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Torus Mandibularis: Etiology and Bioarcheological Utility

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ABSTRACT: Torus mandibularis is a non-metric trait commonly recorded in bioarcheological investigation and often included in the battery of non-metric traits used to analyse biological distance among populations. However, there is considerable debate regarding the etiology of the trait, with genetic and environmental factors both having been posited as the primary factor in torus development. This study of 498 individuals, drawn from eight archeological samples, investigates the variation in torus frequency in different groups as defined by sample, age, sex, and measures of functional stress. Frequencies varied significantly among both samples and dental attrition categories, supporting the idea that mandibular tori are a threshold trait, influenced by both genetic and environmental factors. Results of this study suggest the utility of mandibular tori in bioarchaeology may lie outside of biodistance analyses that rely on the high heritability quotient of non-metric traits to establish population distances. *Dental Anthropology* 2006;19:1-14.

Torus mandibularis is a non-metric trait found in varying frequencies among human populations past and present, and as such is commonly recorded along with a battery of other such traits during the archeological assessment of skeletal remains. Non-metric traits are largely used in analyses of biological distance within and among archeological samples due to the assumption of a high heredity quotient in their occurrence. Berry and Berry (1967) established the utility of several skeletodental traits in biodistance analyses, but several traits commonly included in such analyses lack substantive evidence of genetic involvement.

Torus mandibularis was chosen to test the utility of the trait in establishing biological relationships specifically because of the debate surrounding its etiology. Lacking a clear pattern of genetic inheritance, the trait has been seen by a number of researchers to relate instead to the osteological response of the masticatory complex to mechanical stresses. There has been nearly 100 years of contention as to whether the trait might represent a phenomenon related either to genetic heritability on a population level or to functional stress. This study was intended to provide direct evidence of either a correlation between occurrence and functional stresses on the masticatory complex, or a conclusive lack of correlation. Additionally, the degree to which this data set corresponds to other researchers' assessments of population-level variation is addressed. A total of 498 individuals from 8 archeological collections was assessed here on factors that have been posited to play a role in torus development, namely population group, age, sex, and evidence of functional stress.

Torus mandibularis is recognized as a bony ridge or series of bony nodules or lumps appearing on the lingual surface of the alveolar margin of the mandible, generally in the premolar region (Hauser and DeStefano, 1989). These tori may be completely absent or present in varying degrees, and may present a variety of forms.

Mandibular tori are not associated with any pathological condition and can be easily distinguished from instances where osteological activity is the result of a pathological condition causing abnormal growth, such as trauma or tumor. Torus mandibularis is generally manifested bilaterally, though it may be present just on one side of the mandible. There is often a degree of asymmetry between sides, with the right side most commonly presenting a more pronounced torus than the left (Haugen, 1990; Seah, 1995).

ETIOLOGICAL DEBATE

The question of etiology is vital in assessing whether use of oral tori in biodistance analysis is appropriate. If tori are assumed to be solely under genetic control, then mandibular exostoses are accepted as useful estimators of population distance along with the other traits commonly used as part of the battery of non-metric traits established by Berry and Berry (1967). If, however, environmental factors play a larger role in determining trait frequency, then their use as estimators of population affinity is not acceptable. The relative importance of environmental compared to genetic factors in the

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development of facial tori has been widely debated, with arguments for the functional basis of tori being contradicted by arguments for a higher genetic factor in increasing tori incidence. The trend has been to observe an increasing role for genetic causality, but it remains to be seen whether genetic inheritance fully explains the development of mandibular exostoses. The most recent studies have suggested that the tori arise in response to both genetic and environmental factors (Haugen, 1990; Seah, 1995). There are several particular aspects of tori distribution that have served as foci for debate, and multiple hypotheses that have been constructed to address the significance of population, sex, age, evidence of functional stress, robusticity of mandible, symmetry, and trait interaction in the formation of the mandibular tori.

Multiple studies attempting to assess the heritability of torus mandibularis have been conducted, coming to divergent conclusions—autosomal recessive (Krahl, 1949; Alvessalo and Kari, 1972), autosomal dominant (Suzuki and Sakai, 1960), or polygenetic in origin (Johnson *et al*., 1965; Sellevold, 1980)—that there is a strong argument against a simplistic assumption of genetic transmission of the trait. However, it has been commonly found to occur in family groupings, and children whose parents exhibited the trait were found to be more likely to exhibit the trait themselves in a study of modern Thais (Kerdpon and Sirirungrojying, 1999).

The explanation for these diverse findings may lie in the work undertaken by researchers to establish the heritability of non-metric traits in studies of mice and non-human primates. Grüneberg (1963) established the concept of quasi-continuous variation in non-metric traits, positing that the size or rate of formation of a given trait may be the inherited factor, which he demonstrated by using genetically isolated strains of mice. Wright (1968) followed this by suggesting the idea of a "threshold" trait that appears only once a certain point determined by environmental factors has been crossed; what the individual inherits is a liability towards developing a trait which environmental factors act upon. Berry and Berry (1967) undertook to study the genetic origins of a large battery of non-metric traits in mice, and it is to this work that most researchers utilizing non-metric traits in estimating biological distance refer. Observing the analogues of several human skeletal traits in generations of mice, they proposed that most of the human non-metric traits also originate from normal genetic variation. The degree to which the environment influences mandibular torus prevalence, and the degree to which genetic inheritance does, should be understood in order for this particular non-metric trait to be included in the battery of traits assembled by Berry and Berry (1967) commonly used to establish biological distance among populations.

Factors affecting this debate include the difference in age and sex. Variation between age classes in tori frequency and degree of expression has not been found by all researchers (Hauser and De Stefano, 1989:9), but the largest studies suggest that there is some degree of variation (Eggen, 1954; Korey, 1980; Haugen, 1990; Jainkittivong and Langlais, 2000; Ruprecht *et al*., 2000). Researchers have found in some cases that males are more likely to exhibit tori than females (Haugen, 1990; Seah, 1995; Hjertstedt *et al*. 2001), whilst in others there is no significant sex difference (*e.g*., Bernaba 1974), or that females have higher frequencies of tori (Corruccini, 1974). A brief summation of the disparate results of some of these studies may be found in Table 1. The consensus appears to suggest that there is some degree of sexual dimorphism (Trinkaus, 1978; Haugen, 1990; Seah, 1995), but it is difficult to assess whether this difference is significant in a statistical sense, particularly in archeological samples where sample sizes may be small.

Variation in tori prevalence and expression with increasing evidence of functional stress to the masticatory complex has been the cornerstone of arguments for the primacy of environmental factors in the development of oral tori. Proponents of this view suggest that differences among groups may be accounted for either entirely or partially by non-hereditary factors, in which case mandibular tori are unsuitable for assessing biological distance without consideration of complicating environmental factors. Instead, they would be of greatest utility in assessing differences in environmental factors such as diet or parafunctional use of the jaws. Patterns of dental attrition, as a result of masticatory hyperfunction related to diet or conditions such as bruxism, have been seen to co-occur with mandibular tori in a statistically significant way in several instances. This has not been a universal observation (*e.g*., Scott *et al*., 1991). Sirirungrojying and Kerdpon (1999) found that torus mandibularis was significantly ($P < 0.005$) more common in dental patients suffering from temporomandibular disorder (TMD), perhaps due to high levels of parafunctional activity, such as clenching and grinding of the teeth (bruxism). This led them to suggest that torus mandibularis could be viewed as an early indication of risk for TMD. Larsen (1997) also comments that the general robusticity of the masticatory complex may be closely correlated with the amount of stress placed on the jaws; for example, a smaller, more gracile jaw would be correlated with a softer diet.

Johnson (1959) studied the mechanical stress of the jaws in conjunction with bone histology. The conclusions of his research were published posthumously, however, and the specific details of his findings are not provided; there is just the supposition that tori may be interpreted from histologiy to be the result of functional stress (Johnson, 1959). No subsequent study has found any evidence to support this hypothesis (Haugen, 1990; Seah,

TABLE 1. Frequencies of torus mandibularis in various groups, by sex

Sample	Males(%)	Females (%)	Citation
Poundbury	16.3	10.9	Farwell and Molleson 1993
Cannington	11	15	Brothwell *et al*. 2000
Ukranian	0.0	1.5	Cesnys and Kundruktova 1982[a]
Lapps	26.8	38.8	Schreiner 1935
North American Whites	6.5	8.1	Corruccini 1974
Eskimo	58.1	35.2	Dodo and Ishida 1987[a]
Canadian Eskimo	85.3	80.0	Dodo and Ishida 1987[a]
Aleuts	71.7	75.9	Dodo and Ishida 1987[a]
Brazilian Indians	0.5	0.5	Bernaba 1977
Blacks	6.1	6.2	Corruccini 1974
Japanese	26.7	33.3	Mouri 1976[a]
Ainu	44.3	21.1	Dodo and Ishida 1987[a]
Iglooik Eskimo	38.7	40.8	Mayhall and Mayhall 1971
Hall Beach Eskimo	41.5	32.1	Mayhall and Mayhall 1971
Norwegian	6.36	8.53	Haugen 1990

[a]Cited in Hauser and DeStefano (1996).

1995). An earlier study by Van den Broek (1943), who had formerly supported the hypotheses of functional stress acting to produce the tori, investigated tori histology and found that the structure of the tori did not represent an obvious bony response to mechanical stress.

The symmetry of mandibular torus formation has also been called on to account for trait etiology. Ossenberg (1981) ascribes overall tori frequency to environmental factors, but maintains that the degree of expression and any resulting asymmetricality is a function of genetics. Korey (1980) suggests that genetic factors would be more likely to act equally on both sides of the mandible. McGrath *et al*. further emphasize the importance of assessing asymmetry in measuring non-metric traits, suggesting that asymmetrical development, insofar as it is correlated to environmental causes, may be a clue to an individual's ability to buffer stress (McGrath *et al*., 1984, p 401).

Another suggested explanation of the development of the tori is local inflammation of the periosteum, leading to torus formation (Schreiner, 1935). This was followed by Van den Broek after his (1943) investigation of torus histology failed to support the hypothesis that the tori are laid down to strengthen the structural integrity of the jaw. Little evidence has thus far been provided to further this hypothesis.

HYPOTHESES TESTED

Having examined previous approaches to understanding the etiology of torus mandibularis, several questions remain. Of primary interest here is the suitability of this non-metric trait for use in biodistance analyses; that is, whether there is sufficient genetic control of the tori to warrant its use as a marker of family or population group membership. The prevailing opinion in the most recent summaries of the issue is that mandibular tori are a quasi-continuous or threshold trait (Haugen, 1990; Seah, 1995), having both a genetic and environmental component. If this is accurate, then questions arise concerning what degree of influence

TABLE 2. Characteristics of the samples used in the study.

Sample	n	Males	Females	Unknown	Location	Period
Chumash	47	19	23	6	California Coast, Channel Islands	Prehistoric
Abingdon	103	39	43	21	Oxfordshire, UK	Medieval
Cannington	101	47	37	3	Somerset, UK	Dark Ages and Late Roman (7-8th c. AD)
Spitalfields	100	48	31	12	London, UK	17th-19th century
Poundbury	71	29	32	9	Dorchester, Dorset, UK	Roman 4th c. AD
Hawara	50	28	17	5	Hawara, Fayum, Egypt	Roman 2nd-3rd c. AD
Egypt	23	10	9	4	Abydos, Egypt	Pre- to Dynastic Period
Lachish	13	4	8	1	Lachish, Israel	Mixed Bronze, Iron Age

each factor has on trait prevalence. To address these questions and the impact of the major factors on torus development posited by previous research, the following hypotheses have been formulated.

Firstly, if there is a genetic component to trait prevalence, different ethnic or population groups should show different frequencies of trait development. This does not, of course, rule out any environmental influence, but merely establishes the possibility that genetics could play a role. To firmly establish the genetic etiology of the tori would require a carefully controlled study covering generations, which was not feasible here.

Secondly, significant variation between the sexes would show that there is a level of sexual dimorphism to tori development. If the rates of sexual dimorphism differ significantly from sample to sample, this would indicate that the major force acting on dimorphism for these traits is environmental, rather than genetic, as the mode of genetic transmission of the trait is assumed to not vary between populations, while culturally differentiated sexual labor roles may differ.

Thirdly, variation between age groups in tori prevalence would reflect a difference in frequency caused by either progressive development of the exostoses or by a dynamic process related to functional stress. If the occlusal attrition and robusticity of the mandible are strongly correlated with age and tori prevalence, then the latter hypotheses may be supported. If there is little correlation between indicators of masticatory stress, age, and prevalence, then progressive development would be supported by significant variation between age classes.

Finally, the indications of masticatory hyperfunction—particularly tooth wear—would be greater in individuals with mandibular tori if masticatory hyperfunction is a large factor in determining tori prevalence.

