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Posterior tooth morphology and lower incisor crowding

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ABSTRACT Frequently, only the mesiodistal dimensions of mandibular posterior teeth have been investigated in relation to lower incisor crowding. The aim of the present study was to investigate any relationship between lower incisor crowding and mesiodistal widths, buccolingual dimensions, occlusal area and occlusal perimeter of mandibular posterior teeth. Mandibular dental casts of 50 Caucasians (25 males and 25 females) were used. Mesiodistal widths, buccolingual dimensions, occlusal area and occlusal perimeter were measured using image analysis techniques. Lower incisor crowding was determined using (1) Little's irregularity index and (2) anterior-tooth size arch length discrepancy. Using Pearson correlation, the occlusal area, perimeter, mesiodistal widths and buccolingual dimensions of the lower first molar were significantly, positively correlated with Little's irregularity index. The significant correlation between occlusal area and crowding did not appear to be secondary to larger mesiodistal widths. *Dental Anthropology* 2005;18(2):37-42.

Crowding in the lower arch most commonly is seen in the anterior segment. The etiology of dental crowding seems to be multifactorial and tooth morphology has been suggested as an important component. No single factor has so far been demonstrated to be a major cause of anterior crowding.

Some workers have found a positive correlation between lower incisor and posterior tooth mesiodistal width (MD) and lower arch crowding (Peck and Peck, 1972a,b; Norderval *et al*., 1975; Doris *et al*., 1981); others (Mills, 1964; Howe *et al*., 1983; Radnzic, 1988) have failed to find evidence of such an association. There is coordinated development between different tooth types in the dental arch in size, such that subjects with larger mesiodistal dimensions of lower incisors may have larger tooth size elsewhere in the dental arch (Harris and Bailit, 1988). However, studies of lower incisor crowding and posterior tooth morphology have been limited to measuring only the mesiodistal width. Therefore, the aim of this study was to investigate the relationship between lower incisor crowding and the occlusal surface area, buccolingual and mesiodistal dimensions of mandibular posterior teeth.

MATERIALS AND METHODS

The sample consisted of dental casts of the mandibular teeth of 50 adult Caucasians (25 males and 25 females).

A computerised image analysis technique was used to analyse the dental casts (Brook *et al*., 1998). The apparatus consisted in part of a 32-bit digital camera (Kodak, Nikon DCS 410). Adobe PhotoShop (version 5.0, Adobe Systems Ltd., Europe) was used to acquire images of the teeth. From all models an occlusal image of each posterior tooth was captured, starting from the lower left first permanent molar to the lower right first permanent molar. For all images the position of the tooth was such that the lens of the camera was focused at right angles to the long axis of the clinical crown.

The following measurements were carried out using Image Pro Plus (version 4.0, Media Cybernetics, USA):

1. Area and perimeter: The maximal contour of the occlusal surface of the posterior teeth (from first molar to canine) was traced (Fig. 1) giving rise to area (A) and perimeter (P) measurements.

2. Mesiodistal width (MD): This was measured between the anatomical mesial and distal contacts (Fig. 1).

3. Buccolingual diameter (BL): The buccolingual diameter was measured as perpendicular to and at the midpoint of the mesiodistal diameter (Fig. 1).

4. Lower incisor crowding: Little's irregularity index (II5; Little, 1975) and anterior tooth size-arch length discrepancy (ATSALD) were used to quantify lower incisor crowding. The II5 is the sum of five contact

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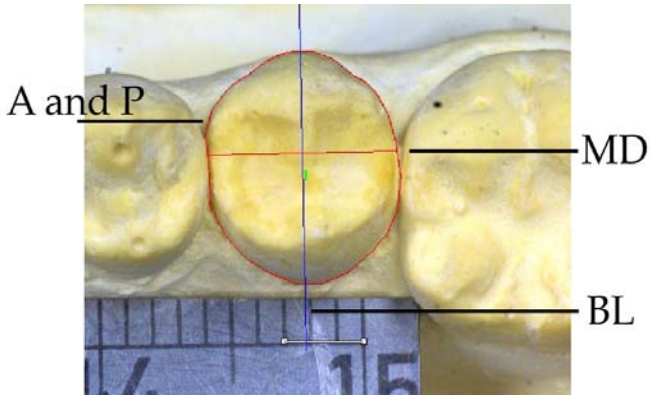

Fig. 1. An image of a lower right second premolar with mesiodistal (MD), buccolingual (BL), area (A) and perimeter (P) dimensions. The steel rule allows linear calibration of each image.

displacements between the lower anterior teeth. It was measured manually using digital calipers (Mitutoyo, Japan).

The ATSALD was measured as the difference between the sum of the individual mesiodistal widths of the four lower incisors and the dental arch length, using the image analysis method. The latter was measured on both sides of the arch from the mesial contact point of canine to the contact between the mesial contact points of central incisors. If there was no contact between the central incisors, it was measured between the mesial contact of the canine and the mesial contact point of the central incisor, which was thought to be in normal position.

Repeatability

All teeth were re-imaged and re-measured on a separate occasion after an interval of one week, to assess the reliability of the method.

The error of II5 was calculated by re-measuring the index manually, on ten models on two separate occasions, one week apart. To examine the reliability of ATSALD, twenty models were re-imaged and re-measured after a one-week interval.

Systematic error was calculated using paired t-tests, and random error was estimated with intra-class correlation coefficients. Descriptive statistics and the Pearson and Spearman correlation coefficients were used to assess the correlation between lower incisor crowding and posterior tooth parameters.

RESULTS

Measurement reliability

From Table 1 it can be seen that the range of error variance for different tooth types for MD dimensions of posterior teeth was between 3% and 6%, and for BL tooth dimensions of posterior teeth between 3% and 10%. For area and perimeter measurements error variance ranged from 1 to 3% among the different tooth types. The mean differences between the first and second measurements after re-imaging the teeth were not statistically significant.

Tooth dimensions and crowding indices

The mean and range of MD, BL, A and P for canines, premolars and first molars of males are given in Table 2 and for females in Table 3.

In the male group some first molar and second premolar variables showed significant correlations with the crowding indices (Table 4). For the occlusal surface of first molars MD, BL, A and P were significantly correlated at the 5% level with II5 (Table 4). First molar MD dimension showed significant correlation with ATSALD ($P = 0.04$), and A and P approached significance ($0.10 > P > 0.05$). However, the correlation coefficients between these variables and the crowding indices ranged from 0.39 to 0.48, indicating that although an association may exist, it is not high.

From Table 4 it can be seen that for second premolars MD and A were significantly correlated with II5, with P approaching significance ($0.10 > P > 0.05$). Only MD approached a significant association ($P = 0.06$) with ATSALD, and the remaining three variables of the second premolar showed no evidence of association with ATSALD. First premolar and canine variables showed no significant correlation.

In contrast, in the female group no evidence was found of an association with either II5 or ATSALD. The Pearson correlation coefficients (r) ranged from zero to

TABLE 1. Intraclass correlation coefficients for re-imaging error of posterior teeth[1]

Tooth type	MD	BL	Area	Perimeter
First molar	0.96 (4%)	0.90 (10%)	0.98 (2%)	0.97 (3%)
Second premolar	0.94 (6%)	0.97 (3%)	0.98 (2%)	0.97 (3%)
First premolar	0.95 (5%)	0.95 (5%)	0.98 (2%)	0.98 (2%)
Canine	0.97 (3%)	0.97 (3%)	0.99 (1%)	0.99 (1%)

[1]Figures in parenthesis indicate proportion of variance in measurements due to method error

TABLE 2. Measurements (in mm or mm^2) for first molar, premolars and canine in the male group

	First molar		Second premolar		First premolar		Canine	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
MD	10.88	9.8-12.13	7.19	6.27-8.14	7.11	6.21-8.01	6.91	5.70–7.89
BL	10.49	9.35-11.86	8.53	7.21-9.62	7.96	6.66–9.29	7.90	5.82–9.57
A	100.64	84.8-124.9	50.04	37.62-67.21	44.17	32.9–54.73	41.6	33.45–56.4
P	35.58	23.7-40.18	25.37	21.11-29.44	23.79	20.45–26.59	23.98	21.19–35.5

0.37 (Table 5).

Spearman's correlation coefficients were calculated for all the significant results to check that these were not due to outliers (Table 6). The correlation between II5 and first molar variables remained significant. However, the correlation between MD of first molar and ATSALD, and MD and A of second premolar and II5 lost significance. This showed that the latter significant result was probably due to the presence of an outlier in the data.

DISCUSSION

In the present study, the error variance for posterior tooth variables did not exceed 10% for different tooth types. Crown area represented the overall size of the tooth and takes into account both MD and BL dimensions. The area of the posterior teeth showed the least error variation in relation to the total variation in the materials studied (1 to 2%). This can be interpreted as suggesting that crown area would be a better single indicator of biological variation than either MD or BL alone, where the error variation was 3 to 10% of the total variation. However, combination of the parameters measured is important in considering the shape of teeth, as two teeth with different shapes may have similar area measurements.

Lower arch crowding is important not only from a clinical point of view, but it also has implications in understanding the controlling factors of tooth size. Begg (1954) reported that there was less crowding in the Aborigines and he attributed this to greater interproximal attrition, due to ingestion of coarse food in that population. Lower incisor crowding has been quantified in different ways, and Little's irregularity index (1975) and ATSALD are the two methods commonly used in orthodontic literature. Even the ATSALD has been measured in many ways by different investigators. Harris (1987) has shown that II5 and ATSALD may not measure the same thing and the present study lends support to that suggestion.

The results show that area of posterior teeth is an important variable when investigating lower incisor crowding. Previous studies have reported a positive correlation between lower incisor crowding and MD dimension of posterior teeth, and this association was interpreted as larger teeth occupying more space in the dental arch, which may result in crowding. In this study, however, we have shown that, in males in addition to MD and BL dimensions, posterior occlusal area may be associated with lower incisor crowding, and the strengths of the association of these variables with crowding are not substantially different from each other (Table 4).

In the female group, there was no association of posterior tooth area with lower incisor crowding. It cannot be explained readily whether such an association did not exist in the first place or whether any such association was undetected.

The work opens a new dimension for future studies, as the association of MD and lower incisor crowding may be secondary to the association of larger posterior tooth area. This is partially supported by previous work (Shah, 2000) where 44 variables were measured on lower study models. The number of variables was subsequently reduced to 5 by using principal component analysis. When regression analysis was performed, area and BL width of posterior teeth entered before MD dimension in the regression equation. It was further shown that when area for posterior teeth was not included in the regression analysis, the BL dimension preceded the MD dimension in significance.

While the positive association of the MD of molars

TABLE 3. Measurements (in mm or mm^2) for first molar, premolars and canine in the female group

	First molar		Second premolar		First premolar		Canine	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
MD	10.41	9.02-11.49	6.91	6.20-7.74	6.86	6.11-7.79	6.45	5.56-7.48
BL	10.22	9.00-11.19	8.32	7.14-9.59	7.60	6.67-8.3/9	7.38	6.30-8.21
A	94.27	77.87-105.00	46.48	36.84-56.87	40.51	31.77-47.64	36.49	25.81-46.01
P	34.87	31.79-36.90	24.42	21.74-27.10	22.78	20.16-24.71	21.80	18.40-24.41

TABLE 4. Pearson correlation coefficients (r) between lower incisor crowding and lower first molar, premolars, and canine in males

	Variable	II5 (r value)	P value	ATSALD (r value)	P value
First molar	MD	0.48	0.02*	0.40	0.04*
	BL	0.44	0.03*	0.29	0.15
	A	0.46	0.02*	0.37	0.07
	P	0.39	0.05*	0.37	0.09
Second premolar	MD	0.42	0.04*	0.38	0.06
	BL	0.31	0.13	0.20	0.16
	A	0.39	0.05*	0.30	0.15
	P	0.38	0.07	0.27	0.19
First premolar	MD	0.26	0.21	0.33	0.10
	BL	0.10	0.64	0.04	0.83
	A	0.16	0.44	0.17	0.42
	P	0.20	0.34	0.22	0.29
Canine	MD	0.12	0.57	0.17	0.41
	BL	0.05	0.82	0.05	0.79
	A	0.15	0.44	0.12	0.57
	P	0.01	0.98	0.10	0.64

* P < 0.05

with lower incisor crowding may be readily understood, the association of occlusal area of molars merits further consideration.

