Americas, Sunda-Pacific, Australia	San	7.6%-71-9%	84.5%
Cusp 6 (M_1) 1+	Western Eurasia	Polynesia, Australia	4.7%-61.7%	31.3%
Cusp 7 (M_1) 1+	Western Eurasia, Americas, Sunda-Pacific, Sahul-Pacific	Sub-Saharan Africa	3.1%-43.7%	33.1%

Data and their sources for high and low frequency groups and world ranges of trait frequencies in Scott and Turner (1997).

SUMMARY AND CONCLUSIONS

This multivariate analysis of dental morphology supports the conclusions of previous studies suggesting that the Neandertal dental morphological pattern is unique among human groups. This is not surprising given the numerous cranial and postcranial differences observed between Neandertals and modern humans (Trinkaus, 1981; Rak, 1986; Stringer and Gamble, 1993; Holliday, 1997), In contrast, the dental morphological pattern of the earliest AMH (represented by Quafzeh/Skhūl) is quite similar to both Upper Paleolithic and recent modern humans.

This study also found that the dental morphology of European Neandertals was the most different from Upper Paleolithic and recent Europeans. Likewise, Near East Neandertals showed no particular affinity to early modern humans (Qafzeh/Skhūl) from the same region. These findings tentatively suggest that if genes were flowing between Neandertals and early modern humans in Europe and the Near East, it did not significantly impact their dental morphology.

As regards the competing models for modern human origins, these findings are consistent with the Recent African Origin model. But do they disprove MRE? While it is true that the MRE model predicts regional continuity between archaic and modern populations in multiple geographic regions, it does not predict that regional continuity between modern humans and their archaic predecessors will be found everywhere (Wolpoff, 1995). Wolpoff and Caspari (1997:277-268) have explicitly stated that:

> If Neandertals could be proved extinct in Europe, without any mixing or contribution to later Europeans, it would not prove Multiregional evolution wrong, but only that replacement was the mode of Multiregional evolution in Europe.

Therefore, while this study suggests dental discontinuity between Neandertals and modern humans in Europe and Western Asia, additional comparative studies among later Pleistocene and recent modern human groups are needed to test hypotheses for modern human origins in other Old World regions.

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Sex Dimorphism in the Deciduous Dentition of Modern Pima

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ABSTRACT A sample of primary teeth from a Pima Native American population was measured to determine the presence and amount of sex dimorphism. An average percent sex dimorphism of 2.40 was found. This finding is in accord with the findings of other researchers of low sex dimorphism in the primary dentition. The percent sex dimorphism for the primary dentition of the Pima was compared to percentages for the primary dentitions of a Caucasian and an Australian population. The amount of sex dimorphism in the Pima was found to be less than that in the Australians, but greater than that in the Caucasians. Finally, the hypothesis that the amount of sex dimorphism in primary and secondary dentitions is similar was tested and found to be true for this population of Pima.

INTRODUCTION

The presence of sex dimorphism in the size of the human permanent dentition has been extensively documented (Anderson and Thompson, 1973; Taylor, 1978; Hillson, 1986; de Paula et al., 1995). Sex dimorphism in the expression of certain nonmetric characters has also been noted (Kirveskari, 1974). This dimorphism has been applied to various archaeological and forensic problems, and its potential for identifying the sex of skeletal remains discussed (Garn et al, 1977; Lukacs and Hemphill, 1991; Bayer-Olsen and Alexandersen, 1995).

At least two questions arise from such research. One question is whether similar sex dimorphism exists in the human deciduous dentition and, if so, whether such dimorphism is also applicable in the archaeological and forensic realms. Numerous researchers have approached this question and have noted sex dimorphism in both size (Lukacs et al., 1983; Axelsson and Kirveskari, 1984; Farmer and Townsend, 1993) and nonmetric trait expression (Kitagawa et al., 1995) of the deciduous dentition. Other researchers have examined the possibility of using size dimorphism in deciduous teeth for sexing skeletons in forensic investigations (Bailit and Hunt, 1964; De Vito and Saunders, 1990), as well as in archaeological studies (Sawyer et al., 1982). A second question which might be asked is whether there is correspondence between the degree of sex dimorphism in the primary and secondary dentitions. This is a question that has not been addressed to a significant extent in the literature.

This paper addresses both of these questions. Results from a study of the deciduous dentition of a population of Native Americans (Pima) from Arizona are described. The teeth were first measured and the measurements tested to determine the presence and quantify the amount of dimorphism. This sex dimorphism was compared to the published information on sex dimorphism in the deciduous dentition of a Caucasian and an Australian aboriginal population. Finally, the percentages of sex dimorphism were compared to the published percentages of dimorphism in the permanent dentition of the Pima.

MATERIALS AND METHODS

The casts were drawn from an assemblage of over 9,000 dental casts of Pima Indians from Arizona. These casts are part of the Arizona State University cast collections. The Pima casts were made under the direction of Albert A. Dahlberg and Thelma Dahlberg, who kept demographic and genealogical data on each individual.

Casts of the deciduous dentition were selected by visual inspection. When possible, casts with a complete set of twenty primary teeth were chosen. Since many of the casts had flaws such as casting defects, caries destruction, excessive interproximal wear, or broken or otherwise abnormal teeth, some casts missing up to two deciduous teeth (usually mandibular central incisors) were used to increase the sample size. Originally, a sample of 50 individuals (25 males and 25 females) was selected; after measurements were made, however, problems were found with three of these casts. These three sets of measurements were discarded, leaving a total sample of 24 males and 23 females.

The mesiodistal and buccolingual dimensions of each tooth were measured. Following Hillson (1986:233), mesiodistal diameter is defined as the distance between the point of contact with the other teeth in the dental arcade or, if the tooth was rotated slightly, where these points of contact should have been. Buccolingual breadth is defined as the maximum diameter of the crown, including the cingulum bulge. Measurements were made by a single observer and no more than seven casts were measured at a single sitting to avoid mismeasurements due to fatigue on the part of the observer. Measurements were taken using needlepoint Hellos dial calipers reading to 0.05 mm. Intraobserver error was checked by randomly selecting and remeasuring casts on different days than when measurements were originally taken. A remeasured sample of 17% of the original sample indicated a mean measurement error of 0.30 mm for this observer. Only measurements of left teeth left were used in the comparisons made in this paper, after (DeVito and Saunders, 1990).

RESULTS

Tables 1 and 2 have summaries of the results of the measurements made on the dental casts. The number of dimensions available for measurement, the mean, range, standard deviation, and percentage of dimorphism for each tooth class are indicated. Percent sex dimorphism ranges from -1.13% for the buccolingual diameter of the lower first molar to 8.12% for the mesiodistal diameter of the lower central incisor. The average percent sex dimorphism for the dentition overall is 2.40.

A Student's t-test was run on those dimensions which exceeded 3.00% sex dimorphism. The results are as follows: MD i_1: t=0.229 (35 df); MD m_2: t=0.122 (43 df); BL i^2 t=0.175 (45 df); BL c^1: t=0.178 (45 df); BL i_1: t=0.103 (35 df). None of these results are significant at the $p \geq 0.05$ level, reinforcing the finding of low sex dimorphism for this population of Pima.

Table 3 gives the results of the analysis of the percent sex dimorphism in the deciduous teeth of three populations: the Pima studied in this report, Australian aboriginal children examined by Margetts and Brown (1978), and Caucasian children from Michigan studied by Black (1978). Margetts and Brown used averaged values from left and right teeth to derive their figures, and their sample sizes for different tooth dimensions range from 8 to 115. Black used the right deciduous teeth of 69 males and 64 females.

Finally, Table 4 has the results of a chi square test of the percent sex dimorphism in the maxillary and mandibular primary and secondary dentitions of the Pima. Data on sex dimorphism in the secondary dentition of the Pima is taken from published information in Garn et al., 1967. The result of the chi square test indicates that the null hypothesis of no difference between percent sex dimorphism in the primary and secondary dentitions cannot be rejected for this population.

DISCUSSION

Sex dimorphism in the permanent and deciduous dentitions has been shown to be due to a longer period of amelogenesis in males than in females, which results in a thicker layer of enamel in male teeth than female teeth (Moss and Moss-Salentijn, 1977; Moss, 1978). While certain environmental factors may influence the morphology and metrics of developing permanent and deciduous teeth (Garn et al., 1979; Hershkovitz et al., 1993; May et al., 1993), for the most part prenatal tooth formation appears to be under strong genetic control (Goose, 1971; Thesleff, 1995) and "absolute variation in prenatal tooth formation is . small" (Smith, 1991:155). This suggests that the sex dimorphism measured by this and other studies is measuring real, genetically determined differences between males and females and not random fluctuations of tooth size.

This study has positively determined the presence and has quantified the amount of sex dimorphism in a sample of a Pima Native American population. The figure of 2.40% average dimorphism is expected in light of the published reports of similar amounts of sex dimorphism in the permanent dentition of the

TABLE 1. Mean mesiodistal measurements (in mm) of left deciduous teeth and percent (%) dimorphism.

	MALES				FEMALES				Dimorphism
Tooth	N	Mean	Range	SD	N	Mean	Range	SD	%
i^1	22	6.83	5.55-7.55	0.494	22	6.81	6.30-7.40	0.284	0.29
i^2	24	5.76	4.95-6.80	0.420	23	5.73	5.30-6.55	0.291	0.52
$c^{maxilla}$	24	7.13	6.20-7.80	0.405	23	6.96	6.10-7.95	0.450	2.44
m^1	23	7.49	5.50-8.50	0.595	22	7.36	6.80-8.05	0.342	1.77
m^2	24	9.75	8.75-10.90	0.509	22	9.53	8.35-10.50	0.459	2.31
i_1	18	4.66	4.25-6.00	0.398	19	4.31	4.00-6.15	0.333	8.12
i_2	23	4.97	4.40-5.55	0.304	23	4.89	4.40-6.15	0.350	1.64
$c_{mandible}$	24	6.14	5.80-7.05	0.317	23	6.03	5.25-6.65	0.341	1.82
m_1	23	8.17	7.70-9.05	0.406	21	8.05	7.15-9.00	0.474	1.49
m_2	23	10.84	10.15-11.90	0.481	22	10.44	9.25-11.85	0.548	3.83
Average									2.42

% dimorphism = 100 (male mean/female mean)-100 (Black, 1978). N number of dimensions available for measurement. SD atandard deviation

TABLE 2. Mean buccolingual measurements (in mm) of left deciduous teeth and percent sex dimorphism

	MALES				FEMALES				Dimorphism
Tooth	N	Mean	Range	SD	N	Mean	Range	SD	%
i^1	23	5.20	4.35-5.95	0.352	22	5.06	4.10-6.45	0.490	2.77
i^2	24	5.15	4.60-5.70	0.321	23	4.88	4.30-5.70	0.380	5.53
$c^{maxilla}$	24	6.37	5.60-7.40	0.439	23	6.03	5.40-7.30	0.428	5.64
m^1	23	9.17	8.50-10.30	0.413	23	9.01	8.30-9.95	0.418	1.44
m^2	24	10.63	9.90-11.80	0.518	21	10.43	9.70-11.40	0.372	1.92
i_1	18	4.09	3.50-4.80	0.310	19	3.94	3.05-4.60	0.414	3.81
i_2	23	4.62	4.30-5.15	0.228	23	4.52	3.90-5.75	0.485	2.21
$c_{mandible}$	24	5.89	5.20-6.60	0.342	23	5.75	5.00-6.65	0.395	2.43
m_1	24	7.86	7.10-8.90	0.424	22	7.95	7.00-9.80	0.714	-1.13
m_2	24	9.64	8.95-10.75	0.357	23	9.72	9.00-11.10	0.513	-0.82
Average									2.38

Pima (Garn et al., 1967) and the fact that sex dimorphism is usually low in the human primary dentition (Black, 1978; Margetts and Brown, 1978; Farmer and Townsend, 1993).

Whether the sex dimorphism found in the primary dentition could be applied to forensic and archaeological problems is questionable because the mean measurements for females occasionally exceed those of males. Table 2 reflects this fact; the female means for the buccolingual diameter of both the mandibular molars exceed the male means. Additionally, a glance at Tables 1 and 2 indicate that the range of size variation can be quite extreme, with the female range extending well into and even surpassing the male range: or example, the mesiodistal ranges for the maxillary canines and the mandibular incisors. Although some of the peculiarities of the figures determined by this study (e.g., the 12% sex dimorphism in the mesiodistal diameter of i_1) might be "smoothed" by a larger sample size, it appears that the generally low sex dimorphism, in combination with the wide range of tooth size variation, make the applicability of sex dimorphism in deciduous teeth to problems of skeletal identification problematic (Taylor, 1978). Other researchers believe, however, that they are able to achieve a more reliable result through the use of multivariate statistical methods (De Vito and Saunders, 1990). In sum, tooth size might be used, in conjunction with other skeletal or cultural evidence, to support a sex assignment for human remains.

