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Variations of Tooth Root Morphology in a Romano-British Population

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ABSTRACT: Tooth morphology can provide valuable evidence in studies of prehistoric, historic and modern populations. The aims of this study were to derive data for root anomalies in a Romano-British population, to investigate associations between anomalies, and to compare findings with other populations to provide evidence concerning etiology. An additional aim was to develop further the methodology and reproducibility in such studies. From the Christian cemetery of 3rd-5th century AD in Poundbury, UK, 385 skulls were suitable for examination. Radiographic technique was standardized with custom-made skull supports and criteria established for each anomaly. There was a high level of reproducibility for the diagnosis of each anomaly. The prevalence of the anomalies in individuals was: three-rooted mandibular first molars 1.8%, fused roots 14.0%, cuneiform roots 16.9%, taurodontism 26.9%, and invaginated teeth 1.1%. There were highly significant ($P < 0.001$) associations between fused and cuneiform roots, and both were significantly associated with third molar hypodontia ($P < 0.002$; $P < 0.05$). These reductions in root morphology were commonly bilateral and more frequent in females, as is hypodontia. The findings of this study are compatible with a multifactorial etiology of these anomalies, showing continuous variation in root morphology. The gradients of anomalies observed are also compatible with the concept of morphogenetic fields. *Dental Anthropology* 2006;19(2):33-38.

Tooth root morphology can provide valuable additional evidence to crown morphology in studies of prehistoric, historic and modern populations. The determination of root morphology may be multifactorial, as is crown morphology, with both genetic and environmental factors involved (Winter and Brook, 1989). Variations of root morphology include the number of roots, as with accessory roots or fused roots, their shape, as in taurodontism, or their size. Ethnic differences in root morphology have been recognized (Dixon and Stewart, 1976).

The present study aimed to derive data for root anomalies in a homogeneous Romano-British population and to investigate associations with other dental anomalies in this group. Also the study aimed to develop further the methodology of measurement and the reproducibility of diagnosis of root anomalies in archeological material, enhancing comparisons with other ancient and modern populations.

MATERIALS AND METHODS

The skulls investigated were from a cemetery of the Roman town of Durnovaria, close to the site of the modern Poundbury, Dorset, UK. The cemetery dates from the 3rd to 5th century AD and is of a Christian character. The population was of native British origin throughout this period (Farwell and Molleson, 1993). The excavated skulls are housed at the British Museum (Natural History), London, UK. The total collection from this burial site consists of 1,100 crania, but a large proportion of these are very fragmented and unsuitable for this study. The criterion for inclusion in the present investigation was a jaw that had at least one permanent molar and one permanent incisor present. Juvenile skulls with a dental age of less than 9 years were excluded. The resultant sample was 385 skulls suitable for examination of root morphology.

Age and sex determinations were made by the staff of the British Museum based on the long bones, pelvic girdles and skulls. Of the sample, 40.0% (154) were estimated male, 38.7% (149) female, and for 21.3% (82) no determination could be made.

Radiographs were taken of all teeth using an industrial apparatus and Kodak ultraspeed dental occlusal films. A pilot study established the optimum voltage, current and exposure time as well as the standardized positioning of the x-ray tube, skull and films. Customized wooden blocks were developed for positioning the skulls. A total of 6 films per skull

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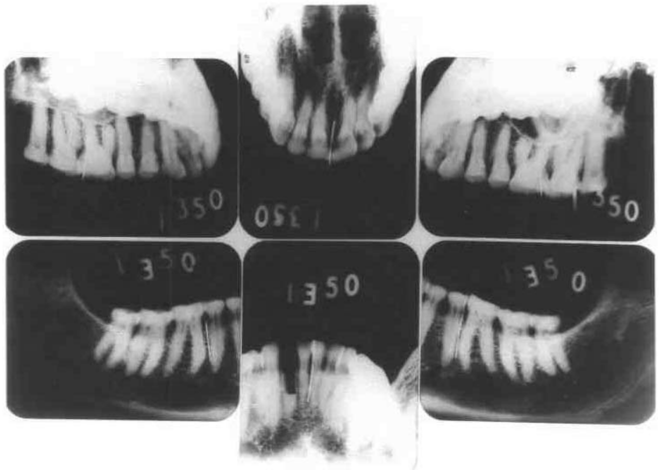


Fig. 1. Full coverage of the dentition using six radiographs.

provided full coverage of the teeth (Fig. 1). To calibrate measurements, all films were taken including a 20 mm length of orthodontic wire. The films were developed and viewed under standardized conditions.

The anomalies diagnosed were three-rooted mandibular first permanent molars, fused (pyramidal) and cuneiform roots, taurodontism and crown and root invaginations.

The radiographic criteria for the five anomalies diagnosed in the study were: (1) three-rooted mandibular first molar: evidence of a third root; (2) fused molar root: a pyramidal root form with no evidence of an interradicular bony septum or periodontal ligament but with separation of root canals; (3) cuneiform molar root: a root form with a central root canal whose shape followed the root outline; (4) taurodontism: criteria of Holt and Brook (1979; Fig. 2); and (5) crown invaginations: criteria of Hallett (1953); types 2, 3 and 4 were scored following Grahnen *et al.* (1959) and Brook (1974).

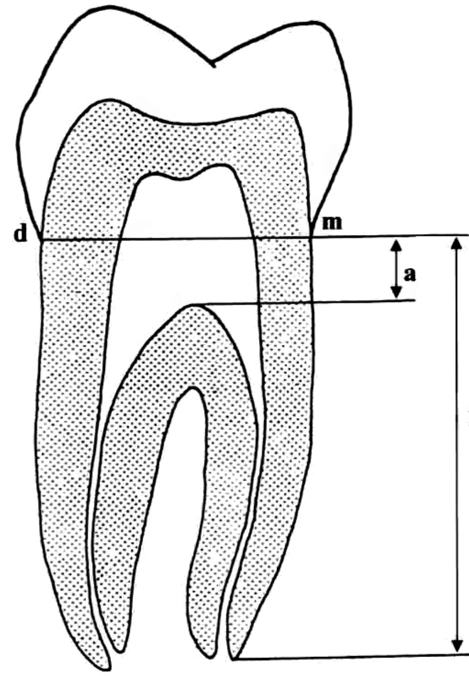
For each anomaly, prevalence for skulls, prevalence for teeth, sex distribution, and symmetry were investigated.

To test the reproducibility of the diagnosis, the radiographs of 20% of the sample were read on a second, separate occasion. The reproducibility findings are in Table 1.

RESULTS

The findings for the prevalence for skulls and sex distribution of the root anomalies studied are shown in Table 2, which also indicates the number of individuals suitable for scoring each anomaly.

Three-rooted mandibular first molars—those with an accessory root—had a prevalence of 1.8% of skulls and a tooth prevalence of 1.5%. In half of the individuals the anomaly was bilateral and equal numbers of males



Baseline = axis between mesial and distal points of amelo-cemental junction.
a = distance from baseline to highest point on pulp chamber floor.
b = distance from baseline to apex of distal root.

Fig. 2. Measurement used for taurodontism (after Holt and Brook, 1979).

and females were affected.

For reduction in root number the prevalence for fused roots was 14.0% of skulls and for cuneiform roots was 16.9% of skulls. The tooth prevalence for reduced root number was 2.7% for fused roots and 3.4% for cuneiform roots, some individuals possessing both anomalies. Maxillary molars were affected more frequently than mandibular molars. Third molars were more often affected than second molars, with no example being found in first permanent molars. The male to female ratios of 1:2.2 for fused roots and 1:2 for cuneiform roots were statistically significant ($P < 0.02$ and $P < 0.01$, respectively). In 30% of affected skulls these anomalies were bilateral, and occasionally a fused root was seen on one side of the dental arch with a cuneiform root on the contralateral tooth.

Taurodontism was found in 26.9% of skulls, with a tooth prevalence in lower molars of 11.7%. Third molars were the teeth most often affected and first molars the least. Taurodontism was bilateral in 47% of affected skulls. The male to female ratio was 1:0.67 and statistically significant ($P < 0.05$). The differences between mean values of a and of a:b ratios (Fig. 2) in those teeth showing taurodontism compared to

TABLE 1. Reproducibility of measurements and diagnosis

A. Clinical diagnosis

Feature	No. diagnosed on first occasion	No. diagnosed on second occasion	No. diagnosed on on both occasions
Three-rooted mandibular first molars	1	1	1
Fused molar roots	11	13	11
Cuneiform molar roots	16	15	15
Invaginations 2 1 | 1 2	1	1	1

B. Using ratios

Feature	No. of teeth measured	No. within 0.5 of ratio on first reading
Taurodont mandibular molars	272	212

those without were highly significant ($P < 0.001$). For measurement b, the differences were statistically significant for second molars ($P < 0.01$) and third molars ($P < 0.001$).

The prevalence of invaginated teeth was 1.1% of skulls. All invaginations in this sample occurred in maxillary lateral incisors. There was no evidence of periapical bone loss in relation to the crown invaginations that were all of the mild Hallett (1953) Class 2 category. No example of root invaginations was seen in this study.

The statistically significant associations between anomalies in this study were between fused and cuneiform molar roots ($P < 0.001$) and between taurodontism and fused molar roots ($P < 0.05$). Using results from a study of anomalies of tooth number and size in this population (Brook and John, 1995) statistically significant associations were found between congenital absence of third molars and fused molar roots ($P < 0.02$), cuneiform molar roots ($P < 0.05$), and taurodont lower molars ($P < 0.001$).

DISCUSSION

The high level of reproducibility of measurements and diagnosis suggests that the present data are reliable within the constraints of the sample (Table 1). Comparisons with other historic and modern sample findings are therefore worthwhile.

In other studies of three-rooted mandibular first molars either radiographs (Souza-Freitus *et al.*, 1971) or extracted teeth (Curzon, 1973) have been used. The radiographs in the present study were of good quality (Fig. 1) having been carefully standardized in the pilot study. For Caucasians the findings for three-rooted mandibular first molars have usually been of the order of 1% of individuals affected, while the frequency in Mongoloid peoples is much higher (Scott and Alexandersen, 1992). The Romano-British figure of 1.8% conforms to modern Caucasian results reviewed by Alexandersen (1963).

The criterion used for the diagnosis of cuneiform roots is shown by Holt (1976) to be highly reproducible, especially in lower molars. In this study, the one reversal of diagnosis (Table 1) was a maxillary molar that on the second occasion was diagnosed as having a fused root. The criterion for fused molar roots was adapted from Brabant and Kovacs (1961) and provided an acceptable degree of consistency (Table 1).

Similar to Brabant and Kovacs (1961), the highest frequency of cuneiform roots was found in maxillary third molars. For mandibular second molars the Romano-British prevalence was 3.2% of skulls, comparable to the findings of Pedersen (1949) in East-Greenland skull material and of Holt (1976) based on Brook's (1974) large population sample of modern British Caucasian schoolchildren. Reduction in root number affecting first permanent molars would seem to be rare as no example was found in these Romano-British skulls or by Pedersen (1949), Holt (1976) or Molnar and Horvath (1995).

The tendency for a bilateral occurrence of anomalies of reduced root number is found in other studies also, with the same trend for fused and cuneiform roots to occur in antimeric teeth where each anomaly was not bilaterally symmetrical (Holt, 1976; Ross and Evanchik, 1982; Tamse and Kaffe, 1981; Molnar and Horvath,

TABLE 2. Prevalences in skulls and sex distributions of root anomalies

Anomaly	No. of affected males	Prevalence	No. of affected females	Prevalence	No. of unknown sex	Prevalence	Sex ratio Male:Female	Total cases	Prevalence
Three-rooted mandibular first molar	3	2.3% (n=132)	3	2.4% (n=127)	0	0% (n=71)	1:1	6	1.8% (n=330)
Fused root (upper and lower molar teeth)	13	8.5% (n=153)	29	19.5% (n=149)	12	14.6% (n=82)	1:2.2	54	14.0% (n=384)
Cuneiform root (upper and lower molar teeth)	19	12.4% (n=153)	38	25.5% (n=149)	10	12.2% (n=82)	1:2	65	16.9% (n=384)
Taurodontism (lower molars)	48	34.8% (n=138)	31	22.3% (n=139)	15	20.5% (n=73)	1:0.67	94	26.9% (n=350)
Root invagination 2|2	0	0.0% (n=111)	0	0.0% (n=103)	0	0.0% (n=65)	0	0	0.0% (n=279)
Crown invagination 2|2	2	1.8% (n=111)	1	1.0% (n=103)	0	0% (n=65)	1:0.5	3	1.1% (n=279)

1995). There is also agreement that these anomalies are more common in females than males (Brabant and Kovacs, 1961; Holt, 1976; Ross and Evanchik, 1981; Table 1).