The literature indicates that, with age, mandibular intermolar and interpremolar widths either increase or remain unchanged (Harris, 1997; Bishara *et al*., 1994, 1997). If the buccal teeth are drifting away from the midline, then the supporting bone ought to remodel to accommodate them. Data show that this does occur and the changes are in the predicted direction (Enlow and Harris, 1964; Enlow *et al*., 1976; Israel, 1979). The upper molars are slanted buccally and the increase in intermolar and interpremolar widths may be due to displacement of molars buccally by the force of occlusion (Harris, 1997). However, Haas (1980) found that by expanding the upper arch, lower intermolar and interpremolar widths also increased and it was suggested that this might be as a consequence of the altered forces of occlusion and muscle balance, with buccal tension diminishing and lingual pressure increasing. In postretention studies,

TABLE 5. Pearson correlation coefficients (r) between incisor crowding and lower first molar, second premolars, and canine in females

	Variable	II5 (r value)	P value	ATSALD (r value)	P value
First molar	MD	0.02	0.92	0.12	0.56
	BL	0.02	0.93	0.21	0.32
	A	0.05	0.81	0.11	0.60
	P	0.11	0.58	0.05	0.80
Second premolar	MD	0.12	0.4	0.37	0.07
	BL	0.01	0.95	0.23	0.28
	A	0.00	0.98	0.26	0.21
	P	0.00	0.99	0.24	0.24
First premolar	MD	0.02	0.93	0.21	0.31
	BL	0.01	0.95	0.19	0.37
	A	0.12	0.35	0.19	0.36
	P	0.12	0.56	0.17	0.40
Canine	MD	0.02	0.92	0.17	0.41
	BL	0.19	0.36	0.21	0.31
	A	0.04	0.83	0.23	0.26
	P	0.05	0.80	0.24	0.25

TABLE 6. Spearman correlation coefficients (r) between incisor crowding and lower first molar and second premolar variables in males.

	Variable	II5 (r)	P value	ATSALD (r)	P value
First molar	MD	0.50	0.01*	0.23	0.20
	BL	0.45	0.02*	0.24	0.25
	A	0.48	0.01*	0.30	0.14
	P	0.38	0.06	0.31	0.13
Second premolar	MD	0.29	0.15	0.38	0.06
	BL	0.33	0.10	0.20	0.16
	A	0.31	0.13	0.30	0.15
	P	0.32	0.12	0.27	0.19

lower incisor alignment appears to be more stable in cases where upper arch expansion has been carried out (Moussa *et a*l., 1995; Elms *et al*., 1996; Azizi *et al*., 1999; Shah 2003). At the same time, arch length and intercanine width decrease. We also know that posterior teeth move forward as a result of mesial drift with age (Begg, 1954; Beek, 1979) and, except for the increase in intermolar and interpremolar widths, all the remaining phenomenons will obviously have an adverse effect on lower incisor alignment. It may be that the simultaneous increase in intermolar and interpremolar width results in less incisor crowding.

Wolpoff (1971) concluded that as the roots of the posterior teeth are inclined forward in the jaws, so chewing forces create a mesial force vector. Therefore, the greater the chewing forces, which are determined by the nature of the diet, the higher the mesial force vector. However, as pressure is force per unit area, theoretically one would expect less pressure application to posterior teeth having a larger occlusal area, assuming there will be larger contact areas in the latter. This would cast doubt on the speculation that chewing forces might be associated with lower incisor crowding and/or mesial migration of the posterior teeth. This is supported in the present study where a larger occlusal area was positively associated with lower incisor crowding. This is further supported by Hidaka *et al*. (1999) who found that when the bite force increased with clenching intensity, occlusal contact area on the whole arch increased but the mean bite pressure (bite force per contact area) remained unchanged.

Therefore, the effect of a larger occlusal area may be operating by different mechanisms. Two possible mechanisms can be offered where larger molar occusal area may cause more lower incisor crowding:

1. *Potential for buccal expansion may be reduced with larger posterior tooth area*. Firstly, the morphology of the crown or root of posterior teeth associated with larger posterior tooth area may not allow the buccal movement of molars and the compensatory mechanism of an increase in intermolar and interpremolar widths does not operate. Secondly, there may be a difference in the path of eruption induced by a particular morphology and the posterior teeth might have less potential for buccal expansion. Thirdly, there may be an alteration in the direction of occlusal forces associated with larger posterior tooth area.

2. *Mesial migration of the posterior teeth may be accelerated*. Mesial migration may increase due to a larger posterior tooth area. This affect would not occur due to an increased bite force, but may be due to alteration in the directions of occlusal forces or due to alteration in the path of eruption of the posterior teeth.

For the posterior tooth variables in the female group, none was significantly correlated with the crowding indices. Why the posterior occlusal area in the female group showed no significant correlation with lower incisor crowding cannot be established. The ages of male and female subjects were comparable, but the crowding scores in the male group were higher than in the female group (Shah *et al*., 2003). The difference in crowding between the two groups may have resulted in different relationships.

In the literature, contact area tightness has been investigated in relation to various parameters, such as head posture, tooth type, location in the jaw and time of day (Southard *et al*., 1990; Dorfer *et al*., 2000). However, there is no literature to investigate the relationship between posterior tooth area and the contact area tightness between adjacent teeth. It would be worthwhile to investigate any association between posterior tooth occlusal area and the contact area tightness pressure, when a given amount of bite force is applied on the molar teeth and a pilot study is being currently formulated.

CONCLUSIONS

1. Image analysis is a reliable technique for measuring the area, perimeter, MD and BL dimensions of posterior teeth.
2. Lower incisor crowding was associated in this study with mandibular posterior tooth area, MD and BL dimensions in males.

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Tooth-Coding Systems in the Clinical Dental Setting

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ABSTRACT Clinical dentists have developed a variety of tooth-coding systems for efficiently recording a patient's dental status. The coding systems may not be self-evident to dental anthropologists lacking dental training. The purpose of this note is to review the tooth designation systems currently in common use. The nature of the charting systems and brief historical origins of three systems are reviewed, namely (1) the Zsigmondy-Palmer system that is becoming largely of historical interest, (2) the Universal system that is common in the United States, and (3) the FDI two-digit system that has been adapted throughout the rest of the world. Use of these three systems is described for the permanent and primary dentitions. *Dental Anthropology* 2005;18(2):43-49.

Dental anthropologists—building on classic anatomical nomenclature—have a precise lexicon of terms for designating specific teeth. There is, for example, no confusion when describing a human's "permanent maxillary right central incisor." Such labels are, however, lengthy and cumbersome, no more so than in the dental clinical setting where a dentist needs to expeditiously document voluminous details on numerous patients in a concise manner (Schwartz and Stege, 1977).

The practical need for conciseness, precision and brevity has led clinicians to develop a variety of tooth coding systems, some of which are intuitive while others are refractory without some clues. The purpose of this note is to delineate the common clinical systems of tooth coding in order to familiarize dental anthropologists with the clinical nomenclature.

Permanent dentition

It is common knowledge that the adult human dentition consists of 32 teeth arrayed into four morphological classes in each quadrant (*e.g.*, Todd, 1918; LeGros Clark, 1959). This leads to the dental formula

$$I\frac{2}{2}C\frac{1}{1}P\frac{2}{2}M\frac{3}{3} \quad \text{or, simply,} \quad \frac{2\;1\;2\;3}{2\;1\;2\;3}$$

which is a symbolic denotation that there normally are 2 incisors, 1 canine, 2 premolars, and 3 molars in each of the four quadrants of the mouth. The etymologies of these dental terms are all from the Latin. Incisor (L. incidere = to cut into) alludes to the incisors' function of incising and nipping; incisors are the "cutting teeth." Canines (L. canis = dog, hound) derives from the prominent, well-developed teeth in the family Canidae (dogs), though their value for prehension has been considerably diminished in humans, where these teeth function essentially as incisors. Most clinical dentists use the term cuspid in place of canine, since these teeth normally consist of one large primary cusp. "Premolars" merely recognizes the anatomical position of these teeth in front of the molars. Clinicians commonly use the term bicuspid in place of premolar, since these teeth commonly (but certainly not always) possess two cusps (*cf*. Kraus and Furr, 1953). Molars (L. molaris = millstone) refers to the grinding, triturating function of these teeth with their substantial occlusal surfaces.

Zsigmondy-Palmer system

The most popular system of tooth designation for much of the 20th century was developed by the Viennese dentist Adolph Zsigmondy (Zsigmondy, 1861, 1874). He broke with tradition, substituting numbers for the eight teeth in each quadrant in place of the lengthy Latin names in use to that time (Schwartz and Stege, 1977; Peck and Peck, 1993). The correspondence is:

1 .... Central incisor
2 .... Lateral incisor
3 .... Canine (cuspid)
4 .... First premolar (bicuspid)
5 .... Second premolar (bicuspid)
6 .... First molar
7 .... Second molar
8 .... Third molar (*dens sapientiae*; wisdom tooth)

Zsigmondy combined his tooth numbering system with a graphical device to specify the quadrant of the mouth. An L-shaped mark (└) was used, with the

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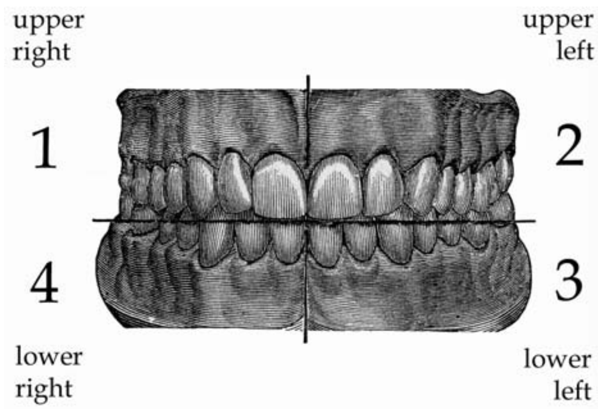

Fig. 1. Facsimile of a diagram by Palmer (1891) showing the division of the dentition into four quadrants. The vertical and horizontal line segments are used in this charting method to specify a tooth's quadrant. Facing the patient, as here, the quadrants are numbered clockwise from the upper left of the figure, so the *patient's* quadrants are (1) upper right, (2) upper left, (3) lower left, and (4) lower right.

vertical line segment being the subject's midline and the horizontal segment his occlusal plane that separates the upper and lower arcades. The clinician could, then, easily code a specific tooth, such as the lower left canine ┌3 or the upper right first molar 6┘. Confusion is pretty much limited to the novitiate's need to remember that the codes refer to the *patient's* left or right side.

History then becomes a bit conflicted because the Ohio dentist Corydon Palmer (Palmer, 1870, 1891) argued for his independent invention of the same coding system. Palmer contended that the natural division of the dentition into quadrants was a well-known, obvious device (Fig. 1). Indeed, Palmer was quite testy in his 1891 paper that he be given all credit for the scheme's development (Fig. 2). The quadrant is denoted by the shape of the symbol, like ┌ for mandibular left, and the tooth position is numbered from 1 (central incisor) through 8 (third molar). The scheme has a naturalness and simplicity such that independent invention seems probable. In any event, most American dentists have been taught the notation as being Palmer's (though also termed the "quadrant system" by some; Sharma and Wadhwa, 1977). The Palmer system also has been labeled the "angular system" and the "grid system" because of the horizontal and vertical line segments that denote the tooth's quadrant.

The obvious down-side of the Zsigmondy-Palmer notation is that, while it is easy to sketch the tooth codes in a patient's record, it is tedious to type or verbalize them. For instance, there is no word for the symbol ┌ or ┘. Gustafson (1966), O'Connor (1983) and others have commented that Palmer's angle symbol denoting side and arch probably was the system's undoing. While it is no effort at all to jot down ┌5 or 7┘ in a patient's record, there is no natural analog for ┌3 with an embedded digit on a typewriter or word-processor. Indeed, it was the need to computerize the dental recording system that marshaled-in the FDI system—and incidentally promoted the use of the Universal system in the United States. Coding a tooth numerically, as #16 or 28, lends itself to word processing.