The average percent sex dimorphism can vary among populations (Harris and Rathbun, 1991), as shown by the comparisons of deciduous dentitions in Table 3 and as shown by Garn et al. (1967) in their Table 2, which compares the permanent dentitions of nine different populations. In this study of primary teeth, the Pima exhibited less sex dimorphism than Australian children, but more than children of European ancestry. The variation in amount of dimorphism among populations is one fact which must be kept in mind when attempting to use the teeth to make a suggestion about the sex of skeletal remains. The percent sex dimorphism and the ranges of male and female variation must be known for the specific population to which those remains belonged before the teeth can be used to bolster a hypothesis concerning the individual's sex.

TABLE 3. Percent (%) dimorphism in deciduous teeth from three different populations.

Tooth Class	Caucasians	Pima	Australians
Maxilla			
i^2	-1.50	1.53	2.66
i^2	-0.09	3.03	2.85
c	2.07	4.04	3.49
m^1	2.34	1.61	3.54
m^2	1.25	2.12	3.09
Mandible			
i_1	-0.60	5.97	3.57
i_2	-1.26	1.93	2.03
c	0.62	2.13	3.14
m_1	1.12	0.18	3.68
m_2	2.13	1.51	2.71
Average %	0.61	2.41	3.08

That the primary dentition may impact the secondary dentition in certain ways (see, e.g. Schulz, 1992) and that certain nonmetric traits may differentiate between populations only in the deciduous dentition (Kitagawa et al, 1995) have been shown. However, the precise correspondence between metric and nonmetric characteristics of the two dentitions has not yet been completely investigated. While, this study did not find a statistically significant difference between the percent sex dimorphism in the permanent and deciduous teeth of the Pima (Table 4), this result may not be true for all populations. In this study the Pima exhibit less sex dimorphism in the primary teeth than do the Australian children, yet more than the Caucasian children. This is interesting when compared with the findings of Garn et al. (1967) who stated that the permanent dentition of the Pima "is characterized by large teeth but small percent dimorphism; Ohio [Caucasian] subjects . . . have absolutely smaller teeth, but a larger percentage dimorphism"(p. 965). While this may be due to the different populations of Caucasians in the two studies, the differences nonetheless suggest that the examination of correspondence (or lack thereof) in size, dimorphism, and nonmetric trait expression between the primary and secondary dentitions could be a fruitful field of study.

TABLE 4. Chi square test of sex dimorphism percentages in Pima deciduous and permanent dentitions.

	Observed	Expected	Observed	Expected	Totals
Maxilla	2.47	2.40	1.67	1.74	4.14
Mandible	2.34	2.42	1.84	1.76	4.18
Totals	4.81		3.51		8.32

$x^2 = 0.50$ (after corrections with Yates correction factor)

SUMMARY and CONCLUSIONS

The measurements from the deciduous teeth of the Pima used in this study indicate a fairly low degree of sex dimorphism. This is expected given the published reports of low sex dimorphism in the deciduous teeth of other human groups. The amount of sex dimorphism was similar between the permanent and deciduous dentitions of the Pima. Sexing subadult remains is always a difficult task; the findings of the paper suggest that using the deciduous dentition to assign a sex may be problematic. A number of research questions concerning the potential of the primary dentition to answer certain archaeological and forensic questions still remain to be explored.

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Taurodontism in Modern Populations

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ABSTRACT Taurodontism is a variation in root formation, resulting in an enlarged pulp chamber (Mena, 1971). This character has been used as a marker for differences between populations. Sex-linked disorders, autosomal chromosome disorders, and environmental factors have been reported to cause taurodontism (Reichart and Quast, 1975; Aldred and Crawford, 1988; Varrela and Alvesalo, 1989). When examining the mode of inheritance of taurodontism, it appears to be a polygenic trait that is controlled by only a few genes. At least one of these genes appears to be located on the X-chromosome. In addition, taurodontism appears to be linked to congenitally missing teeth, however these traits are not interdependent. Further study into the mode of inheritance of taurodontism and its relation to hypodontia is necessary to uncover the significance of taurodontism and its possible application to population studies. However, due to procedural differences in the assessment of this trait, the results between studies are difficult to compare. Therefore, a standard set of measurements is needed to make meaningful comparisons between studies of taurodontism.

INTRODUCTION

Part of understanding humanity is sought in the study of human dental variation. When Sir Arthur Keith first used the term taurodont in 1913, he was attempting to describe a variant in the pulp chamber of molar teeth to distinguish a monothetic difference between *Homo sapiens* and Neanderthals (Mena, 1971). However, cases of taurodontism in modern human populations have been reported (Goldstein and Gottlieb, 1973; Barker, 1976; Shifman and Buchner, 1976). Many researchers now focus upon determining what etiological factors cause this condition (Reichart and Quast, 1975; Varrela and Alvesalo, 1988, 1989). This study attempts to unravel the inheritance pattern of taurodontism.

Taurodontism is defined as an apical displacement of the furcation of the roots, resulting in an enlarged pulp chamber (Mena, 1971). Shaw (1928) created a typology for taurodont teeth by dividing them into three categories: hypotaurodont, mesotaurodont, and hypertaurodont (Fig. 1). Researchers identify taurodontism by comparing molar teeth to drawings similar to Figure 1 (Lysell 1962, 1965). While these categories are still utilized to describe the relative expression of this trait, clear breaks between them do not exist (Laatikainen and Ranta, 1996). In order to correctly recognize taurodontism and compare results with other researchers, a standard method that is more objective than those available is necessary. Many researchers have devised different methods by measuring various criteria, yet no particular scheme is used consistently (Blumberg et. al, 1971; Shifman and Chanannel, 1978; Seow and Lai, 1989). Due to the inconsistencies in the methods of measurement, these studies produce results that are not directly comparable.

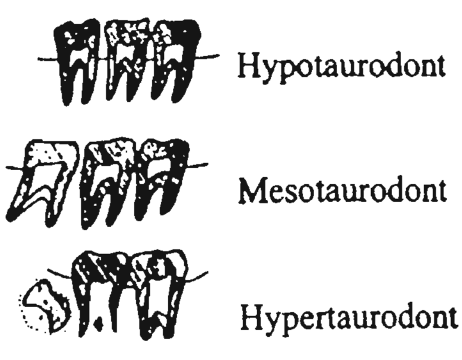

Fig 1. Types of taurodont teeth. Adapted from Lysell (1962).

Lysell (1962) mentions that the degree of taurodont expression decreases from the first molars to the third molars. Following the Butler-Dahlberg polar field concept, the first molar is the most stable and least effected while the third molars are the least stable and most effected (Scott and Turner, 1997). Lysell suggested the use of second molars as the standard for measurement because they are the most likely to express the trait consistently. In addition, the three roots of the maxillary molars tend to obscure identification of taurodontism, resulting in many researchers scoring mandibular molars (Shifman and

Chanannel, 1978; Brinkmann and Scheil, 1993). Yet, scoring mandibular molars is not conventional. Some researchers score both maxillary and mandibular dentition, while others score only maxillary dentition (Blumberg et al., 1971; Darwazeh et al., 1998).

THE USE OF TAURODONTISM

Dental traits, such as taurodontism, can be key in understanding human population variation. When traits are known to be independent, selectively neutral, and easily observable, they can be used to generate information that is characteristic of populations (Scott and Turner, 1997). Crown traits have been the most intensively studied thus far (ibid.). However, with the use of radiographs and orthopantomograms, tooth roots are as easy to observe as crown traits (Tulensalo et al., 1989). In addition, with time and intensive chewing, crown traits can wear off (Scott and Turner, 1997). Taurodontism, a root trait, will persist longer when under duress. Yet, as the crown wears into the dentinal area, secondary dentine is laid down in the pulp chamber and can obscure taurodontism. Taking these factors into account, taurodontism must also be established as an independent or selectively neutral trait.

INHERITANCE PATTERNS OF TAURODONTISM

Genealogical studies on the incidence of taurodontism provide insight into the inheritance pattern of this trait. Laatikainen and Ranta (1996) studied taurodontism in association with cleft lip and/or cleft palate in twins. They determined that taurodontism was present in 31% of monozygotic twins and 46% of dizygotic twins in 39 pairs. Thirty seven percent of these twins were discordant for clefting, though relatively more extreme clefting was highly associated with a higher expression of taurodontism. Also, a pedigree analysis of taurodontism associated with X-linked hypohidrotic ectodermal dysplasia (XHED) showed an increased expression of taurodontism in males than in related females (Crawford et al., 1991). These studies suggest that the expression of taurodontism has a strong genetic component. In addition, both studies linked the expression of taurodontism with hypodontia.

TAURODONTISM ASSOCIATED WITH SEX-LINKED DISORDERS

Studies focusing upon X-linked disorders indicate a high correlation between taurodontism and the presence of extra X-chromosomes. Varrela and Alvesalo (1988, 1989) have examined the effects of extra X-chromosomes in males and females with respect to the occurrence of taurodontism. Focusing upon the mandibular dentition, they determined that 30% of males (n=66) with an extra X-chromosome displayed taurodont molars and 67% of women (n=6) with at least one extra X-chromosome displayed taurodont molars. Their control groups, consisting of normal males and females, had frequencies of taurodontism at 2.5% (n=157) and 2.6% (n=157), respectively. In addition, one relative of a study female displayed taurodont molars. Studies of Turner syndrome, characterized by X-chromosome deficiency (XO), have revealed no patients exhibiting taurodont molars (Midtbo and Halse, 1994; Farge et al., 1985). These studies suggest that genes located on the X-chromosome regulate the expression of taurodont molars.

At a cellular level, the epithelium produces enamel, while the mesoderm produces dentin (Scott and Turner, 1997). Analyzing the ontogeny of teeth, Alvesalo and co-workers (1987, 1991, 1997) and Varrela et al. (1988) have shown that the X-chromosome is involved in enamel production, while the Y-chromosome regulates enamel and dentin production. Hamner and co-workers (1964) noted that the production of dentin is normal in taurodont teeth. They deduced that taurodontism must result from a malfunction in the formation of Hertwig's epithelial root sheath, because dentin is laid down after root sheath production. This means enamel production is in part regulated by sex chromosomes, while the epithelium creates enamel and Hertwig's root sheath. The connection between these factors requires additional study to determine the involvement of sex chromosomes in the production of taurodont teeth.

TAURODONTISM ASSOCIATED WITH AUTOSOMAL CHROMOSOME DISORDERS

Taurodontism is also often reported in association with disorders or syndromes that are inherited on autosomal chromosomes. In a study of 22 children with Down's syndrome, or trisomy 21, Alpoz and Eronat (1997) found that 66% of the children had taurodont molars, while none of the 20 control children exhibited taurodontism. Similarly, Bell and co-workers (1989) examined 33 individuals with trisomy 21 and found that 34.8% of them had taurodont molars. In addition, both studies describe hypodontia and delayed eruption as effects of Down's syndrome. Studies focusing upon the connection between hypodontia and/or oligodontia and taurodontism indicate an association between these two dental traits.

Hypodontia is defined as the congenital absence of at least one tooth, while oligodontia is defined as the absence of six or more teeth within an individual (Shalk-Van DerWeide, et al., 1993). Brook (1984) has determined that hypodontia is more frequently expressed in females, while hyperdontia is more frequent in males. This implies that the inheritance of these traits is sex-linked.

Seow and Lai (1989; Lai and Seow, 1989) studied the relationship between hypodontia and taurodontism. They determined that out of 66 and 67 patients, 34.8% and 34.3% of them displayed the co-occurrence of hypodontia and taurodontism respectively. Their control samples of 66 and 67 individuals with full permanent dentition had rates of 7.5% and 7.1 % of taurodontism respectively. They suggest that either taurodontism and hypodontia are genetically linked or that they occur due to the same unnamed environmental influence. Using the same method of analysis, Shalk-Van Der Weide and researchers (1993) examined the occurrence of taurodontism and oligodontia. Out of 91 patients and 90 control subjects, they found that taurodontism and oligodontia occur together 28.9% of the time, while taurodontism occurred at a rate of 9.9% in the normal population. Also, a study on short root anomalies mentions the occurrence of taurodontism and hypodontia in families (Apajalahti et al., 1999). These findings strongly suggest a correlation between taurodontism and congenitally missing teeth. However, these traits do occur in the absence of one another, so they are not fully interdependent.