For taurodontism, comparisons are limited by the use of different criteria in different studies. Using the same methodology as the present study, Holt and Brook (1979) found that 6.3% of 1,115 modern British Caucasian schoolchildren had a taurodont mandibular first permanent molar compared to 1.8% of the Romano-British skulls. The prevalence and degree of taurodontism is often greater in second and third molars (Molnar and Horvath, 1995); in the present Romano-British sample the prevalence was 26.9% of skulls. Shifmann and Chanannel (1978) report that taurodontism occurred bilaterally in most cases while in this study and in Holt and Brook (1979) approximately equal numbers of tooth pairs were affected bilaterally and unilaterally. The sex ratio in this study of male 1: female 0.67 is similar to that of Holt and Brook (1979).

The prevalence of invaginated teeth in these Romano-Britons at 1.6% is lower than that for modern British, 4.1% (Brook, 1974) and modern Swedish 3.0% (Grahnen *et al*., 1959) samples.

Building on the comments of previous authors who remarked on a tendency for fused and cuneiform molar roots to be found together, this study provides evidence of the highly statistically significant association between these two anomalies. Similarly, the association of root number reduction of molars with congenital absence of third molars noted by Keene (1966) was found to be statistically significant in these Romano-Britons.

Stoy (1960), Stenvik *et al*. (1972) and Holt and Brook (1979) describe the association of taurodontism and hypodontia. In this study the association between taurodontism and hypodontia of third molars was shown to be highly significant statistically. This finding is compatible with a morphogenetic field effect with a varying influence anteroposteriorly.

The strong association between fused and cuneiform molar roots could indicate that the cuneiform root is one extreme of a continuous variation showing different degrees of confluence of roots and their canals. Complete root separation would represent the opposite extreme.

In conclusion, for root anomalies in this Romano-British population, the prevalence for skulls and for teeth, the sex distribution and bilateral symmetry has been established. The radiographic technique developed and the criteria used have high degrees of reproducibility. The statistically significant associations demonstrated in the Romano-Britons showed the relationship between fused roots and cuneiform roots as reductions in root number and shape and also their relationship with congenital absence of teeth. The gradients of anomalies observed were compatible with the concept of morphogenetic fields. The findings were also compatible with multifactorial etiology, showing continuous variation in root size and shape.

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Frequency and Variability of Five Non-Metric Dental Crown Traits in the Primary and Permanent Dentitions of a Racially Mixed Population from Cali, Colombia

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ABSTRACT: The purpose of this study was to determine the prevalence and variability of five non-metric dental crown traits (Carabelli cusp, protostylid, groove pattern, and cusps 6 and 7) in the deciduous (Um2 and Lm2) and permanent (UM1 and LM1) teeth in children in the mixed-dentition, and to compare these frequencies with the literature. A descriptive study was conducted to characterize the dental morphology of young subjects in mixed dentition stages. The Arizona State University Dental Anthropology System (ASUDAS) and Grine, Sciulli, and Hanihara methods were used as reference to compare the prevalence of dental traits in dental casts from 100 subjects from a Colombian racially mixed population. The high prevalence of furrows and pits of the Carabelli cusp, minor expressions of the protostylid (foramen cecum), and the low frequencies of cusps 5 and 6, plus the behavior of the expression of groove pattern collectively suggest that this group reflects influences by both the Mongoloid and Caucasoid dental complexes. Correspondence of trait expression in both the primary and permanent dentition was also demonstrated ($P < 0.05$). Some of the non-metric trait frequencies also exhibited sexual dimorphism. *Dental Anthropology* 2006;19(2):39-47.

Dental anthropology is the area of study that integrates anthropology, dentistry, biology, paleontology and paleopathology in order to holistically investigate the human dentition, such as the anatomical, evolutionary, pathological, and cultural variations with regard to life conditions, culture, feeding patterns and past adaptation processes in human populations. The scope of study includes metric and non-metric dental traits, dental pathology and intentional plus occupational modifications of the teeth (Scott and Turner, 1997, 1998; Alt *et al*., 1998; Rodríguez, 1999; Rodríguez and Delgado, 2000; Mayhall, 2000; Rodríguez, 2004). One facet of dental anthropology is dental morphology. Dental morphology is the discipline used to register, analyze, interpret and understand all aspects of dental crown and root morphology that can inform us about human groups, such as their cultural activities, biological conditions, and quality of life (Rodríguez, 2004).

From this perspective, teeth are informative indicators for the study of human populations, serving as markers and the bases for comparisons of genetic origin, allowing for the classification of human groups in taxonomic, phylogenetic and evolutionarily categories by means of their frequency, sexual dimorphism, bilateral symmetry and morphological characteristics (Rodríguez, 1999; Rodríguez, 2003a). This is possible because teeth commonly are preserved even in the extreme conditions in which skeletal remains are found. Teeth are the organs that are best preserved because enamel is the hardest tissue of the human body, having the capacity to resist high temperatures and taphonomic processes (*e.g.*, time, environment, pH, salinity, humidity, attack by trace elements) (Rodríguez, 2004; Moreno and Moreno, 2005). Consequently, teeth constitute a means of personal identification where other information may be unavailable, thus contributing to an unknown individual's osteobiographical reconstruction through forensic means (Krogman, 1986). Also, in archeological and anthropological contexts, dental anthropology can help estimate a populations' temporal position to clarify its history, origin, formation, contacts and displacements of current and past human groups (Moreno and Moreno, 2005; Rodríguez, 2003a; Turner *et al*., 1991).

Non-metric dental crown traits (NDCT) are phenotypic forms of the enamel that are inherited and controlled in their location, growth and orientation; they result from indirect processes of mineral secretion mediated by proteins the dental morphogenesis, and they are expressed and regulated by the human genome of each individual. These traits can be described as positive (cusps) or negative structures (pits, furrows

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and grooves) that have the potential to be present or absent in a specific place (frequency), in a different form or grade (variability), and in one or more members of a populational group. To date, there are more than 100 non-metric dental crown and root traits described in the human dentition (Rodríguez, 2003a); in the present investigation, three traits were used that occur on the crown complex of primary second molars and permanent first molars.

In the dental literature, NDCT are described using a broad host of names, such as characters, variants, aspects, attributes, polymorphisms, anomalies, discrete traits, and epigenetic or phenotype expressions (Rodríguez, 2003a,b; Rodríguez, 2003). The study of NDCT has demonstrated that the traits are of high taxonomic value; they can be used to estimate biological relationships among groups, allowing researchers to reconstruct and establish intergroup relationships for the comparative analysis of historical, cultural and biological development of primitive and modern human groups. NDCT seem to seldom exhibit sexual dimorphism; statistical associations among traits seem to be low; and there is considerable geographic variation in trait frequencies. NDCT are easily observed and recorded; they thus are useful for establishing population differences according to a group's specific microevolutionary processes, which furnishes information about the displacements and contacts that have taken place (Rodríguez, 2003a,b; Rodríguez, 2003; Tocheri, 2002).

In Colombia, dental anthropology research is primarily concerned with forensic applications and the dental pathological study of pre-Hispanic populations. These interests are carried out by the Physical Anthropology Laboratory of the National University of Colombia, the Biological Anthropology Research Group GIAB, and the Anthropology Departament of Cauca University.

It is necessary to note that the few investigations in this part of the world that have characterized dental morphology have focused on pre-Hispanic populations, plus a few current and modern populations. These latter studies have been limited to the permanent dentition. It is important to keep in mind that the complete primary dentition persists for only a short time; it begins at six months and finishes at two a half years, then it stays intact until about six years, and finally disappears about 12 years of age (Clarke, 1998). In spite of this transience, research on the deciduous dentition provides an excellent model for studying variation of growth within an individual since, in both dental and anthropological contexts, the dentition constitutes a unique source of information about development (Smith *et al*., 1997).

In addition, investigators have studied the primary dentition in various human groups, finding interesting data on the intergroup variations of NDCT. A pioneer in this field was K. Hanihara (*e.g.*, 1966, 1968), who established the Mongoloid dental complex as it relates to the permanent and primary dentitions. Other researchers, such as Kitagawa *et al*. (1995) and Kitagawa (2000), have shown that the morphology of primary teeth is efficient for the study of biological affinities among human populations, contributing to the understanding of human dental evolution. Lease and Sciulli (2005) concluded that the morphology of the primary dentition is useful for establishing the identity of children, for the biological discrimination of two or more human groups, and for establishing differences in development between the deciduous to the permanent dentition.

The objective of the present study was to determine the frequency and variability, sexual dimorphism, and bilateral symmetry of five NDCT, namely Carabelli's trait, the protostylid, molar groove pattern, and cusps 6 and 7, of the primary second molars (Um2 and Lm2) and the permanent first molars (UM1 and LM1), which coexist in the mouth between about six years (± 24 months) and ten years of age (± 30 months) (Schour, 1941; Rodríguez, 2004). The goal, then, was to compare these frequencies in both dentitions, with the purpose of understanding the developmental behavior of these three features, the dominant ethnic influence, and the dental morphological characters of the sample. We hope that these findings will contribute to discussions of the usefulness of dental morphology as an anthropological tool, not only in the context of dentistry, but also that of forensic studies (Edgar, 2005; Moreno and Moreno, 2005; Moreno *et al*., 2004).

MATERIALS AND METHODS

Samples

This is a descriptive cross-sectional study concerning the frequency and variability of five NDCT in 100 children (50 male and 50 female) selected randomly from a single living population of a racially mixed group from Cali, Colombia (Fig. 1). The children studied here were 6 to 12 years of age. In order to be included, the subjects had to met four criteria, namely (1) they had to have Colombian parents and grandparents, (2) they had to be healthy dentally without any congenital anomaly, (3) they had to exhibit no severe attrition or abrasion, and (4) they had to possess upper and lower first permanent molars and primary second molars.

Morphological analysis standardization

For the observation of the five NDCT in the permanent dentition this study used the Arizona State University Dental Anthropology System (ASUDAS) (Turner *et al*., 1991; Turner *et al*., 1994). This system allows for finer discrimination than just the dichotomy of presence-absence of traits, it promotes reproducibility among observers, and it generates data that express the variability of expression of each NDCT along with the potential extremes. For analysis of the deciduous dentition, this study used the ASUDAS method for cusp

Fig. 1. Cali, Colombia geographic localization

7, the Hanihara method (1966) for the cusp 6, the Grine method (1986) for the Carabelli trait, and the Sciulli method (1998) for the protostylid and molar groove pattern. These complementary methods, along with the grading systems, are described in the Appendix.

Turner *et al*. (1991) described 29 NDCT that can be applied in populational investigations based on their prevalence and variability. These authors suggest that this suite of NDCT involves clear expressions of the genotype and that they are little-influenced by environmental factors when scored on key teeth as defined by the morphogenetic field concept (Dahlberg, 1945). For the present study, Carabelli trait, protostylid, molar groove pattern, and cusps 6 and 7 cusps are used.

Calibration

The authors practiced the handling of Arizona State University Dental Anthropology System (ASUDAS) and the Hanihara, Grine and Sciulli methods by making repeated series of observations and then comparing among observers to achieve consistency. Repeated comparisons led to standardization of concepts among observers. We applied the kappa statistic (Stata 6.0) to assess repeatability; analysis disclosed inter-observer agreement values of 82.3% and intra-observer 81.2%, following the method suggested by Nichol and Turner (1986).

Tooth Impressions and study casts

This investigation was endorsed by the Human Ethics Committee of the University of the Valley according to the Ministry of Health of the Republic of Colombia (1993) and the Ethical Principles for Medical Research Involving Human Subjects indicated for the World Medical Association in the Helsinki Declaration (1964). After obtaining the signed written consent and the intraoral examination, dental impressions were taken from the subjects using sterile plastic small buckets (Coe for ID®) and alginate (Hydrogum®). Casts were immediately processed in dental stone (WhipMix®) to prevent distortion.