Desiderata

There are a few other items of note that developed contemporaneous with Zsigmondy and Palmer but do not warrant full-blown descriptions here. The Latin terms

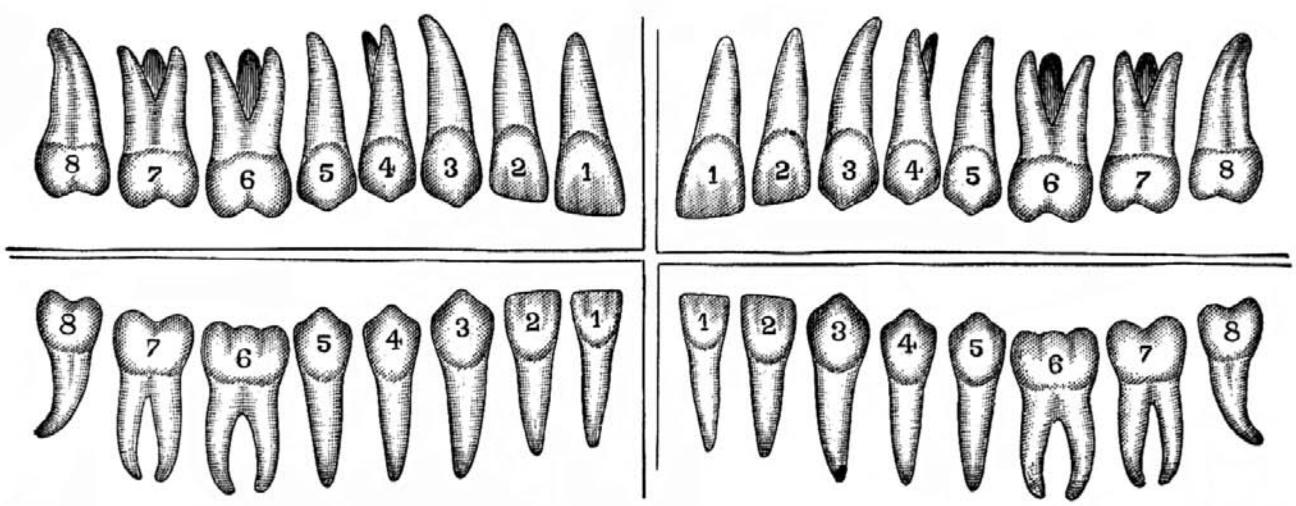

Fig 2. The Zsigmondy-Palmer tooth designation system, where lines define the four quadrants and the teeth are numbered from 1 to 8 in each quadrant (modified from Palmer, 1891).

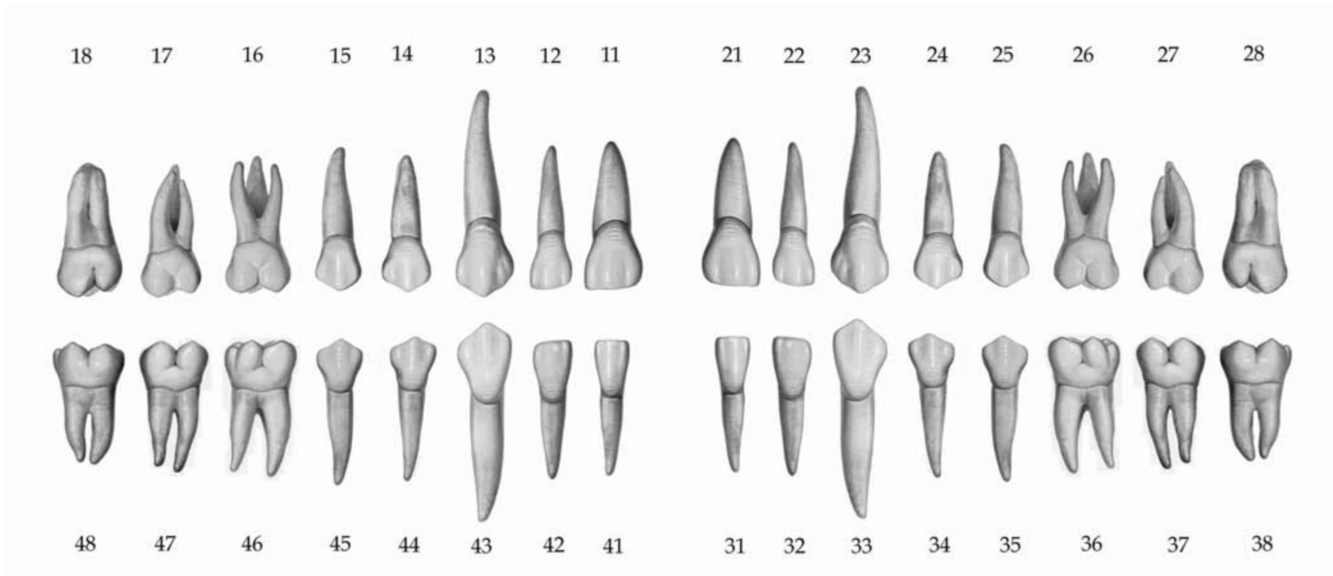

Fig. 3. The FDI two-digit scheme for tooth designations of the permanent dentition. The view is oriented as if you are looking at the subject, so the person's right side (quadrants 1 and 4) are to the left of the page.

superiore (*sup.*) and *inferiore* (*inf.*) will be encountered in the older literature, referring to the maxillary and mandiblar jaws, respectively. Likewise, the Latin words *dextral* (*dext.*) and *sinistral* (*sin.*) commonly were used to denote a tooth in the right or left arcade, respectively. So, for example, de Terra (1905:5) uses the code "I1 *sup. sin.*" to denote the maxillary left I1 (central incisor).

Also, Haderup's (1891) tooth designation system experienced popularity for some decades after its introduction. In place of Zsigmondy's angle (*e.g.*, ┌), Haderup used a plus sign (+) to denote a maxillary tooth and a minus sign (–) for a mandibular tooth, and the sign was placed mesial to the tooth being referred to, so a right upper second molar would be 7+ and a left lower first premolar would be –4.

FDI system

Dentists throughout the world—notably excepting the United States—now use the FDI two-digit system (Fédération Dentaire Internationale). This scheme was developed by a "Special Committee on Uniform Dental Recording" and passed as a resolution of the FDI General Assembly at its 1970 meeting in Bucharest, Romania (Keiser-Nielsen, 1971a,b,c). While the FDI labeled this the "Two-Digit System," it is more commonly referred to as the FDI system. It is useful to consider the five crite-

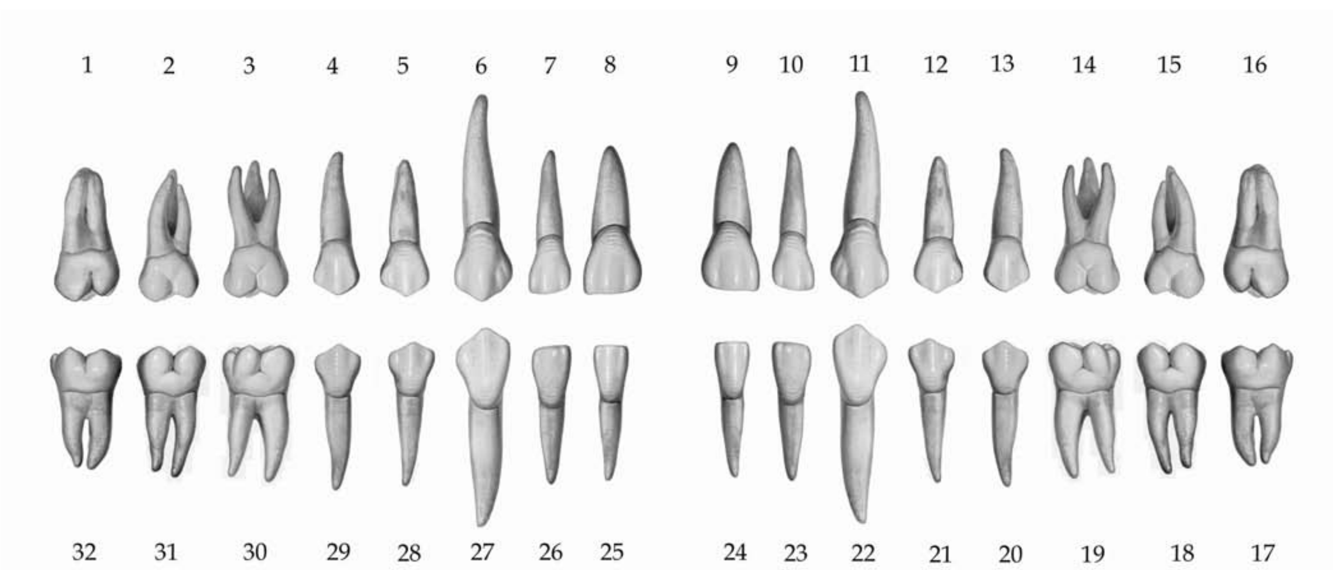

Fig. 4. The Universal scheme for tooth designations of the permanent dentition.

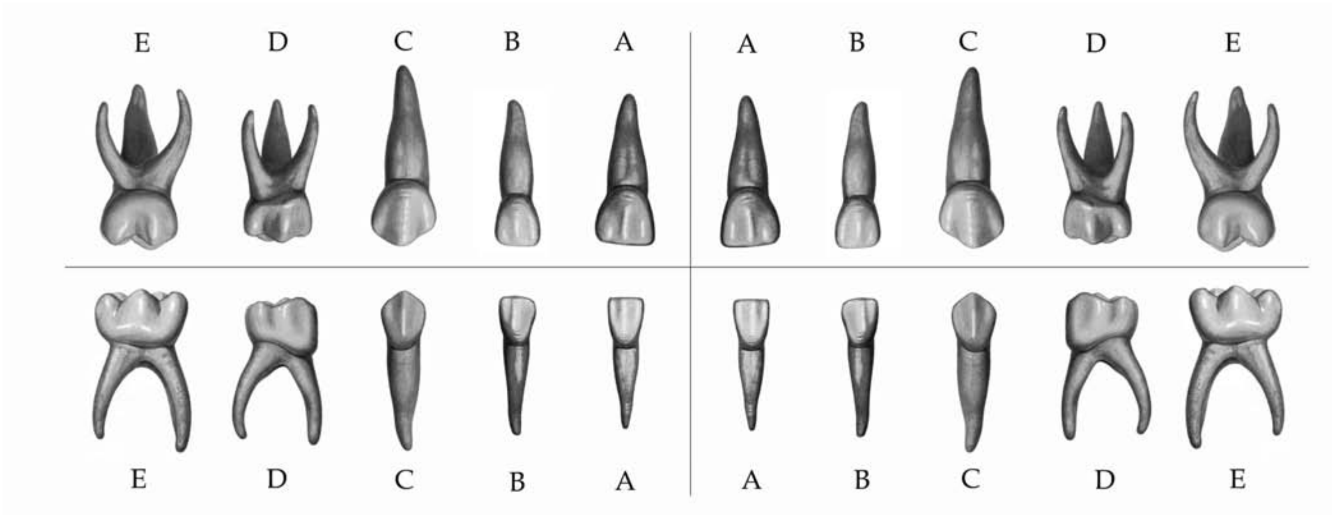

Fig. 5. The Palmer tooth designation system for the primary dentition. The five tooth types in each quadrant are denoted by letters. The quadrant is coded by using the symbol ⌋, ⌊, ⌉, or ⌈.

ria that, according to the Committee, are attained by this two-digit system of designating teeth:

1. Simple to understand and to teach.
2. Easy to pronounce in conversation and dictation.
3. Readily communicable in print.
4. Easy to translate into computer output.
5. Easily adapted to standard charts used in general practice.

As diagrammed in Figure 3, the first digit denotes the quadrant of the mouth, the second digit defines the tooth's normal position in the mouth, front to back.

In all of these systems, the tooth's "number" is its normal, expected position in the arch. Expectation is that there are two incisors, one canine, two premolars, and three molars in each quadrant. "Missing" teeth (due to congenital absence, impaction, extraction, *etc*.) are taken into account when identifying a tooth's number. When a tooth is not present, its designation has to be determined from the positions of the extant teeth. For example, permanent mandibular second premolars are congenitally absent in roughly 3% of modern humans (Stritzel *et al*., 1990; Larmour *et al*., 2005), but determination of whether it actually is the first or second premolar that is missing in a particular case depends on the clinician's differential diagnosis based on teeth that are present and related criteria. Conversely, there is no accommodation in any of these systems for supernumerary teeth; these rare events are simply written-out in the chart.