Autosomal disorders occurring in the absence of hypodontia while exhibiting taurodontism also have been reported. Case reports of these conditions associated with taurodontism include affiliation with supernumerary teeth, dentinal dysplasia type I, short roots, Ellis-van Creveld syndrome, hypophosphaetaemic vitamin D resistant rickets, and amelogenesis imperfecta (Gardner and Girgis, 1977; Aldred and Crawford, 1988; Crawford and Aldred, 1998; Crawford et al., 1988; Goodman et al., 1998; Hattab et al., 1998; Genc et al., 1999; Kosinski et al., 1999). Unfortunately, most of these conditions have not been systematically studied with the intent of determining their relationship to taurodontism.

Taurodontism has been investigated with respect to one type of amelogenesis imperfects (AI H-H T) (Aldred and Crawford, 1988; Crawford et al., 1988; Winter, 1996). Amelogeneis imperfecta (AI) is a discoloration of anterior tooth enamel, resulting from an autosomal dominant, autosomal recessive or X-linked abnormality (Winter, 1996). In a sample of 32 children with AI, 87.1 % of them were found to have taurodont molars (Winter, 1996). Genealogical analysis suggests that AI associated with taurodontism is inherited through an autosomal dominant mechanism (Congleton and Burkes, 1979; Crawford et al.,1988). Studies of the relationship between AI and taurodontism have only recently begun. Further examination into their association is required before any conclusions can be drawn.

TAURODONTISM ASSOCIATED WITH ENVIRONMENTAL FACTORS

Environmental factors have also been shown to influence the expression of taurodontism. Reichart and Quast (1975) examined an individual who exhibited a single taurodontic lower third molar. Between the ages of four and twenty, this individual had a mandibular osteomyelitis infection. Thus, taurodontism in this case appears to be the direct result of a childhood infection. This brief case report indicates that taurodontism can be caused by factors that are not genetic. While previous evidence suggests that taurodontism is often inherited or displayed due to genetic influence, environmental factors may also be responsible for some cases of taurodontism.

Table 1. Population Studies of the Incidence of Taurodontism

Population	%	#	Age	Method	Researcher
Jordan	8.0	875	>18 years	Subjective	Darwazeh, et al (1998)
Iarael	5.6	1,200	20-30 years	Shifman and Channanel measurements	Shifman and Channanel (1978)
Saudi Arabia	11.3	1,281	unreported	Shifman and Channanel measurements	Ruprecht et al. (1987)
American Whites	0.5	2,800	adult	Unreported	Witkop (1976)
American Blacks	4.4	1,074	children<18	Jorgenson et al. subjective measurements	Jorgenson et al. (1982)
Chicago	2.5	11,905	unreported	Reported in Ogden (1988)	Blumberg et al. (1972)
Greece	1.1	730	adult	Zografos et al. measurements	Zografos et al. (1991)
Britian	6.3	1,115	children	Reported in Ogden (1988)	Holt and Brook (1979)
China	46.4	196	15-19 years	Shifman & Channanel modified	MacDonald-Jankowski and Li (1993)

% is the percent of individuals. # is the number of individuals.

RATES OF TAURODONTISM IN POPULATIONS

Population studies, focused on the general public, have examined the incidence of taurodontism. When analyzing taurodontism occurring in the absence of genetic anomalies, it appears to be expressed in different frequencies in different populations (Table 1). These results suggest that taurodontism can be used in conjunction with other traits to identify populations. Yet, many problems arise when comparing these studies. First, taurodontism was identified using different standards between studies. Second, molars used to identify taurodontism vary from examining only first upper molars, only recording the trait on second lower molars, or using any molar that exhibits taurodontism as evidence (Blumberg et al., 1971; Shifman and Channanel, 1978; Darwazeh et al., 1998). In addition, some studies examine adults, some examine children, while others include both in analyses. Though taurodontism occurs in both deciduous and permanent dentitions (Dayan et al., 1984), dental traits can show differential degrees of expression in both cases, again confounding comparison (Scott and Turner, 1997). Third, all studies were performed on living populations that, with a few exceptions, experience greater gene flow than in the past. Therefore, admixture will factor into the reported gene frequencies.

Limitations to the study of taurodontism must be considered. Brinkmann and Scheil (1993) note that dental caries and secondary dentine obscure the identification of taurodontism. They also state that because taurodontism is a continuous trait, identifying the less expressive end can be difficult, especially when subjectively identifying the trait. In addition, most studies focused on taurodontism analyze clinical patients, therefore the samples are not random. Although these conditions exist, carefully constructed research can avoid possible misdiagnosis of the trait and heavily biased samples.

CONCLUSION

The mode of inheritance of taurodontism is still unclear. While Mendelian inheritance patterns do not appear to fit the data, its wide occurrence with many genetic abnormalities suggests that it is very susceptible to change. Researchers generally agree that taurodontism is a polygenic trait (Blumberg et al., 1971). Most polygenic crown traits are resistant to change because many genes are needed to express them (Scott and Turner, 1997). Taurodontism, while polygenic, appears to be controlled by only a few genes. In addition, the clinical research presented here suggests that at least one gene controlling the expression of taurodontism occurs on the X-chromosome.

Further analysis into the relationship between taurodontism and hypodontia is needed. Hypodontia is thought to be under selective pressure favoring dental reduction (Scott and Turner, 1997). If taurodontism is a variation of the adaptation towards dental reduction, it will be necessary to understand the selective pressure effecting the appearance of this trait. In addition, if taurodontism is not an independent trait, it will not necessarily reflect the same genetic processes in all people, thus its use as a population marker would have to be qualified. Comparisons between studies of taurodontism, one set of measurements taken on a specific molar or set of molars is needed.

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Anthropological and Forensic Aspects of Odontological Variation in Two Contemporary Australian Populations

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ABSTRACT The utilization of odontometric variation as a discriminator between modern human groups continues to decline, despite its value in both anthropological and forensic contexts. Traditional odontometric methods, coupled with advanced statistical methods, are applied to illustrate the continuing usefulness of these techniques. The ability to discriminate between the major population groups (Caucasoid and Mongoloid) in the Sydney region of Australia, based on dental dimensions, is extremely valuable in the forensic identification of individuals. Furthermore, metric variation in the dentition of these contemporary populations is poorly understood in this region of the world. The utility of variation in tooth dimensions in discriminating between these two groups is explored. Dental stone casts of the permanent maxillary and mandibular dentition of 198 individuals were made, and mesiodistal and buccolingual crown dimensions were recorded for each tooth. Both univariate and multivariate analyses were used to investigate differences in linear and areal dimensions, as well as the predictive value of these measures in a forensic context, using discriminant function analysis (DFA). DFA produced separation of Caucasoids and Mongoloids with a success rate of 93.9% on the basis of these measurements. Separation of the groups was most apparent in the mesiodistal and buccolingual dimensions of the maxillary first premolar (P^{1}), the mesiodistal diameter of the maxillary second premolar (P^2), and the mesiodistal dimension of the mandibular first premolar (P_1)[1]. The results from this study further highlight the usefulness of dental metrics in forensic applications and contribute to our knowledge of the variation of these features in contemporary human populations.[2]

INTRODUCTION

The variation in the size and shape of the human adult dentition has been used widely to discriminate groups on the basis of racial identity, or population affinity. The durability of the human skeleton, especially the teeth, provides a basis for determination of population affinity from human remains, for example, in the forensic and/or archaeological setting. Further, teeth being the only hard tissues directly observable in the living human, permit noninvasive techniques (e.g., dental casts) to study contemporary populations. Here we utilize dental casts to study two of the major contemporary populations residing in Sydney, Australia. These population groups are Caucasoid and Mongoloid, defined broadly for the exploratory purposes of assessing the feasibility of discriminating between these two groups.

Tooth length and width have become the most extensively documented anthropometric features, utilized for such purposes as estimating biological distance between human populations, and evolutionary considerations (Kieser, 1990). In the mid twentieth century odontometric studies attempted to approximate tooth shape, through indices, such as the crown index (bl/md x 100) and crown module ((bl+md)/2) (e.g., Moorrees, 1957; Rosenzweig, 1970).

The traditional approach to odontometrical studies has been criticized by some investigators for being too simplistic (Lavelle, 1984), too limited (Goose, 1963), overemphasized (Corruccini, 1977b, 1978), underutilizing the available information (Wood and Abbott, 1983), and lacking biological meaning (Corruccini, 1977a). Many of the same concerns have not been expressed for the use of crown areas: a product of mesiodistal and buccolingual dimensions (md x bl). In overcoming the problems with conventional odontometrics, the description of definable tooth crown landmarks on the occlusal surface (Biggerstaff, 1969a), combined with a reliable and accurate method to record them (Biggerstaff, 1969b), led to detailed measurements of the tooth crown. Applications of this methodology have focused on separating groups comprised of various population affinities (Lavelle, 1978, 1984), as well as taxa (Corruccini, 1977b, 1978; Wood and Abbott, 1983). The main drawback to these techniques is the reliance on unworn teeth for data collection, a difficulty when dealing with archaeological collections. Dental work is also likely to obscure landmarks, causing difficulties in studying contemporary populations. Many studies also rely on a single tooth, examining within-tooth variation only.

Here, we use mesiodistal and buccolingual diameters of all maxillary and mandibular teeth in the dental arcades (excluding M3) as the basis for assessing the feasibility of separating Caucasoids and Mongoloids. Further, summed mesiodistal diameters ($\sum$md), summed buccolingual diameters ($\sum$bl), and crown areas (md x bl) are computed for the anterior and posterior (postcanine) teeth and compared in Caucasoids and Mongoloids. Mizoguchi (1981) and Kieser and Groeneveld (1987) have suggested that these two tooth groups represent functional units that characterize the dental arch. The anterior tooth group is further divided into incisors and canine, since the idea of independent control mechanisms of these regions has not been eliminated and is presently unclear.

For all the objections to traditional odontometrical methods, major problems have existed at the level of analysis. Most studies which compare the dental metric variation of two or more groups have focused almost exclusively on individual teeth as units of study, restricting the analysis to tooth-by-tooth inspection (Harris and Rathbun, 1991). With modern computers the realm of multivariate statistics has been available for several decades. Through the use of both univariate and multivariate techniques, populations can be defined on the basis of tooth size alone (Mayhall, 1992). The use of both methods is, in fact, advocated (Potter, 1972). We support this approach by employing the Student's t-test, canonical variate analysis (CVA), and discriminant function analysis (DFA).

A strong genetic component of crown size has long been recognized, with the majority of data suggesting the involvement of multifactorial genetic factors in controlling odontometric traits (Sofaer, 1970). However, an unquestionable environmental component exists in the determination of tooth size. The exact proportions of the genetic and environmental components in odontometric variability remain controversial (Goose, 1967). A value of 64% of the total variability has been assigned directly to genetic factors (Townsend and Brown, 1978), emphasizing the importance of previously overlooked nongenetic influences in the determination of tooth size. This finding may have important considerations for the use of tooth crown dimensions in the forensic setting. We have restricted our investigation to population groups located in a limited geographical region.

Contemporary populations considered presently have been extensively studied with respect to non-metric dental traits. Highly successful separation of Caucasoids and Mongoloids has been achieved due to the recognition of high incidences of shovel-shaped incisors in Mongoloid populations and the cusp form of Carabelli's trait in Caucasoid populations (Hrdlička, 1920; Dahlberg, 1951; Carbonell, 1963; Hanihara, 1968). However, for several reasons the use of these traits may be limited. Non-metric traits may vary along a gradient within the dentition in accordance with Butler's field theory (Butler, 1939; Dahlberg, 1945), where expression is the most intense on the most mesial tooth of each class.

Shovel-shaped incisors are confined to the anterior teeth, which, being single-rooted, (Krogman and İşcan, 1986) are frequently lost postmortem, a consideration in the forensic setting where maxillary central incisors are missing. Shovel-shaped incisors clearly discriminate major regional groups, although other non-metric crown traits associated with the "Mongoloid dental complex" (e.g., protostylid, sixth cusp) (Hanihara, 1967) do not distinguish as clearly between populations as do shovel-shaped incisors. Variations in frequencies exist within all populations. In Mongoloids, as is illustrated by the proposed subdivision into Sinodonty and Sundadonty, the former generally exhibit intensified traits (Turner, 1985, 1989, 1990a,b).