Observation and Statistical analysis

With the obtained study casts, the best calibrated observer performed the analysis using a stereomicroscope (Carl-Zeiss®) at 10-power, evaluating three NDCT: Carabelli trait, protostylid and molar groove pattern in the primary and permanent dentitions. The resulting data were processed using the SPSS® software version 10. Several statistical tests were applied (chi-square tests, univariate and bivariate comparisons, Mann-Whitney U) for each of the NDCT. The conventional level of alpha = 0.05 was considered to be statistically significant.

RESULTS

The principal objective of this research was to observe the existing relationship of the NDCT studied between primary and permanent dentitions. Results were determined to be positive with regard to the Carabelli trait and protostylid frequencies. The groove pattern did not exhibit a significant association between molars in the two dentitions.

Analysis of the expression of the NDCT between girls and boys showed that there was no detectable sexual dimorphism in the primary or the permanent teeth for these three traits, but there was considerable bilateral symmetry of all three features in the primary and permanent dentitions (Tables 2 and 3).

In deciduous and permanent teeth, Carabelli trait most commonly exhibited the fossa form on the cusp. Viewed as a dichotomous trait, it is absent in this sample (Figs. 2 and 3).

The protostylid occurred as grade 1 (foramen cecum) in the majority of cases in both the primary and permanent teeth (Fig. 4). Expressions of the protostylid pit were far more common than the cusp form (Tables 2 and 3).

Inspection of the molar groove patterns showed that the Y and + pattern were common in both dentitions, although in primary teeth there was a higher frequency of the Y configuration and a higher frequency of the + form in the permanent teeth (Table 2; Fig. 5).

The frequency of cusp 6 and 7 was low in both

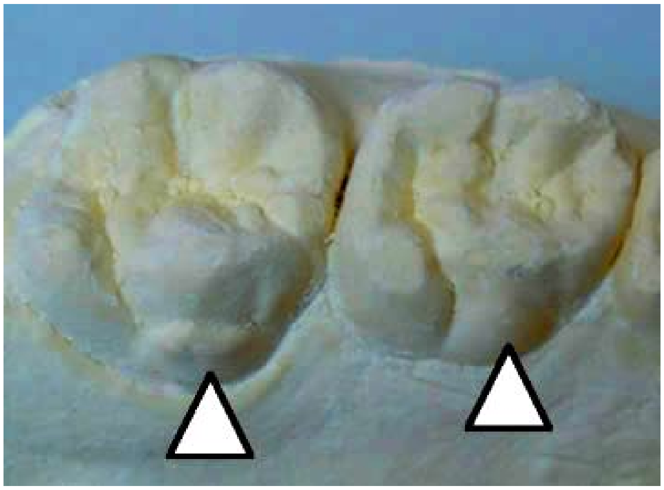

Fig. 2. Carabelli trait: cusp expression in primary second molar (Um2) and permanent first molar (UM1).

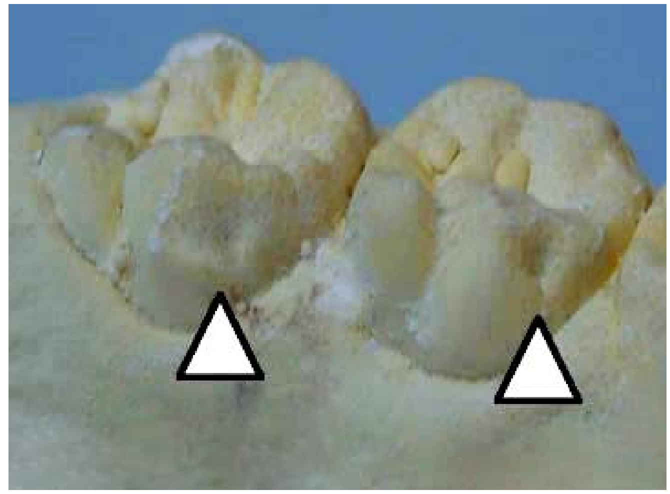

Fig. 3. Carabelli trait: fossa expression in primary second molar (Um2) and permanent first molar (UM1).

dentitions, although cusp 7 is more common than cusp 6 (Table 2; Figs. 6 and 7).

DISCUSSION

Carabelli trait

Kieser (1984) observed a high frequency of this trait in both the deciduous and permanent teeth. Joshi (1975) studied a Hindu population and found that there is a relationship between the prevalence of the feature, bilateral symmetry expression and high prevalence in the groove and fossa forms on the tubercle and cusp forms. Saunders and Mayhall (1982) studied five NDCT on the primary and permanent teeth of a sample of American whites, finding strong positive associations between traits in the two dentitions.

K. Hanihara (1954) carried out several of studies on the trait frequencies of NDCT in primary and permanent dentitions of Asian, Polynesian and Australians, contemporary and prehistoric. Hanihara focused on the NDCT that characterize the Mongoloid complex (shovel-shape, protostylid, deflecting wrinkle, cusps 6 and 7) and the Carabelli trait. As for this last trait, Hanihara (1976) determined that Caucasoid populations can be distinguished from Asian populations, predominantly in this last the groove and pit forms.

TABLE 2. Frequencies of nonmetric dental traits[1]

Tooth	Trait	Total Frequency (left side)	Males	Females	U test P Value	Bilateral Symmetry Left	Bilateral Symmetry Right
um2	Carabelli trait	15	16	14	0.951	15	16
UM1	Carabelli trait	42	42	42	0.952	42	40
lm2	Protostylid	1	0	2	0.239	1	0
LM1	Protostylid	4	4	4	0.407	4	5.1
lm2	Groove pattern Y	81	80	82	0.731	81	72
lm2	Groove pattern +	17	16	18	0.731	17	26
lm2	Groove pattern X	2	4	0	0.731	2	2
LM1	Groove pattern Y	41	54	28	0.009	41	39
LM1	Groove pattern +	59	46	72	0.009	59	54
LM1	Groove pattern X	0	0	0	0.009	0	7
lm2	Cusp 6	12	16	8	0.025	12	8
lm2	Cusp 7	24	28	20	0.103	24	20
LM1	Cusp 6	4	3	5	0.320	4	4
LM1	Cusp 7	19	22	16	0.084	19	17

[1]The Mann-Whitney U test assessed sexual dimorphism based on just left sides.

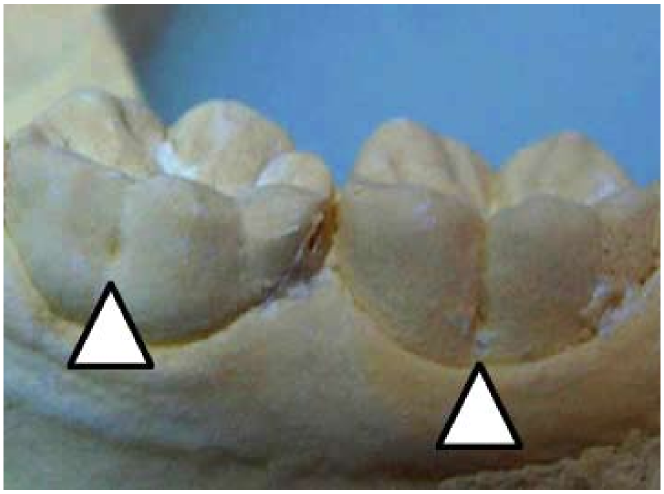

Fig. 4. Protostylid pit expression in primary second molar (Lm2) and permanent first molar (LM1).

Fig. 5. Groove pattern Y5 on primar second molar (Lm2) and +5 on permanent first molar (LM1).

Studies from India (Kannapan and Swaminathan, 2001) and Saudi Arabia (Salako and Bello, 1998) show the relationship of the frequency, bilaterally and absence of sexual dimorphism between temporary and permanent teeth. Pinkerton *et al*. (1999) observed Carabelli trait in both dentitions in 245 pairs of monozygotic and dizygotic Australian Caucasoid twins, finding little influence of sexual dimorphism on the primary or permanent dentition. Their findings showed that some traits (like Carabelli) of the primary dentition exhibited considerable genetic control and, thus, little alteration by the environment.

The frequency of the Carabelli trait is highest in Caucasians and lower in other populations, though American Negroes show relatively high frequencies of this trait compared to Japanese, Ainu and Pimas, and the cusp is practically absent in Eskimos (Hanihara, 1976). Moreno *et al*. (2004) and Moreno and Moreno (2005) report the Carabelli trait frequency to be 40.5%.

In the present study, Carabelli's trait is sexually dimorphic; it is expressed bilaterally; and the furrow and pit forms predominate over the tubercle and cuspid forms in both the primary and permanent dentition, suggesting that there is ambivalence in the population discrimination of this trait. The association of the trait between the dentitions may suggest a strong genetic control for its expression (Tables 4 and 5).

Protostylid

The protostylid has been defined as an "American feature" due to the occurrence of high frequencies in the European, African and Asian populations of the

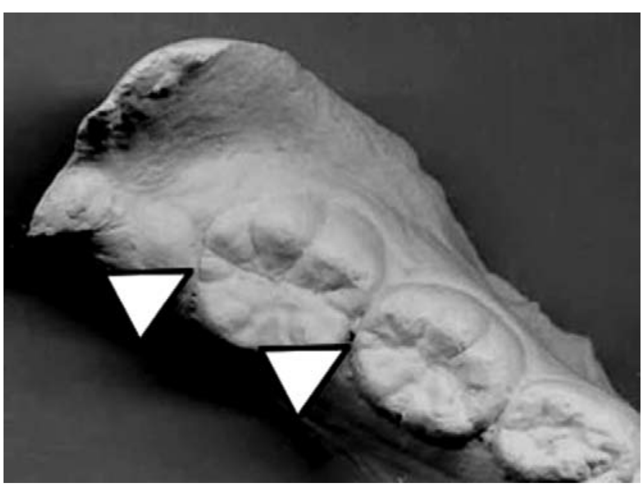

Fig. 6. Cusp 6 on primary second molar (Lm2) and permanent first molar (LM1).

Fig. 7. Cusp 7 on primary second molar (Lm2) and permanent first molar (LM1).

Americas, and to the particularly high prevalence of the foramen cecum in American populations (Rodríguez, 1999, 2004). Robbins (1998) indicated that the fossa or pit forms (foramen cecum) of the protostylid prevail over the cuspal form in the primary and permanent dentitions. Hanihara (1976) found that cusp forms of the protostylid were found in low frequency in most populations, rarely occurring in modern human groups, notably Asians. This led him to note that this trait is useful for differentiating the Mongoloid dental complex of the Caucasoid and Negroid. In primary teeth, it is common to find the fossa form of the protostylid, but the trait rarely reaches the height or size of a cusp.

In the deciduous dentition, the protostylid is frequently observed on the mandibular second molars. Frequencies of this trait seem to be highest in Eskimos and the Pima, and relatively low in Japanese and Ainu. In Caucasians and American whites, it was seldom observed (Hanihara, 1966, 1976). Moreno *et al*. (2004) and Moreno and Moreno (2005) found a frequency of this feature in permanent teeth of 1.5%, with a high frequency of the Point P. The population observed in this study presents a retention of the Amerindian dental complex, evidenced by the high frequency of the grade 1, which is the fossa or pit in the buccal developmental groove that separates the mesiobuccal and distobuccal cusps (Tables 4 and 5).

Groove pattern

This trait is defined by the basic arrangement of grooves and cusps of the occlusal surface of deciduous and permanent molars (Hillson, 1996). Smith *et al*. (1987) analyzed children from five ethnic groups, concluding that there are no significant differences between expressions of the groove pattern between the first permanent molar and the second primary molar, with the Y pattern occurring most frequently. A study of children with Caucasoid characteristics from India (Kaul and Prakash, 1981) reported the common occurrence of the pattern Y in primary and permanent teeth, the same as in an Eskimos from Alaska (Hasund and Bang, 1985). This trait characterizes the occlusal surface of the low molars by means of a contact pattern of the cusps, that can be configured in the Y, + or X forms. Y is the ancestral pattern considered as present, while X and + configurations are reductions or absences (Scott and Turner, 1997), frequently observed in Caucasoid groups. The temporary mandibular second low molars show a bigger tendency to the configuration Y.

In this study the behavior of the intercusp contact furrows was given by the Y pattern or " Dryopithecus " for the primary lower second molars and + or a "cross-like structure" for the permanent lower first molars; this can be due to that the primary dentition present a stronger genetic control, for what the Dryopithecus pattern native of the last Asian populations have conserved. In the case of the permanent first molars, it is assumed that the miscegenation processes mark a tendency toward the + pattern, which is a characteristic of the Caucasoid populations. In both dentitions, bilateral symmetry is observed in trait expression, but sexual dimorphism is not discernible.