MATERIALS AND METHODS

The materials used in this study come from the large collection of human skeletal material held by the Department of Anthropology of the Natural History Museum of London. The collection comprises material from over 20,000 individuals, gathered throughout the 19th, 20th, and 21st centuries from archeological excavations, anthropological fieldwork, and donated private collections (R. Kruzynski, pers. comm.). The larger coherent samples included here were largely archeological samples, groups that were spatially and chronologically limited to the time and location of excavated burials. The ideal sample size, based on both statistical and temporal concerns, was established as 100 individuals for each population. However, this was not possible in all cases. Some samples were comprised of fewer than 100 individuals, such as the Egypt group, which remains in the final analysis despite the smaller size in an effort to broaden the regional scope of the study. The Lachish sample was dramatically limited by the disassociation of mandibles from crania and was not considered sufficient to be included as anything other than an ancillary note in the population-based analysis, though it is included in the overall analyses. A summary of the samples included here is given Table 2.

On the individual level, inclusion was dictated by several criteria. As mentioned above, and particularly in the case of the Lachish sample, all groups were of course limited by the number of individuals with associated mandibles. Additionally, inclusion occasionally depended on the level of preservation encountered, as the most fragmented remains could not be scored for all points of interest. In order to avoid biasing the samples in favor of more robust crania less likely to suffer a high degree of fragmentation, however, every effort was made to include both fragmented and non-fragmented remains where scores could be taken. Exclusion of individuals only occurred where it was not possible to take the scores of presence or absence of the tori.

For the collected data, a total of 41 measurements or scores were taken and used to create the final scores that are used in analysis. The aim behind the selection of these measurements was to provide standardized and, thus, easily comparable, data on age, sex, trait expression and frequency, mandibular thickness, temporomandibular joint remodeling, and tooth macrowear. Where published figures on the samples investigated here were available, they were compared with the assessments of this study. Age and sex assignments were established solely on cranial material due to the time constraints on the present study. Assignments were analyzed against previous published results drawn from both cranial and postcranial material, and in the exceptional case of the Spitalfields material, drawn from individuals of known age and sex. Insufficient discrepancy was found to warrant any adjustment of my own assessments, and because a standardized method was applied to all samples under discussion, the study is certainly internally coherent.

Age and sex were established after the Chicago Standards (Buikstra and Ubelaker, 1990). Not used here as a criteria for age estimation was the degree of dental attrition. Attrition, or the wear on the occlusal (chewing) surface of teeth, progresses with age, though at variable rates and is commonly used to assess biological age among archeological samples (Brothwell, 1986; Hillson, 1996). Samples may differ widely in their rates of attrition, as the amount of abrasive material in the diet and functional stress acting to wear the teeth differ among groups and even between the sexes (Walker *et al*., 1997, p 174). Lacking a comparable population with known age, sex, diet, and functional stresses, age estimates based on tooth attrition may be seriously distorted by a number of variables depending on the population in question. As attrition is also used here to examine the

Fig. 1. Example of slight expression of torus mandibularis in a skull (SK34) from Cannington Cemetery (courtesy Natural History Museum, London).

Fig. 2. Example of moderate expression of torus mandibularis in a skull (SK112) from Cannington Cemetery (courtesy Natural History Museum, London).

functional stresses placed on the masticatory complex, the age estimates garnered from scoring tooth wear were excluded. Sutural closing of the cranium was used instead, though this method is rightfully criticized for its unreliability (Masset, 1976). Therefore, the age categories used here are very broad—young adult (17-34 years of age), adult (35-54 yr), and older adult (55+). This study counts trait presence in three categories, namely absent, unilateral, and bilateral. Metric equivalents of these categories (measured as maximum tori breadth on the transverse plane) are delineated in 2 mm increments with less than 2 mm being "slight," 2-4 mm "moderate,"and greater than 4 mm "pronounced." Examples of the slight and moderate categories are provided in Figures 1 and 2. An example of the trait as it appears in a living individual can be found in Figure 3.

Attrition was scored at the left first and second molars, both upper and lower, and the "edentulous" category represents individuals who had premortem loss of the teeth. Remodeling activity at the temporomandibular joint (TMJ) was assessed on morphological changes to the joint surface both on the mandibular and the temporal bones (*e.g.*, excessive porosity, osteophyte activity).

Robusticity was of the mandible was assessed as the variable BODTH after Humphrey *et al*. (1999). The measurement is of mandibular body thickness, taken from the left side of the mandible by spreading calipers placed parallel to the occlusal plane at M1 in the center of the mandibular body. This measurement was seen to correlate strongly with overall metric measures of size in the mandible (Humphrey *et al*., 1999).

The presence of maxillary tori—a similar non-metric trait that is nearly identical to torus mandibularis in manner of expression and the degree of understanding regarding its etiology—was also recorded according to the same methodology as mandibular tori. As a second example of exostoses of the dental arch, this trait was considered likely to have similar factors affecting its

TABLE 3. Counts of unilateral and bilateral forms of torus mandibularis by sample[1]

Sample	Absent	Unilateral	Bilateral	Total
Chumash	47		1	48
Lachish	13			13
Hawara	43	1	6	50
Cannington	65	2	24	91
Abingdon	98	2	3	103
Spitalfields	96	2	2	100
Poundbury	56	5	9	70
Egypt	20	1	2	23
Total	438	13	47	498

[1]Chi-square = 56.639; df = 14; P value < 0.000; chi square for unilateral and bilateral categories grouped as "present" = 41.348; df = 7; P value < 0.000.

Fig. 3. Example of torus mandibularis in a living individual (courtesy S. Gill, Laguna Hills, CA).

development.

There were two primary areas in which the functional stresses placed on the masticatory complex were assessed in this study. The best skeletal evidence of stresses associated with excessive chewing and/or grinding motions necessitated by either a tough diet or a pathological condition (*i.e*., bruxism) in an individual is found in morphological changes in the masticatory apparatus (Eggen and Natvig, 1986). Representing these changes in the skeleton are, firstly, the degree of occlusal wear of the molar dentition of the upper and lower jaws, and, secondly, osteological activity in the TMJ.

ANALYSIS

All of the data collected for this study were entered into a computerized database to facilitate statistical and comparative analysis. This database was created in SPSS Version 11.0, a statistical processing application authored by Norusis (1994), which was used to produce the final analyses. The variables of interest were cross-tabulated in SPSS to provide the tables for this article. Chi-square tests were conducted for each cross-tabulation by SPSS, as well as correlation statistics. Generally, an alpha level of 0.05 was used to distinguish significant results, though trends that were discernable by direct observation of visual representations of data but fell slightly outside of the significant range are noted on occasion. Due to the small sample size provided by some of the groups, it is possible that some trends would be found to be significant if larger samples were available.

RESULTS

The tables included here give the results of the statistical cross-tabulation of the factors discussed above in tori frequency. All P-values given in the text are the result of Pearson's chi-square test unless otherwise noted. As with all archeologically derived data sets, it is important to remember that the standard statistical procedures used to test significance and correlations of variables assume a random sample of a normally distributed population, which is very rarely the case with archeological material. Therefore, where trends were observed in the distribution of the data but not deemed to be significant at the $P < 0.05$ level, they are

TABLE 4. Occurrences of torus mandibularis by age group and by sample.

	Age Group											
	Less than 35[2]				35-54 Years[3]				55 and Over[4]			
Sample	A	U	B	T	A	U	B	T	A	U	B	T
Chumash	11		1	12	13			13	23			23
Lachish	6			6	4			4	3			3
Hawara	18		1	19	15		3	18	10	1	2	13
Cannington	34		11	45	12	1	6	19	19	1	7	27
Abingdon	43			43	34	2	2	38	21		1	22
Spitalfields	17	1	1	19	41		1	42	29	1	30	30
Poundbury	7		1	8	24	1	3	28	25	4	5	34
Egypt	8		1	9	9			9	3	1	1	5
Total	144	1	16	161	152	4	15	171	133	8	16	157

[1]Trait expression codes: Absent (A), Unilateral (U), Bilateral (B), and Total (T).

[2]Pearson chi square = 24.455; df 14; P value = 0.040; combining categories of presence $X^2 = 15.634$; df = 7; P value = 0.029.

[3]Chi-square = 23.945; df 14; P value = 0.047; combining categories of presence $X^2 = 16.788$; df = 7; P value = 0.019.

[4]Chi-square = 25.636; df 14; P value = 0.029; combining categories of presence $X^2 = 19.805$; df = 7; P value = 0.006.

TABLE 5. Occurrences of torus mandibularis by sex and sample

	Unknown[2]				Females[3]				Males[4]			
Sample	A	U	B	T	A	U	B	T	A	U	B	T
Chumash	6			6	22		1	23	19			19
Lachish	1			1	8			8	4			4
Hawara	5			5	14		3	17	24	1	3	28
Cannington	3		3	6	27	2	8	37	35		12	47
Abingdon	20	1		21	38	1		39	40		3	43
Spitalfields	12			12	29	1	1	31	46	1	1	48
Poundbury	7		2	9	26	3	3	32	23	2	4	29
Egypt	4			4	6	1	2	9	10			10
Total	58	1	5	64	170	8	18	196	201	4	23	228

[1]Trait expression codes: Absent (A), Unilateral (U), Bilateral (B), and Total (T).
[2]Chi-square = 23.514; df = 14; P value = 0.052; combining categories of presence X^2 = 16.826; df = 7; P value = 0.019.
[3]Chi-square = 23.435; df = 14; P value = 0.054; combining categories of presence X^2 = 18.307; df = 7; P value = 0.011.
[4]Chi-square = 27.631; df = 14; P value = 0.016; combining categories of presence X^2 = 18.888; df = 7; P value = 0.009.

still described, but all results should be viewed with this caveat in mind.

Populations

Highly significant variability in frequency of occurrence of torus mandibularis was found among the samples in this study (P < 0.000). Table 3 provides the frequencies by sample of mandibular tori, along with the results of chi-square tests for significance. Variation in frequency of torus mandibularis among age groups defined by degree of sutural closing, as shown in Table 4, was also found to be significant among samples. The variability in prevalences between the sexes in different samples is greater for males (P < 0.09) than females (P < 0.11) or those of unknown sex (P < 0.19), as shown in Table 5.

Also found to be highly significant was the variability of mandibular torus expression (torus size) among groups (P < 0.000), as seen in Table 6.

Sex

The degree of expression of the torus (whether slight, moderate, or pronounced) did not vary significantly between sexes. As mentioned above, however, variability between the sexes is evident among samples, particularly in males.

Age

Variation among age groups for mandibular tori, as defined by sutural closing, was not significant unless, as with sex, "group" is added as a variable. However,

TABLE 6. Occurrence of torus mandibularis expression by sample[1]

	Torus Mandibularis Expression				
Sample	Absent	Slight	Moderate	Pronounced	Total
Chumash	47	1			48
Lachish	13				13
Hawara	42	7			49
Cannington	65	17	8	1	91
Abingdon	98	5			103
Spitalfields	96	3	1		100
Poundbury	55	10	4		69
Egypt	20	3			23
Total	436	46	13	1	496

[1]Chi-square = 55.688; df 21; P value = 0.000; combining trait expressions, X^2 = 54,280; df = 14; P value = 0.000.

TABLE 7. Occurrence of torus manibularis by grade of occlusal attrition on LM1[1]

Torus mandibularis	Grade of LM1 Attrition[1] 1	2	3	4	5	6	7	8	9	Total
Absent	1	14	51	67	43	31	17	29	149	402
Unilateral		1	2		2	1		2	3	11
Bilateral		1	2	16	4	5	9	4	4	45
Total	1	16	55	83	49	37	26	35	156	458

[1]Chi-square = 55.688; df = 21; P value < 0.000; combining grades of presence X^2 = 27.430; df = 8; P value = 0.001.

if age were to be defined by dental attrition classes as opposed to sutural closing, very significant variation in torus mandibularis is observed. The results of such a comparison are given under the Functional Stress: Attrition heading below. Torus mandibularis expression was not seen to vary between age classes.

Functional stress: attrition

Torus mandibularis showed significant variation in frequency between classes of occlusal tooth wear in the lower first molar (P < 0.001), as shown in Table 7. Significant (P < 0.01) differences between degree of expression of the mandibular tori in the different attrition classes was observed and may be seen in Table 8.

Functional stress: mandibular robusticity

No significant variation was found between size categories of mandible and occurrence of torus mandibularis as measured by maximum mandibular breadth and defined in millimetre increments. Nor was any significance seen in the variation in degree of torus expression between size categories.

Functional stress: activity at TMJ

There was no significant difference in levels of osteophyte activity or porosity at the temporomandibular joint and degree of torus mandibularis expression or the incidence of mandibular tori.

Trait interaction

No significance was attached to the co-occurrence of mandibular and maxillary tori or to the degree of expression of either tori with co-occurrence or the degree of expression of the co-occurring tori.