Observations of dental non-metric traits can be subjective. Only within the past fifty years have three-dimensional graded standards for scoring procedures been devised (Dahlberg, 1956; Hanihara, 1961; Turner et al., 1991). Also, particular problems have been reported with scoring procedures of Carabelli's trait (Kieser and van der Merwe, 1984).

The objectivity and reliability of odontometric studies (Moorrees, 1957) has led us to investigate the differences that exist in tooth crown dimensions and to quantify the degree of separation achievable in Caucasoid and Mongoloid groups residing in the Sydney area.

The investigation of sexual dimorphism follows in a later study and will assess the feasibility of separation of the sexes, as well as the nature of sexual differences, within both Caucasoids and Mongoloids. Possibly, sex differences are unique to a given population group (Hanihara, 1978; O'Higgins et al., 1990). Therefore, population affinity variation and sex variation require independent consideration. Consequently, we caution that when the data allow independent classification by sex, indeed as in the case of Mongoloids and Caucasoids, sex within each population affinity is best described by a unique discriminant function. Determination of the population affinity first and then the sex of unprovenanced remains by the function appropriate to sex within that population affinity is the wisest.

MATERIALS AND METHODS

A sample of 198 dental stone casts (from alginate impressions) of contemporary Caucasoid (44 male, 57 female; total 101) and Mongoloid (53 male, 44 female; total 97) subjects were prepared from volunteer subjects living in the Sydney region. The majority of participants were recruited through the student body of the Faculty of Dentistry, University of Sydney, Australia. Age of individuals ranged from young adult to middle age adult (18-50), thereby more likely to display the full permanent dentition than younger or older persons.

Population affinity of individuals comprising the sample, as well as biological parents, was assessed through the use of questionnaires. Both parents had to originate from the target sample in order to be included in the study. Most of the Mongoloid sample originated from South-East China, Vietnam, and Hong Kong. Most of the Caucasoid sample originated from Northern Europe. Independent visual estimation of Caucasoid or Mongoloid derivation confirmed the information obtained from questionnaires. The purpose of this was to informally assess the forensic utility of population affinity, since the identification of an individual as a member of a particular population group in life is commonly reflected by physical appearance.

No attempt was made to assess specific prenatal environmental influences which may affect tooth size. Also, no obvious reason was found for excluding from the sample those individuals who have undergone orthodontic treatment, since the final shape and size of the tooth crown is determined well before its eruption into the mouth (Kieser, 1990) and, therefore, unaffected. However, recently we learned that upon removal of orthodontic prostheses, the tooth surface may be stripped very slightly, having the potential to slightly decrease the buccolingual dimension of the tooth crown (personal communication, Dr. Robert B.J. Dorion, Forensic Odontologist, Laboratory of Forensic Medicine, Montreal, Quebec). Presumably, this effect is of such small magnitude it does not significantly influence the results, and will be random in affecting either population group.

Mesiodistal and buccolingual linear measurements of the tooth crown were made using dial calipers with specially machined tips, which allowed insertion between the teeth. Measurements were recorded to the nearest 0.05 mm. All permanent teeth in maxillary and mandibular dental arches, except the third molars, were included. All measurements were taken by the primary author and are defined as follows:
Mesiodistal diameter (md) "...the greatest distance between the approximate surfaces of the crown with a sliding caliper held parallel to the occlusal-surface of the crown. Where a tooth was rotated or malposed in relation to the dental arch, the measurement was taken between the points on the approximate surfaces of the crown where the worker judged that contact with neighboring teeth 'normally' should have occurred" (Barrett et al., 1963).

This method of measurement was chosen for its congruence with methods used by forensic workers in the Sydney region (personal communication, Associate Professor Christopher J. Griffiths, Director of Diagnostic Dentistry, Dental Clinical School, Westmead Hospital and Chief Forensic Odontologist, NSW Institute of Forensic Medicine, Sydney, Australia).

Buccolingual diameter (bl) "...the greatest distance between the labial or buccal surface and the lingual surface of the tooth crown ... was measured ... with a sliding caliper held at right angles to the mesiodistal crown diameter of the tooth" (Barrett et al., 1964).

The variation in tooth size is of small dimensions, emphasizing the importance of reducing possible sources of error. Systematic errors, arising from limitations in the instruments and the materials, were minimized. Limiting possible inaccuracies through operational procedure included adherence to the prescribed mixing time of alginate (Algident, Australia), compliance with correct tray filling techniques, and pouring of casts with dental stone (Boral Investo, Australia) as soon as possible after removal of the impression from the mouth. However, a slight linear distortion, regardless of the technique or material used, is reported (Lysell and Myrberg, 1982). The use of stone casts fabricated from alginate impressions as a representation of actual tooth size is widely used and preferred to taking direct measurements from the mouth (Hunter and Priest, 1960). Modified calipers (Mitutoyo, Japan), as described above, were used. The following criteria were also established. Teeth were rejected on the basis of carious lesions or restorations, which affected the mesiodistal or buccolingual diameters of the crown, including deposits such as plaque or calculus reproduced on the cast. Malformed or incompletely/partially erupted teeth were excluded from measurement, as well as those teeth rendered immeasurable due to faulty casts or impression flaws. Apparent loss of tooth substance due to occlusal attrition or those teeth in which interproximal attrition had markedly reduced the crown diameter were also not measured. Differences in the extent to which worn teeth are included in statistical work occur (Brothwell, 1967). Slight differences in measuring technique amongst observers (Utermohle et al., 1983), as well as the value for a given measurement from the same observer, are likely to occur. These experimental errors were minimized by assessing the precision and accuracy of repeat measurements intra-observer and inter-observer, via the double determination of Dahlberg (also known as the method error statistic) (Dahlberg, 1940).

Statistical Manipulations

Differences between groups are initially assessed through the Student's *t*-test to provide some indication of the significance of differences between the means of Caucasoids and those of Mongoloids on each tooth dimension. In assessing the achievable degree of group separation, canonical variates analysis (CVA) determines the linear combinations of variables that maximizes group differences, relative to variation within groups. Variables that contribute most to the discriminatory power of the derived functions are identified though their correlations with the discriminant function. Loadings greater than ± 0.30 are interpreted as part of the variate (Tabachnick and Fidell, 1996).

The success of the linear combination of variables in separating Caucasoids and Mongoloids from each other based on tooth crown dimensions is evaluated by discriminant function analysis (DFA), by assigning cases to groups, and constructing a confusion matrix, a breakdown of classified and misclassified cases. Direct DFA is used, entering all variables at the one step. Tolerance levels are set routinely to protect against the statistical instability caused by multicollinearity and singularity, an important consideration with the reported strong positive collinearity between tooth crown variables (Moorrees and Reed, 1964). Although CVA precedes the DFA, for ease of interpretation of results, the multivariate techniques utilized here will be discussed in combination. SPSS (release 6.1 for the Macintosh) is used for all statistical manipulations described hitherto, except the randomization procedure (*vide infra*).

The statistical significance of the classification success rates is examined using a randomization method from The MV-NUTSHELL Brochure (Wright, 1994), insuring that the results of the multivariate analyses do not occur by chance alone (Manly, 1991). The method of randomization utilized in the present study is one that makes no assumptions about the distributions of the variables in the populations from which the samples are drawn (personal communication, Richard VS. Wright, Emeritus Professor of Anthropology, University of Sydney, Australia). The mean scores for each category (e.g., Caucasoid, Mongoloid), and the difference between the means is found. Each individual in the original data set is randomly assigned to one of the two groups. The difference between the two means based on this randomized allocation into population group is then determined. This is repeated 99 times, and the categories are randomized across the sample in each analysis. The test therefore involves comparing the observed difference between the groups with the distribution of differences found with random allocation (Manly, 1991). With the randomization procedure, computation of confidence limits for the success rates achieved from randomizing the data is possible. At the 99% confidence limit, the probability of another success rate derived from the randomized within the limits is 99%. If the actual success rate falls outside the confidence limits established for the randomized data, it is considered significant ($p < 0.01$). That is, the differences in tooth size between groups have not occurred by chance alone.

In addition to utilizing mesiodistal and buccolingual crown diameters to explore variation between Caucasoids and Mongoloids, summed mesiodistal crown diameters, summed buccolingual crown diameters, and crown areas of incisors, canine, and postcanine teeth are compared between groups. To compare the degree of differences, the total difference is divided by the number in a tooth group (i.e., two in the incisor region, one for the canine, and four in the postcanine region). This effectively gives the average difference between groups per tooth and counterbalances the additive effects of tooth groups with a greater number of objects than other tooth groups.

RESULTS

The intra-observer measurement errors, as indicated by the Dahlberg statistic (Dahlberg, 1940), range from 0.03 mm to 0.07 mm. Inter-observer errors range from 0.10 to 0.18 mm. As expected, inter-observer errors are greater in magnitude than intra-observer errors. However, they remain comparable with the double determination results of other investigators (e.g., Townsend, 1976), are very small in magnitude, and are unlikely to effect subsequent analyses. Only two cases in which a tooth dimension was not selected for measurement by the primary author and measured by a second observer occurred, indicating a more conservative approach to selection criteria by the investigator engaged in data collection than the secondary observer.

Detailed preliminary analyses of each variable were performed to investigate the accuracy of the data files, the distributions of observed values, inter-trait correlations, and the presence of outliers or extreme values. While perfect distributions are probably unobtainable, few problems were noted. The results are not discussed here. Suffice to say that the central limit theorem reassures us that with large sample sizes, sampling distributions of means are normally distributed regardless of the distributions of variables.

Asymmetry was assessed prior to analyses with paired Student's *t*-tests ($p<0.05$). The Caucasoid pooled sex group has nine significantly asymmetric variables: I^1 and I_1 (bl), I^2 (md), UC (bl), P^2 (md), M_1 (md and bl), M^2 (bl), and M_2 (bl). More variables are significantly asymmetric in the buccolingual dimension than in the mesiodistal dimension. The Mongoloid sample is significantly asymmetric in I^2 (md), UC(md), and M_1 and M_2 (bl). At $p=0.05$, the number of asymmetric measurements expected by chance alone is one to two for each sub-sample, or about four overall. Clearly, true asymmetry occurs across the dentition. However, in accordance with anthropological convention, the left side of the dentition was used for statistical analyses (Lavelle, 1970). Analyses were also conducted for right hand side measurements, although the results are not presented. They will be discussed, albeit briefly, with regards only to general differences between results arising from left and right hand side measurements.

Missing data appeared to be randomly distributed throughout Caucasoid and Mongoloid groups, and were substituted with the within-group means to maximize the potential of the data for the multivariate analyses. Since the missing data lacked a pattern, consideration of omitting one or a few variables or deleting individuals from the analyses was not feasible. Leaving the data blank would have resulted in about half of the dataset being lost in multivariate analysis, since it handles complete data only. In total, the variables consisted of 28 measurements for each individual and all the original 198 cases were included.

Univariate Results

Results of Student's *t*-tests are found in Table 1. Caucasoid and Mongoloid tooth crown dimensions differ significantly ($p<0.05$) on 18 of a total 28 variables. This includes all variables in the mesiodistal dimension except I^1, M^2, and M_2. Relatively fewer variables in the buccolingual dimension are significantly different between groups, those being I^2, P^1, P^2 I_1, P_1, M_1, and M_2.

The direction of differences is such that tooth crown dimensions of Mongoloids exceed those of Caucasoids in almost every instance. Exceptions to this are the mesiodistal diameter M^2 and buccolingual diameters of the mandibular anterior teeth, that is, I_1, I_2, and LC. Of these relatively larger Caucasoid measurements, only the formermost is significant.

Two variables (P^2 (md), M^1 (bl)) required the computation of *t*-tests using separate variances, since the assumption of homogeneity of variance (Levene's test) was violated. For both variables, this yielded very slight decreases in the *t*-values and standard errors of the difference, and small decreases in the degrees of freedom (<10%), compared with calculations based on pooled variances. The significance values were unchanged.

Multivariate Results

Univariate analyses of equality of group means precedes the CVA and DFA. Since the missing data have been substituted with means, the groups become homogenized, thus potentially creating artificial separation of the groups. To assess this crudely, one-way analysis of variance (ANOVA) was performed on the two datasets that were utilized for univariate and multivariate analyses, in which the latter is modified by substitution of the missing values with within-group means. Although, no overall effect on whether or not variables show significant differences is seen, the effect of replacing missing values (in the 'new' dataset) has increased the F values slightly, and subsequently each variable approaches $p<0.01$ more closely, compared to the original dataset retaining missing values. The only

TABLE 1. Univariate differences (Student's t-test) of tooth crown diameters between Mongoloids and Caucasoids.