In most publications, the groove pattern and the number cusp have been described together, for example Y5 or +4, although the number of cusps varies independently of the groove pattern (Mayhall, 2000). In the present sample, the Y5 configuration was observed in the deciduous second low molar which is a characteristic of Mongoloid and African populations. In the permanent first low molar prevailed +5 configuration, characteristic of Caucasian and hybrid European groups (Rodríguez, 2003) (Tables 4 and 5).

Cusp 6

The sixth cusp is known as the *tuberculum accessorium posteriore internum* (Mayhall, 2000). Hanihara (1966, 1976) shows that this feature is an accessory cusp, and, when it appears, it is located between the distolingual and the distobuccal cusps of the primary and permanent mandibular molars. The incidence of this cusp, in primary and permanent dentitions, has been studied by several researchers, and it has been described as a racial characteristic of Mongoloid populations.

Frequencies of cusp 6 also show a distinct contrast between populations. The expression of this trait occurs fairly commonly in Japanese, Ainu, and the Pima. Similar results are observed in the primary dentition (Hanihara, 1976). In one study, the frequency of this characteristic was 5% (Moreno *et al*., 2004; Moreno and Moreno, 2005) (Tables 4 and 5).

Cusp 7

This is another accessory molar cusp, and it is located at the marginal border between the mesiolingual and distolingual cusps. It was originally described using the term *tuberculum accessorium mediale internum*, and many occurrences have been reported by several authors in the fossil and recent primates including man. Among the permanent and deciduous mandibular molars of recent man, American blacks show the highest frequency, which distinguishes blacks from other populations. In primary mandibular second molars, the difference in frequencies of this character is much greater (Hanihara, 1976). Moreno *et al.* (2004) and Moreno and Moreno (2005) observed that the frequency of this characteristic to be 25% on permanent molars in a racially mixed population (Tables 4 and 5).

In overview, (1) the high frequency of the groove and fossa forms of Carabelli trait, (2) the high frequency of the protostylid grade 1 (foramen cecum), (3) the low frequencies of cusps 5 and 6, and (4) the expression of the molar groove pattern and number cusp collectively

TABLE 3. Three nonmetric trait frequencies in the primary and permanent dentitions

Trait	Deciduous Grade	Deciduous Percent	Permanent Grade	Permanent Percent
Carabelli trait	0	3	0	31
	1	82	1 - 4	55
	2 - 4	15	5 - 7	14
Protostylid	0	6	0	19
	1	93	1	76
	2	1	2 - 7	5
Groove pattern	Y	81	Y	41
	+	17	+	59
	X	2	X	0
Cusp 6	0 - 1	88	0 - 1	96
	2 - 5	12	2 - 5	4
Cusp 7	0	76	0	81
	1 - 3	24	1 - 4	19

suggest that the sample has received influence of the Mongoloid and Caucasoid dental complexes. This inference agrees with the studies of Moreno *et al*. (2004), Moreno and Moreno (2005), León and Riaño (1997), Herrera and Osorno (1994), Turner (1984, 1990), Sciulli (1998) and Hanihara (1966, 1968) who affirm that all indigenous American groups exhibited a Sinodont pattern of dental morphology (*i.e*., Mongoloid dental complex subdivision of NE Asia). It is supposed that this pattern has persisted since the original immigrants from Asia peopled the Americas by way of Beringia. Subsequently, the Colombian historical development is such that the dental morphology of the current populations is the reflection of hybridization among Mongoloid (pre-Hispanic indigenous), Caucasoid (Spanish conquerors) and African (African slave) ethnic groups. As such, the sample observed in this study can be considered a hybrid group composed primarily from

TABLE 4. Frequency of nonmetric dental traits in permanent dentition

Samples	Carabelli trait	Protostylid	Groove pattern	Cusp 6	Cusp 7
Japanese[a]	6.5	6.6	26.0 (+)	25.3	6.7
Pima[a]	6.9	19.4		26.6	8.2
Eskimo[a]	13	28.6	20.1 (Y)	50	20
Caucasian[a]	39	0	59.5 (+)	5.2	5.1
American blacks[a]	16.3	0	49.0 (+)	6.5	46.3
Sinodonty[b]	32.1	34.7	10.9 (Y)	47.8	9.8
Sundadonty[b]	30.6	30	19.6 (Y)	35.5	7.4
North American Indian[b]	35.6	41.9	8.1 (+)	49.2	10.2
South American Indians[b]	41.9	29.8	9 (+)	55.8	9.6
Thailanders[c]	26.6	20.4	71.8 (Y); 25.6 (+)	17.1	2.4
American caucasoid[d]	45	0	84.1 (+)	5.2	5.1
Colombian Living Indians	20 - 90	0 - 60	-	0 - 80	0 - 80
Páeces (Colombian Indians)[e]	0.6	0.2	-	-	38
Guambianos (Colombian Indians)[e]	0.2	0.1	-	-	-
Emberá (Colombian Indians)[e]	60	20	-	-	-
Obando pre-Hispanic[f]	50	10	51.6 (Y) - 31 (+)	38.9	-
Bogotá racially mixed[g]	28	4	-	-	-
Cali racially mixed[h]	40.5	1.5	-	5.0	25.0
Present study	50.0	4.0	41 (Y) - 59 (+)	4.0	19.0

[a]Hanihara (1976, 1992), [b]Turner (1984, 1990), [c]Manabe *et al*. (1997), [d]Rodríguez JV (1999, 2003), [e]León and Riaño(1997), [f]Rodríguez (2002), [g]Herrera and Osorno (1994); [g]Moreno *et al*. (2005).

TABLE 5. Percentages of nonmetric dental traits in the primary dentition

Sample	Carabelli trait	Protostylid	Groove pattern	Cusp 6	Cusp 7
Japanese[a]	11.9	47.7	-	36.9	73.7
Eskimo[a]	13	28.6	-	37.7	79.4
Caucasian[a]	35.7	14.5	-	7.3	40.7
American Negroes[a]	11.8	19.1	-	12	46.8
Modern Japan[b]	11.5	53.8	-	33.3	87.0
Pima[c]	5.1	80.8	88.7 (Y)	36.8	70.8
Hindus[d]	66.1	-	-	-	-
Saudi Arabia[e]	58.7	-	-	-	-
Present Study	15.0	1.0	81.0 (Y); 17.0 (+)	12.0	24.0

[a]Hanihara (1976), [b]Kitagawa (2000), [c]Tochieri (2002), [d]Joshi (1975) and [e]Salako and Bello (1998)

Mongoloid and Caucasoid complexes (Tables 4 and 5).

CONCLUSIONS

The data presented here suggest, based on the NDCT studied, that dm2 is more conservative in form than the permanent M1. The morphological similarities between the two teeth are well established with regard to the frequencies of Carabelli trait, protostylid, molar cusp pattern, and cusps 6 and 7.

There is correspondence in the expression of the Carabelli trait and the protostylid between the primary and permanent dentitions, which implies a strong genetic control in its frequency and variability. In the case of the molar groove pattern, more investigations should be carried out on other Colombian groups with increased sample sizes to better analyze the behavior of this feature among the two dentitions. Sexual dimorphism does not exist and bilateral symmetry is observed in the expression of the five NDCT studied in th deciduous and permanent dentitions. The data presented in this research indicate, based on the NDCT studied, that dm2 is more conservative in form than M1.

According to the frequency and variability of the NDCT studied, it is indicated that the dental morphology of the sample constitutes a mix of the Mongoloid and Caucasoid dental complexes, which is reflected in the intermediate expressions of Carabelli trait. The high frequency of the the pit form (grade 1) of the protostylid suggests that it is a genetic conservation of the Amerindian dental complex as a result of the historical processes of peopling, distribution and establishment of the pre-Hispanic human groups and admixture after the arrival of the Europeans to the New World. The high expression of cusp 7 in grades 1 and 2 suggests an influence of the Negroid dental complex.

Studies should be carried out on the frequency and variability of other NDCT to increase interpopulation information and better characterize the dental morphology, not just of mixed populations with Caucasian characteristics, but also of the Afro-American and indigenous communities of the region, in order to better understand how information from the teeth inform us about the micro-evolutionary aspects, displacements, contacts, isolations and historical process on the Colombian population.

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APPENDIX. Trait descriptions

Tooth, Trait	Code	Grade	Reference
Primary upper second molar, Carabelli's trait	Um2	0. Absent 1. U or Y-shaped depression 2. Two parallel furrows 3. Small cusp 4. Free cusp	Grine (1986)
Permanent first upper molar, Carabelli's trait	UM1	0. Smooth surface 1. Groove present 2. Pit present 3. Small Y-shaped depression 4. Large Y-shaped depression 5. Small cusp 6. Medium cusp 7. Free cusp	ASUDAS Turner *et al*. (1991)
Primary second mandibular molar, protostylid	Lm2	0. Absent 1. Pit or furrow 2. Cuspid	Sciulli (1998)
Permanent first lower molar, protostylid	LM1	0. Smooth surface 1. Pit present 2. Buccal groove curve distal 3. faint groove extending mesial from the bucal groove 4. Groove more pronounced 5. Groove stronger 6. groove extend across the buccal surface 7. Free cusp	ASUDAS Turner *et al*. (1991)
Primary second lower molar, groove pattern	Lm2	+. Cusp 1,2,3 and 4 are in contact X. Cusp 1 and 4 are in contact Y. Cusp 2 and 3 are in contact	Sciulli (1998)
Permanent first lower molar, groove pattern	LM1	Y. Cusp 2 and 3 are in contact +. Cusp 1,2,3 and 4 are in contact X. Cusp 1 and 4 are in contact	ASUDAS Turner *et al*. (1991)
Primary second lower molar, cusp 6	Lm2	0. Absent 1. Cusp 6 << cusp 5 2. Cusp 6 < cusp 5 3. Cusp 6 = cusp 5 4. Cusp 6 > cusp 5 5. Cusp 6 >> cusp 5	ASUDAS Turner *et al*. (1991)
Permanent lower first molar, cusp 6	LM1	0. Absent 1. Cusp 6 << cusp 5 2. Cusp 6 < cusp 5 3. Cusp 6 = cusp 5 4. Cusp 6 > cusp 5 5. Cusp 6 >> cusp 5	ASUDAS Turner *et al*. (1991)
Primary second lower molar, cusp 7	Lm2	0. Absent 1. Through trace 2. Small cusp 3. Well developed	Hanihara (1961)
Permanent lower first molar, cusp 7	LM1	1. Faint cusp (two weak grooves) 1A. Fine cusp without free apex 2. SmalL cusp 3. Medium-sized cusp 4. Large cusp	ASUDAS Turner *et al*. (1991)

Variation in Dental Crown Morphology in Malaysian Populations

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ABSTRACT: Dental crown variation was studied in the four main population groups living in Malaysia using dental casts (upper and lower) obtained from 790 individuals. The aims of the study were to characterize variation in 13 dental crown traits, within groups as well as between groups, and to assess affinities between the groups based on frequencies of occurrence of dental features. Using chi-square analysis and Fisher's exact test, the majority of dental traits were found to be bilaterally symmetrical and to demonstrate low sexual dimorphism. Comparisons of trait frequencies between groups revealed similarities between Malays, Jahai (Negritos) and Chinese who conformed to Mongoloid Sinodont-Sundadont dental patterns, whereas the Indians conformed to an Indo-European pattern. Phenetic distance analysis, using the mean measure of divergence, showed that Indians were markedly separated from the other three groups, while Malays were closer to Jahai than to Chinese. These findings based on dental traits are consistent with historical explanations of affinities between modern Malaysian populations. *Dental Anthropology* 2006;19(2):49-60.

In terms of historical migrations and interrelationships of people, Malaysia has been compared to the United States of America (Nagata, 1979) in being a home to many different people from different ethnic backgrounds. Until now, descriptions of contemporary Malaysian dental crown morphology have been lacking, with only two published reports available, as far as we aware.

Tratman (1950) described dental variations between Mongoloids and Indians from the Malaysian Peninsula and Singapore. He combined Malays and Chinese into one regional group for his comparisons, while Indians were categorized as representing Indo-Europeans; however, his report was limited to anatomical descriptions without statistical analyses (except for a few traits) due to loss of data during World War II. Another report on the dentition of Malaysians by Rusmah (1992) presented frequencies of occurrence for Carabelli cusp, which was present in 52.2% of the sample. Rusmah reported that no sexual dimorphism or bilateral asymmetry was evident for this trait.