DISCUSSION

"Group" appears to be a significant variable in prevalence of torus mandibularis and torus maxillaris. The results of this study are not surprising in confirming what is already an observed trend in the literature on the subject; that tori incidence rates vary widely according to group. The trait is seen here to occur in different frequencies and to different degrees in geographically and chronologically separated groups. No previous investigations of tori incidence have contested this variability, yet there remains a multitude of hypotheses as to why this variation occurs. It is useful to look to the reasons why multiple studies have reached such divergent conclusions in the light of the results of the present study.

Perhaps the largest factor in the disparity of conclusions arises from the different variables assessed among investigations. The variables tested in other works may have been chosen based on assumptions on the investigators part as to what factors could be involved in tori development. Thus, in those studies that began with an assumption of genetic inheritance acting as the sole factor (Suzuki and Sakai, 1960; Gould, 1964),

TABLE 8. Grade of torus manibularis tabulated against grade of occlusal attrition on LM1[1]

Torus mandibularis	Grade of LM1 Attrition[1] 1	2	3	4	5	6	7	8	9	Total
Absent	1	14	51	67	42	31	17	29	148	400
Slight		2	2	11	5	5	7	4	6	42
Moderate			2	5	1	1	2	1	1	13
Pronounced								1		1
Total	1	16	55	83	48	37	26	35	155	456

[1]Chi-square = 42.059; df = 24; P value = 0.013.

TABLE 9. Grade of torus mandibularis partitioned by whether the cases was dentate or edenulous[1]

Torus mandibularis	Dentate	Edentulous	Total
Absent	366	69	435
Unilateral	13		13
Bilateral	45	2	47
Total	424	71	495

[1]Chi-square = 6.887; df = 2; P value = 0.032.

it is unsurprising that family relationships were the only variables considered. Unfortunately, family relationships are very difficult to ascertain in archeological samples, and these could not be considered here. However, the disparity of modes of inheritance posited by familial studies and the concurrence of environmental factors with the frequency of tori suggest that a simple Mendelian-mode of inheritance is not adequate to explain the variation in tori incidence among samples. Other factors seem to play a role in determining the prevalence of these traits.

As significant differences were found between the sexes in only some of the samples, the conclusions of previous researchers of an actual difference in prevalence rates between males and females, regardless of group, appear unsupported. However, as sexual dimorphism is known to differ in degree among groups (Brothwell, 1981), it is possible that the variation observed here is a product of this difference, acting to influence robusticity of the masticatory complex. Additionally, culturally defined sexual roles may include different functional stresses for men and women, further skewing any evidence of an actual tendency in tori prevalence should functional stress be a factor in development of the trait. It is worth noting here that Haugen (1990) observed greater frequency of mandibular tori in Eskimo men, though the ethnographic accounts of Pederson (1944) make it clear that Eskimo women had greater functional stresses placed on their jaws.

As with variability between sexes, the variability among age groups in development of the tori of the jaws is less obvious from the results of this study than that among groups. "Age" as a variable becomes especially problematic when it is assessed on skeletal material for a number of reasons. Because archeological samples do not generally provide individuals of known ages, the categorization of individuals into age groups must be done on the basis of morphological changes in the skeleton that are normally associated with ageing. These techniques are only accurate to the degree that other factors influencing the morphology of the skeleton can be controlled for. Walker (1978) points out that attrition rates depend not only on the age of an individual but also on the abrasiveness of the diet. The possibility that tori develop in response to the changing functional pressures on the jaw and teeth, along with this caveat, is why dental wear is not used here as an indication of age. This leaves the closing of cranial and palatine sutures as a basis for ageing the material studied here. An additional issue in using age as a variable arises, however, with the realization that the morphological changes to the cranium associated with age may be part of other skeletal processes affecting an individual's pattern of sutural closing (*e.g.*, trauma, *etc.*). An overall tendency towards early or late ossification due to genetic or nutritional factors, or several other conditions (*e.g.*, general tendency to robusticity, *etc.*) that affect the skeleton may act to conflate or deflate evidence of a relationship between chronological age and the development of tori. In the first case, all care was taken to remove individuals with obvious disruptions to the normal pattern of sutural closing. The possibilities associated with the second case are discussed further below, while the remaining multitude of possible factors acting to influence skeletal morphology must remain as a caveat in assessing the import of age in development of torus mandibularis and torus maxillaris.

The results of this investigation do show a significant variation between the age groups in development of mandibular and maxillary tori when "group" is added as a variable. This possibly reflects population-level differences in the morphological characteristics on which age was assigned, but other investigations have suggested that age is indeed a factor in tori development. Mandibular torus is very rare in juveniles, excepting those samples that normally have a high frequency of the trait (Haugen, 1990). Development of tori is generally agreed to begin within the first 30 years of life, though may occasionally occur later (Seah, 1995). The contention that tori development is not a slow, progressive process but rather a dynamic one (Seah, 1995, contra Haugen 1990) is perhaps supported by the evidence of this study, as degree of expression was not found to vary significantly among age classes. This has not been a universal finding; Halffman *et al*. (1992) and Eggen and Natvig (1986) found that tori were more frequent in the middle-aged, and Eggen (1989) also found no significant increase in frequency after *ca*. 30 years of age. Johnson (1959), however, mentions that tori resorption, or shrinkage, has been observed in both the very old and those whose teeth have been removed. The results of this study show that the most significant variation in age groups between populations occurs within the 55+ age group ($P < 0.03$). These results suggest that is not so much a causal factor in development of the tori, but rather a covariant which is affected by the same factors acting to effect torus development.

The first and foremost of the variables associated with age is the degree of occlusal wear of the dentition. Tooth wear is strongly correlated with age, and commonly used in archeological samples to categorize age. In this study, tooth wear was significantly correlated with the age assignments (r = 0.233, at a significance of $P < 0.000$). Generally, attrition increases with age (Walker, 1978; Brothwell, 1981; Waldron, 2001). But age is not the only factor acting to wear the dentition (Walker *et al*., 1991). Coarseness of diet or differing levels of functional stress on the teeth may hasten the normal process, with the result that individuals with different diets or stresses may show markedly different wear rates. Wear rates may be expected, then, to vary among groups (Walker, 1978). One of the most widely observed examples of this difference is found in the Eskimos of North America, Iceland, and Greenland, who have very high attrition rates as well as a high frequencies of chipping and pitting of the teeth that coincide with the high functional demands they place on them. In the samples observed here, there is a definite variability among rates of attrition, as evidenced by the molars.

The frequency of torus mandibularis is significantly correlated with the level of attrition recorded at the first molar ($P = 0.000$). The distribution of the tori over the wear classes clearly shows a gradual increase up to a peak in the number of occurrences around the fourth stage of wear, with the subsequent pattern of decline in frequency only occasionally interrupted. This is very suggestive when the reasons posited for development of the tori are considered. If the tori arise as a response to functional stress, evidenced by tooth wear, expectation is that the frequency of torus mandibularis would be low in individuals with low levels of wear. Frequency would be expected to increase as functional forces acting to wear the teeth increase. Should the tori develop as a skeletal response to mechanical forces, frequency would be expected to be highest in individuals with the most severe wear, with those exerting the most stress presumably exhibiting the most wear. However, frequency does not dramatically increase after the fourth stage of wear. A partial explanation for the lesser number of tori in the latter stages may be that, as tooth wear increases, the functionality of the teeth may be impaired, and the need for functional strengthening of the jaw may decrease if the jaw is no longer used due to tooth loss. The resorption of bone from the mandible in edentulous individuals due to this loss of function may partially explain the reduction of occurrence with the most severe wear. In examining torus mandibularis occurrences in dentulous and edentulous individuals, as defined by the premortem loss of the first and second molars, significant variability is found, which lends strength to this suggestion (Fig. 4).

This study did not find that osteophyte activity at the temporomandibular joint was significantly varied between those individuals with torus mandibularis. Nor was there a significant difference in levels of porosity. This does not necessarily rule out the possibility of an association between disorders of the joint and the development of torus mandibularis; temporomandibular disorder (TMD) is only generally identifiable in the most severe cases from skeletal remains (S. Hillson, pers. comm.). In clinical studies, torus mandibularis has been seen to correspond very significantly ($P < 0.0005$) to TMD as well as to one of the most common causal factors for TMD, namely parafunctional activity such as bruxism (Kerdpon and Sirirungrojying, 1999).

Radiographic measures of bone density at multiple locations in the body taken in a study of torus mandibularis suggest that higher bone mass density is significantly associated with development of the trait (Hjertstedt *et al*., 2001), but, again, this was something the present study was unable to assess.

General robusticity of the jaw has been thought to have some relation to development of torus mandibularis. Eggen and Natvig (1986) suggested that individuals with better developed jaws had higher frequencies of torus mandibularis. Ossenberg (1981) hypothesized that the development of tori after puberty is possibly related to the greater food intake necessitated by growth, which in turn necessitates greater muscular power in order to process the larger amount of food. While many of the samples observed in the literature –with high prevalence rates of tori are generally robust in terms of skeletal build, the quality of robusticity is so ill-defined as to make analysis of this variable nearly impossible. With robusticity here defined by the thickness of the mandibular body, no significant

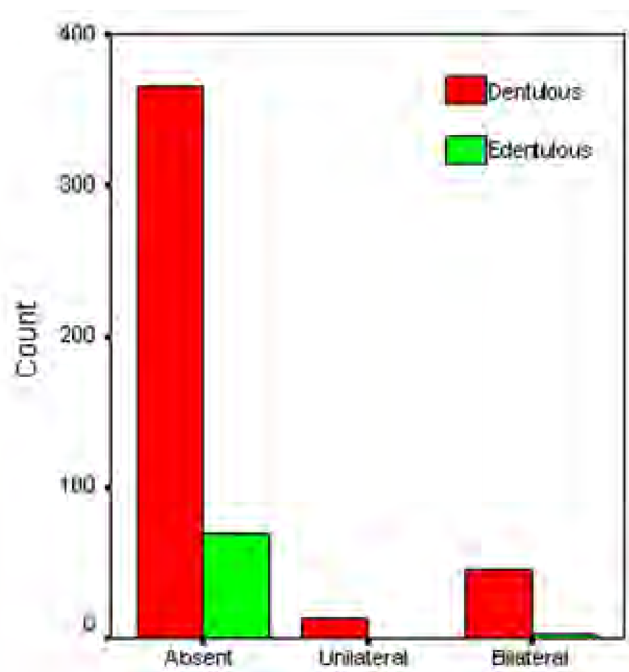

Fig. 4. Bar graph of the occurrence of torus mandibularis depending on whether the subject was dentate.

relationship between torus mandibularis and general robusticity was observed.

This brings the discussion to the hypothesis of trait interaction. The concurrence of the two exostoses included in this study was insufficient to suggest a strong correlation. Other researchers have debated the co-occurrence of torus palatinus, with some finding a correlation between the traits and some not. The investigations using the largest sample sizes have not seen a strong correlation, and the investigations into the effects of bone mineral density (Hjertstedt *et al*. 2001) and parafunctional activities (Eggen, 1954; Eggen and Natvig, 1986; Kerdpon and Sirirungrojying, 1999) have shown different prevalence rates for torus palatinus. In this study, the co-occurrence of torus mandibularis and torus maxillaris was not found to be significant in either degree or expression of frequency of incidence. This finding, taken in conjunction with results showing no correlation between possible causal factors in torus mandibularis development and torus maxillaris development, suggests that the two traits are not the result of a single causal factor, either environmental or genetic. The lack of co-occurrence in familial studies of the traits and in studies of environmental or functional stress lead to the conclusion that the tori arise due to separate stimuli. That is not to say absolutely that the same factors aren't responsible for development of both maxillary and mandibular tori, but the inconclusive efforts to relate the maxillary tori to those factors, which show a significant relation to mandibular tori, suggest that the developmental process of the former is not identical to the latter. Due perhaps to the rarity of torus maxillaris, less can be said about the possible correlations of environmental or functional stress. This finding follows logically in steps of the growing consensus that the other major tori of the jaw, torus palatinus and torus mandibularis, are affected by different factors (Kolas *et al*., 1983; Haugen, 1990; Seah, 1995).