Variable	df	$\bar{X}$M-$\bar{X}$C[1]	SE of difference	t	p(2 tail)[2]
I^1 (md)	187.00	0.0718	0.082	0.87	0.384
I^2 (md)	182.00	0.4855	0.089	5.47	0.000**
UC (md)	189.00	0.3513	0.066	5.30	0.000**
P^1 (md)	170.00	0.5641	0.071	7.97	0.000**
P^2 (md)	161.75	0.5359	0.067	8.02	0.000**
M^1 (md)	186.00	0.1762	0.082	2.14	0.034*
M^2 (md)	168.00	-0.0276	0.090	-0.31	0.760
I^1 (bl)	178.00	0.0599	0.084	0.72	0.475
I^2 (bl)	177.00	0.1969	0.091	2.17	0.031*
UC (bl)	184.00	0.1168	0.095	1.22	0.223
P^1 (bl)	170.00	0.5925	0.089	6.66	0.000**
P^2 (bl)	168.00	0.2229	0.093	2.41	0.017*
M^1 (bl)	166.17	0.0022	0.083	0.03	0.979
M^2 (bl)	171.00	0.0907	0.103	0.88	0.379
I_1 (md)	185.00	0.2282	0.054	4.26	0.000**
I_2 (md)	187.00	0.1712	0.058	2.95	0.004**
LC (md)	191.00	0.3030	0.062	4.88	0.000**
P_1 (md)	179.00	0.4201	0.062	6.75	0.000**
P_2 (md)	166.00	0.2598	0.066	3.94	0.000**
M_1 (md)	176.00	0.3896	0.094	4.14	0.000**
M_2 (md)	172.00	0.1098	0.095	1.15	0.251
I_1 (bl)	181.00	-0.1882	0.068	-2.75	0.007*
I_2 (bl)	180.00	-0.0301	0.061	-0.49	0.624
LC (bl)	180.00	-0.0269	0.083	-0.32	0.747
P1 (bl)	175.00	0.3896	0.075	5.18	0.000**
P_2 (bl)	166.00	0.0855	0.081	1.06	0.290
M_1 (bl)	175.00	0.2562	0.079	3.22	0.002**
M_2 (bl)	177.00	0.1665	0.083	2.00	0.047 *

[1]M=Mongoloid, C=Caucasoid. 2* (p<0.05), **(p<0.01)

exception to this is I_2(bl), where the converse trend was observed. Since substitution of missing values utilizing within-group means increases the likeness of each group and makes each group slightly more distinct from the other, the effect on F ratios is logical. The most marked example of the described effect is P_2(bl), where the initial computation yielded F=5.7856, with p=0.0172, clearly significant ($p<0.05$). The second computation, after missing values for this variable were replaced by within-group means, yielded F=7.5904 with p=0.0064, being highly significant ($p<0.01$). Certainly, no F value is altered from not significant to significant, or vice versa, as a result of replacing missing values.

Interdependencies between variables are examined through pooled within-group correlation matrices, derived from the averaged separate correlation matrices for each group. Few strong correlations exist, no doubt due to the inclusion of variables from only one side of the dental arch. The highest correlations (>0.70) are found between equivalent measurements in the maxilla and mandible and in the same morphological class.

Differences between groups are generally small in proportion to the total variability for many of the variables. This is shown by Wilks lambda (Table 2). In descending order, the variables with the greatest differences in means across the two population groups (U statistic<0.7) are P^2 (md), and P^1 (md). Smaller differences in means than those of P^2 (md) and P^1 (md) (U statistic<0.8) are shown by P^1(bl) and P_1(bl).

A single canonical discriminant function is computed since the separation of two groups is required. Summary data for this discriminant function are found in Table 3. Canonical discriminant function coefficients are derived for each variable for each function, which in their unstandardized form are useful for forming a discriminant equation of the form:

$$D = C_o + C_1X_1 + C_2X_2 + ... + C_vX_v + k$$

where D is the discriminant score; C is the unstandardized discriminant function coefficient; X is the value of the variable; and K is a constant. Unstandardized coefficients are found in Table 4. The cut-off point for the equation form is +0.03164. The derivation of this sectioning point is discussed later. If the equation yields a score greater than this value, an individual is classified as Mongoloid based on tooth crown dimensions. If the equation yields a score below the sectioning point, the individual is classified as Caucasoid. The canonical discriminant function equation, derived from unstandardized scores, takes into account the size of each variable. Thus, the magnitude of the coefficient does not necessarily correspond to the weighting or importance of the variable in the solution.

The structure matrix (Table 5, Fig. 1), consisting of pooled within-group correlations between discriminating variables and the canonical discriminant function, demonstrates the relative importance of variables in separating population groups. The tooth crown dimensions contributing significantly to the separation between Caucasoids and Mongoloids are P^1 (md and bl), P^2 (md), and P_1 (md). Only these four variables possess loadings $\geq \pm 0.30$. The variables having substantial between group variation compared to within group variation, as indicated by F-ratios, correspond fairly well to the structure matrix (Table 2).

The nature of the contribution of each of the variables to separation is also indicated in Figure 1. The majority of variables have positive correlations, while only a few have negative correlations that are of such small magnitude as to seem insignificant. Reference to the canonical discriminant functions evaluated at the group means (Caucasoid = -1.53459, Mongoloid = +1.59787) shows that the Mongoloid group (group 1) has a positive group centroid, while the Caucasoid group (group 2) has a negative group centroid. The loadings of each variable are interpreted in the same way. Positive loadings of variables indicate their larger size in the Mongoloid group than in the Caucasoid group and, thus, smaller sizes in the Caucasoid group than in the Mongoloid group. This is also related to the unstandardized canonical discriminant function coefficients: a positive score classifies an individual as Mongoloid based on tooth crown dimensions. A positive score is clearly then generated by larger tooth crown size dimensions than other tooth crown dimensions.

The effectiveness of the discriminant function in separating Caucasoids and Mongoloids based on tooth crown size is quantified by the success of classification. The overall success rate for correct classification is

93.94%. The confusion matrix (Table 6) summarizes the predicted group membership. Of the Mongoloid cases, 95.9% (93/97) are correctly classified and 4.1% (4/97) are incorrectly classified as Caucasoid. Exactly the same number of cases in the Caucasoid group are correctly classified, although a lower proportion than the Mongoloid group, since it is a slightly larger group (92.1% or 93/101) than the Mongoloid group, meaning a greater number of misclassified cases 7.9% (8/101) than the Mongoloid group.Twice as many Caucasoid cases are misclassified as Mongoloid, compared to the converse situation. The total error rate is 6.06%, since a total of 12 of the 198 cases had incorrect group predictions.

The discriminant scores on each case are proportional to the probability of classification of an individual and, again, cases with negative discriminant scores are classified as Caucasoid, and those with positive discriminant scores were classified as Mongoloid. Nine cases in the Caucasoid group (id. 56, 122, 125, 147, 158, 188, 57, 115, 200) and one case (id. 102) in the Mongoloid group are classified with very high probability (1.0000). The discriminant scores for these cases range from |-3.2197| to |+3.9314|. The next highest discriminant score is |+3.1729| for case 4 which is classified with a probability of 0.9999, indicating that a discriminant score $\pm 3.1729 < x < \pm 3.2197$ is required for certain classification at five significant figures.

The graphical illustration of discriminant scores (Fig. 2) shows relatively few cases misclassified in either group, though more occur in the Caucasoid group than the Mongoloid group. Interpretation of discriminant scores deserves special attention. In examining discriminant scores or any graphical representation of them the cut-off point, although very close to zero (y=0), is in fact the midpoint between the group centroids, which is (-1.53459+1.59787)/2 = +0.03164. Thus, any discriminant score below +0.03164 is classified as Caucasoid. This explains why, in the Caucasoid group, nine cases have positive discriminant function scores and fall on the Mongoloid side of the axis, but only eight cases are actually misclassified as Mongoloid. Case 49 has a very small discriminant score = +0.0098, which is <0.03164, and is therefore classified as Caucasoid, despite appearing on the graph as Mongoloid.

Caucasoid cases appear to be classified correctly with marginally more certainty than Mongoloid cases, as indicated by the average height of columns (depicting the discriminant score). Misclassified cases in either group appear to be approximately equally spread throughout groups, that is, no particular cluster of misclassified cases. This is of interest since cases were numbered in grouped order of male and female subsamples. This is to say that neither males nor females appeared to be misclassified more than the other.

The actual success rate of 93.94% was compared with the success rates computed via the randomization procedure.

TABLE 2. Wilks Lambda (U-statistic)

Variable		Wilks Lambda	F	Significance[1]
I^1	(md)	0.99588	0.8101	0.3692
I^2	(md)	0.85090	34.3437	0.0000**
UC	(md)	0.86637	30.2306	0.0000**
P^1	(md)	0.69883	84.4676	0.0000**
P^2	(md)	0.69676	85.3033	0.0000**
M^1	(md)	0.97214	5.6178	0.0187*
M^2	(md)	0.99925	0.1465	0.7024
I^1	(bl)	0.99697	0.5965	0.4408
I^2	(bl)	0.97252	5.5385	0.0196*
UC	(bl)	0.99163	1.6547	0.1998
P^1	(bl)	0.76879	58.9447	0.0000**
P^2	(bl)	0.96272	7.5904	0.0064**
M^1	(bl)	0.99987	0.0254	0.8734
M^2	(bl)	0.99532	0.9207	0.3385
I_1	(md)	0.90469	20.6493	0.0000**
I_2	(md)	0.95330	9.6019	0.0022*
LC	(md)	0.88633	25.1360	0.0000**
P_1	(md)	0.78348	54.1670	0.0000**
P_2	(md)	0.89925	21.9588	0.0000**
M_1	(md)	0.89836	22.1759	0.0000**
M_2	(md)	0.99314	1.3548	0.2459
I_1	(bl)	0.95779	8.6367	0.0037**
I_2	(bl)	0.95779	0.2223	0.6378
LC	(bl)	0.99924	0.1495	0.6995
P_1	(bl)	0.85325	33.7093	0.0000**
P_2	(bl)	0.99191	1.5994	0.2075
M_1	(bl)	0.93227	14.2396	0.0002**
M_2	(bl)	0.97299	5.4411	0.0207*

1* (p<0.05), **(p<0.01)

TABLE 3. DFA summary statistics and significance tests.

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation		After function	Wilks lambda	Chi-square	df	Significance[1]
					:	0	0.287597	226.808	28	0.0000**
1	2.4771	100.0	100.0	0.844	:					

[1] **(p<0.01)

Ninety-nine percent confidence limits were 57.6% - 73.7%. Since the actual success rate falls well outside these confidence limits, the results of the multivariate analysis were significant at p<0.001.

Summed Diameters and Tooth Crown Areas

In maxillary and mandibular teeth, summed mesiodistal diameters are significantly larger in Mongoloids compared to Caucasoids for all tooth regions. The greatest differences (p<0.001) for mesiodistal diameters in the maxilla exist for the canine, followed by the postcanine teeth and then incisor teeth. In the mandible postcanine teeth have greater differences between groups than the canine and incisors, respectively. Differences between groups in summed mesiodistal diameters are greater in the maxilla than the mandible. In the buccolingual dimension, highly significant differences (p<0.001) between Caucasoids and Mongoloids are apparent in the posterior teeth for both maxillary and mandibular teeth. Significant differences (p<0.05) are also shown for the canine, followed by the incisors. The summed buccolingual diameters are significantly different between groups for the postcanine group only, where Mongoloids are larger than Caucasoids. Results are found in Table 7.

In areal dimensions (md x bl) of the incisor group, canine and postcanine group, the maxillary variables again show greater differences than mandibular variables. In the maxilla, the crown area of incisors, the canine, and postcanine teeth are all significantly larger in Mongoloids compared with Caucasoids (p<0.05). In the mandible, only the areas of the canine and the postcanine teeth are significantly different between groups, with Mongoloids again larger than Caucasoids. Results are found in Table 7.

DISCUSSION

Results of statistical analyses indicate greater differences between the dentition of Mongoloids and Caucasoids in univariate analyses compared to the multivariate analyses. This is not surprising, since univariate statistics are known to overestimate significant differences in treating each variable individually, and fail to consider the correlations between variables. Many investigators (e.g.., Oxnard, 1968; Potter, 1972) have cautioned against relying solely on univariate statistics, although studies utilizing only these methods persist in the literature.