Previous studies of dental affinities among Asians have revealed that Mongoloid people can be subdivided into Sinodonts, represented by Northern Asians and Native Americans, and Sundadonts comprising peoples of South-East Asia (Turner, 1987; 1990). From 28 traits used initially to separate East Asians into Northern and Southern divisions, Turner (1990) found eight traits that discriminated between Sinodonts and Sundadonts. All of these traits occurred more frequently in Sinodonts, except for 4-cusped lower second molars. Turner described Sinodonts as having trait intensification, that is, higher frequencies of crown trait occurrence and addition (*e.g.*, three rooted lower first molars), while Sundadonts showed crown simplification or moderate frequencies of occurrence, and retention of old traits (*e.g.*, two-rooted upper first premolars).

Traditionally, relationships among Malaysian populations have been based only on historical perspectives. Malays and Orang Asli are considered to be the natives of Malaysia, while Chinese and Indians arrived for trade and economic opportunities mainly during the British colonization period in the early 19th century (Nagata, 1979; Pusat Perkembangan Kurikulum, 1998; Zainuddin, 2003). Many questions still remain about the origins of Malaysians and their affinities from a biological point of view.

It is important to describe the nature and extent of dental variation within populations before attempting to characterize variation between them. This includes

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consideration of the nature and extent of sexual dimorphism, bilateral asymmetry and inter-trait associations. Scott and Turner (1997) have concluded that dental morphological traits are suitable for population characterization due to their low sexual dimorphism and strong symmetry, and several researchers have found no evidence of significant sexual dimorphism for various dental traits (Garn *et al*., 1966b; Bang and Hasund, 1971; Bang and Hasund, 1972; Hanihara, 1977; Turner and Hanihara, 1977; Turner and Scott, 1977; Hershey, 1979; Scott, 1980; Hassanali, 1982; Mayhall *et al*., 1982; Kieser, 1984; Thomas *et al*., 1986; Townsend *et al*., 1986; Haeussler *et al*., 1989; Townsend *et al*., 1990; Manabe *et al*., 1992; Rusmah, 1992; Kannappan and Swaminathan, 1998). Other researchers, however, have noted higher frequencies for certain features in males (Rothhammer *et al*., 1968; Escobar *et al*., 1977; Scott, 1977; Townsend and Brown, 1981; Iwai-Liao *et al*., 1996; Hsu *et al*., 1997) and occasionally in females (Harris and Bailit, 1980). Several studies have indicated that dental traits tend to be expressed symmetrically (Baume and Crawford, 1979; Harris and Bailit, 1980; Noss *et al*., 1983b; Townsend *et al*., 1990) while others have reported evidence of asymmetry (Meredith and Hixon, 1954; Mayhall and Saunders, 1986; Moskona *et al*., 1996).

Given the limited information available about Malaysian odontological variation, this study aimed to characterize variation of dental crown traits within four major Malaysian ethnic groups prior to undertaking a study of the affinities between them.

MATERIALS AND METHODS

A total of 790 sets of dental casts (maxillary and mandibular) were examined in this study. Table 1 shows the sample distribution according to sex and age for each of the four ethnic groups. All groups comprised teenagers from the districts around Kelantan and Perak, except for the Jahai (Negritos) who were older. The Jahai represent a sub-group of Negritos who live mainly in the northern part of the Malaysian Peninsula. The Negritos are one of three Orang Asli tribes who live only on the Malaysian Peninsula. Power studies following the methods of Dupont and Plummer (1997) indicated that sample sizes of 72 for each group would be sufficient to provide 80% power for our study. Logistic, financial and time constraints restricted the number of Jahai who could be recruited into the study and, consequently, results for this group should be interpreted with caution.

The classification of dental crown traits, except those for the entoconulid, Carabelli trait and groove pattern, was simplified from the Arizona State University (ASU) classification system (Turner *et al*., 1991). Teeth were not scored if wear obscured the trait under investigation. The ASU reference plaques were used when scoring all traits to provide additional guidance. The definition of Townsend *et al*. (1990) was used for entoconulid classification as it includes observation of the entoconulid on four-cusped molars, whereas the ASU system only scores entoconulids on five-cusped molars. Carabelli trait was scored according to Dahlberg's plaque P12A, and molar groove pattern was assessed using plaque P10 (Dahlberg, 1956). For the other traits, the original ASU gradings were simplified into two or three grades of expression only (Table 2). Table 2 also provides the breakpoints chosen for the dichotomous data.

Dental casts for 167 individuals were scored twice and intra-observer errors for graded scales and presence/absence for all traits were calculated as percentages of discordance following Nichol and Turner (1986). These authors set 10% discordance as a benchmark for 2-grade discrepancies and presence-absence data.

The extent of asymmetrical expression of the dental traits in males was compared initially with that in females using chi-square analysis or Fisher's exact test when expected cell frequencies were less than five (Howitt and Cramer, 2003). Absent-absent pairs were excluded from the analysis. These preliminary tests were used to determine whether it would be appropriate to pool data for subsequent analyses of symmetry/asymmetry. An adjusted alpha level was set at 0.05/12 = 0.004 (Bonferroni's adjustment).

Comparisons of the frequencies of occurrence of dental traits on corresponding right and left teeth were tested using non-parametric analyses, either Fisher's exact test, or Monte Carlo Estimates (SPSS Inc., 1989-2001, version 11.0.1).

Frequencies of occurrence and degrees of expression were calculated for all traits. Sexual dimorphism was

TABLE 1. Distribution of participants according to sex and age within four ethnic groups[1]

Ethnic group	Sex	n	Mean (years)	sd
Malays	Female	167	15.6	1.2
	Male	126	15.1	1.3
	Total	293	15.4	1.3
Chinese	Female	88	14.5	1.3
	Male	90	14.7	1.5
	Total	178	14.6	1.4
Indians	Female	131	15.8	1.4
	Male	121	15.6	1.3
	Total	252	15.7	1.3
Negritos (Jahai)	Female	33	28.3	8.2
	Male	34	30.5	13.1
	Total	67	29.4	10.9
Total	Female	419	16.4	4.4
	Male	371	16.6	6.1
	Total	790	16.5	5.2

[1]n is sample size; sd is standard deviation

TABLE 2. Dental crown trait classification used in this study

Trait	Tooth	Classification	ASU grade	Score[1]	Breakpoint for dichotomous data[2]
Winging	11,21	Bilateral winging	1	1	1-present
		Unilateral winging	2	2	2,3-absent
		Counter wing and straight	3,4	3	
Shovel	11,21	Absent		0	0 0,1-absent
		Trace	1,2	1	2,3-present
		Semi	3,4	2	
		Shovel	5,6	3	
Metaconule	16,26	Absent	0	0	0-absent
		Weak cuspule	1,2	1	1,2,3-present
		Small cuspule	3	2	
		Small to moderate cusp	4,5	3	
Carabelli trait[3]	16,26	Absent	a	0	0-absent
		Pit & furrow	b,c	1	123-present
		Tubercle	d,e,f,g	2	
		Cusp	h	3	
Hypocone	17,27	Absent or ridge	0,1	0	0,1-absent
		Cuspule	2	1	2,3-present
		Reduced cusp	3,4	2	
		Large	5,6	3	
Distal accessory ridge	33,43	Absent	0	0	0-absent
		Weak	1,2	1	1,2-present
		Strong	3,4,5	2	
Lingual cusp number	35,45	One		1	1-one cusp
		Two		2	
		Three		3	2,3,4-not one cusp
		Four		4	
Protostylid	36,46	Absent	0	0	0-absent
		Weak	1,2,3	1	1,2-present
		Strong	4,5,6,7	2	
Metaconulid	36,46	Absent	0,1,5	0	0-absent
		Small	1,2,3	1	1,2-present
		Large	4	2	
Entoconulid	36,46	Absent	0	0	0-absent
		Weak	1,2	1	1,2-present
		Strong	3,4	2	
Deflecting wrinkle	36,46	Absent	0,1	0	0,1-absent
		Weak	2	1	2-present
		Strong	3	2	
Cusp number	37,47	Four		4	4-four cusp
		Five		5	5,6-not four cusp
		Six		6	
Groove pattern[4]	37,47	Y	Y	1	1-Y pattern
		+	+	2	2,3-+,X pattern
		X	X	3	

[1]score used in this study
[2]breakpoint based on[1]
[3]observation using Dahlberg plaque P12A
[4]observation using Dahlberg plaque P10.

TABLE 3. Tests of bilateral symmetry for 12 dental crown traits using graded-scale data (pooled-sex data)[1]

Traits and Teeth		Malays	Chinese	Indians	Negritos (Jahai)
Shovel 11,21	n	266	170	218	46
	% symmetry	95.1[a]	90.6[a]	96.8[a]	100.0[a]
	% symmetry (absent-absent exc.)	95.0	90.6	96.7	100.0
	rho	0.91[b]	0.80[b]	0.93[b]	1.00[b]
Carabelli trait 16,26	n	275	170	238	46
	% symmetry	83.6[a]	88.8[a]	81.1[a]	78.3[a]
	% symmetry (absent-absent exc.)	80.7	84.8	78.3	76.7
	rho	0.81[b]	0.91[b]	0.73[b]	0.81[b]
Metaconule 16,26	n	223	165	204	36
	% symmetry	82.1[a]	79.4[a]	81.4[a]	69.4[a]
	% symmetry (absent-absent exc.)	71.2	63.4	73.8	57.7
	rho	0.82[b]	0.73[b]	0.83[b]	0.62[b]
Hypocone reduction 17,27	n	231	127	192	54
	% symmetry	86.6[a]	84.3[a]	84.9[a]	92.6[a]
	% symmetry (absent-absent exc.)	-	-	-	-
	rho	0.88[b]	0.82[b]	0.83[b]	0.80[b]
Distal accessory ridge 33,43	n	278	165	230	53
	% symmetry	85.3[a]	81.8[a]	90.4[a]	90.6[a]
	% symmetry (absent-absent exc.)	59.0	48.3	60.7	68.8
	rho	0.68[b]	0.56[b]	0.71[b]	0.75[b]
Lingual cusp number 35,45	n	263	155	235	59
	% symmetry	84.0[a]	85.8[a]	84.3[a]	86.4
	% symmetry (absent-absent exc.)	-	-	-	-
	rho	0.63[b]	0.74[b]	0.74[b]	0.43[b]
Protostylid 36,46	n	248	146	227	37
	% symmetry	87.5[a]	96.6[a]	93.0[a]	91.9[a]
	% symmetry (absent-absent exc.)	76.5	94.5	77.8	66.7
	rho	0.80[b]	0.95[b]	0.88[b]	0.73[b]
Deflecting wrinkle 36,46	n	159	105	196	19
	% symmetry	76.7[a]	79.0[a]	87.2[a]	100.0[a]
	% symmetry (absent-absent exc.)	51.9	52.2	69.9	100.0
	rho	0.61[b]	0.63[b]	0.78[b]	1.00[b]
Metaconulid 36,46	n	258	167	235	43
	% symmetry	95.7[a]	96.4[a]	94.0[a]	95.3[a]
	% symmetry (absent-absent exc.)	35.3	53.8	41.7	60.0
	rho	0.50[b]	0.76[b]	0.76[b]	0.75[b]
Entoconulid 36.46	n	244	161	218	31
	% symmetry	94.3[a]	91.3[a]	95.0[a]	80.6[a]
	% symmetry (absent-absent exc.)	77.0	67.4	79.2	40.0
	rho	0.85[b]	0.77[b]	0.87[b]	0.53[b]

Continued

TABLE 3. Continued

Traits and Teeth		Malays	Chinese	Indians	Negritos (Jahai)
Cusp number 37,47	n	232	132	188	41
	% symmetry	85.8[a]	83.3[a]	92.6[a]	87.8[a]
	% symmetry (absent-absent exc.)	-	-	-	-
	rho	0.82[b]	0.78[b]	0.84[b]	0.77[b]
Groove pattern 37,47	n	223	132	206	35
	% symmetry	77.1[a]	78.8[a]	76.7[a]	68.6
	% symmetry (absent-absent exc.)	-	-	-	-
	rho	0.63[b]	0.63[b]	0.68[b]	0.36

[1]exc, excluded; the dashes (-) indicate that no analysis was performed because definition of "absent" is equivocal.
[a]$P = 0.0037$
[b]$P < 0.05$

assessed using univariate non-parametric analyses. Bonferroni's adjustment was adopted for multiple univariate testing (13 independent variables) to control Type 1 error. The alpha level of 0.05 was divided by 13, yielding an adjusted alpha value of 0.0037.