Most dentists, as with most dental anthropologists, are right handed, so quadrant 1 (maxillary right) is closest to the dentist when examining a patient and is scored first, then the upper left quadrant, then one drops down to the lower left quadrant, finishing with teeth in the lower right quadrant (Fig. 1). More formally, the quadrants are numbered "in a clockwise sequence … starting on the upper right side" when viewing the subject from

Upper Right															Upper Left
			E	D	C	B	A	A	B	C	D	E			
8	7	6	5	4	3	2	1	1	2	3	4	5	6	7	8
8	7	6	5	4	3	2	1	1	2	3	4	5	6	7	8
			E	D	C	B	A	A	B	C	D	E			
Lower Right															Lower Left

Fig. 6. Arrangement of the permanent tooth codes in the Zsigmondy-Palmer system along with the corresponding codes (letters) for the primary teeth. Such a chart is commonly found in older dental settings (Sharma and Wadhwa, 1977), though it is being upgraded to the more easily computerized Universal or FDI systems.

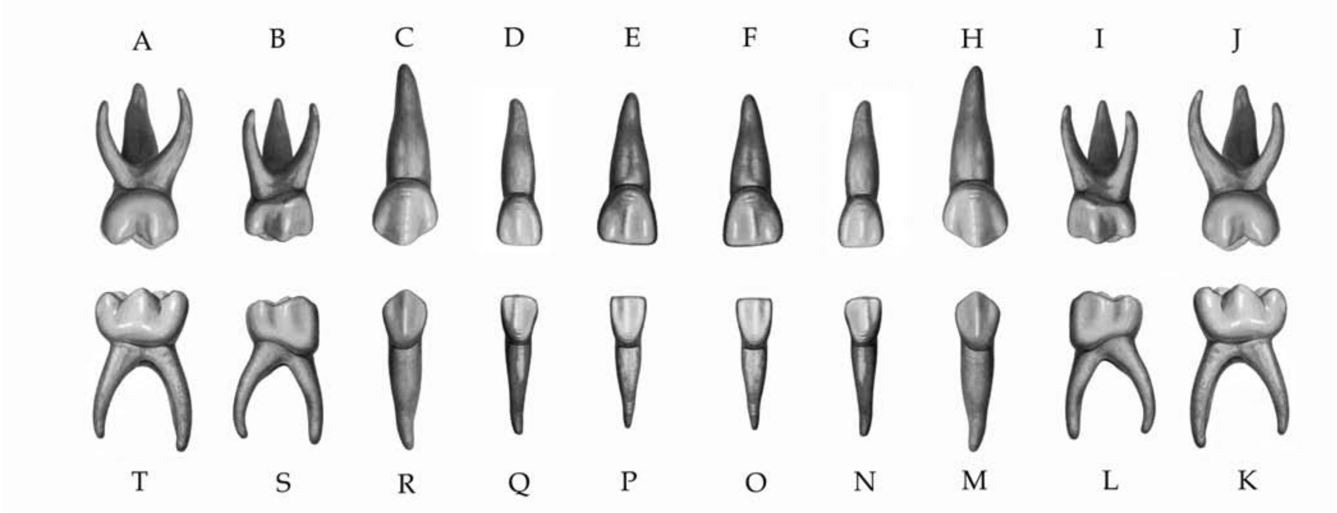

Fig. 7. The Universal system for the primary dentition, coding each tooth with a letter. As with all of these systems, the orientation refers to the *patient's* own right and left sides, so the patient's maxillary right quadrant is to the upper left of this diagram.

the front (Keiser-Nielsen, 1971a:105). This is to say that the upper right side (quadrant 1) is the *patient's* upper right side. The FDI's description also suggests how to verbalize the system, namely "The digits should be pronounced separately; thus, the permanent canines are teeth one-three, two-three, three-three, and four-three" (1971a:1034).

The FDI committee fully recognized that it was combining Zsigmondy-Palmer's tooth numbering system with the prefix number denoting the quadrant. The committee termed this a "compromise" system. The committee also pointed out that its quadrant-numbering sequence adopted the same pattern used by the Universal system, making it familiar to U.S. dentists. With this logical system, there is no ambiguity as to side, quadrant, or arcade.

Universal Numbering System

What has become the Universal system was proposed by J. Perreidt in 1882. Perreidt disliked the redundancy and potential confusion of Zsigmondy's use of tooth numbers 1 through 8 in all four quadrants. Instead, he numbered the permanent teeth 1 through 32, starting at the upper right and continuing to the upper left, then the lower left to the lower right (Fig. 4). The main benefit is that Zsigmondy and Palmer's angular symbol (└) is irrelevant, each tooth having its unique numerical designation.

Today, the "Universal"system of tooth-coding is an interesting misnomer, because it is only used in the United States. The ADA (American Dental Association) by a unanimous decision of its Council on Dental Care Programs adopted the Universal System of numbering teeth on April 18, 1975 (Schwartz and Stege, 1977). Numerous dentists subsequently have editorialized about the unnatural, illogical nature of the Universal system—not to mention the unheeded complaints from fledgling dental students. The universal system is disarmingly simple in concept, just number the 32 permanent teeth from 1 through 32 (Fig. 4). The difficulty is in learning to associate specific teeth with their numbers. Once learned, of course, the system is effortless. Starting with the third molar in the upper right quadrant (tooth #1), the teeth are numbered around the arch so the maxillary left third molar is tooth #16. One then drops down to the mandibular left third molar (#17) and numbers the teeth around the lower arcade, finishing with the mandibular right third molar (#32).

There is no easy way to relate these 32 numbers to the natural, anatomic arrangement of the teeth. There is, for instance, no way to know intuitively that the second premolars are #4, #13, #20 and #29. One simply has to learn the system by rote. The compelling value of the Universal system (as with the FDI system) is the ease of computerizing the data, which is its singular selling point for automating office systems ("paperless offices"), completing insurance and other third-party reimbursement forms (certainly a financial incentive), and accelerating communication (providing that both parties understand the codes).

With both the FDI and Universal systems, each tooth has a unique identifier. This can be invaluable when irreversible procedures such as extractions or endodontic treatment are requested by one dentist from another.

Primary dentition

The primary teeth are ephemeral in that they only

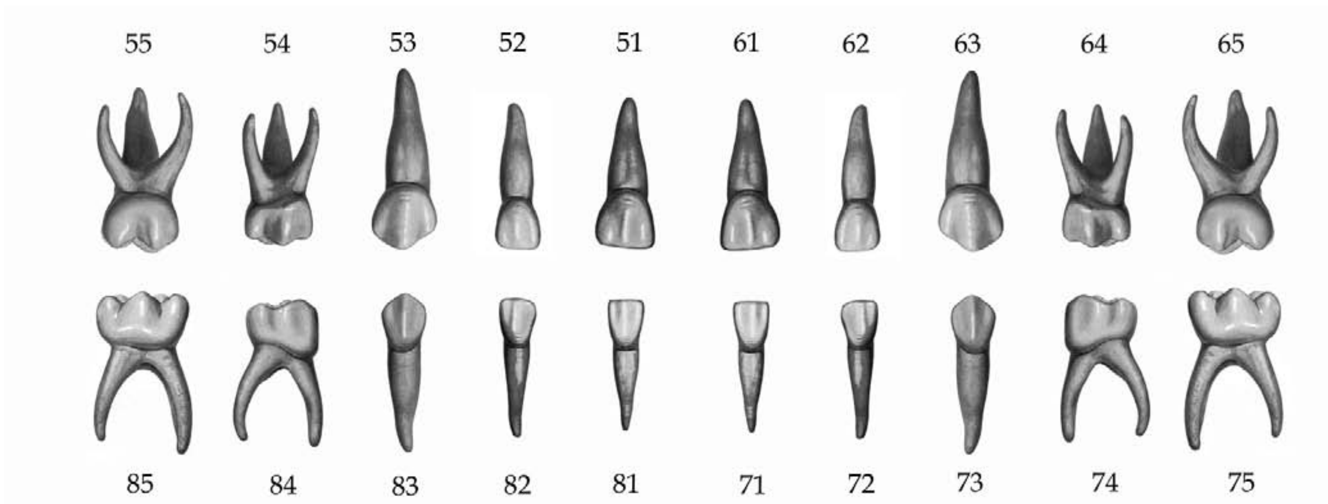

Fig. 8. The FDI system for the primary dentition. Quadrants for the primary dentition are numbered 5 through 8. Quadrant numbers 1 through 4 are used for the permanent dentition, primarily because the dentist's attention on the permanent dentition is so much greater than with the primary dentition.

need to function for a few years before being replaced by (generally) larger and better-constructed permanent teeth with greater longevity. Typically, the first primary teeth (the incisors) erupt through the oral mucosa at 7 or 8 months of age (*e.g.*, Tanguay *et al*., 1984), and the last primary teeth are exfoliated around 12 years of age, when the primary molars are replaced by the permanent premolars (*e.g.*, Hurme, 1949; Moorrees *et al*., 1963). There are 20 succedaneous permanent teeth that "succeed" and replace the 20 primary teeth; the three permanent molars in each quadrant erupt distal to the primary teeth, so they are additional rather than replacement dental elements. "Primary" would seem to be the preferred term here, but common synonyms are the deciduous teeth, the baby teeth, and the milk dentition. Morphologically, the 20 primary teeth are categorized into three tooth types, incisors, canines, and molars, with the dental formula of 2:1:2 in each quadrant. Fewer clinical coding systems have been developed for the primary dentition, but there still are plenty to provide confusion for the uninitiated. The three systems analogous to those described above for the permanent dentition are presented here.

Palmer analog. Letters have commonly been used to denote the primary teeth; some systems use lower-case letters (perhaps mimicking the subadult nature of these teeth; Churchill, 1932), but capital letters are encountered more often (Fig. 5). Again, the side and arcade are denoted by line segments: $\underline{\text{B}|}$ is the maxillary right lateral incisor, and $\overline{|\text{E}}$ is the mandibular left second molar.

Primary teeth have also been designated by Roman numbers (I—V), which can further confuse the novice (Churchill, 1932; Sharma and Wadhwa, 1977), particularly since still other systems have used Roman numerals to designate quadrants in the permanent dentition. A chart as in Figure 6 commonly is used in dental offices, and inspection shows that the numerals conform to Palmer's notation for the permanent teeth. while the capital letters are for the primary teeth.

Universal system. The 20 primary teeth are coded alphabetically from A through T (Fig. 7). There is no anatomic parallel with this system. One simply has to memorize the system by rote. If using this system infrequently, it helps to remember that A, J, K and T are the second molars (at the distal ends of the quadrants) and that E, F, O and P are the central incisors. Since there are only five teeth per quadrant, one can generally visualize the other tooth codes.

FDI system. So much clinical attention is spent on the permanent teeth that they are coded as quadrants 1 through 4. The convention is to use numbers 5 through 8 to code the four primary quadrants even though they develop first (Fig. 8). This numerical oddity was the subject of considerable discussion by the FDI committee, but it was reasoned that, "mainly because deciduous teeth function for such a short time in comparison with permanent teeth that the bulk of dental data to be collected and computerized in the future would obviously concern permanent teeth" (Keiser-Nielsen, 1971a:1035).

Overview

There are two major motivations to develop a tooth-coding system. One is to conserve energy and communicate telegraphically. Writing or speaking (or typing) "the permanent mandibular right second premolar" is much more taxing than referring to this tooth as #29 or 45, especially if teeth consume one's professional life. There is the need to be specific but also to be as concise as practical. The other, recent driving force is to computerize ever-increasing masses of data, and numeric codes (and their alphabetic equivalents) lend themselves to this end. The greatest emphasis has been from third-party payment systems with the need for the dentist to code the services rendered for reimbursement.

One minor spin-off of the trend toward globalization is the need for standardization—so all of the participants understand the same set of "rules" and can communicate effectively. The FDI system seems to be the solution in terms of dental-coding systems. This leaves the U.S. "Universal" system as an anachronism, but it doubtlessly will persist as a system paralleling the FDI system until the U.S. also converts to the metric system—which is moving glacially, at best. In scientific circles, though, an increasing number of dental journals is requiring its authors to use of the FDI system for tooth designations.