Eighteen tooth size variables are identified by Student's *t*-tests as being significantly larger in Mongoloids compared to Caucasoids, whereas canonical variate analysis identified four variables as significant discriminators between groups. Larger dimensions of Mongoloid teeth compared to Caucasoid teeth have previously been reported in the deciduous dentition (Lavelle, 1970). Variables ranked highest from 1 to 14 in the structure matrix were highly significantly different (p<0.01) according to *t*-tests, while variables ranked 15 to 18 in the structure matrix were also consistently significant but to a lesser extent (p<0.05) than the other variables in *t*-tests. The small discrepancy may be explained by the fairly arbitrary cut-off points set for the univariate analyses. Those values falling just outside significance levels are virtually identical to those falling just within the level of significance. Smith (1999) takes the approach that those variables marginally insignificant in the univariate analyses, but significantly contributing to the separation in multivariate analysis, could most probably be interpreted as truly contributing to the separation between samples. Although a conservative approach is to declare non-significance at a set cut-off point, the biological implications of marginally significant variables can possibly be ignored in this way.

A larger size of some premolar dimensions is evident in Mongoloids compared to Caucasoids, implicating the premolars in being particularly effective for separation of these groups. However, that only select premolar dimensions are involved in the remarkable separation between Mongoloids and Caucasoids based on simple tooth crown diameters, is obvious. Even so, additional premolar dimensions feature strong correlations with the discriminant function. P_1(bl) is fairly strongly correlated with the discriminant function (0.26350), as is P_2(md) (correlation with discriminant function = 0.21267). Consideration of these two variables, in turn, gives an impression of tooth crown areas of P^1 and P_1 being larger in Mongoloids than Caucasoids, and mesiodistal diameters of P^2 and P_2 also larger in Mongoloids than Caucasoids. Curiously, the buccolingual dimensions of P^2 and P_2 are fairly weakly correlated with the discriminant function and are certainly non-significant, especially the mandibular component (P^2 = 0.12504; P2 = 0.05739). These latter two variables cannot be included in the concept of larger premolar dimensions in Mongoloids than in Caucasoids. These results are interesting in showing the relatively greater contribution of P1 over P2, generally, to separation of groups, as well as greater contribution of mesiodistal over buccolingual diameters. The P_2 is known to be more variable in form than P_1 (Carlsen and Alexandersen, 1994). Although humans have lost the true upper and lower first and second premolars, reduction takes place from the most distal one, mesially in both jaws or only in the lower jaw (Grahnén, 1962).

Briefly, similar results are obtained for CVA and DFA on tooth crown measurements from the right hand side of the dental arch. Identical premolar dimensions are significant separators of groups, although the first two variables are reversed in order: P^1(md), P^2(md), P^1(bl), and P_1(md). In addition, the maxillary canine (UC, md) and P_1(bl) are also significant contributors to separation. As in analysis of the left side measurements, P_2 (md) is just below the threshold for significant contribution to separation, while P_2(bl) is very weakly correlated with the discriminant function. In spite of the asymmetry detected in initial paired t-tests, little overall effect on multivariate analyses is seen.

Possibly, the multivariate analysis has been unduly affected by the presence of outliers, which may distort the results in any direction. In preliminary screening and examination of the data, not a single multivariate outlier was identified. Univariate screening of the data was conducted. For the sake of brevity boxplots and z-scores are not provided but are summarized as follows: for the cases misclassified by DFA, two individuals in the Caucasoid group (id. 45 and 112) had some tooth size dimensions identified as univariate outliers through examination of boxplots. Two cases in the Mongoloid group (id. 48 and 139) had variables identified as univariate outliers through boxplots, and one case (id. 60) had variables identified as an univariate outlier based on boxplots and z-scores. Outliers can occur in any direction.

TABLE 4. Unstandardized discriminant function coefficients.

Variable	Unstandardized Discriminant Function Coefficients
I^1 (md)	-0.7577334
I^2 (md)	0.3853306
UC (md)	-0.0850442
P^1 (md)	0.4662808
P^2 (md)	2.1581784
M^1 (md)	-0.3218897
M^2 (md)	-0.9167015
I^1 (bl)	0.2282310
I^2 (bl)	0.4667222
UC (bl)	-0.0767832
P^1 (bl)	1.3962831
P^2 (bl)	-1.1856690
M^1 (bl)	-0.2368220
M^2 (bl)	-0.1252859
I_1 (md)	0.4540023
I^2 (md)	-0.1307232
LC (md)	0.2121910
P_1 (md)	0.1648197
P_2 (md)	-0.2242924
M_1 (md)	0.9447300
M_2 (md)	-0.3020549
I_1 (bl)	-1.6685050
I_2 (bl)	0.6123724
LC (bl)	-0.3871803
P_1 (bl)	0.5232794
P_2 (bl)	-0.3686911
M_1 (bl)	-0.1814727
M_2 (bl)	0.3608481
(constant)	-6.8177253

TABLE 5. Pooled within-groups correlations between discriminating variables (DV) and the discriminant function (DF)

Variable	Within-groups correlation between DV and DF
I^1 (md)	0.04085
I^2 (md)	0.26597
UC (md)	0.24953
P^1 (md)	0.41711
P^2 (md)	0.41916
M^1 (md)	0.10757
M^2 (md)	-0.01737
I^1 (bl)	0.03505
I^2 (bl)	0.10681
UC (bl)	0.05838
P^1 (bl)	0.34844
P^2 (bl)	0.12504
M^1 (bl)	0.00724
M^2 (bl)	0.04355
I_1 (md)	0.20623
I^2 (md)	0.14063
LC (md)	0.22754
P_1 (md)	0.33402
P_2 (md)	0.21267
M_1 (md)	0.21372
M_2 (md)	0.05283
I_1 (bl)	-0.13338
I_2 (bl)	-0.02140
LC (bl)	-0.01755
P_1 (bl)	0.26350
P_2 (bl)	0.05739
M_1 (bl)	0.17126
M_2 (bl)	0.10586

That some of the cases correctly classified in DFA are also found to be outliers is not surprising. A few cases that were classified with a probability of 1.0000 in the Caucasoid group, were also identified as univariate outliers by boxplots (id. 56, 122, 200).

Possibly, the premolar dimensions that are larger than others, particularly in the buccolingual diameter, may have resulted from additional cuspules analogous to Carabelli's cusp on the maxillary molars. However, premolars appear to have arisen from the reduction of molars, via reduction of the protocone, and suppression of the lingual cingulum which forms the hypocone and Carabelli's cusp (Korenhof, 1960). Therefore, to find these kinds of features on the premolars is highly unlikely.

Based on mean crown diameters, Moorrees (1957) has reported no differences in the size of premolars of Mongoloids and Caucasoids. Lavelle (1973) also reports little discrimination of Mongoloids and Caucasoids based on maxillary premolar dimensions, including mesiodistal and buccolingual crown diameters, cusp heights, and intercusp distances. When maxillary molar measurements were added to the canonical analysis, the discrimination improved. This outcome is not surprising since discernibility between groups (e.g., subpopulations, species, suborders) is increased as an increased number of characteristics of teeth are measured and analyzed (Stern and Skobe, 1985). If mesiodistal and buccolingual measurements only were utilized, different results again would probably be obtained. The evidence for this rests with the report of conflicting discriminant functions following the use of different sets of measurements for the canine teeth of humans and chimpanzees (Bronowski and Long, 1951; Yates and Healey, 1951). As far as the author is aware, the same 28 variables utilized in the present study have not been applied to the same population groups to create a DF, precluding any direct comparisons.

"Within" Premolar Differences

While the present research presents evidence of discernible differences between contemporary Caucasoids and Mongoloids in the gross crown size of premolars with respect to the remaining dentition, differences are reported within the premolars, themselves. This finding supports the notion that additional significant information can be gained from measurements of gross dental morphology (Moss et al., 1967; Biggerstaff, 1969a; Wood and Abbott, 1983; Lavelle, 1984). The investigation of "within-tooth" differences of the postcanine dentition was established by Biggerstaff (1969a), who identified definable tooth crown landmarks, as well as a reliable and accurate method to record them (Biggerstaff, 1969b).

Corruccini (1977b; 1978) demonstrates substantial discrimination between humans and extant pongids based on a single premolar tooth. Principal components analysis of ten landmarks to describe the crown component variation of P_2 and canonical analysis of seven landmarks quantifying the crown variation of P^1 produced similar results. Observed differences are attributed to functional observations.

Human population differences in metric crown profiles of premolars are reported (Lavelle, 1978, 1984). Canonical analyses utilizing mandibular premolars provide better separation of groups than analyses involving maxillary counterparts (Lavelle, 1978). First and second premolar measurements are more effective separators than second premolar measurements alone, which in turn are notably more effective than maxillary measurements alone, the least effective separators. These results are summarized as follows:

$$P_1+P_2>P_2>P^1+P^2\geq P_1>P^1$$

TABLE 6. DFA Confusion Matrix

Actual Group	Number of Cases	Predicted Group Membership	
		1	2
Group 1	97	93	4
MONGOLOID		95.90%	4.10%
Group 2	101	8	93
CAUCASOID		7.90%	92.10%

% of "grouped" cases correctly classified: 93.94%

These results are intriguing, since we find the overall dimensions of maxillary premolars to be better discriminators than mandibular premolars, with first premolars contributing more than second premolars. In effect, overall dimensions and within-tooth differences of premolars seem to provide conflicting results.

A new approach to quantitative assessment of teeth has been suggested (Morris, 1981), and involves angular measurements to appraise anterior buccolingual compression and posterior expansion of P^1. Although the observed differences between Caucasoids and Mongoloids are inconsistent regarding angular measurements, refinement of the technique and incorporation with a suite of crown measurements might prove rewarding. Interestingly, tooth size is apparently not the reason for angular differences, since small-toothed urban South African Indians showed larger angles than the relatively larger-toothed Africans (Central Sotho) (Morris, 1981), implicating proportional differences within the tooth.

Series of measurements of the occlusal surfaces of tooth crowns have resolved some of the objections to traditional odontometrics. While the information is valuable and interesting, we must be cautious not to limit the scope of odontometrics too greatly. Although not yet a problem, in foresight we propose that traditional dental measurements be retained. Prior to the introduction of detailed crown measurements of the occlusal surface, "...descriptive and mensurational studies of the dentition occupy a major role in the armamentarium of anthropology, comparative anatomy, and palaeontology" (Moss and Chase, 1966). With access to the enormous body of conventional odontometric data collected since the inception of dental mensuration, investigators are offered an unparalleled body of data available for comparative purposes.

Summed Tooth Diameters

Summed mesiodistal diameters are significantly larger in Mongoloids compared to Caucasoids more often than summed buccolingual diameters. This result is expected since for Student's *t*-tests of individual diameters, a greater number of mesiodistal diameters are significantly different between groups, than buccolingual diameters. Summed buccolingual diameters were significantly larger in Mongoloids than Caucasoids for the postcanine teeth only. In fact, Caucasoids are larger than Mongoloids in the summed buccolingual diameters of the mandibular incisors and mandibular canine. Although neither comparisons are significant, the incisors approach significance so closely as to warrant special, albeit brief, discussion here. Perhaps this observation is related to a compensatory mechanism of some nature. The high frequencies of shovel-shaped incisors in Mongoloids (Hrdlicka, 1920; Dahlberg, 1951; Hanihara, 1968) may function to strengthen the anterior tooth crowns in the way that engineering data identify the I-beam as structurally superior to a solid oblong-shaped girder. Perhaps, in the absence of genetic information to code for shovel-shaped incisors, Caucasoids have developed thicker anterior teeth than those of Mongoloids to provide the required strength. We stress that the incidence of shovel-shaped incisors has not been assessed in this sample, and we wish merely to offer a possible explanation for our results.

Table 7. Univariate differences (Student's t-test) between Mongoloids and Caucasoids in summed mesiodistal diameters, buccolingual diameters, and crown areas of incisors, canines, and post-canine teeth.