Calculation of the Mean Measure of Divergence (MMD) between groups took account of the issues raised by Harris and Sjøvold (2004) and (Irish, 2006). Differences in the frequencies of occurrence of each of the 13 dental traits between the four groups were analyzed using chi-square analysis at an alpha level of 0.05 to identify influential traits. According to Harris and Sjøvold (2004), these tests are important for selection of traits, as only those associated with significant outcomes should be used as input into the mean measure of divergence (MMD) computations to avoid negative values. These researchers also recommended that negative MMD coefficients be replaced with zero only when the coefficients are used for subsequent graphical representation.

The MMD analysis utilized dichotomous data. The frequencies of occurrence were transformed using Anscombe computations (Equation 2) to stabilize sampling variance. Harris and Sjøvold (2004) defined the computation of the MMD as follows: "the difference between samples i and j for the frequencies of trait k is calculated and then this difference is squared and the correction term is subtracted. The sum of corrected squared differences was averaged according to the number of traits."

Mean measure of divergence (MMD) is

$$MMD = \frac{1}{r}\sum_{k=1}^{r}\left(\theta_{ik}-\theta_{jk}\right)^2 - \left(\frac{1}{n_{ik}+0.5}+\frac{1}{n_{jk}+0.5}\right)$$

r, number of traits
k, dental trait
i, j, samples from group i ,j
n_{ik}, scorable samples in i group for trait k
n_{jk}, scorable samples in j group for trait k
Anscombe's transformation,

$$\theta = \sin^{-1}\left(1-2\left(\frac{m+\frac{3}{8}}{n+\frac{3}{4}}\right)\right)$$

m, frequency of trait presence
n, scorable specimens

The standard deviation of MMD is

$$SD = \sqrt{\frac{2}{r^2}\sum_{k=1}^{r}\left(\frac{1}{n_{ik}}+\frac{1}{n_{jk}}\right)^2}$$

The MMD coefficients are considered to be significant at an alpha level of 5% when they are twice the corresponding standard deviations.

For ease of interpretation, MMD coefficients were used as input into a hierarchical cluster analysis to generate a classification tree dendrogram. Clustering methods used Ward's linkage and measurement between pairs of groups was based on squared Euclidean distance. The output was rescaled to numbers between 0 and 25.

TABLE 4. Percentages of occurrence and sexual dimorphism for 13 dental traits using the individual count method and graded-scale data in four ethnic groups[1]

		Malays			Chinese			Indians			Negritos		
Traits	Score	M	F	T	M	F	T	M	F	T	M	F	T
n		125	164	289	89	87	176	128	116	244	32	27	59
Winging	1	11.2(14)	7.9(13)	9.3(27)	13.5(12)	17.2(15)	15.3(27)	2.6(3)	4.7(6)	3.7(9)	28.1(9)	14.8(4)	22.0(13)
	2	6.4(8)	4.3(7)	5.2(15)	7.9(7)	11.5(10)	9.7(17)	9.5(11)	4.7(6)	7.0(17)	15.6(5)	3.7(1)	10.2(6)
	3	82.4(103)	87.8(144)	85.5(247)	78.7(70)	71.3(62)	75.0(132)	87.9(102)	90.6(116)	89.3(218)	56.3(18)	81.5(22)	67.8(40)
n		118	159	277	88	84	172	115	126	241	25	26	51
Shovel	0	2.5(3)	1.3(2)	1.8(5)	0.0(0)	0.0(0)	0.0(0)	3.5(4)	4.0(5)	3.7(9)	12.0(3)	3.8(1)	7.8(4)
	1	57.6(68)	54.7(87)	56.0(155)	21.6(19)	27.4(23)	24.4(42)	73.9(85)	69.0(87)	71.4(172)	64.0(16)	76.9(20)	70.6(36)
	2	39.0(46)	43.4(69)	41.5(115)	75.0(66)	72.6(61)	73.8(127)	21.7(25)	27.0(34)	24.5(59)	24.0(6)	19.2(5)	21.6(11)
	3	0.8(1)	0.6(1)	0.7(2)	3.4(3)	0.0(0)	1.7(3)	0.0(0)	0.9(1)	0.4(1)	0.0(0)	0.0(0)	0.0(0)
n		119	157	276	89	88	177	126	111	237	28	26	54
Metaconule	0	37.0(44)	42.7(67)	40.2(111)	40.4(36)	45.5(40)	42.9(76)	22.5(25)	29.4(37)	26.2(62)	39.3(11)	19.2(5)	29.6(16)
	1	33.6(40)	28.7(45)	30.8(85)	27.0(24)	25.0(22)	26.0(46)	48.6(54)	38.1(48)	43.0(102)	35.7(10)	61.5(16)	48.1(26)
	2	26.1(31)	23.6(37)	24.6(68)	27.0(24)	28.4(25)	27.7(49)	22.5(25)	30.2(38)	26.6(63)	21.4(6)	19.2(5)	20.4(11)
	3	3.4(4)	5.1(8)	4.3(12)	5.6(5)	1.1(1)	3.4(6)	6.3(7)	2.4(3)	4.2(10)	3.6(1)	0.0(0)	1.9(1)
n		126	164	290	88	88	176[a]	118	131	249	30	33	63
Carabelli trait	0	15.1(19)	15.9(26)	15.5(45)	14.8(13)	38.6(34)	26.7(47)	11.0(13)	16.8(22)	14.1(35)	6.7(2)	21.2(7)	14.3(9)
	1	7.9(10)	14.6(24)	11.7(34)	12.5(11)	8.0(7)	10.2(18)	25.4(30)	14.5(19)	19.7(49)	10.0(3)	18.2(6)	14.3(9)
	2	65.1(82)	63.4(104)	64.1(186)	63.6(56)	50.0(44)	56.8(100)	56.8(67)	66.4(87)	61.8(154)	56.7(17)	57.6(19)	57.1(36)
	3	11.9(15)	6.1(10)	8.6(25)	9.1(8)	3.4(3)	6.3(11)	6.8(8)	2.3(3)	4.4(11)	26.7(8)	3.0(1)	14.3(9)
n		114	148	262	76	70	146	106	117	223	33	29	62
Hypocone	0	17.5(20)	20.3(30)	19.1(50)	13.2(10)	27.1(19)	19.9(29)	30.2(32)	39.3(46)	35.0(78)	0.0(0)	13.8(4)	6.5(4)
	1	2.6(3)	5.4(8)	4.2(11)	1.3(1)	8.6(6)	4.8(7)	4.7(5)	6.0(7)	5.4(12)	0.0(0)	0.0(0)	0.0(0)
	2	60.5(69)	58.1(86)	59.2(155)	76.3(58)	54.3(38)	65.8(96)	45.3(48)	44.4(52)	44.8(100)	54.5(18)	51.7(15)	53.2(33)
	3	19.3(22)	16.2(24)	17.6(46)	9.2(7)	10.0(7)	9.6(14)	19.8(21)	10.3(12)	14.8(33)	45.5(15)	34.5(10)	40.3(25)
n		126	164	290	90	86	176	116	129	245	29	31	60[a]
Distal access. ridge	0	61.9(78)	67.1(110)	64.8(188)	54.4(49)	74.4(64)	3.3(3)	74.1(86)	76.7(99)	75.5(185)	44.8(13)	87.1(27)	66.7(40)
	1	34.1(43)	31.1(51)	32.4(94)	42.2(38)	25.6(22)	0.0(0)	24.1(28)	22.5(29)	23.3(57)	55.2(16)	12.9(4)	33.3(20)
	2	4.0(5)	1.8(3)	2.8(8)	3.3(3)	0.0(0)	1.7(3)	1.7(2)	0.8(1)	1.2(3)	0.0(0)	0.0(0)	0.0(0)

Continued

TABLE 4. Continued

		Malays			Chinese			Indians			Negritos		
Traits	Score	M	F	T	M	F	T	M	F	T	M	F	T
n		121	163	284	89	83	172	119	129	248	33	33	66
Ling. cusp no. LP2	1	27.3(33)	16.6(27)	21.1(60)	29.2(26)	24.1(20)	26.7(46)	34.5(41)	21.7(28)	27.8(69)	15.2(5)	6.1(2)	10.6(7)
	2	67.8(82)	79.8(130)	74.6(212)	65.2(58)	69.9(58)	67.4(116)	55.5(66)	72.1(93)	64.1(159)	78.8(26)	93.9(31)	86.4(57)
	3	5.0(6)	3.1(5)	3.9(11)	5.6(5)	6.0(5)	5.8(10)	10.1(12)	6.2(8)	8.1(20)	6.1(2)	0.0(0)	3.0(2)
	4	0.0(0)	0.6(1)	0.4(1)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)
n		124	158	282	82	82	164	118	129	247	28	23	51
Protostylid	0	43.5(54)	48.1(76)	46.1(130)	28.0(23)	41.5(34)	34.8(57)	72.0(85)	64.3(83)	68.0(168)	67.9(19)	69.6(16)	68.6(35)
	1	4.8(6)	3.2(5)	3.9(11)	12.2(10)	8.5(7)	10.4(17)	1.7(2)	4.7(6)	3.2(8)	0.0(0)	8.7(2)	3.9(2)
	2	51.6(64)	48.7(77)	50.0(141)	59.8(49)	50.0(41)	54.9(90)	26.3(31)	31.0(40)	28.7(71)	32.1(9)	21.7(5)	27.5(14)
n		124	163	287	89	88	177	120	127	247	30	25	55
Metaconulid	0	90.3(112)	95.7(156)	93.4(268)	89.9(80)	95.5(84)	92.7(164)	87.5(105)	91.3(116)	89.5(221)	83.3(25)	96.0(24)	89.1(49)
	1	8.9(11)	4.3(7)	6.3(18)	5.6(5)	2.3(2)	4.0(7)	6.7(8)	6.3(8)	6.5(16)	10.0(3)	4.0(1)	7.3(4)
	2	0.8(1)	0.0(0)	0.3(1)	4.5(4)	2.3(2)	3.4(6)	5.8(7)	2.4(3)	4.0(10)	6.7(2)	0.0(0)	3.6(2)
n		124	157	281	89	88	177	115	124	239	21	22	43
Entoconulid	0	77.4(96)	72.0(113)	74.4(209)	64.0(57)	79.5(70)	71.8(127)	81.7(94)	70.2(87)	75.7(181)	57.1(12)	77.3(17)	67.4(29)
	1	21.0(26)	26.8(42)	24.2(68)	31.5(28)	19.3(17)	25.4(45)	16.5(19)	29.0(36)	23.0(55)	38.1(8)	18.2(4)	27.9(12)
	2	1.6(2)	1.3(2)	1.4(4)	4.5(4)	1.1(1)	2.8(5)	1.7(2)	0.8(1)	1.3(3)	4.8(1)	4.5(1)	4.7(2)
n		105	131	236	71	78	149	114	118	232	9	17	26
Deflecting wrinkle	0	49.5(52)	54.2(71)	52.1(123)	52.1(37)	62.8(49)	57.7(86)	57.0(65)	56.8(67)	56.9(132)	88.9(8)	88.2(15)	88.5(23)
	1	37.1(39)	31.3(41)	33.9(80)	28.2(20)	19.2(15)	23.5(35)	36.0(41)	30.5(36)	33.2(77)	11.1(1)	5.9(1)	7.7(2)
	2	13.3(14)	14.5(19)	14.0(33)	19.7(14)	17.9(14)	18.8(28)	7.0(8)	12.7(15)	9.9(23)	0.0(0)	5.9(1)	3.8(1)
n		116	150	266	80	75	155	105	112	217	24	24	48
Cusp no. LM2	4	45.7(53)	49.3(74)	47.7(127)	26.3(21)	50.7(38)	38.1(59)	72.4(76)	80.4(90)	76.5(166)	58.3(14)	62.5(15)	60.4(29)
	5	47.4(55)	41.3(62)	44.0(117)	56.3(45)	37.3(28)	47.1(73)	26.7(28)	17.9(20)	22.1(48)	37.5(9)	33.3(8)	35.4(17)
	6	6.9(8)	9.3(14)	8.3(22)	17.5(14)	12.0(9)	14.8(23)	1.0(1)	1.8(2)	1.4(3)	4.2(1)	4.2(1)	4.2(2)
n		116	150	266	79	77	156	114	124	238	25	25	50
Groove pattern	1	6.9(8)	10.0(15)	8.6(23)	6.3(5)	5.2(4)	5.8(9)	36.8(42)	41.9(52)	39.5(94)	4.0(1)	4.0(1)	4.0(2)
	2	59.5(69)	60.7(91)	60.2(160)	57.0(45)	61.0(47)	59.0(92)	51.8(59)	46.8(58)	49.2(117)	68.0(17)	80.0(20)	74.0(37)
	3	33.6(39)	29.3(44)	31.2(83)	36.7(29)	33.8(26)	35.3(55)	11.4(13)	11.3(14)	11.3(27)	28.0(7)	16.0(4)	22.0(11)

[1]n is sample size; group codes are: males (M), females (F), and total of males and females (T); frequencies of occurrence are shown in parentheses.
[a]P = 0.0037.