In relation to the hypotheses surrounding torus etiology outlined previously, this study has found the following:

- Frequency of both mandibular and maxillary tori varies between populations to a significant degree, suggesting that genetic inheritance could play a role in torus etiology.
- Sexual dimorphism in tori frequency is found to be significant within some populations, but not significantly varied in others, possibly as a result of the different effects of culturally defined labour roles on the sexes. Additionally, this may explain the disparate results of previous work in establishing whether the traits are more prevalent in males, females, or neither.
- Age is not found to be a significant factor in torus development when measured on criteria other than dental attrition, suggesting a more dynamic, possibly environmentally induced, pattern of growth. While robusticity of the mandible was not strongly correlated with age or tori frequency, age was strongly correlated with attrition classes. The interaction of age with tooth wear is well established, which may explain why previous research has suggested age as a factor in torus development.
- Masticatory hyperfunction, evidenced by tooth wear, is seen to be correlated with mandibular torus prevalence. However, frequency of the trait is greatest at a lower level of wear and there is a pronounced difference in trait distribution between dentulous and edentulous individuals. This may suggest that mandibular tori are a successful response to functional stress, as opposed to the result of loss of masticatory function with increasing dental attrition

CONCLUSIONS

The results of this study conform to a pattern suggested by the most recent research into tori etiology. In the last 15 years, the general consensus has been that mandibular tori at least arise from a combination of genetic and environmental factors. A more consistent observation of any correlations, might have been observed, should they exist, if all investigations included the multiplicity of variables proposed as affecting the occurrence of mandibular torus. However, because research designs have often been constructed in a dichotomizing either/or fashion to show the significance of one particular variable in the development of tori at the expense of any other factors, there has been a tendency to include only those factors the investigator wishes to demonstrate as being either positively or negatively correlated with tori incidence. This is unfortunate, because the widely divergent results produced by such studies only serve to cloud the issue further. By incorporating as many variables as possible into an investigation of tori development, the polarised results of earlier studies become understandable as partial glimpses of a multifactorial etiology only discernable when a wide ranging investigation is carried out.

The results obtained here suggest that functional stress plays a large role in the development of mandibular tori. The correlation of age to torus development remains unclear, though it is vital to remember that tooth wear is strongly correlated with age. Had the age assessments used here relied on attrition categories to define age, as is common with archeological samples, the variation between age categories and attrition categories would be identical. A possible result of this correlation is the overemphasis of the importance of age in tori development, as the passage of time allows increasing amounts of wear and stress to act on the jaw. Significant variation in tori development between classes of tooth wear were found that support the idea of the torus arising as a response to functional stress acting on the mandible in the form of increased functional demand on the masticatory complex. However, histological studies have not borne out the expectation that the bony structure of the tori themselves would reflect the direction of this mechanical force. This leads to the conclusion that the exostoses of the mandible are not purely a skeletal response to pressure, an argument that also finds support in this study's finding a lack of significant correlation between overall mandibular robusticity and trait incidence. Further refuting the idea of a single variable, functional stress, as the sole causal factor in tori development, are the familial studies carried out in living populations of known biological relations. Variation among populations of different origins in torus frequency must be accounted for, and the most appropriate explanation may be found in the concept of the threshold trait as proposed by Wright (1963). If the inherited factor of torus mandibularis is a liability for development, an individual tendency towards formation of either this particular exostosis or exostoses in general, then etiology must be multi-factorial, with environmental factors acting to determine whether or not the threshold for development is surpassed. This model explains both the variability in frequency among groups and among dental attrition classes found in this study.

It is hoped that future research into the development of mandibular tori will address the issues raised by this study. Paramount of these issues is the establishment of a standardised method of recording the presence of the tori, which may only be accomplished by assigning metric categories to what have been somewhat arbitrary size distinctions. Additionally, the correlation between relatively good periodontal conditions and torus development should be investigated in a broader, cross-population context. A final direction of considerable interest is towards a better understanding of trait interaction, particularly between all exostoses of the face and skeleton, such as palatine and maxillary tori.

In conclusion, it seems necessary to reconsider the suitability of torus mandibularis for analysis of biological distance between populations. Unless environmental factors can be completely controlled for, population frequencies may differ or converge without relation to the degree of genetic relation between groups. This study has shown the significance of dental attrition in variance of torus mandibularis frequency, suggesting that environmental factors should be carefully weighed when assessing the genetic component of tori etiology. While the entire battery of non-metric traits is beyond the scope of this study, the findings related here suggest that careful consideration of trait etiology is a necessary step in choosing variables for biodistance analyses. Not all non-metric traits can be considered a priori products of genetic variation, as the investigation of the etiology of torus mandibularis shows.

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Dental Pathology, Wear, and Diet in a Hunting and Gathering Forest-Dwelling Group: The Batak People of Palawan Island, The Philippines

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ABSTRACT Described are observations on Batak foods, tooth use, oral hygiene, and resulting wear and oral pathology in dental casts of 29 Batak ranging from 15 to 49 years of age. Commonly consumed foods are roughly 80 percent plant, and 20 percent animal products. Cooking is common. Eating includes one or two main daily meals with occasional snacking. Cariogenic commercially-manufactured flour and sugar are rarely available. Oral hygiene involves "finger-brushing" of anterior teeth with fine sand. The practice is more common in females than in males. Caries are rare in both sexes as is antemortem tooth loss. Tooth chipping is more common in males. Periodontal disease is generally slight and nearly equal in the sexes. Tooth wear is relatively slight but strongly age-related as in many other populations. *Dental Anthropology* 2006;19(1):15-22.

Most of human prehistory saw our ancestors living in small groups as opportunistic hunters and gatherers. Studies of pre-agricultural teeth have repeatedly shown that diet and tooth use behaviors were abrasive, tough, and destructive, producing much tooth wear, periodontal disease, alveolar abscessing, and tooth chipping and fracturing. On the other hand, hunter-gatherers were largely free of both occlusal and interproximal caries and other disorders linked to cariogenic diets. Despite archaeologically-derived pre- and early agricultural human teeth having been described many times around the world, there are very few accounts in the dental anthropological literature that include ethnographic observations of actual diet and tooth-use behaviors coupled with descriptions of the related oral pathologies and wear. This is especially so for remnant living groups whose consumption of refined sugar and flour is limited. The best known of such ethno-dentally described populations with minimal modern contact and exchange are the Australian Aborigines studied by T. D. Campbell (1925, 1939) and the East Greenland Eskimo researched by P. O. Pedersen (1938) . Both workers were trained as dentists, which explains their interest in diet, tooth-use, and oral pathology. Ethnologists, on the other hand, almost always describe diet and food preparation techniques, but seldom comment on the resultant oral conditions. Bioarchaeologists with paleo-ethnographic and dental interests describe oral health but generally lack the means to do more than infer diet based on archaeologically-recovered foodstuffs and artifacts involved in food-preparation. Such artifacts include grinding stones, cooking vessels, butchered bones, and similar materials. Rarely, human coprolites are recovered in archaeological excavations. These metabolic residues are inherently rich in dietary information.

While the strength of bioarchaeological inference about diet and tooth-use behavior can be quite substantial, it is always desirable to have actual observations when dealing with uniformitarian cause and effect relationships, which in this case are diet, tooth use, and oral health. Hence, this brief report identifies some of the foods and tooth-use behaviors of the Batak observed by ethnologist and co-author JFE, and the resultant effects on the dentition identified by bioarchaeologist CGT. Information concerning the origin and affinity of the Batak based on the dental morphology of the sample described herein can be found in Turner and Eder (2005). We hope this note will stimulate further dental anthropological study in the few remaining hunter-gatherer groups around the world.

The Batak are one of approximately twenty ethnolinguistically-distinct groups of so-called "Negrito" peoples inhabiting various hinterland regions of the Philippines. Like other Filipinos, they today speak languages of the Austronesian language family,

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and they share many cultural beliefs and practices with neighboring farming peoples. But Philippine Negritos stand out by virtue of their mobile forest foraging life way and the bundle of physical attributes—short stature, dark skin, and curly hair—that earned these distinctive-looking peoples their name (Eder, 1987).

The Batak themselves inhabit a series of eight river valleys lying along the east coast of the north central part of Palawan Island, in the southwestern corner of the Philippine archipelago. Their subsistence economy today combines hunting and gathering, collection and sale of commercially valuable forest products, shifting cultivation, and wage labor for outsiders. Wild yams and wild honey once provided the bulk of the carbohydrates in the Batak diet. Today, rice, corn, sweet potato, cassava, and plantain are also important starch sources. Some brown sugar is used, but in small quantities and almost exclusively to sweeten coffee. Protein sources include wild pig, gliding squirrels, porcupines, wild chickens, and other forest animals, and fish, eels, mollusks and crustaceans obtained from rivers and streams. Bamboo shoots, rattan pith, and a variety of wild nuts, fruits, and greens are also consumed (Eder, 1987).

Most food is roasted in wood fires or cooked (typically by boiling) in cast iron cooking vessels. Typically there are two meals a day, one at noon and one in the evening, but sometimes there is only one. There is often considerable snacking in the course of the day, as foods are encountered on the trail or brought into camp. The contemporary diet is low in animal protein, low in vegetables, and probably even low in calories. Actual food consumption patterns can be narrow and monotonous for extended periods of time. Drinking water is obtained from springs and streams. Teeth are cleaned with toothpicks and finger-brushed with fine sand or (sometimes) with toothbrushes. Betel nut chewing is common, and all adult teeth are stained accordingly.

MATERIALS AND METHODS

Eder and helpers collected dental impressions of 29 Batak natives whose ages ranged from 15 to about 49 years. The sample size was limited by the amount of impression powder (Jeltrate®) and plaster that could be conveniently carried into the field along with other more critical supplies. Positive plaster casts were poured immediately after the impressions were made.

	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4
14																				
16	F	F	F																	
18	M	F																		
20		F	F																	
22		F	F	F																
24				F																
26			M		M															
28			M	F	M	M														
30				F				F		M										
32																				
34																				
36										M										
38																				
40																				
42																				
44																				
46							M		M	F					M					
48																				
50																				F

Fig. 1. Distribution between the average wear (horizontal axis) and the person's age (vertical axis) for maxillary teeth. Average wear was based on the 5-grade ordinal scheme: 0 = no wear, 1 = dentine exposed, 2 = cusps worn off, 3 = pulp exposed, 4 = root stump functional (Turner, Nichol and Scott, 1991). The correlation coefficient between age and mean wear for Batak male maxillary teeth is $r = 0.749$; for Batak females, $r = 0.894$. Sex of the specimen is coded as male (M) or females (F).

	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4
14																				
16	F	F	F																	
18			F																	
20		M		F																
22			F	F																
24			F	F	F															
26			M		F															
28			M	F	M															
30			M			M														
32				F		F	M													
34																				
36							M													
38																				
40																				
42																				
44																				
46											F						M			
48											M		M							
50							F													

Fig. 2. Distribution between the average wear (horizontal axis) and the person's age (vertical axis) for mandibular teeth. Average wear was based on the 5-grade ordinal scheme: 0 = no wear, 1 = dentine exposed, 2 = cusps worn off, 3 = pulp exposed, 4 = root stump functional (Turner, Nichol and Scott, 1991). The correlation between age and mean wear for Batak male maxillary teeth was r = 0.749; for Batak females, r = 0.894. Sex of the specimen is coded as male (M) or female (F).

Descriptions of the dental conditions are based on standards used in the Arizona State University Dental Anthropology System (ASU DAS) (Turner, Nichol and Scott, 1991).

RESULTS

Wear

Tooth wear was scored for all observable occlusal surfaces. The mean scores for each of the studied Batak males and females is given in Tables 1 and 2. As is evident, tooth wear is strongly related to age, *i.e*. mean wear, which was calculated by summing the wear scores for each tooth in an individual and dividing by the number of teeth that the individual possessed. For example, male number 3 in Table 1, age 19, had a total maxillary wear score of 9.0, which divided by his 16 teeth gives a mean wear score of 0.56. In contrast, the 47 year old male number 7 has a mean maxillary wear score of 1.10. This is almost exactly twice that of Batak number 3.

The relationship between age and mean wear is plotted in Figures 1 and 2. The age-mean wear relationship is quite evident, that is, strongly positive. The correlation coefficients for upper male age-mean dental wear is r = 0.749; for female upper teeth r = 0.894. For the lower jaws, male r = 0.860; female r = 0.866. These values suggest that the tooth wear scores provided here could serve as a useful guide for estimating age in prehistoric hunter-gatherers who lived in habitats similar to that of the Batak.

A relationship between tooth wear and caries in these hunter-gatherers can also be seen. In Tables 1 and 2, some of the males and females with one or more carious teeth have mean wear scores somewhat less than non-carious individuals of comparable age. One interpretation of this relationship is that individuals with caries do not chew as much or as heavily as do caries-free individuals. Obviously, the relationship between caries and tooth wear would have some effect on how much one can rely on wear to aid in estimating age of prehistoric human remains. Although interproximal caries could not be looked for in our dental casts, we assume that there were some, and that they also contributed to lowered use of the jaws due to pain and discomfort.