Variable		$\bar{X}M-\bar{X}C$[1]	average difference/tooth	SE of diffrence	t	p (2tail)[2]
$I^1 + I^2$	(md)	0.5465	0.2733	0.155	3.53	0.001**
UC	(md)	0.3513	0.3513	0.066	5.30	0.000**
$P^1 + P^2 + M^1 + M^2$	(md)	1.1200	0.2800	0.278	4.03	0.000**
$I_1 + I_2$	(md)	0.3935	0.1968	0.105	3.76	0.000**
LC	(md)	0.3030	0.3030	0.062	4.88	0.000**
$P_1 + P_2 + M_1 + M_2$	(md)	1.2503	0.3126	0.305	4.10	0.000**
$I^1 + I^2$	(bl)	0.2321	0.1161	0.162	1.43	0.154
UC	(bl)	0.1168	0.0068	0.095	1.22	0.223
$P^1 + P^2 + M^1 + M^2$	(bl)	0.9112	0.2278	0.380	2.40	0.018*
$I_1 + I_2$	(bl)	-0.2363	-0.1182	0.120	-1.97	0.051
LC	(bl)	-0.0269	-0.0269	0.083	-0.32	0.747
$P_1 + P_2 + M_1 + M_2$	(bl)	0.8709	0.2177	0.318	2.74	0.007**
$I^1 + I^2$	(mdxbl)	5.1995	2.5998	2.168	2.40	0.018*
UC	(mdxbl)	3.8404	0.8404	1.143	3.36	0.001**
$P^1 + P^2 + M^1 + M^2$	(mdxbl)	17.5458	4.3865	6.161	2.85	0.005**
$I_1 + I_2$	(mdxbl)	1.4447	0.7224	1.236	1.17	0.244
LC	(mdxbl)	2.0109	2.0109	0.936	2.15	0.033*
$P_1 + P_2 + M_1 + M_2$	(mdxbl)	19.8457	4.9614	5.620	3.53	0.001**

[1]M is Mongoloid; C is Caucasoid; [2] *(P<0.05). **(p<0.01)

Postcanine Area

The computation of tooth crown areas indicates that the postcanine teeth, as a unit and on a per-tooth basis, exhibit the greatest areal differences for both maxillary and mandibular dimensions between Mongoloids and Caucasoids. This is expected in light of the convincing differences in premolars between groups. The method of calculating crown area in the molar region overestimates the actual occlusal area (Wood and Engelman, 1988). Also, we define mesiodistal diameter as the distance between the interproximal contact points, rather than the maximum length of the crown, probably resulting in a smaller area than might normally be estimated. These two considerations act in opposing directions towards a cancelling-out effect. Although the extent of each effect not known, it is likely to differ according to tooth type since different ratios of length to breadth exist across tooth classes. Even though the crown area measurements obtained here may not be as accurate as is achievable with today's technological aids, they serve sufficiently for comparative purposes across the dentition.

The function of a larger postcanine area in humans than in other species has not been specifically addressed and remains unclear, although a brief discussion follows. Clearly, the main function of the teeth in humans is as a food-processing device. In order to glean the significance of a relatively larger postcanine tooth size area, one has to understand the function of the postcanine tooth. The single most important oral

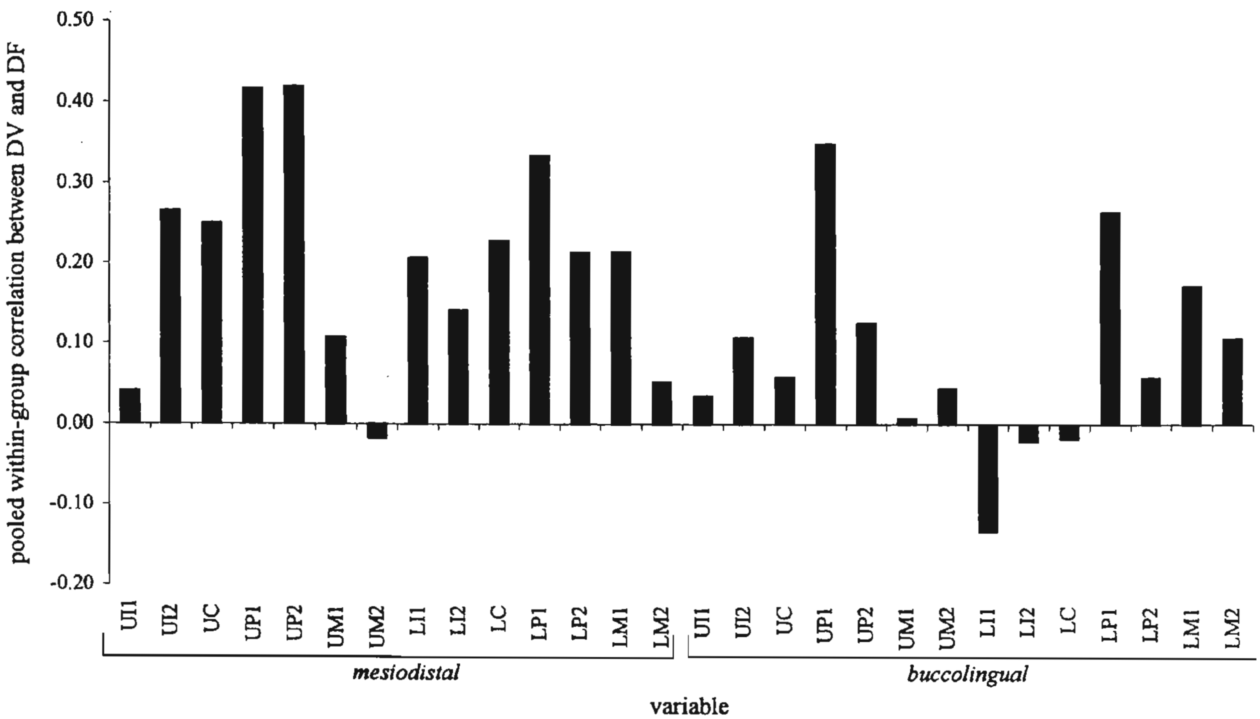

Fig. 1. Structure matrix. U = upper. L = lower.

variable in human studies that influences the rate of food breakdown is the postcanine tooth size (Manly, 1951; Helkimo et al., 1978; Kayser, 1980).

Several studies have attempted to correlate the size of postcanine teeth with diet (e.g., folivore, frugivore, omnivore) in primates (e.g., Kay, 1975; Goldstein et al., 1978; Gingerich et al., 1982). Lucas et al.(1986) have suggested that in anthropoid primates, natural selection should favor a greater buccolingual width than mesiodistal width of the postcanine teeth, since food particles form a ball or bolus in the mouth which can then be distributed to the teeth *en masse* by lateral movements of the tongue. Lateral movements of the tongue are the most likely to distribute the bolus of food to the postcanine teeth, where the chance of breaking food particles is improved. Chemically sealed non-sticky food particles, such as vegetable matter, demand a large postcanine tooth row in which tooth length is as important as tooth width, and no tooth is necessarily larger than any other. In contrast, high volumes of large and/or sticky food particles require a small wide tooth row with large central teeth in the postcanine row (Lucas et al., 1986). Possibly, the differences elucidated in this study are a result of dietary differences, but this certainly requires further research. Although an original assessment of diet was attempted in our research design, the information was too incomplete and non-specific to attempt any analysis. Generally, though, the dietary composition of the populations in Sydney is rather similar between populations due to the diverse and multicultural nature of this large city. Traditional Asian diets are less likely to exist than in people's homeland. While, the adaptation of teeth to the mechanical properties of food has been emphasized (e.g., Maier, 1984; Lucas et al., 1986), just how far the analysis of diet can explain tooth form is unclear, since this approach fails to consider the design of structural supports of the teeth, jaws, and face to accommodate the additional effects of bite forces (Lucas et al., 1986).

P1 vs P2

Examining the relationship between P1 and P2 is valuable. According to mean values, the first premolar is larger than the second premolar more frequently in Mongoloids compared with Caucasoids, perhaps emphasizing its discriminatory power. In the maxillary premolars, P1>P2 occurs in the mesiodistal diameter of both Mongoloids and Caucasoids. In the buccolingual diameter of the maxillary premolars, P1>P2 appears in Mongoloids only. In Caucasoids the P1<P2 is seen. In the mesiodistal diameter of the mandibular premolars, the first premolar is marginally larger than the second premolar in Mongoloids (P1≥P2), and the second premolar is larger than the first in Caucasoids (P1<P2). In the buccolingual diameter of the mandibular premolars P1<P2 in both Mongoloids and Caucasoids. Preliminary unpublished analyses show that all measurements of P1 and P2 are significantly different from each other within population groups, except the mandibular mesiodistal diameter of Mongoloids. Differences between the premolars were also examined with respect to the crown areas (md x bl). Equivalent results for Caucasoids and Mongoloids are observed in the maxilla and mandible, with maxillary premolars displaying P1>P2, with Mongoloids showing P1>>P2. In mandibular premolars the trend is reversed, with P1<P2, with Caucasoids (P1<<P2) showing a more marked difference in areal dimensions of P1 and P2 than Mongoloids. All comparisons are highly significant ($p<0.001$). Clearly the buccolingual diameter strongly influences the trend observed in areal measurements of the mandibular premolars.

Swindler (1976) records a trend in the relative size of the crown areas of the two maxillary premolars in primates, with the mean values of P3 crown being consistently larger than those of the equivalent P4. Robinson (1956) comments on the relative homomorphy among hominid maxillary premolars, stating that "there is consequently not a clear distinction between prehominid (i.e., australopithecine) and euhominid (i.e., *Homo*) maxillary premolars". Hence it appears that observations made for early hominid premolars can be applied to the human situation. Although both population groups display the trend of occlusal area P1>P2 in the maxillary premolars, the effect is more marked in the Mongoloid dentition. Wood and Engelman (1988) conclude that in finding P3>P4 is most likely to be a primitive trait of maxillary premolars for the African ape/human clade. However, Hillson (1996) states that whist usually maxillary P1>P2 in humans, australopithecine (especially *Paranthropus*) premolars show the reverse trend. Gregory (1922) points out that the premolars of humans show a considerable range in size, and large premolars are regarded as primitive and small ones as recent forms. We are wary of making conclusions relating to this sample.

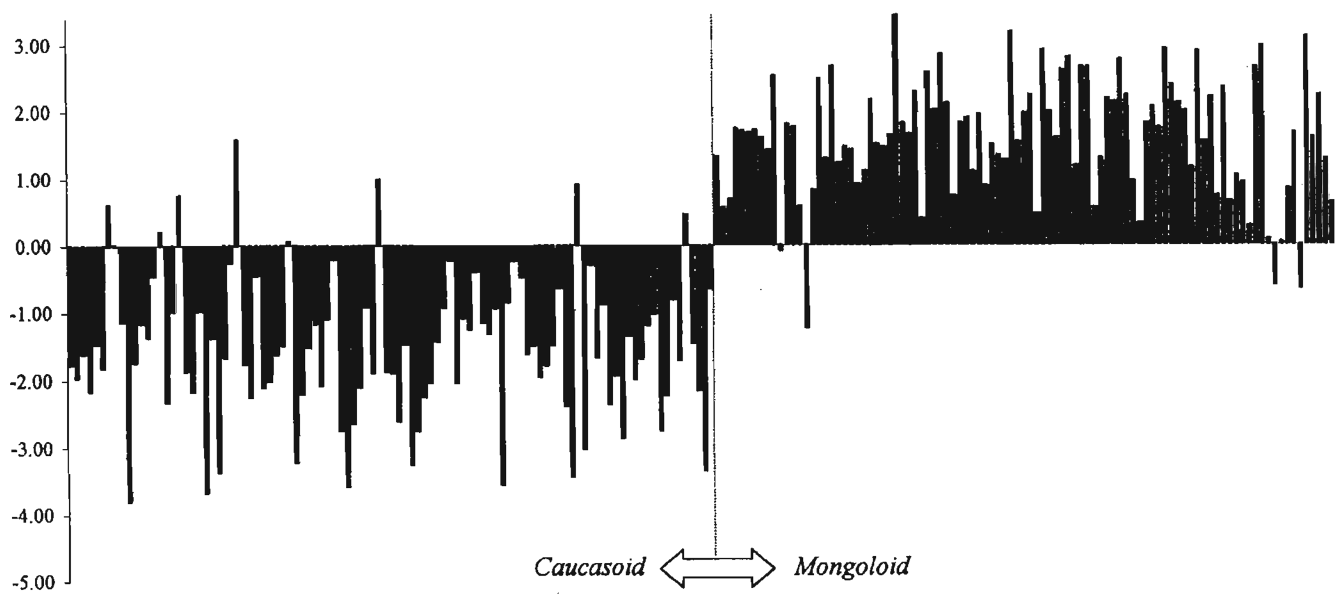

Fig. 2. Discriminant Scores

CONCLUSIONS

We wish to emphasize the successful separation of two contemporary populations based on simple tooth crown diameters combined with multivariate statistical techniques. The discrimination of the major groups living in Sydney, the largest city in Australia, has important implications for identification of heavily decomposed and skeletal remains in the forensic setting. Successful application of these results is likely, although further exploration is required prior to the implementation of this new knowledge. The allocation or assignment of individuals should be considered separately and independently to discrimination or classification (Campbell, 1984; Kieser and Groeneveld, 1990). Examination of the literature illustrates the inappropriate use of discriminant analysis in allocating an individual to group membership. These issues have been discussed, but continue to be largely ignored. Our results, as they relate to allocation, will be reported in a later study. We are presently concentrating on developing the statistical means to achieve these analyses, based on the work of Campbell (1984) and Kieser and Groeneveld (1990). Meanwhile, we recommend that all available criteria be utilized in combination for the problem of determining population affinity.