RESULTS

Most of the intra-observer errors using absence-presence data were less than 10% and only 15 of 100 intra-observer error observations were in the range of 11% to 18%. The percentages of error recorded for full-grade scoring were higher than for absence-presence data and the differences were only one grade apart.

The patterns of symmetry-asymmetry were similar in both sexes, except for hypocone reduction in Chinese and Jahai, and the metaconulid in Indians. After combining the data for both sexes, most traits were expressed symmetrically based on high to moderate values of correlation coefficients and concordance analyses (Table 3).

Table 4 shows frequencies of occurrence of dental traits in males and females for each of the four ethnic groups. Winging of upper central incisors, shoveling, metaconule, deflecting wrinkle, groove pattern, metaconulid, protostylid, hypocone, lingual cusp number of premolar, four-cusped lower second molar, and entoconulid showed no evidence of significant sexual dimorphism in any of the four ethnic groups. Sexual dimorphism was found to be significant at an alpha level of 5% (Bonferroni's adjustment) for a couple of traits. Carabelli cusp (maximum expression of Carabelli trait) occurred more frequently in males than females in the Chinese sample, while pit and furrow forms were more frequent in female Chinese. The distal accessory ridge was significantly more frequent in Jahai males than females.

Figure 1 shows significant differences at the 5% significance level in the frequencies of occurrence of 11 dental traits (sexes combined) between the four ethnic groups and compares the overall profiles of frequencies between the four ethnic groups. Ethnic group differences were not significant for two dental traits; entoconulid and metaconulid. Malays showed intermediate frequencies of occurrences for all dental traits while Chinese tended to show high frequencies for some traits and low frequencies for others. Shoveling, winging, protostylid, deflecting wrinkle, distal accessory ridge,

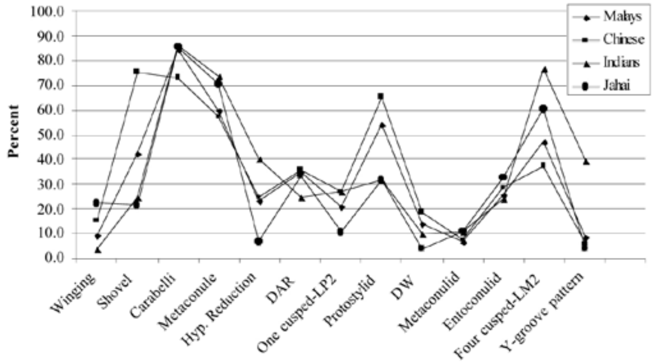

Fig. 1. Frequencies of occurrence of dental crown traits in four ethnic groups using dichotomous data.

and one-lingual cusped premolar frequencies were high in Chinese, whereas Carabelli trait, metaconule and four-cusped molars were the least frequently observed traits. The Indian group was characterized by a high frequency of Carabelli trait, metaconule, reduced hypocone, four-cusped lower second molars and Y-groove patterns, and a low frequency of winging, shoveling, distal accessory ridge, protostylid and entoconulid. The Jahai exhibited low frequencies of occurrences of shoveling, hypocone reduction, one-cusped premolars, deflecting wrinkle, and Y-groove patterns. Only winging frequency was found to be high in the Jahai cohort. Differences of 10% or less in frequencies of occurrence were not associated with statistical significance, as shown by the entoconulid and metaconulid.

Nine dental traits discriminated Indians from Malays and Chinese. Five showed high frequencies in Malays and Chinese; namely, winging, shoveling, distal accessory ridge, protostylid, deflecting wrinkle, whereas four were associated with high frequencies in Indians: metaconule, hypocone reduction, four-cusped lower second molars, and Y-groove pattern. Four other dental traits were not discriminative; Carabelli trait, one-cusped premolars, entoconulid and metaconulid.

When comparing Malays and Chinese, winging, shoveling, one-cusped premolars, protostylid and deflecting wrinkle were present more frequently in Chinese, while Carabelli trait and four-cusped molars were more frequent in Malays. All other dental traits examined did not discriminate between Malays and Chinese.

Table 5 shows the MMD coefficients matrix including tests of significance. All MMD coefficients were statistically significant at $P < 0.05$. MMD coefficients derived from an average of 11 dental traits (the frequencies of entoconulid and metaconulid were not statistically significant in all four ethnic groups and were, therefore, excluded from the MMD analysis) were further subjected to hierarchical cluster analysis to produce a dendrogram. Figure 2 shows the affinities between the four ethnic groups. Indians were separated at a rescaled number of 25 from the other three groups; Malays, Jahai and Chinese. At a rescaled number of approximately 14, Chinese were separated from Malays and Jahai.

DISCUSSION

Despite considerable time spent on training, the intra-observer error rates for some traits in this study were larger than those reported in other studies (Turner and Scott, 1977; Turner, 1987; Turner, 1990). This reflects the subjectivity involved in scoring methods for dental morphology. The categorical nature of the available scoring systems does not allow grading of the quasi-continuous spectra of tooth morphologies that may fall between categories. Nichol and Turner (1986) indicated that if a discordance of more than two-grades occurred,

TABLE 5. Mean measure of divergence coefficients matrix[1]

	Malays	Chinese	Indians	Jahai
Malays	----	0.068	0.144	0.075
Chinese	0.000	----	0.320	0.227
Indians	0.000	0.000	----	0.186
Jahai	0.000	0.000	0.000	----

[1]Tests of significance in cells below diagonal; MMD coefficients in cells above diagonal.

and the presence-absence discordance was more than 10%, then problems exist in the scoring method. Comparing intra-observer error for full-graded scoring and presence-absence scoring between this study and that of Nichol and Turner (1986) revealed similar results for entoconulid, groove pattern, cusp number of lower second molar and hypocone reduction. The results in the present study indicated better reliability for scoring several traits including shoveling, Carabelli trait, distal accessory ridge, deflecting wrinkle, protostylid and lingual cusp number of lower second premolar, whereas results for the metaconule and winging were slightly better in the study by Nichol and Turner (1986). Difficult traits to score consistently in the three major ethnic groups were the metaconule and distal accessory ridge using dichotomous categories. This study confirmed, as one would expect, that dichotomous data display better reliability, as quantified by concordance rates, than full-graded scoring methods. Consistent with those results, Palomino *et al*. (1977) indicated their preference for using dichotomous data rather than full-graded scoring methods that increase the likelihood of misclassification.

Bilateralism was expressed similarly in males and females for all four ethnic groups. This result justified combining males and females for subsequent asymmetry-symmetry analysis. The frequencies of occurrence and degrees of expression of most traits showed significant symmetry, reflecting common developmental control for both sides of the dentition (Potter *et al*., 1976). Exceptions were lingual cusp number and groove pattern in Jahai, suggesting caution is needed in using dental traits observed on the distal tooth of a series because these teeth showed evidence of higher asymmetry (Garn *et al*., 1966a). However, these traits are useful to comparing

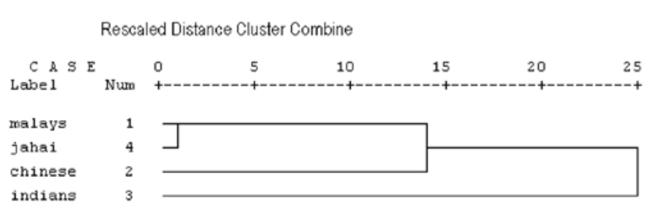

Fig. 2. Dendrogram of four ethnic groups with sexes pooled.

trait simplification between groups.

Several of our findings were similar to those of previous studies in other populations. Percentages of symmetrical expression were generally higher than 75% for the majority of traits, similar to findings of Harris and Bailit (1980) and Noss *et al*. (1983b). When absence-absence pairs were excluded from the analysis, symmetry percentages were reduced (Mayhall and Saunders, 1986) especially for traits displaying low frequencies of occurrence (Townsend *et al*., 1990). Two traits in Jahai, lingual cusp number of lower second premolars and molar groove pattern, did not exhibit significant symmetry and were associated with moderate to low correlations in contrast to the results of Baume and Crawford (1979) who reported strong correlations but non-significant symmetry in Mexican and Belizean populations. Several traits showed high symmetry but the values of correlation coefficients were not consistently high. Percentages of concordance between sides, when absent-absent pairs were excluded, paralleled the values of correlation coefficients. Excluding absent-absent pairs is thought to reduce bias in the analysis of asymmetry (Townsend *et al*., 1990).

Assessment of asymmetry for each grade revealed large discordance for several traits, ranging from absence on one side to maximum expression on the antimeric tooth. This occurred infrequently and to varying degrees among the four ethnic groups. Two traits consistently showed large discordances in the four ethnic groups; deflecting wrinkle and protostylid. There were three traits, shoveling, Carabelli trait and distal accessory ridge, which were consistently free from large discordances in all four ethnic groups. In conclusion, the present findings support the premise of common genetic control on both sides of the dentition with environmental influences causing minor deviation from perfect symmetry. This suggests that replacement of missing values with antimeric values is biologically and statistically acceptable.

Significant sexual dimorphism (after Bonferroni's adjustment) was found only in Chinese and Jahai; Carabelli trait in Chinese and distal accessory ridge on the canine in the Jahai. The distal accessory ridge was found more often in Jahai males, which is consistent with Scott (1977) who studied the frequencies and degrees of expression of the distal accessory ridge in seven ethnic groups in the United States of America. Carabelli trait in Malaysian Chinese was more common in males, a similar result to that reported in Japanese and Chinese samples (Iwai-Liao *et al*., 1996), Southern Chinese (Hsu *et al*., 1999), Australian Aborigines (Townsend and Brown, 1981) and Indian Jats (Kaul and Prakash, 1981). In contrast, Hanihara (1977), Turner and Hanihara (1977), Scott (1980), Manabe *et al*. (1992) and Rusmah (1992) did not find any sexual dimorphism in the occurrence of this trait. In essence, the amount of sexual dimorphism for dental trait expression seems to vary between different populations.

Based on our preliminary analyses of within-group variations, the 13 dental traits scored in this study were considered to be suitable for population variation studies (Turner *et al*., 1991). This suitability was based on several criteria, such as an apparently strong genetic influence on the ontogeny of the traits (Tocheri, 2000), low sexual dimorphism and strong symmetry.

Inter-sample comparisons have been used in the past to define so-called "racial dental complexes" for Mongoloid, Caucasoid and Australoid groups. Hanihara's (1968) Mongoloid dental complex identifies four traits, UI1 and UI2 shoveling, deflecting wrinkle, protostylid and metaconule. In our samples the observed dental traits generally conformed to accepted models, except for the metaconule, for which the Indian sample displayed the highest frequency compared with Malays, Chinese and Jahai.

According to Turner's Mongoloid dichotomy (Turner, 1990), four crown traits distinguish Sinodonts from Sundadonts. Shoveling, double shoveling and deflecting wrinkle are common in Sinodonts, whereas 4-cusped lower second molar are common in Sundadonts. In our results Jahai and Malays fitted the Sundadont description, while Chinese showed the Sinodont crown trait pattern.

Tratman (1950) described Indians as Indo-Europeans who frequently exhibit Carabelli trait, and the Malays and Chinese as Mongoloids who show high frequencies of shoveling, double shoveling, entoconulid and more complex occlusal surfaces. In our study, findings for Malays, Chinese and Jahai were consistent with some of Tratman's comments but those for Carabelli trait, entoconulid and double shoveling were not. Double shoveling was not scored in our study. The entoconulid did not provide statistically significant discrimination in the present study, although Indians exhibited the lowest relative frequency.