TABLE 1. Batak maxillary dental wear

Individual Number	Age	Total Wear	Number of Teeth	Mean Wear	Caries
		Male Maxilla			
3	19	9.0	16	0.56	
27	26	12.0	16	0.75	
1	28	13.0	16	0.81	
21	28	14.0	16	0.87	
20	29	12.0	16	0.75	RM1
23	29	17.0	16	1.06	
11	31	22.0	16	1.37	
10	36	21.5	15	1.43	
5	45	26.5	13	2.04	
22	>45	31.5	14	2.25	
7	47	16.5	15	1.10	LP1
13[a]	Adult	15.5	12	1.29	
		Female Maxilla			
2	15	8.0	16	0.50	
9	15	10.5	14	0.75	RM1
26	15	8.0	14	0.57	
28	18	7.0	14	0.50	
8	20	10.0	16	0.62	RM1
4	21	11.0	16	0.69	
25	22	9.0	16	0.56	
24	22	11.5	15	0.77	
14	23	13.0	14	0.93	
17	23	12.0	16	0.75	LM3
18	24	12.5	16	0.78	
12	26	15.0	16	0.94	
16	~ 28	13.0	16	0.81	
29	30	19.5	16	1.22	
19	30	12.5	16	0.78	
6	46	23.0	16	1.44	
15	~ 49	36.0	15	2.40	LRM1

[a]Man had congenital absence of four upper teeth (LRI2, RC, LM3) and three lower teeth (RI1, LRM3). See Figs. 7 and 8.

Table 3 provides the frequencies of crown caries, antemortem tooth loss, crown chipping, periodontal disease, and oral hygiene. Inasmuch as these observations were made from plaster casts, the values probably err slightly on the side of under-reporting; for example, caries and toothpick grooves could not be looked for on interproximal crown surfaces including those of the roots. The extent of general bone loss from periodontal disease, which is easily studied in skeletal remains, is largely hidden by gum tissue in the living.

Caries

The number of Batak with one or more crown caries (31.0%) is unexceptional for a hunting and gathering population, although it is at the upper end of the range. Among the Middle to Late Period (*ca*. 1,000 B.C.) Jomonese of central Japan (a hunting, fishing, gathering, and possibly small scale horticultural population), the percentage of individuals with one or more caries was 42.7% (Turner, 1979). The frequency of Batak carious teeth (2.1%), mostly molars, is well in line with prehistoric hunting and gathering economies around the world. Within the Batak sample, there is no statistically significant difference between males and females for caries.

Antemortem loss

The low amount of antemortem tooth loss is consistent with the low frequency of caries—caries being viewed as the major cause of antemortem loss,

Fig. 3. Labial surface smoothing of upper left and right central and lateral incisors. The cast (number 3) was from a young Batak adult male, age 19 years (CGT neg. 3-22-02:27).

Fig. 4. Labial surface smoothing of cast number 7 upper central incisors, an adult Batak male, age about 47 years. Periodontal disease was judged to be "medium" (CGT neg. 3-22-02:24).

especially for molars, which is the situation in this sample. Two lost incisors occurred in males. Trauma likely was the cause of the loss. Combining antemortem loss and carious teeth, only 3.0% of all teeth have one or both of these conditions. This is far less than what occurs in agricultural populations with their highly processed, sticky, and cariogenic cereal-based foodstuffs.

Chipping

Occlusal surfaces of an individual's teeth may exhibit one or more nicked or chipped edges. Chipped areas are usually less than 0.5 mm in diameter (Figs. 5 and 8). Chipping is attributable to various activities ranging from the heavy use of teeth as vice-like tools, breaking up of hard materials like starvation-driven scavenging of bone, gritty mineral food contaminants, to accidental trauma arising from falls, and other sources. Both individual and tooth counts show that the Batak males have significantly more chipping than do the females. Almost all males have one or more chipped teeth (91.7%) in contrast to females (35.3%) who have only about one third of their number exhibiting chipping. Pooled, the number of chipped teeth occur more often in the back of mouth (chipped incisors, 9; canines, 3; premolars, 21, molars, 26), suggesting dietary and tooth use activities as the major contributor to Batak chipping rather than trauma. Eder notes that chipping was not likely caused by fighting since males never fight among themselves. There is nothing in these values to suggest excessive inter-sex conflict where one would expect either comparable overall female tooth chipping (females being abused and hit; male chipping due to heavy tooth use), or excessive anterior tooth chipping (falls by children, adolescent hitting, being shoved, *etc.*). Eder feels that the observed pattern

Fig. 5. Arrows point to occlusal chipping of cast number 21, an adult Batak male, age 28 years (CGT neg. 3-22-02:20).

Fig. 6. Periodontal disease of cast number 14, an adult Batak female, age 23 years. Disease grade judged to be "slight" (CGT neg. 3-22-02:22).

TABLE 2. Batak mandibular dental wear

Individual Number	Age	Total Wear	Number of Teeth	Mean Wear	Caries
			Male Maxilla		
3	19	9.0	16	0.56	
27	26	11.0	16	0.69	
1	28	12.0	16	0.75	
21	28	14.0	16	0.87	
20	29	10.5	16	0.66	
23	29	17.0	16	1.06	
11	31	18.0	16	1.12	
10	36	17.5	16	1.09	LRM2, M3
5	45	25.0	12	2.08	
22	> 45	27.0	16	1.69	RM2
7	47	19.5	16	1.22	
13	Adult	20.0	13	1.54	
			Female Maxilla		
2	15	8.0	16	0.50	
9	15	8.0	14	0.57	LM1
26	15	9.5	14	0.68	
28	18	10.0	14	0.71	
8	20	12.5	16	0.78	
4	21	12.0	16	0.75	
25	22	11.5	15	0.77	
24	22	12.5	16	0.78	
14	23	11.0	14	0.79	
17	23	14.5	16	0.91	
18	24	12.5	16	0.78	
12	26	15.0	16	0.94	
16	~ 28	13.5	15	0.90	RM1,2; LRM3
29	30	15.5	16	0.97	
19	30	12.0	16	0.75	
6	46	24.0	16	1.50	
15	~ 49	14.0	13	1.08	LM2

almost certainly relates to a disproportionate tendency for men more than women to put non-food items in their mouths in the course of producing artifacts, or ad hoc tools. Despite the sexes basically eating the same foods, he has seen Batak men more often than women biting on lengths of rattan, and using their teeth to crack open nuts, break bones to obtain the marrow, and even chewing on turtle carapaces. After such sorts of tooth use to access nutrients, the man would share with his wife or others.

Periodontal disease

While nearly all of the 29 Batak exhibit some degree of gingival border recession, detachment, and swelling, indicating bacterial infection and inflammation, we characterize the amount as having been mostly slight in both sexes (Fig. 6). There is, as expected, a small degree of age-related expression of periodontal disease, but the relationship is weak. Periodontal disease among the Batak sample seems more idiosyncratic than systematic. Thus, the Batak oral activities, while culturally and environmentally channeled, have also a degree of individual determination. This can include regularity of oral hygiene practiced, immune strength, amount of fibrous and other foods consumed that have the inherent capability to remove plaque, and other such variables, including choices of foods that might possess antibacterial or anti-inflammatory qualities.

Oral hygiene

The type of oral hygiene that can be detected from our Batak dental casts includes an interesting flattening of the labial surface of one or more upper incisors and canines (Figs. 3 and 4). As Eder observed,

TABLE 3. Batak oral health

Condition	Male n	Male Percent	Female n	Female Percent	M & F X^2 P-value	n	Total Percent
Individuals, 1 or more caries	4	33.3	5	29.4	n.s. (> 0.80)	9	31.0
Individuals, no caries	8	66.7	12	70.6		20	69.0
Carious incisors, n = 227	0	0	0				
Carious canines, n = 115	0	0	0				
Carious premolars n = 232	1	0	1				
Carious molars n = 315	6	11	17				
Carious teeth n = 889	7	11			n.s. (> 0.80)	18	2.1
Antemortem loss, incisors	2	0	2				
Antemortem loss, canines	0	0	0				
Antemortem loss, premolars	0	0	0				
Antemortem loss, molars	3	4	7				
Caries & antemortem loss, n = 898	12	3.3	15	2.9		27	3.0
Individuals, chipping, n = 29	11	91.7	6	35.3	sig. (< 0.01)	17	58.6
Teeth, chipping, n = 887 (male = 366; female =521)	37	10.1	14	2.7	sig. (< 0.01)	51	5.7
Periodontal disease, individuals							
Absent	0	0.0	4	25.0		4	13.8
Slight	8	66.7	10	62.5		18	62.1
Medium	3	25.0	1	6.2		4	13.8
Severe	1	8.3	1	8.3		2	6.9
Total	28	96.5					
Upper labial flattening, inds.	6	54.5	15	88.2	sig. (< 0.01)	21	75.0
Lower labial flattening, inds.	0	0.0	0	0.0		0	0.0
Central incisors, flattened	10	50.0	34	88.2	sig. (< 0.01)	54	81.5
Lateral incisors, flattened	6	30.0	20	58.8	sig. (< 0.05)	54	48.1
Canines, flattened	3	14.3	14	41.2	sig. (< 0.05)	55	30.9

this labial flattening results from the abrasive action of finger-brushing using fine sand or silt in water. There are significantly more females (88.2%) with labial-abrasion than males (54.5%). This holds also for the actual number of abraded teeth (Table 3). The absence of abraded lower anterior teeth is interesting from a cosmetic standpoint, as it is primarily the upper anterior teeth that are apparent during smiling or other teeth-displaying behavior.

Congenital absence

Figures 7 and 8 show upper and lower dental casts of a Batak male who likely had seven congenitally missing teeth. While congenital absence is not normally considered as an oral pathology, we nevertheless include the illustrations to indicate some manner of developmental disturbance that might have had a link to fixed or unfixed external environmental factors, even possibly involving the degree of group inbreeding or population genetic bottle-necking sometime in the past. In any event, congenital absence is a category of dental variation that often gets left out of both morphological and pathological characterizations of human populations.

DISCUSSION

As hunting and gathering disappears as an economic way of human life, the opportunity to observe the ethnography of dentally related activities and diet, and to match these observations with the resultant effects on teeth, is drawing to a close. In fact, very few ethnographic observations on tooth use and

Fig. 7. Absence of four maxillary teeth of cast number 13, a Batak male, age about 34 years. Presumably congenitally missing are the right lateral incisor and canine, the left lateral incisor, and the left third molar. The right third molar is peg-shaped with a lingual-buccal diameter of 6.5 mm. There is a cone-shaped supernumerary tooth between the central incisors (CGT neg. 3-22-02:15).

Fig. 8. Absence of three mandibular teeth of cast number 13 (Fig. 7). Missing are the right central incisor, and both third molars. Cusp 2 of the right second molar is chipped (CGT neg. 3-22-02:17).

diet, coupled with oral pathology examinations, can be found in the dental anthropological literature. Those that are best known were made by dentists, seldom anthropologists. Hence, this brief report represents a contribution to an uncommon line of investigation of human tooth use and its results. Our sample comes from a remnant forest-dwelling hunting and gathering group living in the Philippines, the Batak. The results of our pathology examination (wear, caries, antemortem loss, chipping, periodontal disease, oral hygiene) of living Batak people are nicely in line with other dental studies of prehistoric hunting and gathering people throughout the world. The dentally destructive diet associated with cariogenic agricultural foodstuffs and processing is not evident in the Batak sample. What stands out as markedly different is the effect of oral hygiene on the Batak upper anterior teeth, the observed actual activities demonstrably producing the labial flattening of the upper anterior teeth. This flattening would normally have been considered as intentional modification had the acts of teeth cleansing not been observed by the ethnographer (JFE). Also, the probable cause of tooth chipping has been identified as a result of ethnographic observation.

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Approximal Attrition and Permanent Tooth Crown Size in a Romano-British Population

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ABSTRACT The aim was to measure mesiodistal crown size of both sexes in different age groups of a well characterised Romano-British population to determine the progressive effects of approximal attrition. From the collection in the British Museum of Romano-British skeletons excavated from Poundbury, aged and sexed by Museum staff on established criteria, two samples were selected randomly from those with intact permanent dentitions. The first examiner measured the teeth of 30 males and 30 females aged 14-24 years and the second examiner those of 59 males and 51 females distributed across the four age groups, namely 14-24, 25-34, 35-45, over 45 years. The mesiodistal diameter of each permanent tooth was measured on two separate occasions and the mean for each tooth type in each age group calculated. Differences were explored with two sample t-tests and multiple regression analysis. The intra-operator reproducibility for difference tooth types ranged from r = 0.92 to r = 0.99 and for inter-operator reproducibility from r = 0.74 to r = 0.99. In the youngest age group males had larger teeth than females with this difference being statistically significant for most tooth types. There was a pattern of decreasing tooth size over the four age groups, with males more affected than females. Different tooth types showed different reductions, the greatest being in upper and lower incisors and upper first molars and the least in lower second molars, upper second molars and third molars. The average total arch length reduction estimated by two different methods between aged groups 1 and 4 was 10.0 mm in the upper jaw and 6.4 mm in the lower jaw. Thus, in this Romano-British sample all tooth types showed reduction in mesiodistal diameter with increasing age, the extent varying between the sexes, the jaws and tooth types. From comparable studies, this approximal attrition was slightly greater than for mediaeval Swedes and considerably greater than modern Swedes and other Caucasians. *Dental Anthropology* 2006;19(1):23-28.