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FOOTNOTES

[1]Full descriptive statistics are available on request to the authors.

[2]Human premolars are referred to as P3 and P4 in paleontological termonology, but P1 and P2 are used mainly here.

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BOOK REVIEW

PERSPECTIVES IN HUMAN BIOLOGY, VOLUME 4(3): DENTO-FACIAL VARIATION IN PERSPECTIVE. Edited by Grant Townsend and Jules Kieser. Series Editor: Charles Oxnard. Centre for Human Biology, Department of Anatomy and Human Biology, University of Western Australia (paperback), 1999. 172 pp. ISBN: 0-86422934-8.

Dento-Facial Variation in Perspective consists of 20 peer-reviewed articles based on presentations made at the Joint Conference of the Australian Society for Human Biology (ASHB) and the Commission of Human Ecology of the International Union of Anthropological and Ethnological Sciences (IUAES) held in Adelaide in 1997. These concise papers, incorporating state of the art technology and powerful statistical models, are organized around four central themes: the influences of genes and environment on dento-facial variation; dental wear; dento-facial variation across human populations; and the use of new imaging techniques in morphometric analyses. Unifying the contributions to this volume is the useful theoretical perspective of the dento-facial complex as a functional, dynamic system.

John Mayhall's keynote address focuses on the problem of using dental complexes to understand population affinities in the absence of a firm understanding of the interaction of genetic and environmental influences on variation in dental morphology. Mayhall's address is a lead-in to several papers dealing with the interaction of genetic and environmental influences on dento-facial variation.

Authors Dempsey, Townsend, and Martin demonstrate the effectiveness of structural equation modeling to determining the genetic basis of crown size. Among other advantages, this method improves on traditional approaches by separating common (or family) environments from genetic factors. Of all the permanent teeth examined, the canine and first premolar appear to be most strongly influenced by non-additive genetic effects while maxillary first molars are most strongly effected by common environment. In their paper, Pinkerton and colleagues find that concordance for the Carabelli trait is higher in monozygous (MZ) as opposed to dizygous (DZ) Australian twins, reflecting the strong influence of genetic factors on this trait. Thomas's and Townsend's study on interdental spacing in the primary dentition again compares MZ and DZ Australian twins, finding higher concordance of spacing type in MZ twins. The Australian twins participating in these studies of dento-facial growth were examined for concordance of handedness by Dempsey et al., who found no association between handedness and zygosity. While this study is well-designed and interesting, why the editors chose to include it in a volume devoted to the subject of dento-facial variation is not clear.

Dento-facial asymmetry is the subject of papers by Townsend, Dempsey, and Richards (asymmetry in the deciduous dentition) and Winning, Brown, and Townsend (human facial asymmetry). In the first of these papers, the authors find no evidence for greater asymmetry in the deciduous teeth of twins relative to singletons, even though competition of twins for nutrition during gestation and more stressful intrauterine environments than singletons might be supposed. In the second of these papers, facial asymmetry is found to exhibit extensive individual variability during growth, but no overall trend for changes in facial asymmetry with increasing age.

Genetic abnormalities can reveal important aspects of dental development, as is shown in papers by Narayanan, Smith, and Townsend (cleft lip and palate) and Townsend and Alvesalo (Klinefelter's syndrome). The authors of the first paper find that fluctuating dental asymmetry is not only elevated in the region of the cleft, but also in other regions of the dentition, indicating both local and systemic developmental disruption. The authors of the second paper report greater intercupsal dimensions in the premolars of 47,XXY individuals relative to normal controls, consistent with Alvesalo's previous research demonstrating the influence of the X chromosome on enamel thickness.

The next group of papers examines dental wear as affected by craniofacial morphology, tooth-grinding, diet, and culture. Authors Richards et al. find significant relationships between tooth wear patterns and craniofacial morphology in three Australian populations. Kaidonis, Townsend, and Richards show that dental microwear not only results from diet and culture but from tooth-grinding, while Springbett et al. find, in their study of Australian Caucasians and Aboriginals, that wear processes differ between the two groups, reflecting cultural and dietary differences.

Five papers documenting dento-facial variation across populations include studies of Cook Islanders, South Pacific Peoples, Mioriori, Maori, Chinese, and Caucasians, substantially broadening the perspective of this volume, which, until this point, relies heavily on Australian populations. Kageyama, Mayhall, and Townsend use moiré contourography and digital image analysis to study three-dimensional occlusal form in the dentition of Australian aborigines. Kondo and colleagues find sex differences in the talonid dimensions but not in the trigonid dimensions of Cook Islanders' mandibular molars, perhaps reflecting the fact that the talonid forms later in development than the trigonid. In their paper, Aboshi et al., find that Fijians are less like Kirbatians and Western Samoans, who are more like each other than other samples in the size and shape of their dental arches. An interesting paper by Kieser and colleagues examines the relationship between basicranial flexion and glenoidal depth in Moriori, Maoiri, Indians, and Caucasians, finding that the glenoidal fossa deepens as the basicranial angle decreases. Data derived from a CT scan of STS 5 (*A.africanus*) conforms to this trend. The authors believe that the vulnerability of the TMJ to dysfunction could be related to the deepening of the glenoid in hominid evolution, in turn a result of the progressive increase in cranial flexion. This cross-cultural section concludes with Tasman Brown's paper on providing standards for soft tissue profiles of Caucasians and Chinese for use in clinical settings.

The last three papers of this volume concentrate on the use of new imaging techniques to analyze craniofacial structures. While these papers are of clinical relevance, the techniques described will certainly be of interest to dental anthropologists. Chintakanon et al. show that magnetic resonance imaging is a highly effective method of describing variation in TMJ morphology. Netherway and colleagues use computer tomography for characterizing the human craniofacial skeleton in three dimensions, and Abbott et al., use computer tomography to demonstrate that intracranial volume is not smaller than normal in subjects with non-syndromal craniosynostosis while it is significantly larger than normal in those with syndromal craniosynostosis.

Overall, this volume in the Perspectives series coalesces important recent research on the dento-facial complex, with emphasis on the interaction of genes and environment. While many of the studies involve research on Australian populations, the editors have included studies on other populations, as well. This volume applies powerful new statistical methods and imaging techniques to enhance the understanding of environment interactions and the analysis of variation in dento-facial form. Owing perhaps to space constraints, some studies have only brief discussions. In one respect this is unfortunate because the studies themselves are so interesting. However, concise statements of research problems, materials, methods, and results highlight the many significant and illuminating aspects of these studies.

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Dental Anthropology Association Annual Meeting, April 13, 2000

Shara E. Bailey (left) accepts the first Albert A. Dahlberg Prize from A.M. Haeussler, competition coordinator.

The Annual Meeting of the Dental Anthropology Association was held on April 13, 2000, in San Antonio, Texas. The major items of business were the presentation of the first Albert A. Dahlberg Prize and the election of officers.

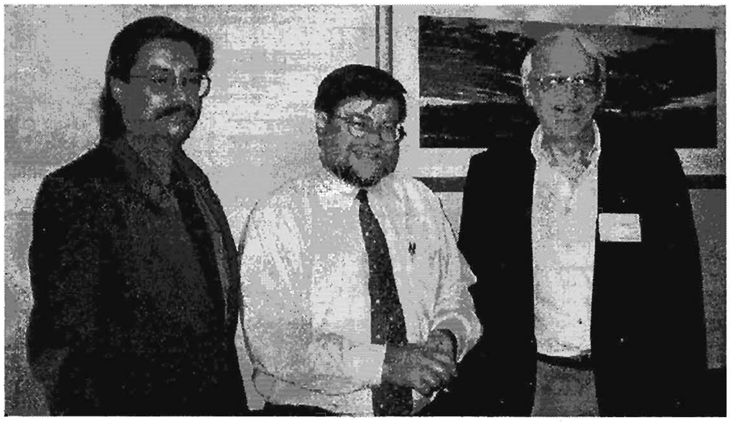
The Albert A.Dahlberg Prize was awarded to Shara E. Bailey (Arizona State University) for the best student paper submitted to the Dental Anthropology Association by January, 31, 2000. Three Honorable Mention awards were presented. Alison Chiu (University of Sydney) was presented her award at the meeting. Annalisa Alvrus and Jill Sears, both of Arizona State University, received their awards after the meeting. This issue contains the prize-winning papers.

Edward F. Harris, University of Tennessee, was confirmed as president. Joel D. Irish, University of Alaska, Fairbanks, was voted president-elect.

Annalisa Alvrus
Honorable Mention

Honorable Mention awards were presented to Annalisa Alvrus (left), Alison Chiu (above) receiving her award, and Jill Sears (right).

Jill Sears
Honorable Mention



Dental Anthropology Association presidents: Left to right Joel D. Irish, president-elect; Edward F. Harris, president; and John T. Mayhall, past-president.

Left to right: Andrea Cucina and Alfredo Coppa (Universita La Sapienza), Helen Liversidge (Royal London School of Medicine and Dentistry), and Ebba During (Stockholm University) at the business meeting.

INFORMATION FOR CONTRIBUTORS TO *DENTAL ANTHROPOLOGY*

A. Manuscripts and other correspondence should be sent to the editor, A.M. Haeussler, Department of Anthropology, Arizona State University Box 872402, Tempe, AZ 85287-2402, U.S.A.

B. Books for review should be sent to Debbi Guatelli-Steinberg, Department of Anthropology, 1218 University of Oregon, Eugene, OR 97403, U.S.A.

C. Manuscripts are reviewed by members of the Editorial Board. In cases of specialized topics, manuscripts are reviewed by at least one specialist in the subject of the manuscript.

D. All manuscripts, including illustrations, must be submitted as printed copy. Copies of manuscripts on diskette are welcomed. *Dental Anthropology* uses *Word Perfect 6.1*© on a DOS© platform that can run on Windows 95© or Windows 98©. Dental Anthropology is not compatible with an Apple©/ Macintosh© platform.

INSTRUCTIONS FOR MANUSCRIPTS

1. An original and two copies of the manuscript for review should be submitted. The copies can be xeroxes, if they are clear.
2. Each manuscript should be printed double space or typed double space.
3. Each photograph, each graph, and a list of figure captions should be printed on a separate piece of white paper.
4. The manuscript should consist of a title page, an abstract, text, and a bibliography. Photographs, maps, and graphic representations of data are welcome.
5. The title page should have the title and the running (abbreviated) title of the manuscript; the name(s) of the author(s); the name(s) and address(es) of academic affiliation(s); Email; and telephone and fax numbers.
6. The abstract should concisely give the purpose, the research, and the main observations and conclusions of the work presented in the text.
7. The text should have an introduction; sections on materials and methods, results, discussion, and conclusion; and a summary.
8. The bibliographic style, both in the text and in the section, "Literature Cited", follows that used in the *American Journal of Physical Anthropology* (AJPA).
   The AJPA guide was published in Volume 108, Number 1, pages 131-135 (1999).
   Authors can also view the AJPA guide on the Dental Anthropology Association web site (http:/www.anth.ucsb.edu/faculty/walker).
9. Abbreviations of journal names are the same as those used in the *Index Medicus*. Unusual and non-English titles are spelled out.
10. Nouns should be maximized. Pronouns should be minimized. Unreferenced pronouns, including "it" and "there" (e.g., "it is" and "there are") should be avoided.
11. Comparative adjectives should be followed by "than" and the base on which they are compared (e.g., Human teeth are larger than mice teeth.). Stand alone comparative adjectives (e.g., Human teeth are larger.) should be avoided.
12. Abbreviations should be avoided in the text. When they are used, the terms abbreviated should be spelled out with the first appearance of the abbreviation. Abbreviations in tables and figures should be explained in the last line of a table or in the caption of a figure.
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14. The current issue of Dental Anthropology follows the approved style and has numerous examples of format, including those of text, tables, figures, and text and bibliographic citations.

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