Only the three most common and long-lived systems are described here. Numerous others have been proposed and may be encountered (see reviews in Gustafson, 1966, and Schwartz and Stege, 1977).

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A Brief Survey

G. Richard Scott and I are updating the history of dental anthropology that appeared in our 1988 review article on dental anthropology in the *Annual Review of Anthropology*, and in the history section of our 1997 book, *The Anthropology of Modern Human Teeth*. We would like to add a table indicating who is teachin dental antrhopology and where the courses are being taught. The *Dental Anthropology Association* membership seems like the best group at which to direct such an inquiry.

If you have in the last 15 years taught a course titled dental anthropology, or an anatomical or osteological course with a significant dental anthropology component, could you please let us know. You can either e-mail me, or fill out the enclosed questionnaire. If you use the questionnaire, please return to Dr. Christy G. Turner II, 2208 N. Campo Alegre Dr., Tempe, AZ 85287-1105. In the latter case, if you have a short syllabus, we would be grateful to have a copy.

Thank you.

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Biomechanical Analysis of the Canine Tuberculum Dentale

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ABSTRACT We evaluate the structural significance of the development of a canine tuberculum dentale by means of three-dimensional finite element analysis. Using a scanned human permanent canine, we construct a computer generated canine, together with alveolar bone and periodontal ligament onto which we morph two cingulum shapes, namely a flat palatal surface and a stylised tuberculum dentale. We then subject the three shapes (flat, normal cingulum, and pronounced tuberculum dentale) to a normal occlusal force and we record principal and von Mises stresses in the crowns. Our results show that stresses are concentrated at the cingulum and in the approximal areas, and that these do not differ between the three forms. We conclude that the development of a tuberculum dentale does not confer biomechanical advantage to the human canine. *Dental Anthropology* 2005;18(2):50-54.

The canine tuberculum dentale is a cingular derivative found on the lingual surface of the maxillary anterior teeth (Scott and Turner, 2000). It varies in expression from a low ridge to a well-formed cusplet (Hillson, 1986). While a number of studies have reported on its incidence and expression in modern and archaic populations (*e.g.*, Scott and Dahlberg, 1982; Cucina *et al.*, 1999; Bailey, 2000), to the best of our knowledge none has focused on its biomechanical significance. In this paper, we use three-dimensional finite element analyses on two canines, one with and one without a tuberculum dentale, morphed from a scanned image of a human upper canine, to investigate whether this trait plays a significant role in the structural response of the tooth under functional loading.

MATERIALS and METHODS

Source model and morphing

We scanned a human permanent upper canine, extracted for periodontal reasons, on a micro-CT scanner (SkyScan 1072 system). The sections were taken at 15-micron intervals, yielding a stack of 1954 slices. Using in-house software, an initial assembly of two meshes of the surfaces and interfaces of the canine was generated. The result was an initial surface mesh that enclosed the volumes of enamel and dentine. The root cementum layer was not modeled because of its particularly small dimensions and the limited relevance for our study.

We then morphed two crown shapes, one with a stylized tuberculum dentale and the other with a flattened palatal surface. Morphing was carried by simultaneously displacing the vertices of the outer and inner surfaces of the enamel volume and keeping the enamel thickness in the morphed models similar to that of the original scanned tooth. Hence, three geometrical tooth crowns were generated this way: a source model constructed from the micro-CT data, a model with a stylized tuberculum dentale and model with a flat palatal shape.

Finite element models

After applying the surface meshing we performed a NURBS conversion (Non-Uniform Rational B-Splines) that defined the respective solid volumes for each of the three models. This was done by patching, using a feature available with a general purpose CAD software (Smurf for Rhinoceros 3D for Windows, Robert McNeel and Associates, USA). Patching consisted of applying quadrilateral NURBS onto the surface of the mesh, hence covering the original mesh with tiles of rational surfaces with tangent continuity that are later joined into closed solids.

Two matching bodies were thus been created, one representing the enamel and the other the dentine, in contact along the entire dentinoenamel junction. For reasons of computational-efficiency, the anatomic roughness of this junction, well captured on the CT reconstruction was neglected and a smoother junction created.

The pulp space was modeled as a void inside the dentine volume, because its Young's modulus is negligibly small compared with that of the surrounding enamel and dentine (Hojjatie and Anusavice, 1990).

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TABLE 1. Material properties used in the present FEA analysis (O'Brien, 2002)

Tissue	Elastic modulus	Poisson's ratio
Enamel	130 GPa	0.3
Dentine	14.7 GPa	0.3
Periodontal ligament	12.0 MPa	0.45
Alveolar bone	490 MPa	0.3

We then simulated the periodontal ligament creating a uniform 0.3 mm shell around the root, and also a bone supporting volume to receive the socket thus created. The upper limit of the bone was set 2 mm below the cervical line of the tooth, thus simulating the actual anatomic situation (Schroeder, 1991).

A 2.3 mm^2 loading area was defined on the crown, circumscribing a hypothetical palatal wear facet where the lower canine occluded. The high-fidelity shape generated from micro-CT allowed an easy recognition of the wear facets and a realistic placement of functional loading was achieved. The loading area was positioned identically in all three models.

The resulting geometric assemblies were imported into general-purpose FEA software (Cosmos DesignStar, Structural Research and Analysis Corp., USA) and meshed using parabolic tetrahedral solid elements. This yielded 62,925 elements for the flat cingulum model, 62,964 elements for the unaltered shape and 63,010 elements for the prominent cingulum model.

The models were rigidly restrained along the lateral and basal surfaces of the bone with the tooth free to move within the defined periodontal space. We assigned isotropic homogenous materials properties for the enamel, dentine and cancellous bone as described in the literature (Table 1). It is known that the tooth structures are made of non-homogenous and anisotropic materials yet the regional property variation is restricted to a microscopic scale and comparisons with real physical specimens have shown that the material behavior is elastic during functions (Kinney *et al*., 1999; Qin and Swain, 2004).

The periodontal ligament was assumed to be a linear elastic material with an elastic modulus of 12 MPa and Poisson's ratio of 0.45. We obtained these values in a preliminary analysis by steadily increasing the elastic modulus of the material until the unaltered canine intruded 0.3 mm under an axial load of 300 N. This mobility was employed to fit previous in vivo mobility data reported in the literature (Muhlemann, 1967). Because this showed that during incision the canine cingulum area was stress-free, we discarded this loading case. Therefore only the palatal contact was prescribed as the loading condition, simulating the occlusion, with the force acting on the previously defined areas.

Because no data were available for the contact angle between the upper and lower canines, we approximated this to be 160º based on the angle of the incisors (Milot and Stein, 1992). The biting force was estimated at 200 N (derived from Miyaura *et al*., 1999) for all three cases. We then assessed the principal stresses (σ_1 and σ_3) and von Mises stresses for each loading case.

RESULTS

For a given loading case, the stress analysis results show that the modest tuberculum dentale shape has little influence if any, upon the structural loading of the canine crown. First principal stress plots reveal two areas of high tension in all three models which are located

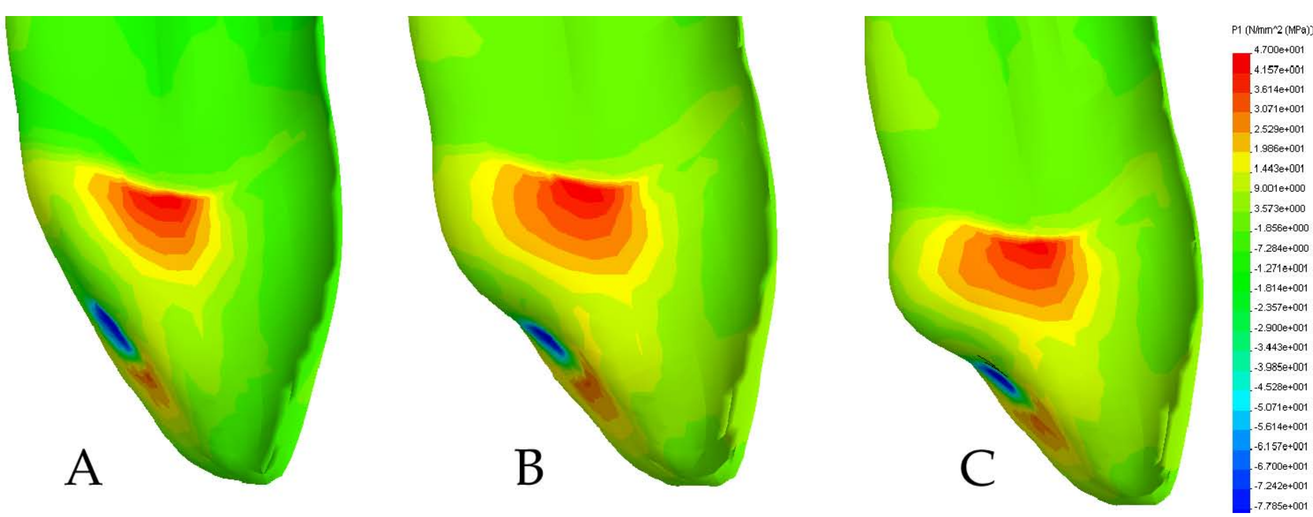

Fig. 1. First principal stress in (A) flat palatal surface, (B) normal, and (C) stylized tuberculum dentale models. Note the constant distribution of tensile stresses on the proximal surfaces of the crown, adjacent to the cementoenamel junction.

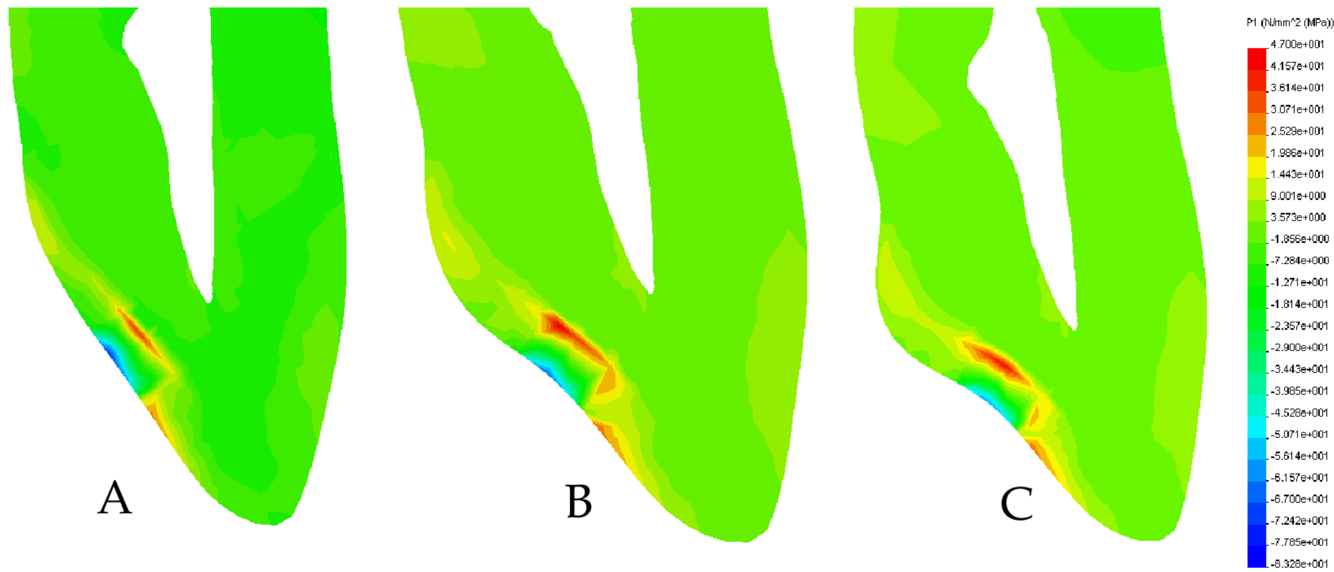

Fig. 2. Axial section plots in (A) flat palatal surface, (B) normal, and (C) stylized tuberculum dentale models.

on the proximal surfaces, close to the cementoenamel junction. The values of this proximal tensile stress are close to the reported ultimate tensile strength of the enamel (Fig. 1).