In studying variation between populations tooth crown size is a valuable parameter of dental development (Keiser, 1990). Crown size is a continuous variable, which is multifactorially determined by both genetic and environmental factors (Brook, 1984). However, in seeking to determine tooth crown size in ancient populations, extensive attrition is a complicating factor. Attrition may vary from one population to another and in different periods of time (Molnar, 1971; Brothwell, 1989). Archeological populations appear to show a more regular increase in attrition with age than do modern populations with males tending to have higher attrition scores than females (Solheim, 1998).

Therefore, in an earlier population to establish tooth size and to investigate the progress of attrition it is necessary to have sufficient suitable material for various age groups and for both sexes. The Romano-British skeletal material from Poundbury, Dorset, United Kingdon, fulfils these requirements.

This study aimed to determine the initial mesiodistal tooth crown size and to measure the extent of progressive approximal attrition by determining mesiodistal crown dimensions in different age groups in this Romano-British sample.

MATERIALS AND METHODS

Excavation of a Romano-British Christian cemetery, which was in use from AD 200-400, provided the material used in this study. The excavated skeletons of this homogeneous population are housed in the British Museum (Natural History), London. The sex determination and age estimation of 650 adult specimens had been carried out by staff of the British Museum. To estimate age at death the methods of Brothwell (1963) and Miles (1963a,b) were applied.

Adult males (n = 310) and adult females (n = 339) had been placed in the four age groups of 14-24 years, 25-34 years, 35-45 years, and over 45 years. Skulls for the current study were selected from those with intact or nearly intact dentitions using random number tables.

For the tooth size study 30 male and 30 female skulls

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TABLE 1. The number of skulls measured in each age group by sex

Examiner 1 14-24 years		Examiner 2	Age Groups 14-24 yrs	25-34 yrs	35-45 yrs	Over 45 yrs	Total
Male	30	Male	10	20	16	13	59
Female	30	Female	12	17	13	9	51
Total	60	Total	22	37	29	22	110

were selected from the youngest age group and were measured by examiner one (LKF).

For the attrition study approximately equal numbers were randomly selected from each of the four age groups (Table 1) and were measured by examiner two (CAU).

Excluded from the study were teeth with caries or fractures involving an approximal surface, hypoplasia, rotations, or gross supragingival calculus. The mesiodistal diameters of the teeth were measured using dial calipers (Mitutuyo, Japan) and the criteria of Moorrees *et al*. (1957). Each dentition was measured on a second occasion several days later without access to the initial measurement. The mean of the two measurements was then used in the results.

Before commencement of the study the two examiners underwent training. The reproducibility was determined by remeasurement of 20 skulls selected using a random number taken on three occasions over 10 weeks. The intra-operator reproducibility for different tooth types ranged from r = 0.92 to r = 0.99. Inter-operator reproducibility ranged from r = 0.74 to r = 0.99.

For the main study, the differences between mean measurements in each age group were examined for statistical significance using two sample t-tests. In order to take into account fluctuations across age groups related to numbers in each cell and sex differences, three-way multiple regression was also carried out for all individual teeth.

TABLE 2. The mesiodistal crown diameters obtained by two examiners obtained for 2 samples from age group[1]

	Male						Female					
	Examiner 1			Examiner 2			Examiner 1			Examiner 2		
Tooth	n	$\bar{x}$	sd	n	$\bar{x}$	sd	n	$\bar{x}$	sd	n	$\bar{x}$	sd
U1	24	8.41	0.48	16	8.43	0.32	30	8.15	0.45	17	7.80	0.34
U2	42	6.64	0.56	19	6.57	0.40	49	6.23	0.53	19	6.43	0.37
U3	49	7.63	0.38	20	7.60	0.33	51	7.28	0.40	17	7.28	0.22
U4	50	6.50	0.49	19	6.48	0.35	47	6.28	0.40	17	6.26	0.29
U5	44	6.39	0.45	19	6.16	0.44	40	6.10	0.36	19	6.05	0.28
U6	47	10.05	0.66	20	9.94	0.45	44	9.66	0.40	24	9.45	0.40
U7	45	9.35	0.39	21	9.41	0.59	45	9.08	0.47	23	9.11	0.59
U8	37	8.37	0.78	13	8.77	0.95	31	8.54	0.89	14	8.58	0.78
L1	14	5.15	0.37	22	5.11	0.24	23	4.99	0.36	19	4.96	0.25
L2	26	5.83	0.43	21	5.77	0.33	36	5.55	0.36	20	5.53	0.37
L3	41	6.63	0.48	20	6.68	0.32	46	6.29	0.37	20	6.30	0.21
L4	43	6.73	0.51	19	6.65	0.34	52	6.54	0.40	21	6.37	0.30
L5	42	6.64	0.50	18	6.63	0.35	43	6.48	0.47	23	6.51	0.38
L6	47	11.15	0.61	17	10.99	0.50	50	10.60	0.54	24	10.53	0.34
L7	45	10.43	0.63	20	10.49	0.38	51	10.12	0.71	20	10.16	0.54
L8	32	10.31	0.77	14	10.58	0.77	37	9.85	0.97	13	10.20	0.52

[1]n = number of teeth measured

$\bar{x}$ = average mesiodistal tooth diameter (mm)

sd = standard deviation

TABLE 3. The mean mesiodistal diameters of each tooth type in four different age categories (mm) and their standard deviations

	Age Group 14-24				Age Group 25-34				Age Group 35-45				Age Group over 45			
	Male		Female		Male		Female		Male		Female		Male		Female	
Tooth	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd
U1	8.42	0.30	7.87	0.34	8.26	0.60	8.22	0.43	7.47	0.87	7.60	1.16	7.01	1.08	7.07	1.20
U2	6.57	0.40	6.43	0.37	6.53	0.78	6.12	0.58	6.02	0.82	6.35	0.59	5.75	0.78	5.53	0.95
U3	7.60	0.32	7.28	0.24	7.54	0.50	7.38	0.37	7.36	0.42	7.08	0.52	6.94	0.73	6.64	0.78
U4	6.48	0.35	6.26	0.29	6.43	0.40	6.23	0.38	6.25	0.60	6.46	0.46	5.90	0.93	5.60	1.00
U5	6.16	0.43	6.06	0.28	6.26	0.45	5.90	0.29	6.27	0.69	6.19	0.43	5.70	0.93	6.02	0.60
U6	9.90	0.45	9.45	0.40	10.01	0.53	9.68	0.39	9.26	0.85	9.90	0.42	7.82	0.49	9.00	0.34
U7	9.40	0.59	9.10	0.60	9.47	0.60	8.94	0.67	8.99	0.39	9.10	0.57	8.65	0.97	8.80	0.52
U8	8.78	0.95	8.58	0.79	8.47	0.63	8.47	0.80	8.26	0.38	8.30	0.98	8.70	0.90	8.28	0.58
L1	5.11	0.25	4.96	0.25	5.11	0.40	5.00	0.45	4.25	0.67	4.70	0.59	4.22	0.74	4.18	0.49
L2	5.77	0.32	5.53	0.37	5.70	0.35	5.69	0.40	5.20	0.60	5.48	0.44	5.09	0.63	4.90	0.57
L3	6.68	0.31	6.30	0.21	6.70	0.39	6.42	0.30	6.63	0.49	6.30	0.32	6.46	0.55	5.90	0.47
L4	6.65	0.34	6.37	0.30	6.60	0.35	6.33	0.48	6.46	0.56	6.25	0.40	6.20	0.62	6.36	0.35
L5	6.62	0.35	6.50	0.38	6.60	0.40	6.34	0.41	6.42	0.50	6.26	0.50	6.24	0.64	6.27	0.66
L6	10.99	0.49	10.50	0.34	11.20	0.50	10.51	0.60	11.18	0.60	10.70	0.77	10.49	0.60	10.20	0.89
L7	10.48	0.37	10.16	0.55	10.54	0.64	9.99	0.55	10.50	0.73	10.26	0.98	9.99	0.57	10.30	0.69
L8	10.58	0.77	10.20	0.14	10.75	0.68	10.16	0.90	10.35	0.90	10.27	0.78	10.39	0.70	9.70	0.78

$\bar{x}$ = average mesiodistal diameter (mm)
sd = standard deviation

RESULTS

Since there was no significant difference for individual tooth type between the findings from different sides of the mouth, right and left side measurements were pooled in these results.

In Table 2 the means and standard deviations of the mesiodistal crown diameters of each tooth type for age group 1, the 14-24 year olds, are given for the sample measured by examiner 1 and that measured by examiner 2. For almost all tooth types the measurements differed by less the 0.2 mm between the two examiners. The mean mesiodistal measurements for male teeth are larger than for females for all tooth types and this difference is statistically significant for upper central incisors, canines, first and second molars and for lower lateral incisors, canines, first and second molars.

In Table 3 the means and standard deviations of the mesiodistal crown diameters of each tooth type in the four different age categories determined by examiner 2 are given. The standard deviations of the means tend to be larger in the older age groups. These standard deviations are also greater for posterior compared to anterior teeth. However, they are similar for males and females in each age category. These "raw" figures show a pattern of decreasing tooth size over the four age groups, this trend being greater in males.

To investigate these changes further in Table 4 the differences between mean mesiodistal crown diameters at ages 14-24 years and over 45 years are given. For all tooth types except the lower second molar in females, the mesiodistal diameter is smaller in age group 4 than in age group 1. Using a two sample t-test this difference is statistically significant to varying degrees for all tooth types except the upper second premolar, the upper third molar and the lower first and third molars (Table 4). The greatest reductions were in the upper and lower incisors, the upper canines and upper first molars.

In Table 5 the outcome of the multiple regression analysis is given. This confirms the decrease in mesiodistal crown diameters with increasing age. This decrease was significant with this analysis as indicated by the T ratio for the age group coefficient, in all upper teeth except the second premolar (U5) and third molar (U8) and all the lower teeth except the molars (L6, L7

TABLE 4. Difference between the average mesiodistal crown diameters (mm) at age group 1 and age group 4 for males (column 1), females (column 2), and pooled male and female data (column 3)[1]

	Difference between mean mesiodistal crown diameters for age group 1 and age group 4				
Tooth	Male	Female	Pooled sexes	Difference between male and female	Regression equation estimation
U1	1.41***	0.81*	1.11***	+0.60	1.25
U2	0.81**	0.90*	0.86***	-0.10	0.80
U3	0.67**	0.64**	0.65***	+0.03	0.66
U4	0.53	0.62*	0.65**	-0.08	0.47
U5	0.46	0.03	0.24	+0.43	0.20
U6	2.12***	0.44*	1.28***	+1.68	0.89
U7	0.76	0.32	0.54*	+0.45	0.46
U8	0.08	0.30	0.19	-0.22	0.27
L1	0.89***	0.78***	0.84***	+0.11	0.96
L2	0.68***	0.58**	0.63***	+0.10	0.69
L3	0.22	0.38**	0.30*	-0.16	0.30
L4	0.44*	0.01	0.22*	+0.43	0.24
L5	0.38*	0.24	0.31*	+0.14	0.34
L6	0.50	0.33	0.41	+0.17	0.22
L7	0.49*	-0.18	0.16	+0.67	0.11
L8	0.19	0.48	0.33	-0.29	0.36

[1] The difference between male and female difference is also given in (column 4). The mesiodistal tooth reduction as estimated by the regression equation has also been included for comparative purposes (column 5)
*Significant at 5% level
**Significant at 1% level
***Significant at 0.1 level

TABLE 5. T-values of multiple regression analysis[1]

Tooth	Female-Male	Age group	Tooth	Female-Male	Age group
U1	NS	-6.50*	L1	NS	-7.88*
U2	NS	-4.90*	L2	NS	-6.53*
U3	3.29*	-5.89*	L3	6.36*	-3.55*
U4	NS	-3.42*	L4	2.81*	-2.49*
U5	NS		L5	2.03*	-3.17*
U6	NS	-4.86*	L6	5.68*	NS
U7	2.55*	-2.72*	L7	3.37*	NS
U8	NS		L8	2.73*	NS

[1]Where t value not quoted, value was below 2 and was not significant

and L8).

The multiple regression analysis also indicates the tendency for female teeth to be smaller than male was significant, as shown by the T ratio for the sex coefficient, for all lower teeth except the incisors and for the upper canine and second molar.

The total reduction in mesiodistal diameter for each tooth from age group 1 (14-24 years) to age group 4 (over 45 years) can be estimated by multiplying the age group coefficient by three. The totals estimated by this method are given in Table 4. The totals for each tooth from the last column in Table 4 can then be added together and this figure doubled, to estimate a total upper and lower arch length reduction of 10 mm and 6.4 mm, respectively.