The frequencies of Carabelli trait found in this study were generally high when compared with other published material for Mongoloid populations (Rusmah, 1992; Iwai-Liao *et al*., 1996; Hsu *et al*., 1999). Only one article about Wainwright Eskimos by Hershey (1979) provides figures that approximate those obtained for Carabelli trait in this study. Hershey found a 92% frequency of occurrence for Carabelli trait while in this Mongoloid sample the frequency was around 75%-85%. An unexpected trend was found in the cuspal category (maximum expression for Carabelli trait). According to Tratman (1950), Indians should have a high frequency of Carabelli cusp but in this study they actually recorded the lowest frequency of 4.4% only. Several other researchers including Kraus (1959), Hershey (1979), Mayhall *et al*. (1982), and Mayhall (1999) have opined that only the Carabelli cusp (maximum category) provides discrimination between Caucasoid and Mongoloid groups. In fact, they suggested that the pit and intermediate categories occurred more frequently in Mongoloid populations. In this Malaysian sample, total frequencies of occurrence of Carabelli trait only discriminated Chinese from the other three groups but they failed to show any discriminating power for Malays, Jahai and Indians. This result raises doubt about the utility of Carabelli trait as a Caucasoid marker.

The Indian sample generally displayed less complex occlusal and palatal surfaces, consistent with Tratman's (1950) anatomical descriptions of his sample, and partially compatible with the Caucasoid dental complex (Mayhall *et al*., 1982). From six dental traits proposed by Mayhall *et al*. (1982), only two traits, low prevalence of shovel and high prevalence of hypocone reductions, fit the Indian dental characteristics found in this study.

The Jahai, who represent Negritos from the Malaysian Peninsula, have a similar pattern of dental characteristics as the Aetas from the Philippines (Hanihara, 1992). The similarities noted include low frequencies of shoveling, deflecting wrinkle, and high frequencies of 4-cusped lower second molars.

Phenetic distances based on dental variations seem to support historical reports. The first documented reports suggest that for a period of time Malays lived side by side with Orang Asli until the "Perang Sangkel" war broke out between them, causing the Orang Asli to move deep into the jungle (Pusat Perkembangan Kurikulum, 1998). Another documented report is that the Malays could have originated from mixture of proto-Malays (Orang Asli) with other ethnic groups, such as Thailanders, Arabs or Chinese (Nagata, 1979; Dentan *et al*., 2001). Unfortunately, our results do not enable us to decide which historical version better explains the close affinity between Malays and Orang Asli. Both documented reports generate postulations of potential genetic admixture and sharing of ancestors that could explain the phenetic closeness between the two groups.

CONCLUSIONS

Most of the dental traits studied showed symmetrical expression in their frequencies of occurrences and low sexual dimorphism. The analyses performed indicated that there are two main groups of Malaysians. The Mongoloid group comprises Malays, Negritos (Jahai) and Chinese, whereas the Indian sample can be classified as Indo-European. The Mongoloid group can be further subdivided, with the Jahai and Malays fitting the Sundadont profile and the Chinese conforming to a Sinodont profile, as described by Turner (1990). Phenetic distances based on dental variation lend support to the historical perspectives of Malaysian population relationships.

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Minutes of the 21st Annual Dental Anthropology Association Business Meeting March 9th, 2006 Anchorage, Alaska

Call to Order:

President Debbie Guatelli-Steinberg called the meeting to order at 7:45 pm. There were 17 members in attendance.

Old Business:

Debbie Guatelli-Steinberg announced that at the end of the meeting, the presidency would be turned over to the President-Elect, Simon Hillson.

New Business:

1. Editor's Report: Edward Harris sent word that Volume 18 was complete with with two issues. He called for submissions to the journal, including case reports, lab descriptions and newsy reports, as well as scholarly articles. Past issues of the Journal are now available on line as adobe acrobat files through The Ohio State Anthropology department's website.

2. Secretary-Treasurer's Report: Heather Edgar reported that as of March 6, 2006, the DAA has $1450 in operations funds, and $1540 in the AA Dahlberg prize fund. Funds are low, so the secretary called for people to be sure to pay their dues soon. There are 248 members in the association who are current with their dues or one-year past-current. There has been a recent increase in student members of the organization.

3. A.A. Dahlberg Student Prize: The winner of the 2006 was Robin Brenna Hassett, for her paper entitled "Torus Mandibularis: Etiology and Bioarcheological Utility." She received $200, a certificate of award, a year's free membership in the DAA, and has had her article published in the journal [*Dental Anthropology* 2006;19:1-14].

4. John Lukacs suggested that the DAA sponsor a symposium at the 2007 AAPA meetings. He suggested the topic be centered on oral health and gender in an evolutionary perspective.

5. Brian Hemphill (California State University at Bakersfield) was elected President-Elect.

Adjournment:

Debbie Guatelli-Steinberg adjourned the meeting at 8:30 pm. The meeting was followed by a period of socializing around the DAA cash bar.

Submitted by:
Heather J. H. Edgar
DAA Secretary-Treasurer

Book Review

Verwandschaftsanalyse im alemannischen Gräberfeld von Kirchheim/Ries (Analysis of Relationships within the Alemannic linear graveyard of Kirchheim/Ries [In German]) By Kurt W. Alt and Werner Vach. Basler Hefte zur Archäologie Volume 3 2004. Archäologie-Verlag Basel.

Archaeologists have long been stymied when confronting a fundamental aspect of ancient social systems—kinship. While kinship terms and systems are featured in every beginning cultural anthropology textbook, archaeologists were left wondering if their ceramic design motifs or the spatial patterning in cemeteries really provided insight into relations of marriage and descent in ancient societies. In response to this need, Alt and Vach set out to develop a method of assessing genetic relationships among individuals in skeletal samples derived from archaeological contexts. The method has been used on skeletal material collected from a large variety of archaeological contexts of varying sample sizes, such as a mass grave from the Roman Imperial period, Neolithic mass graves in Germany and Abu Dhabi, a Paleolithic triple burial, an Early Iron Age cemetery, a late Slavic cemetery, and a Merovingian cemetery, several reports of which have also been published in English (Alt *et al*., 1995a; Alt *et al*., 1995b; Alt *et al*., 1997; Alt and Sedlmeier, 1990; Alt and Vach, 2001; Alt *et al*., 1995c; Alt *et al*., 1992).

This monograph concerns the skeletal sample at the Alemannic cemetery of Kirchheim/Reis, which represents the largest sample yet investigated using their methods. The body of the monograph is written in German, although summaries in French, Italian and English present basic information about the cemetery, the methodology, and the results. The authors begin Chapter 1 with a consideration of the goals of a biological kinship analysis and how it can serve to further the traditional archaeological goal of understanding ancient social systems. They include a critical consideration of how the terminology and concepts employed in biological kinship analysis intersect with established (although sometimes contentious) concepts within socio-cultural anthropology and archaeology. The authors make it clear that socially defined kinship relations do not necessarily have biological components and therefore cannot be investigated using techniques that rely on genetic relationships among individuals. The authors realize that the results of their analyses provide only part of the picture and that additional sources of archaeological and anthropological data must be consulted.

In Chapter 2, the authors present the methodological foundation of their approach for investigating biological kinship among ancient populations. Dr. Alt, a physical anthropologist, and Dr. Vach, a statistician, have developed a statistical method to assess biological kinship based on the comparison of similarities among individuals using a large catalog of non-metric traits of the skull, jaws, and teeth (Alt, 1997). Certain assumptions and potential issues must be considered when using this approach. For example, the method relies on a comparison of phenotypic similarities. In other words, it relies on the portion of any shared genetic information that is actually expressed as traits in common among individuals, and therefore does not directly identify the specific genetic relationship between individuals. In addition, the analysis is based on the observation of non-metric traits with varying penetrance and expressivity. This means that family members can only be identified in the event that they express traits typical of their family and that such traits are observable. In many cases, traits are obliterated by dental wear and disease as well as taphonomic processes. For a large, relatively well-preserved sample such as Kirchheim/Ries, these problems are minimized.

In order to find related individuals, the method employs a statistical search procedure that compares each individual and each trait to create combinations of individuals (termed "structures"). Significant structures are based on non-metric traits with low frequencies in the population, which also have a low global probability of conspicuousness (G-value), indicating a low probability of observing the same combination by chance among unrelated individuals in the sample. More detailed discussions of the method and its statistical basis have been published in English (Alt and Vach, 1991; Alt and Vach, 1992; Alt and Vach, 1993; Alt and Vach, 1998).

In Chapters 3 and 4, Alt and Vach present the results of their analyses of the cemetery at Kirchheim/Ries. In total, 460 individuals were scored for 933 non-metric traits of the skull, jaws, and teeth. Since the sample of individuals from the total cemetery was quite large, the authors were able to investigate subgroups within the cemetery and still maintain reasonable sample sizes. This procedure ensured that the analysis was not dominated by large, very robust groups or individuals with a large number of well-preserved, rare traits. They looked for both general patterns based solely on the non-metric traits, and on subgroups created using archaeological attributes such as chronological time period, sex of the individual, spatial organization, wealth of grave goods, and types of grave goods.

Results of the analysis of all graves revealed eight familial structures, some of which have additional archaeological characteristics that indicate a social relationship as well. An unexpected result from the analysis of all graves is the relatively large number of individuals who appear in more than one of the eight groups, which suggests genetic interrelationships among the eight possible families that used the cemetery.

Archaeological mortuary analyses rely upon spatial patterning in cemeteries, grave construction, and assemblages of grave goods to recreate a sense of the social identity of an individual. Comparison of these data for all the individuals in a cemetery facilitates the reconstruction of the social organization as expressed in burial practice. However, there has been debate as to which aspects of burials reflect which aspects of social organization, for example vertical social status (wealth), horizontal social status (one's position in relation to others within the same level of a hierarchy), or membership in other types of groups such as kin groups, trades, or religious groups. In their analysis of the cemetery at Kirchheim/Ries, Alt and Vach demonstrate that, for some types of grave goods, it is possible to identify biological kin structures that are at least partly correlated with certain types of grave goods.

In a previous cemetery analysis, Jorgensen (Jorgensen *et al.*, 1997) identified 14 likely familial groupings of graves based on archaeological mortuary data. Tests seeking a biological basis for the 14 archaeologically defined familial groupings revealed only one convincing biological family structure (Group IV), although sample sizes for some of the hypothesized archaeological family groups were small due to poor preservation. Analysis of subgroups defined by the presence of specific grave goods met with more success. Several new familial structures were identified, and these frequently showed spatial clustering as well. In many cases, the structures contained several graves with a particular item, but also some graves without it. Additionally, the same items also occurred in graves that were not in the structure. This phenomenon illustrates the difficulties of identifying familial structures based on archaeological evidence alone, as well as the utility of testing archaeological subgroups in biological kinship analysis.

Perhaps the most powerful results for the understanding of the social organization at the cemetery of Kirchheim/Ries come from the analysis of the "traditional aristocracy" (those showing unusual wealth) within the main cemetery and the analysis of the spatially distinct "noble burial compound", which contained wealthy burials dating only to the final three chronological phases of the cemetery. Previous archaeological interpretations had speculated that the nobles were locals originally interred as part of the general population, who later founded their own distinct cemetery to emphasize their separate identity. Analysis of the "traditional aristocracy" within the main cemetery shows biological kinship structures among its members, as well as possible connections to other burials within the main cemetery. Analysis of the spatially distinct noble burial compound revealed fundamental differences between its population and the main cemetery that can only be explained by the presence of two genetically distinct populations. Archaeologically, individuals interred in the noble burial compound show affinities to the Avars (an eastern tribe contemporaneous with the Alemanni) in both material culture and burial rituals.

A contentious area of archaeological research lies in understanding the process of the introduction of new material culture and cultural practices. It is often unclear whether the appearance of new elements indicates the movement of actual people or the diffusion of goods and ideas, especially in times of intensive population movement. Although the geographic origin of the individuals within the noble burial compound cannot be identified based on their skeletal traits, the biological kinship analysis did reveal that the appearance of foreign material culture and burial practices at the cemetery of Kirchheim/Ries coincided with the arrival of a genetically distinct population.

Alt and Vach's analysis of the Alemannic cemetery at Kirchheim/Ries provides an excellent example of the effective use of non-invasive, non-destructive methods for analyzing dental and skeletal data in a truly bioarchaeological context. The results of their analyses demonstrate the potential for biological kinship analysis to add a new dimension to mortuary analysis and a new source of data that can be applied to some of archaeology's most perplexing problems.

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