An axial section shows that tensile stresses follow a similar path in all three canine shapes, with a high of 38-43 MPa located under the loading area, on the dentinoenamel junction. Tensile loading on the cingulum area increased from 17 MPa in the flat shape to 14 MPa in the normal cingulum and 11MPa in the tuberculum dentale shape (Fig. 2).

The third principal stress analysis reveals that the compressive stress is located on the buccal half of cervical margin and also at the loading point. The numerical values were similar for all three cases ranging from 47 to 50 MPa (Fig. 3).

Von Mises stresses show a similar pattern in all three models, with two main concentration areas, one along the cervical margin and the other on the loading sites. However, a small decrease in von Mises stresses is recorded parallel with the increase in size of the tuberculum dentale (Fig. 4).

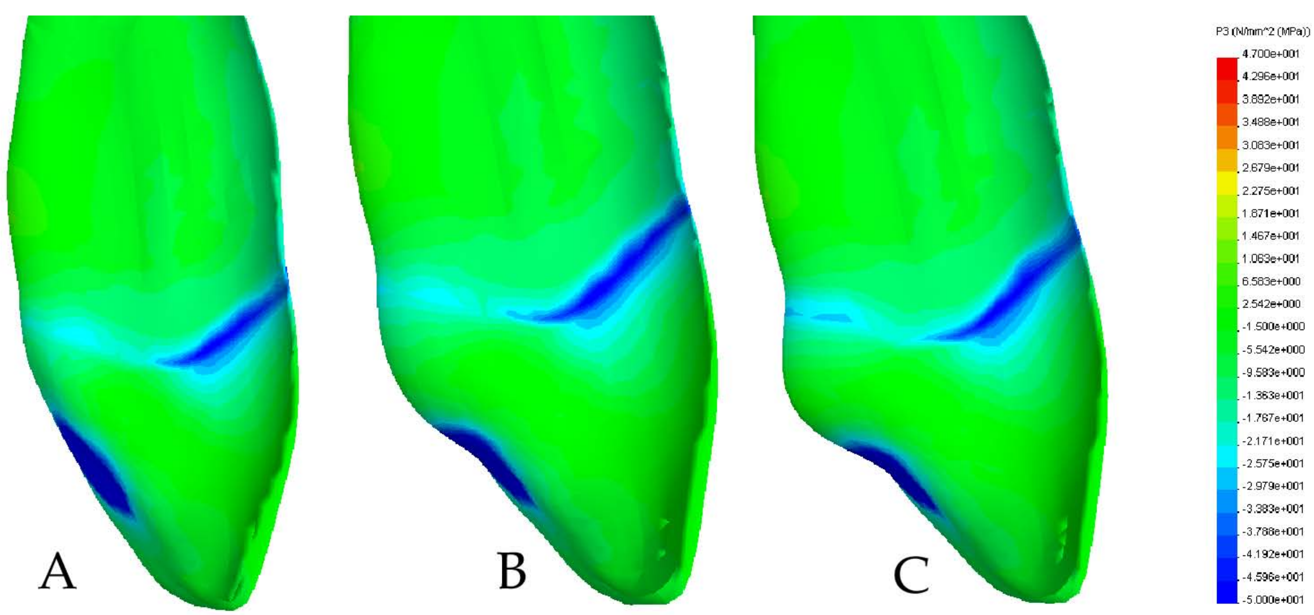

Fig. 3. Axial section plots of the third principal stress in (A) flat palatal surface, (B) normal, and (C) stylized tuberculum dentale models. The distribution of the compressive loading on the buccal half of the CEJ is evident.

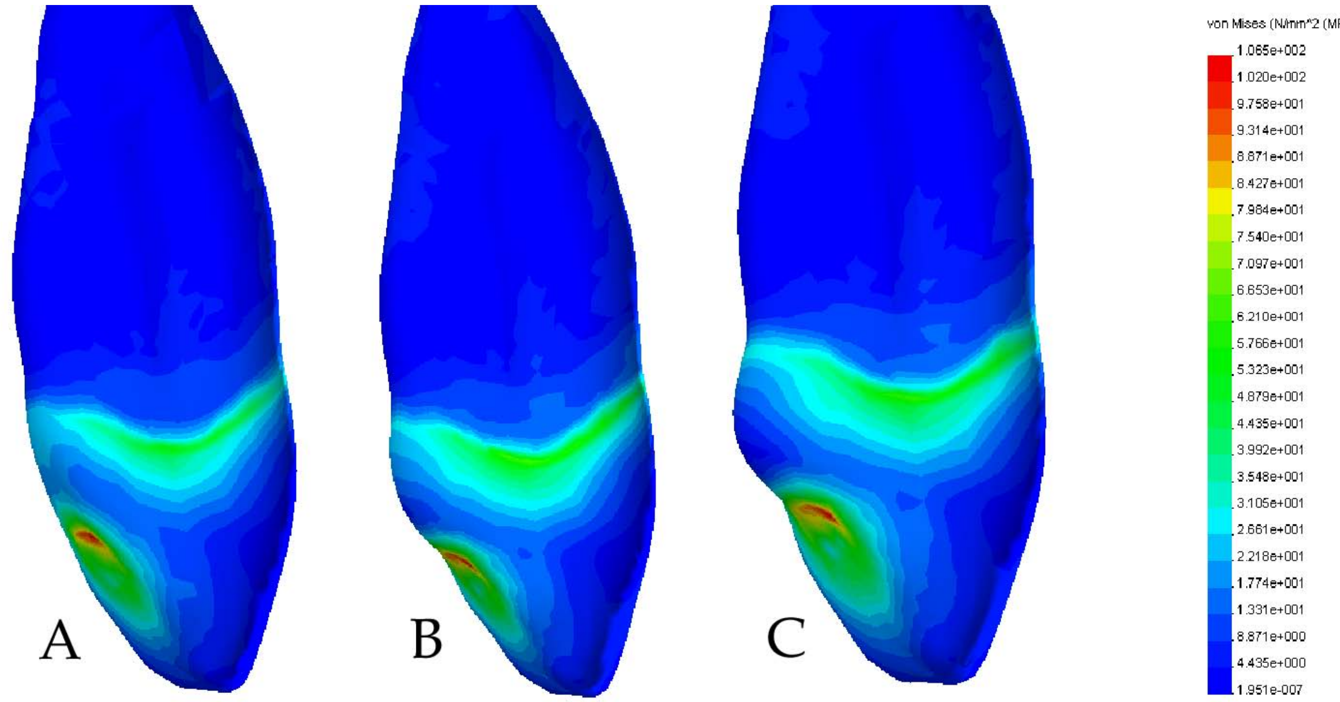

Fig. 4. Von Mises stresses in the (A) flat cingulum, (B) normal, and (C) prominent cingulum models.

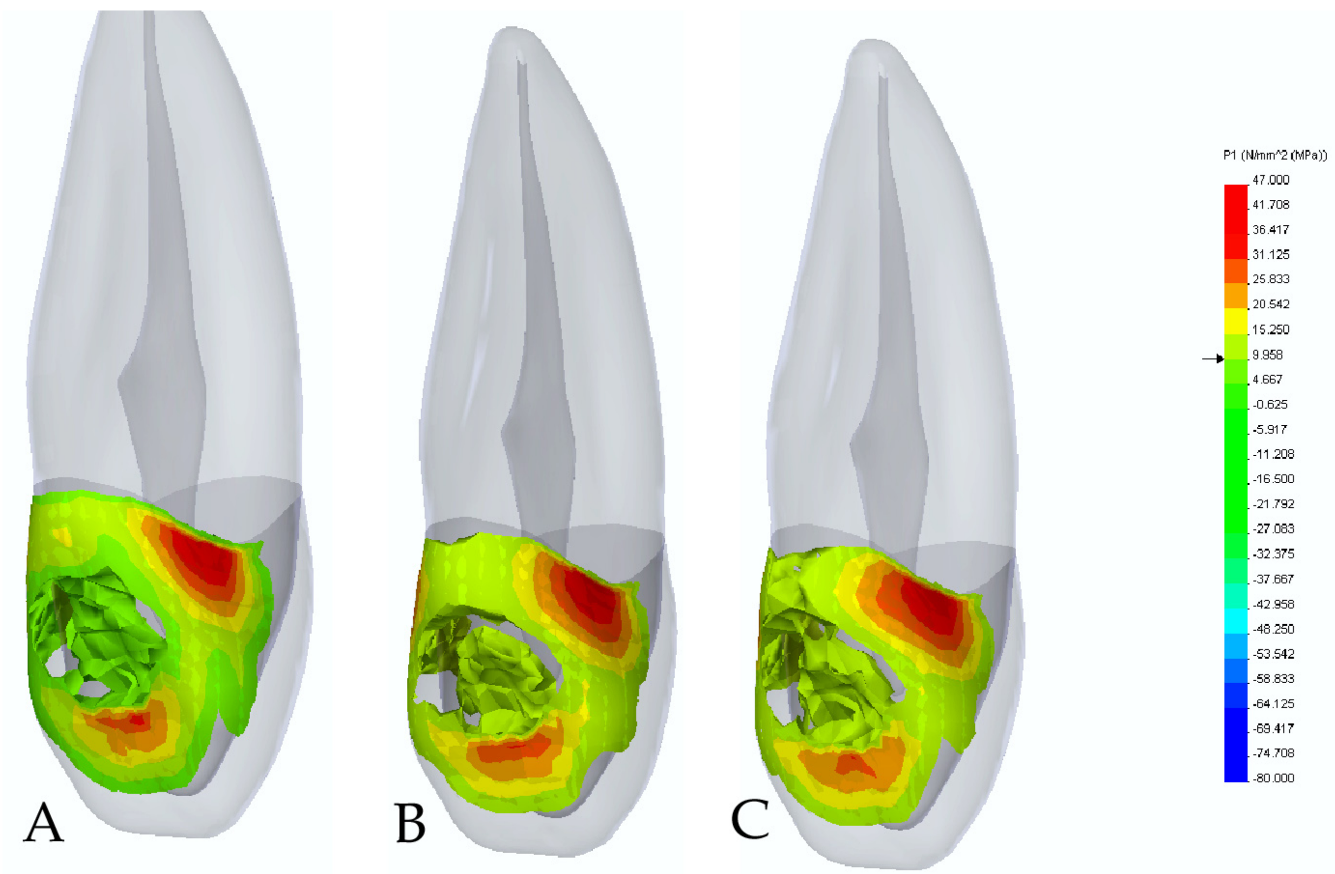

Fig.5. The "resistance frame" inside the crown showing the volume that will experience tensile stresses over 10 MPa. Note the hoop-like shape and the maximal tensions on the proximal surfaces.

DISCUSSION

Recently, Bailey (2000) presented data on a number of dental non-metrical traits to ascertain relationships among early and recent human populations. One of her interesting findings is that Neandertals showed an average frequency of 87.5% for the tuberculum dentale, which contrasts sharply with trait frequencies in British (25.5%) and North African (38.8%) populations. This is not surprising, given the numerous craniodental and postcranial differences in robusticity reported between Neanderthals and modern humans (*e.g*., Rak, 1986; Stringer and Gamble, 1993; Holliday, 1997). The question now arises, does the tuberculum dentale confer additional robusticity to the typical Neanderthal canine?

In this paper we test the hypothesis that the tuberculum dentale plays a significant role in the structural response of the canine tooth under functional loading. To this end, we compare the numerically determined values of three different shapes of the canine cingulum area under identical loading conditions. For each crown form, we analyze the loading case, the principal stresses, σ_1, σ_3 and von Mises stresses.

We show that compressive stresses are located mainly on the buccal side, along the cementoenamel junction, with determined values well within the biological material safety limits of enamel (Figs. 1, 2). Tensile and von Mises stresses are dominant on the cervical third of the lingual aspects of the crown in each of the three morphological shapes (Figs 3, 4), again with minimal differences between cingulum forms. This strongly suggests that the tuberculum dentale does not in fact strengthen the canine under occlusal loads.

The tensile stress analysis allows for a "resistance frame" to be defined inside the crown which shows the part of the structure that is experiencing the greatest tension (Fig. 5). In structural terms, this frame will provide stiffness to the crown.