An alternative way of using the data to estimate the total reduction in mesiodistal tooth diameter is to subtract the average measurements of teeth in age group 4 from those in age group 1. Table 4 also gives the results obtained by this second method. The table confirms that the reduction in diameter is usually greater in males. When the average of the male-female difference is compared with the reduction estimated from the regression equation, the two estimations are within 0.15 mm, except for the upper lateral incisor, upper first molar and lower first molar, where they are greater when estimated by the second method, and the upper central incisors, where they are smaller. The total upper and lower arch reductions estimated by the second method are 10.9 mm and 6.4 mm, respectively.

DISCUSSION

It was important that the gender of the skeletons was determined prior to tooth measurement, because if, for example, a far larger number of female teeth were included in a particular age group, measurements would tend to be reduced due to the sexual dimorphism of tooth size. This would also tend to distort the estimates of mesiodistal attrition gained by comparing dimensions. It is possible that this may have occurred in some previous studies where the sex of the skeletal remains was not specified. Mortality amongst young females in earlier populations was high, possibly from childbirth, but also from neglect compared to boys (Farwell and Molleson, 1993). Therefore skulls from such populations where the third molar is just erupting may more frequently be female.

Small numbers of certain tooth types were included in age group 4, age over 45 years, because only a limited number of skulls were available for selection and many of these did not satisfy the criteria for inclusion. Whilst caution is necessary in interpreting results from small numbers, the multiple regression analysis did take this into account.

The finding that measurements for mesiodistal crown diameters for the youngest age group, 14-24 year, gave closely similar results for the two samples and the two operators suggests that the data obtained are reliable. While some mesiodistal wear may have occurred even in this group it is unlikely to have yet made any significant differences to those dimensions. Supporting this contention there were no significant differences between age groups 1 and 2.

In the present study there was a statistically significant change in diameter between age groups 1 and 4 (Table 4). This reduction in mesiodistal size is associated with marked occlusal attrition in age group 4, and can be ascribed to approximal attrition. In a sample of 97 mediaeval Swedish skulls Lysell (1958a,b) showed a comparable reduction in mesiodistal tooth diameters between “juvenile” and “mature” age groups.

Also in the present study it was seen that these reductions were greater in some tooth types than others (Table 4). Similarly Lysell’s (1958a,b) results show different interproximal attrition in different tooth types. In Lysell’s (1958a,b) study the teeth showing the greatest approximal wear are the upper and lower incisors and the upper first molars. While these teeth were also markedly affected in the present study, so also were the upper and lower canines and, to a lesser extent the premolars (Table 4). As an explanation for this pattern and therefore time in occlusion may be considered. However, against this suggestion is the fact that in the present study and Lysell's (1958a,b) the lower first molars were not significantly affected, and in the present study the later erupting canines were more affected. Therefore, considering the patterns shown in Tables 4 and 5, it seems probably that a more complex etiology for the attrition must be considered as well as time lapsed since eruption.

There are a series of factors affecting attrition (Hillson, 1996). These include masticatory forces, non-chewing parafunctions, the use of teeth as tools and the nature of the diet. The combined effects of lateral, anteroposterior and axial forces during mastication result in complex movements of one approximal surface against another. The magnitude and duration of these masticatory forces is added to by such non-chewing use as bruxism, which may occur in some individuals when asleep or unconsciously whilst awake. In addition a tough fibrous diet required heavy prolonged mastication and the abrasiveness of diets in early populations containing barley or rye was increased by the incorporation of grit from hand grinding using stone querns.

The people of Poundbury had large jaws and edge to edge occlusion; they ate coarse food that required prolonged chewing (Farwell and Molleson, 1993). They probably had an agricultural life style fulfilling the criteria of Hinton (1981) with cereals as the predominant element in the diet. Interesting facets arising from the present study are the sex difference in the degree of approximal attrition and the pattern across tooth types, which contrasts with that for occlusal attrition for this population described by Whittaker *et al*. (1982).

For the mesiodistal crown diameters of all tooth types in age group 1, female measurements were smaller than male measurements (Table 2). However in age group 4, over 45 years, only the lower canine is statistically significantly smaller in the female and for several tooth types, namely the upper central incisor, second premolar and first and second molars and the lower premolars and second molar, the sex difference is reversed (Table 3). These findings suggest that males exhibit greater approximal attrition than females overall, although the extent of this difference varies between the different tooth types (Tables 4 and 5).

CONCLUSIONS

In these Romano-Britons there is a progressive pattern of approximal attrition with increasing age. This attrition was greater in males than females and varied among different tooth types. The estimated total arch length reduction was comparable for the two methods used and was slightly greater than some other historical populations. The etiology of the attrition is multifactorial and reflects the lifestyle of this population. This study has also illustrated the importance of sampling and establishment of a baseline group for comparisons.

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Inheritance of Bilateral Fusion of the Lower Central and Lateral Incisors: A Pedigree of a Maya Family from Yucatan, Mexico.

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ABSTRACT: A pedigree with five individuals exhibiting bilateral fusion of lower central and lateral incisors is described. It is the first pedigree ever published presenting this condition, and the individuals affected are the 6th through 10th cases in the literature. Bilateral fusion of the lower central incisors may be the consequence of an autosomal dominant gene in this family. Crown height and mesiodistal measurements on the permanent dentition of the affected individuals were compared to the same measurements taken on unaffected persons in their population. Buccolingual and mesiodistal measurements on the deciduous dentition were compared to published means for populations around the world. Fusion was associated with a genetic tendency towards tooth reduction, affecting tooth number in the jaw, and overall size. It also was concluded, as suggested by previous investigators, that fusion and gemination are under separate genetic control. *Dental Anthropology* 2006;19(1):29-34.

Double teeth have been described in the literature as the result of two developmental events taking place during the bud stage of tooth formation. These events are called gemination and fusion. The term gemination is described as an attempt at formation of two teeth from a single tooth bud, and fusion is the joining together of two teeth (Shafer *et al*., 1974; Pindborg, 1970; Grahnen and Granath, 1961). This being the case, gemination can more accurately be described as the result of an incomplete bifurcation of a single tooth bud at the early stages of development. Fusion, on the other hand may result from the union of the epithelial cells of two different tooth buds, which will later develop into a single mesiodistally enlarged tooth.

Both fused and geminated teeth may share an enlarged pulp chamber and a single root canal, or may have separate root canals or bifurcated pulp chambers (Maibaum, 1990; O'Reilly, 1990; Hosomit *et al*., 1989; Reeh and El Deeb, 1989; Levitas, 1965). As a consequence, the identification of double teeth as geminated or fused teeth based on their shape is difficult, even when using radiographs. Furthermore, some authors have argued that since both fusion and gemination are developmental processes that cannot be observed and that, to avoid confusion, they should not be separated for analysis (Killian and Croll, 1990; Mader, 1979; Brook and Winter, 1970). In fact, the only practical way to classify them is by counting the double tooth as a single one. If the dental arch contains a normal set of teeth, the double formation is classified as gemination. On the other hand, if a tooth is missing, the event is classified as fusion (Pindborg, 1970; Levitas, 1965). This approach is far from perfect since the synchronous presence of gemination, fusion, supernumerary teeth, and congenitally missing teeth could lead to misclassifications.

Moody and Montgomery (1934) suggested that the formation of double teeth is under genetic control. Since then, data supporting their hypothesis have continued to mount in human and nonhuman cases. For instance, double teeth have been encountered in a strain of Lakeland terriers (Hitchin and Morris, 1966) and in human twins (Nik-Hussein and Salcedo, 1987; Dixon and Stewart, 1976; Grahnen and Granath, 1961). Trait frequencies vary among populations, being most common among people of Asian and Amerindian origins (Bedy and Moody, 1992; Barac and Skrinjaric, 1991; Skrinjaric and Barac, 1991; Ishida *et al*., 1990; Salem, 1989; Hagam, 1988; Stevenson, 1983; Brook and Winter, 1970; Pindborg, 1970; Curzon and Curzon, 1967; Grahnen and Granath, 1961; Saito, 1959). There has been disagreement, however, as to the mode of transmission of double teeth. Dixon and Stewart (1976), based on Moody and Montgomery (1934), and Hitchin and Morris (1966) proposed that double teeth may involve Y-linked or holandric transmission. Saito

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(1959) studied 7,589 infants and 2,740 older children from 141 families with at least 1 affected individual. He considered both fused and geminated teeth as double teeth, and concluded that the trait follows a simple mendelian segregation ratio, and "double teeth" is due to a dominant gene with 73.8% penetrance in the primary dentition, 62.3% penetrance in the permanent, and 90.2% for both.

Double teeth most commonly involve (1) the central and lateral incisors and (2) the lateral and the canine, and they are more common in the primary dentition (Grahnen and Granath, 1961; Pindborg, 1970; Ishida *et al*., 1990; Duncan and Helpin, 1987). They also are more common in the mandible than the maxilla (Brook and Winter, 1970). Finally, they are just as likely to be found in males as in females (Jarvinen *et al*., 1980).

In an effort to predict tooth number in the permanent dentition from the primary dentition, Gellin (1984) investigated two independent relationships. First he found that there were associations between oligodontia, microdontia, and fusion. He then confirmed associations between supernumerary teeth, macrodontia and gemination. In addition, he found that while in all cases the teeth involved are the incisors and the canines, fusion (along with oligodontia) occurs predominantly in the lower jaw. In contrast, gemination and supernumerary teeth are usually found in the maxilla arch. These tendencies had already been reported by Pindborg (1970), and later studies have supported these results (Barac and Skrinjaric, 1991; Skrinjaric and Barac, 1991; Ishida *et al*., 1990; Hagam, 1988).

Duncan and Helpin (1987) reviewed the cases on bilateral fusion and gemination published in the literature up to 1987. Cases reported by Bricker and Martin (1987), Maibaum (1990) and Nik-Hussein (1989) were added to these and are summarized in Table 1. As may be observed, bilateral fusion and gemination follow

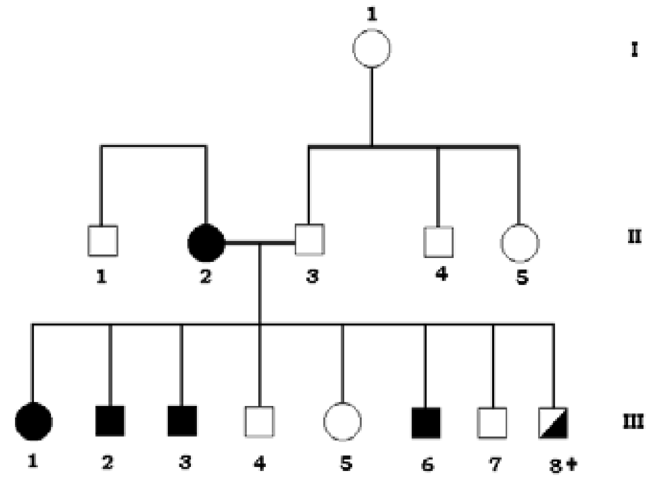

Fig. 1. Pedigree of mandibular fusion of central and lateral incisors in a Yucatecan Maya family (symbols for affected individuals are filled in).

the observed patterns as their unilateral counterparts. The most commonly affected teeth in both situations are the incisors and the canines. Gemination, both in the primary and secondary dentition, is predominantly a feature of the maxillary dentition, while fusion is more common in the mandible, especially in the primary dentition. Fusion in the lower jaw, as in the unilateral cases, is accompanied by what could be considered oligodontia, while gemination is often associated with a supernumerary tooth.

These differences suggest that fusion and gemination result from independent events. Fusion may be associated to a mandibular process of tooth reduction and gemination to a maxillary process of tooth enlargement and increment in number. This being the case, the two processes may be under different genetic control, and regarding them as one may have hindered previous attempts to estimate the mode of inheritance

TABLE 1. Total cases of bilateral fusion or gemination reported in the literature

Condition	Location	Teeth
Gemination primary dentition	75% maxilla	Central and lateral incisors.
Gemination permanent dentition	100% maxilla	Central incisors.
Fusion primary dentition	92.3% mandible	61.53% lateral incisors and canines. 38.46% central and lateral incisors.
Fusion permanent dentition	57.14% mandible, 42.85% maxilla	1 lateral incisors and canines. 5 central incisors and supernumerary (maxilla). 4 central and lateral incisors. 2 lateral incisors and canines.

TABLE 2. Crown height percentiles in mm. for Yucatecan Maya populations

	Males ages 10 to 15 years old							Females ages 30 to 40 years old						
		Percentile							Percentile					
Tooth	n	5	25	50	75	95	C6	n	5	25	50	75	95	B6
LI1	100	7	8	8	9	10	6	77	6	7	8	9	10	8
RI1	99	7	8	8	9	10	6	76	6	7	8	9	10	8
LC	90	6	7	7	8	9	6	92	6	7	8	8	10	7
RC	90	6	7	7	8	9	6	91	6.6	7	8	8	10	6

of double teeth.

The present paper presents the 6th through 10th cases of bilateral fusion of the lower central and lateral incisors as near as can be determined. They were all detected in a single family, which makes this the first published pedigree of bilateral fusion. It would seem to be useful to determine the mode of inheritance of this pedigree.

MATERIALS AND METHODS

During 1992, in the town of Zavala, located in the Maya region, state of Yucatan, Mexico, a family was examined as part of a survey on the frequency of enamel hypoplasia (Gurri and Balam, 1992). Upon inspection of the mother's dentition, it was noted that she exhibited bilateral fusion of the lower central and lateral incisors. Her children and husband where then examined, and it was observed that 4 of her offspring also exhibited the trait (Fig. 1). In a subsequent visit, hydrocolloid impressions and plaster casts were made of all affected individuals except for a 1.5 year old child with a very small dental arch. Attempts were also made to locate all living relatives.

The casts were analyzed in the dental laboratory in the Department of Anthropology of Indiana University. Discrimination between fusion and gemination was based on counting the anomaly as one tooth, and summing the total number of teeth in the dental arcade (Pindborg, 1970; Levitas, 1965).

To test for the presence of microdontia, the crown height measurements of individuals II2 and III6 where compared to the local population. Crown heights on the permanent upper central, lower central incisors and lower canines were taken in this population as part of the research on enamel hypoplasia. However, no measurements were taken on the deciduous dentition. The mesiodistal and buccolingual dimensions of the upper central incisors, and the upper and lower canines of individuals III2 and III3 were compared to measurements published by Grine (1986) for different populations around the world.

Measurements in the Maya population were taken in vivo with a plastic vernier caliper and recorded to the nearest millimeter. Measurements on the subject family were obtained from plaster casts with the same instrument.

RESULTS

The pedigree in Figure 1 shows the results. The trait appeared in the mother (II2 Fig. 2), the youngest daughter III1, and 3 of the sons (III2, III3, III6; Figs. 3-5). In all, 4 out of 7 live children have bilateral fusion of the central and lateral incisors, 3 in the primary dentition (III1, III2, III3) and 1 in the permanent (III6). The last child had died, and it was impossible to determine his dental condition since the family was unaware of its

TABLE 3. Mesiodistal breadth percentiles in mm. for Yucatecan Maya populations

	Males							Females						
		Percentile							Percentile					
Tooth	n	5	25	50	75	95	III6	n	5	25	50	75	95	II6
LI1	195	7	8	8	9	9	8.6	185	7	7	8	8	9	7
RI1	191	7	8	8	9	9	8.2	183	7	7	8	8	9	7.25
LI1	205	4	5	5	5	6	7	218	4	5	5	5	6	8
RI1	204	4	5	5	5	6	5.25	220	4	5	5	5	6	7
LC	187	5.4	6	7	7	8	6	208	5	6	6	7	7	5
RC	187	5	6	7	7	8	6	209	5	6	6	7	7	5.5

*TABLE 4. Mean mesiodistal diameters in the primary dentition of selected groups**

Group	Maxillary I1	Maxillary I2	Maxillary C	Maxillary C
South African	6.47	5.32	7.08	6.02
Japanese	6.70	5.53	6.70	5.88
Native American	6.86	5.72	7.15	6.20
Australian Aborigine	7.40	6.19	7.41	6.44
European Caucasian	6.60	5.46	7.04	6.04
American Caucasian	6.40	5.24	6.88	5.92
Average	6.74	5.58	7.04	6.08
III2	6.10	5.58	6.90	6.00
III3	6.30	5.59	7.50	6.90

*(Grine 1986)

existence.

A brother (II1) and a first cousin of the affected mother were found, neither of whom was found to have the condition. Affinal relatives were also available for examination, but, as shown on the pedigree, neither her husband (II3) nor anyone in his family (I1, II4, II5) was affected.

Table 2 shows a crown height percentile distribution for Maya women, ages 30 to 40, and males, ages 10 to 15. The 4 crown heights for individual II6, a female age 36, correspond to the 25th, 50th, 25th and 5th percentiles. All of the crown height measurements on individual III6, a 12 year old boy, fell within the 5th percentile of his population.

Table 3 shows mesiodistal percentile distributions for males and females in the local Maya population. Mesiodistal measurements for the lower canines in III6 correspond to the 25th percentile and in II6 to the 5th. The central upper incisors in B6 correspond to the 5th and 25th percentiles, and the mesiodistal dimensions of C6 correspond to the 50th.

Tables 4 and 5 show the mesiodistal and buccolingual diameters of UI1, UI2, UC and LC for different populations, and for individuals III2 and III3. Except for UI1, whose mesiodistal dimensions are smaller than the average of any of the reference populations, all other teeth appear normal. The buccolingual breadths of III2 and III3, on the other hand, are extremely small. In comparison to the reference populations, III2 and III3 these buccolingual breadths are extremely narrow.

DISCUSSION

All cases of bilateral fusion encountered here support the observations of Barac and Skrinjavic (1991), Skrinjavic and Barac (1991), Ishida *et al*. (1990), Hagam (1988), and Gellin (1984). The independence between the processes determining the number of anterior teeth on each jaw is clear. In each case, fusion is only present in the mandible. Tooth size on both upper and lower dentition appears to be affected. As anticipated, fusion is accompanied by an apparent crown size reduction expressed as reduced buccolingual dimensions in the deciduous dentition and lower crown heights in the permanent dentition. Why this should affect both the upper and lower dentition is not clear. Perhaps this lack

*TABLE 5. Mean buccolingual diameters in the primary dentition of selected groups**

Group	Maxillary I1	Maxillary I2	Maxillary C	Mandibular C
African	4.98	4.85	6.16	5.48
Australian Aborigine	5.47	5.24	6.61	6.05
Naisoi	5.15	4.79	5.91	5.31
American Caucasian	5.13	4.71	6.11	5.6
Mean	5.18	4.90	6.20	5.61
III2	4.60	4.25	5.50	4.75
III3	5.00	4.20	5.60	4.20

*(Grine 1986)

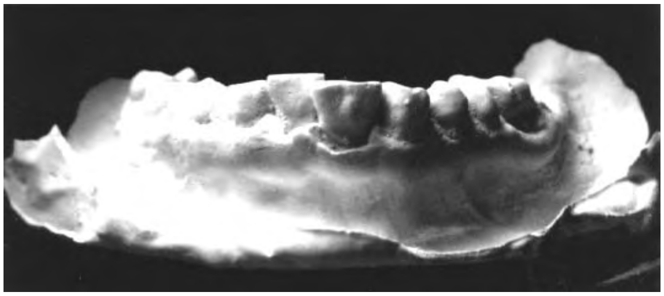

Fig. 2. Fusion of the permanent lower incisors of individual II1 (frontal view).

Fig. 4. Fusion of the deciduous incisors of individual III2. His right incisor is the only one that shows some separation in this series (frontal view).

Fig. 3. Fusion of the deciduous lower incisors of individual III3. Fusion is so advanced that, except for the exaggerated mesiodistal width, this case could be mistakenly classified as agenesis of the lateral incisors (frontal view).

Fig. 5. Fusion of the permanent lower incisors of individual III6 (three-quarter view).

of independence between the upper and lower jaws with regard to tooth size is related to the generalized trend towards tooth reduction that accompanies oligodontia (Garn, 1977). If this is the situation, fusion should not only be associated with frontal tooth reduction but third molar agenesis as well.

Although Moody and Montgomery (1934) did not differentiate between fusion and gemination, they described what appears to be unilateral fusion of the lower incisors. The pedigrees they present suggest that inheritance of the trait is controlled by a single dominant gene. However, the fact that their study showed only females inheriting and transmitting this trait make it difficult to establish its autosomal nature. In the study by Saito (1959)—based on a large sample of infants, children and their families—the trait indeed seems to be transmitted as an autosomal dominant character. Saito, however, did not distinguish between fusion and gemination when attempting to establish the mode of inheritance. The attendant confusion of including what may be two different genetic processes may also have led to his inference that the trait exhibited incomplete penetrance.

The pedigree presented in the present paper, however, makes it clear that if bilateral fusion of the lower incisors is indeed the consequence of an autosomal dominant gene—as appears to be the case—this pedigree exhibits full penetrance. Unfortunately, the present pedigree lacks a third generation from the side of the family that possesses the trait. The husband of the affected mother is not related to her, as far as could be determined, and no one in his family exhibits the trait. Nevertheless, since the husband (II3) is from the same home town as his affected wife (II2), the possibility of inbreeding and the presence of a rare recessive allele cannot be completely ruled out.

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University of Łódź Hosts Excellent Dental Morphology Symposium

The 13th International Symposium of Dental Anthropology was held in Łódź, Poland from August 24-27, 2005. The meeting was organized by a committee headed by Elżbieta Żądziska, Chair of Anthropology at the University of Łódź, whose gracious hospitality made all the participants feel right at home. The scientific sessions consisted of 49 podium presentation, 30 posters, and 7 keynote lectures. As in previous years, research topics varied widely, including work on genetics, evolution, ontogeny, and technology as well as traditional anthropological dental morphology. While the research presented was certainly interesting, in many ways the highlight of the meetings was the coming together of dental researchers from all over the world in informal conversations. The Table lists the country of origin for authors listed in the program and the number of authors from each country.

In addition to the scientific session, the local arrangements committee organized several social events for the symposium participants. A gala dinner was held at a beautiful restaurant, which was in the converted house of one of Łódź's industrial baron's homes. There was also a bus excursion highlighting the city's industrial past, followed by a fantastic grill party held at a rambling university property outside of town. Łódź is a very interesting town. Known as the film capitol of Poland, it's main tourist street features a star walk similar to streets in Hollywood. There is also an excellent museum of contemporary art, and the largest Jewish cemetery in Europe accessible by tram on the edge of the city.

The symposium proceedings are to being peer-reviewed and will be published in 2006. The next International Symposium of Dental Anthropology is to be held in Germany in 2008.

Reported by
Heather J. H. Edgar
University of New Mexico

TABLE. Number of authors from each country represented

Country	Number of authors
Australia	5
Belarus	2
Canada	4
China	1
Croatia	3
Czech Republic	4
Finland	9
France	3
Germany	8
Japan	12
Kenya	1
Korea	1
Norway	1
Poland	28
Russia	1
United Kingdom	9
Ukraine	1

Dental Anthropology in Campeche

Joel D. Irish, University of Alaska, Fairbanks

A dental anthropology-focused symposium was recently presented at the XIII Coloquio Internacional de Antropología Física "Juan Comas." This bi-annual Asociación Mexicana de Antropología Biológicas meeting was held November 6th-11th, 2005 in Campeche, Mexico, on the Yucatan Peninsula's west coast.

In late 2004, I was invited by Dr. Francisco D. Gurri García, AMAB Vice President and ECOSUR Investigador, to organize the symposium which came to be "Trends in dental anthropology: Multiple methods and myriad results." Part of the symposium's objectives are reproduced here:

The study of teeth has long played a functional, albeit ancillary, role in the description, classification, and comparative analyses of fossil and living human and non-human primate taxa. ... It was not until 1953 that the analysis of human and other primate teeth finally came to be recognized as a primary field of study in its own right, with the publication of Klatsky and Fisher's book "The Human Masticatory Apparatus: An Introduction to Dental Anthropology."

A number of Dental Anthropology Association members were invited to participate in the symposium (aka. mesa de trabajo). Particpating members were Alma Adler, Cathy Cooke, Robin Feeney, Michelle Field, Debbie Guatelli-Steinberg, Brian Hemphill, John Lukacs, Greg Nelson, and Elizabeth Newell.

Dr. Adler was unable to attend the meeting, although she was able to supply me with a copy of her presentation. I also presented a paper entitled The 'Mechtoid' mystery: North African dental affinities since the Pleistocene. All papers were well-received and attended, despite the language barrier; fortunately, with the exception of Dr. Newell's language expertise, our group's deficiency in speaking/understanding Spanish was nicely compensated for by the audience's comprehension of English. The symposium discussant was Dr. Gurri García.

In addition to our session, we enjoyed the other paper and poster presentations, lavishly-catered dinners, traditional entertainment, and guided tour of the nearby Mayan site of Edzná. We were also explored the surrounding countryside (Fig. 1). In sum, we want to thank the many Coloquio organizers (including President, Andrés del Ángel Escalona, among others), attendees, and native campechanos who all made us feel welcome.

Fig. 1.The dental symposium participants atop Structure II, at the Mayan site of Calakmul. From left to right: Joel Irish, Greg Nelson, Brian Hemphill, John Lukacs (in back), Jaymie Brauer Hemphill, and Elizabeth Newell.

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Abstract	Figure Legends
Text	Figures
Literature Cited	

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