The frame thus generated encircles two-thirds of the cervical contour on the lingual aspect of the tooth and extends towards incisal surface, along the marginal ridges of the crown. Neither the locations nor the intensity of the peak tensile stresses are affected by differences in the development of the canine cingulum. Again, this supports the suggestion that the tuberculum dentale does not play a significant role in the structural response of the canine tooth under functional loading.

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Dental Indications of Polynesian Affinity for Prehistoric Rotuma Islanders, South Pacific

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ABSTRACT Human skeletal reburial, reasonable from a religious and personal point of view, nevertheless diminishes the physical record of human evolution. The present study preserves some information for a small but rare Pacific Basin skeletal assemblage. Prehistoric human tooth-bearing cranial and jaw fragments and loose teeth of probably 19 individuals excavated on Rotuma Island were examined for crown and root morphology. The purpose of the examination was to assess whether these individuals were morphologically more like Melanesians or Polynesians. Rotuma is in the Polynesian culture area north of the Fiji group, which exhibits archaeological and ethnographic evidence of colonists from both Oceanic populations. Polynesians belong to the Malayo-Polynesian language family, so if the Rotuma teeth are similar to Polynesians they should also be more similar to Southeast Asian teeth than to those of linguistically different Melanesians or Australians. Indeed, this seems to be the case, although the small Rotuma sample size reduces confidence somewhat in this finding of Rotuma similarity with Polynesians and Southeast Asians. *Dental Anthropology* 2005;18(2):54-60.

This note is based on observations made on a small sample of prehistoric human teeth from excavations on Rotuma Island submitted to the author for analysis by Richard Shutler, Jr. He and Jamie Evrard directed test excavations in June and July, 1981, one resulting in the recovery of human remains from ROT 2-9, an archaeological site in the Oinafa District location called Risumu on the east end of Rotuma Island. Rotuma is remotely located in the mid-Pacific. Volcanic in origin and only 25 km^2 in area, it is in the western Polynesian Outlier culture division of Oceania at approximately 12˚ 25′ S and 177˚ 5′ E. The Risumu site is the legendary landing place of the first immigrants, supposedly from Tonga, who are said to have arrived about one thousand years ago (Shutler and Evrard, 1991:136). The people of Tonga are Polynesians, and the present-day Rotuma islanders speak a language that is classified as Polynesian, although its exact genetic relationship to other Polynesian languages is unclear (Shutler, 1998: 252). Melanesian populations occupy the Solomon Islands to the west and Fiji to the south, whereas Polynesians are settled on Samoa to the east. The human remains were found in a burial mound (Rot 2-9, test 4, level 4) at a depth of 90-100 cm. There were no cultural remains associated with the human teeth and bones. This small but geographically rare assemblage has since been reburied after study. However, before reburial Shutler had a sample of the human bone dated in the carbon 14 laboratory on his campus at Simon Fraser University, Burnaby, British Columba, Canada. The assay (SFU-118) produced an uncorrected date of 1,000 BP ± 100 radiocarbon years (Shutler, 1998).

MATERIALS AND METHODS

The number of Rotuma individuals based on maxillary teeth is 14; mandibular teeth, 17; maxillary and mandibular, 18; probable total, 19. Following standardized observation and scoring procedures for non-metric dental traits (Turner *et al.*, 1991), crown and root morphology was analyzed by univariate and multivariate statistics to estimate Rotuma's phenetic dental relationships with selected comparative populations. The regions chosen for comparison were (1) South Pacific, because of geographic proximity; (2) Southeast Asia, because of ultimate linguistic homeland; and (3) Native America because of T. Heyerdahl's (1952) hypothesis that Polynesians originated from the Americas. Although large samples are always desired in assessing affinity for archaeologically-derived and usually incomplete and fragmentary skeletal samples, it appears that the Rotuma series is adequate for moderately confident inferences about probable past inter-group relationships. The ten comparative dental series used to identify Rotuma relationships are part of the published and unpublished data base in the author's computer and other files. The traits selected for comparison are those that occur most frequently in the Rotuma series. Incisor shoveling, for example, was used because some teeth are present with, and have limited wear of, the trait that permits confident scoring,

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TABLE 1. Dental trait frequencies in Rotuma and comparative series

Tooth	Trait	Break Point	Rotuma	. Marques.	Tahiti	Easter Island	Guam	New Britain	Australia	Thailand	Indonesia	Peru	NW Coast
UI1	Winging	1/1-4	50.0 (2)	16.0 (50)	– (0)	– (0)	18.2 (22)	25.0 (112)	13.3 (30)	31.0 (42)	14.8 (61)	83.7 (49)	33.3 (66)
UI2	Shovel	2-7/0-7	66.7 (6)	41.5 (70)	100.0 (1)	0.0 (1)	50.0 (34)	21.6 (130)	45.8 (24)	60.4 (48)	67.3 (58)	97.7 (43)	96.8 (63)
UI1	Dub-shov.	2-6/0-6	50.0 (4)	9.4 (64)	0.0 (1)	– (0)	5.6 (36)	3.7 (107)	7.4 (27)	12.5 (48)	30.5 (59)	93.8 (16)	51.0 (49)
UI2	Tub. dental	+/+, 0	66.7 (6)	60.9 (46)	0.0 (1)	0.0 (1)	83.3 (6)	45.8 (120)	54.5 (22)	47.2 (36)	63.8 (47)	52.9 (34)	77.0 (61)
UC	Bushman	1-3/0-3	0.0 (8)	1.4 (74)	0.0 (2)	0.0 (1)	2.8 (36)	2.2 (137)	8.3 (24)	2.4 (42)	2.2 (89)	0.0 (60)	0.0 (87)
UC	DAR	2-5/0-5	83.3 (6)	69.2 (39)	– (0)	– (0)	79.0 (19)	36.6 (60)	80.0 (5)	72.2 (18)	77.8 (54)	81.0 (21)	85.3 (34)
UP1	Uto-Aztec	+/+, 0	0.0 (6)	– (0)	– (0)	– (0)	0.0 (8)	– (0)	0.0 (9)	0.0 (31)	0.0 (4)	0.0 (118)	0.0 (34)
UM3	Metacone	1-5/0-5	100.0 (5)	– (0)	– (0)	– (0)	100.0 (6)	– (0)	100.0 (3)	100.0 (31)	100.0 (1)	98.1 (107)	100.0 (13)
UM2	Hypocone	1-5/0-5	100.0 (4)	98.3 (121)	100.0 (6)	100.0 (9)	96.4 (56)	97.2 (179)	100.0 (45)	97.1 (70)	93.8 (195)	94.7 (244)	93.2 (148)
UM1	Cusp 5	1-5/0-5	25.0 (8)	61.5 (130)	100.0 (5)	66.7 (6)	47.7 (44)	68.4 (155)	79.2 (24)	34.9 (63)	33.7 (181)	15.4 (162)	24.0 (121)
UM1	Carabelli	2-8/0-8	22.2 (9)	37.4 (155)	16.7 (6)	10.0 (10)	36.2 (47)	41.9 (177)	45.8 (24)	39.4 (61)	38.7 (209)	38.6 (163)	23.4 (124)
UM3	Parastyle	1-5/0-5	0.0 (5)	5.4 (56)	0.0 (2)	0.0 (1)	0.0 (6)	5.7 (123)	7.7 (52)	0.0 (34)	2.3 (86)	4.7 (128)	3.9 (129)
UM1	Enamel ext	1-3/0-3	44.4 (9)	45.5 (145)	55.6 (9)	46.2 (13)	31.4 (51)	20.7 (150)	50.7 (73)	47.5 (80)	66.5 (221)	66.5 (310)	71.6 (222)
ULP12	Odontome	+/+, 0	0.0 (10)	1.5 (135)	0.0 (8)	0.0 (14)	20.0 (5)	2.1 (146)	0.0 (27)	0.0 (11)	1.7 (115)	3.2 (154)	5.2 (97)
UP1	1-root	1/1-3	87.5 (8)	60.0 (135)	80.0 (15)	87.0 (23)	49.1 (57)	48.8 (125)	59.3 (81)	52.2 (67)	53.9 (267)	89.3 (280)	90.9 (231)
UM2	3-root	3-5/1-5	100.0 (3)	61.7 (120)	36.4 (11)	40.0 (20)	82.0 (50)	86.3 (139)	76.7 (60)	85.3 (34)	78.0 (223)	44.8 (239)	43.4 (191)
UM3	Red/peg/ca	+/+, 0	0.0 (5)	40.0 (95)	25.0 (8)	46.2 (13)	81.5 (27)	16.7 (156)	10.1 (69)	29.5 (44)	41.7 (175)	20.9 (302)	8.1 (186)
LP2	>1 L cusp	2-3/0-3	100.0 (7)	90.0 (90)	100.0 (4)	87.5 (16)	93.9 (33)	91.5 (153)	91.3 (23)	87.5 (56)	81.4 (70)	24.4 (82)	40.5 (79)
LM1	Anterior fovea	1-5/0-5	100.0 (6)	– (0)	– (0)	– (0)	100.0 (4)	– (0)	– (0)	66.7 (3)	– (0)	88.1 (59)	85.7 (7)
LM2	Y groove	Y/Y, +, X	22.2 (9)	16.4 (116)	33.3 (9)	12.5 (16)	18.5 (65)	25.4 (181)	19.1 (47)	20.5 (73)	15.8 (101)	7.9 (152)	12.4 (137)
LM1	Cusp 6	6/4-6	71.4 (7)	55.0 (109)	71.4 (7)	37.5 (8)	53.7 (54)	49.0 (157)	54.5 (22)	22.6 (62)	34.6 (81)	63.7 (91)	40.7 (91)
LM2	4-cusps	3-4/3-6	28.6 (7)	39.6 (106)	33.3 (9)	53.8 (13)	13.6 (59)	51.8 (170)	12.5 (32)	44.1 (68)	37.1 (97)	9.4 (159)	2.9 (136)
LM1	Deflecting wr.	1-3/0-3	85.7 (7)	56.8 (74)	100.0 (3)	– (0)	74.4 (43)	59.8 (107)	40.0 (10)	73.1 (26)	54.5 (44)	65.5 (58)	51.1 (45)
LM1	Trigonid crest	+/+, 0	12.5 (8)	1.4 (72)	0.0 (6)	0.0 (8)	0.0 (6)	0.0 (113)	5.6 (18)	0.0 (16)	7.8 (51)	3.3 (121)	11.3 (71)
LM1	Protostylid	1-8/0-8	62.5 (8)	13.9 (122)	14.3 (7)	30.0 (10)	30.0 (60)	21.2 (189)	6.7 (30)	40.8 (76)	35.6 (90)	26.9 (160)	37.2 (113)
LM1	Cusp 7	1-5/0-5	0.0 (9)	7.2 (125)	12.5 (8)	0.0 (13)	11.8 (68)	13.0 (192)	6.2 (32)	11.5 (87)	10.9 (101)	10.8 (167)	7.9 (127)
LC	2-roots	2/1-2	0.0 (4)	0.0 (100)	0.0 (15)	0.0 (27)	0.0 (55)	0.0 (97)	0.0 (60)	0.0 (36)	0.0 (92)	1.5 (199)	0.0 (156)
LM1	3-roots	3-4/1-4	10.0 (10)	2.1 (141)	23.1 (13)	7.4 (27)	0.0 (75)	4.5 (155)	6.9 (72)	8.9 (90)	12.2 (131)	5.1 (217)	16.4 (214)
LM2	1-root	1/1-4	44.4 (9)	24.2 (120)	20.0 (15)	26.9 (26)	9.5 (63)	2.0 (149)	6.8 (73)	11.9 (67)	27.3 (121)	35.2 (182)	36.3 (201)
LP1	Tomes root	4-5/0-5	0.0 (2)	0.0 (85)	20.0 (15)	3.6 (28)	0.0 (7)	10.6 (94)	14.8 (54)	7.3 (41)	11.1 (90)	2.3 (86)	11.5 (165)

whereas other traits are either absent (missing data) or their amount of occlusal wear exceeds the maximum for confident scoring (see various comments about wear in Turner *et al*., 1991). Most of these crown traits, but not the root traits, have been previously subjected to hereditary study and are believed to have a strong genetic component in their occurrence and expression (Scott, 1973; Harris, 1977; Nichol, 1990). Table 1 shows the various trait frequencies for Rotuma and the comparative assemblages. Counts are by individuals, sexes are pooled, and dichotomizing frequency break points are identified in Table 1, which are necessary for the computation of both chi-square and the multivariate Mean Measure of Divergence statistic (Berry and Berry, 1967; Sjøvold, 1973). This multivariate statistic is preferred over others because of its relative simplicity and because it readily handles the problem of missing data.

RESULTS

Univariate comparisons using chi-square (1 df, Yates corrected when any expected cell is less than 5, P significant at 0.05, all observed cells had to be greater than 0) between Rotuma and the ten comparative Oceanic and circum-Pacific samples in Table 1 gave the following percentages of significant trait frequency differences: Rotuma and Easter, 0.0% (0 out of 23 possible comparisons); Indonesia, 0.0% (0/29); Marquesas, 3.7% (1/27); Tahiti, 4.0% (l/25); Thailand, 6.7% (2/30); Guam, 6.7% (2/30); Peru, 6.7% (2/30); Northwest Coast of Alaska and western Canada, 10.0% (3/30); Australia, 10.3% (3/29); New Britain, 14.8% (4/27). In terms of culture area and linguistic family classifications, Easter, Marquesas, and Tahiti are Polynesian; Indonesia and Thailand are Southeast Asian; Guam is Micronesian; Australia and New Britain are Australmelanesian; and Northwest Coast and Peru (the two areas that Hyerdahl suggested Polynesians might have come from) are Native American-Amerind.

The Rotuma dental traits that showed significant inter-group frequency differences were: Shoveling (Rotuma vs. New Britain, 2 = 4.3; Peru, 4.5; Northwest Coast, 4.7); double-shoveling (New Britain, 8.6); upper molar cusp 5 (Tahiti, 4.3; New Britain, 5.3; Australia, 6.7); peg-reduced-congenitally absent upper third molars (Guam, 10.1); >1 lingual cusp of lower second premolar (Northwest Coast, 7.1; Peru, 14.3); lower molar cusp 6 (Thailand, 6.0); 4-cusped lower second molar (Northwest Coast, 5.9); protostylid (New Britain, 5.8; Marquesas, 9.4; Australia, 10.9); 1-rooted lower second molar (Thailand, 4.7; Guam, 6.0; Australia, 8.8; New Britain, 27.7). Several nearly significant frequency differences possibly would have been significant had the Rotuma series been larger, and these differences likely would have enhanced the differences between Rotuma and the Australmelanesian and American dental series.

Since five percent significant differences can be expected on the basis of chance alone, these univariate comparisons suggest that this Rotuma dental sample is statistically indistinguishable from those originating in the Marquesas, Tahiti, Easter, and Indonesia locations (which includes teeth from younger levels at Niah Cave, Malay near Singapore, other Malays, Philippines, Bangkok, and the Atayal of Taiwan), and only barely distinguishable from teeth from Guam, Thailand (archaeological Don Klang, Ban Tong, Non Nok Tha, and Ban Chiang pooled), and Peru. The Rotuma dental sample is easily distinguished from those originating in New Britain, north and south Australia, and Northwest Coast of North America.

Univariate comparisons show Rotuma to be indistinguishable from the known Polynesian samples. Compared with Australmelanesians, Rotuma and the Polynesians possess relatively high frequencies of incisor shoveling, deflecting wrinkle, protostylid, 3-rooted lower first molar, and 1-rooted lower second molars. They have low frequencies of the pronounced mesial-ridged upper canine (Bushman canine), Carabelli's cusp, and the parastyle. These frequencies are characteristic of the Southeast Asian dental pattern I have called Sundadonty in contrast to the Northeast Asian and New World pattern termed Sinodonty (Turner, 1979, and elsewhere).

Multivariate comparisons were made using 23 to 30 traits available in the comparative samples (Table 2). Because the Rotuma series is small, few of the computed Mean Measures of Divergence (MMD) are significant. This coupled with the fact that the number of traits compared differed slightly between comparative pairs, indicates that more reliability should be placed on the univariate findings and inferences. Definitely, no strictly "literal" interpretation should be made of the MMD values, however, relatively, they generally follow what was inferred from the univariate comparisons. Given that the number of trait pairs was not identical in all inter-group comparisons, I perhaps should have attempted to "standardize" the MMD values. It is a happy coincidence that I did not, because following the submission of this article to *Dental Anthropology*, I have read the important article by Harris and Sjøvold (2004) that, among other MMD considerations, convincingly demonstrates the inappropriateness of MMD standardization.

As with the univariate comparisons, the MMD values of Table 2 show that Rotuma is more like most Polynesians than like New Britain. Australia occupies an intermediate position, both in relation to Rotuma (MMD = 0.061) and New Britain (MMD = 0.057). Rotuma has no measurable MMD dissimilarity to Tahiti, Thailand and Indonesia, and effectively no divergence from Easter. This odontological association of Rotuma with Polynesians and Southeast Asians is

TABLE 2. Mean Measures of Divergence for Rotuma and comparative dental samples[1]

	ROT	TAHI	THAI	INDO	EAST	NWC	AUST	GUAM	MARQ	PERU	NEW B
ROT		25	30	29	23	30	29	30	27	30	27
TAHI	0.000		25	25	23	25	25	25	25	25	25
THAI	0.000	0.041		29	23	30	29	30	27	30	27
INDO	0.000	0.071	0.000		23	29	29	29	27	29	27
EAST	0.007	0.000	0.015	0.045		23	23	23	23	23	23
NWC	0.057	0.223	0.223	0.135	0.303		29	30	27	30	27
AUST	0.061	0.000	0.067	0.050	0.033	0.262		29	27	29	27
GUAM	0.074	0.130	0.065	0.050	0.100	0.313	0.097		27	30	27
MARQ	0.090	0.021	0.058	0.073	0.000	0.324	0.039	0.060		27	27
PERU	0.138	0.307	0.347	0.275	0.270	0.093	0.452	0.450	0.452		27
NEW B	0.160	0.087	0.074	0.182	0.028	0.528	0.057	0.152	0.075	0.665	

[1]Whole numbers are the number of pairs of traits used to calculate the inter-group MMD values. Thus, there were 25 traits involved in the MMD comparison between Rotuma and Tahiti, and 30 used for the Rotuma-Thailand MMD. MMD values are shown as fractions with small values representing greater similarity than larger values. Thus, Rotuma is more similar to Easter (0.007) than it is with New Britian (0.160). MMD values were calculated according to C.A.B. Smith (Berry and Berry, 1967) with the modifications suggested by Sjøvold (1973) and Green and Suchey (1976).

quite suggestive of proximate (when the Rotuma people were alive) and close ties with known Polynesians, and close ultimate links with Southeast Asian Sundadonts. Insofar as sample size permits, Rotuma cannot be multivariately distinguished from Polynesians, whereas it can be when compared with Melanesians. Since Polynesian and Melanesian populations are the most realistic geographic sources for this Rotuma sample, the former are a better bet than the latter for having been close relatives. The Micronesian people of Guam belong to the Sundadont dental class, so it is not unexpected that inter-group similarities and differences parallel those of Rotuma. Given the very great oceanic distance separating Guam and Rotuma, their relative similarity is best attributed to their shared ultimate Sundadont ancestry in Southeast Asia. A similar inference was made earlier by Harris *et al*. (1975:231) regarding the stronger dental relationships between the Yaps of Micronesia and Polynesians, in contrast to the much weaker relationship between Yaps and Australmelanesians. In large-scale comparisons, both Pietrusewsky (1990), using craniometric observations, and the author (Turner, 1990) using dental morphology, found Guam skulls and teeth to be much more like those of Southeast Asians and Polynesians than like various Australian, Melanesian, and Tasmanian samples. However, when Turner pooled Rotuma and Fiji dental samples, because of their relative Oceanic closeness, this combined group was most like samples from Early Malay Archipelago, and from Melanesian-Polynesian border islands. Fiji has a history of both Polynesian and Melanesian occupation. The Fiji dental sample was considered to be Polynesian, but it would appear this was incorrect because the Fiji-Rotuma combination clustered with Australmelanesians instead of Sundadont Southeast Asians, Polynesians, and Guam Micronesians. Yet, the study by Weets (1996) on the dentition of Vanuatu islanders, near Fiji, in eastern Melanesia, found that these people were more like Polynesians and east Asians than like Melanesians. Hence, large-scale boundaries in Oceania defined culturally and linguistically generally have high correspondence with dentally-defined communities. Rotuma alone classifies as Polynesian, but when combined with nearby Fiji its affiliation becomes ambiguous.

DISCUSSION

Both univariate and multivariate statistical comparisons of the small Rotuma dental sample indicate a closer relationship with Polynesians than with Melanesians or American Indians. In addition, the Rotuma teeth are very similar to those of Southeast Asians. Since numerous other assessments of affinity based on these same dental traits have produced expected results when evaluated with independent archaeological, linguistic, or ethnographic information (Scott and Turner, 1997), there is good reason to hypothesize a strong Rotuma-Polynesian linkage, depending, of course, on how one feels about the size of the Rotuma sample. Although no cultural remains were found with the Rotuma bones and teeth, Shutler and Evrard (1991) argued that the Rotuma oral traditions strongly indicated a Polynesian cultural affiliation.

Differences between human groups are due to evolutionary processes, with genetic drift or founder's effect figuring prominently in small groups, especially for traits of little or no identifiable adaptive value, such as enamel extensions or occlusal surface characters that wear off early in life. Such traits, especially if their mode of inheritance is relatively simple, should show increased inter-group frequency differences, with increased amounts of temporal separation. For example, the MMD between American Indians and Northeast Asians is 0.154 (Turner, 1986). Most archaeological evidence suggests that these two geographic groups have been physically separated on the order of 12,000 to 15,000 years (Fiedel, 2004; several others). The averaged MMD between Rotuma and the Polynesians, compared with Thailand-Indonesians is 0.038, about four times less that the Indian-Northeast Asian MMD value. As time and MMD values between separated groups has been suggested as roughly proportional (Turner 1986), then an MMD separation estimate between Polynesians and Southeast Asians would be about 3,000 years. Such an estimate corresponds fairly well with radiocarbon dates of about 1,000 B.C. from early Tonga (Shutler and Shutler, 1975; Bellwood, 1979) and several other excavated Polynesian sites (Green, 1994).

Pooling the same Rotuma and Polynesian samples and comparing their MMD values with New Britain gives an averaged MMD of 0.087. This is two to three times greater that the Rotuma-Polynesian/Southeast Asian comparison and produces an estimated 8,000 to 9,000 years of separation. Such a date vastly exceeds any dated archaeological site in Polynesia. So, it would seem that archaeological chronometrics when linked to mega-regional dental MMD values, also leans towards a Polynesian identification of this Rotuma dental sample. Finally, nothing more needs to be said regarding a New World origin for Polynesians, other than there is no dental evidence in support of this hypothesis. This is as true today as it was more than 25 years ago when the author and G. Richard Scott (1977) set out to describe and assess the affinity of living Easter Islanders based on dental morphology. Then, as now, Easter and all other Polynesian dental evidence points to Southeast Asia as the Polynesian homeland, not the Americas nor Melanesia.

Finally, a word or two needs to be said about the population history of the ultimate ancestral homeland of the Rotuma and other Polynesian islanders. This ancestral homeland is usually considered to be in Southeast Asia, which is referred to as Sundaland when in ice age Pleistocene times sea levels were lower and all of island and mainland Southeast Asia were connected by dry land. The prehistoric and recent teeth of the people of Sundaland possess the dental pattern previously referred to as Sundadonty. Recently, Matsumura and Hudson (2005) have challenged the local evolution hypothesis used to explain the origin of Sundadonty, returning instead to the older idea of "southern Mongoloids" being the result of Neolithic migrants from China mixing with Southeast Asian Australmelanesians. There are several reasons why the old migrant-mixture scenario is flawed, not the least of which is that hybridized populations sometimes do not breed true (Turner, n.d.). There can be resulting offspring that exhibit the original characteristics of the parental stocks instead of the hybrid intermediacy condition. None of the samples of Polynesians that I have examined exhibit a dental pattern that could be considered Australmelanesian or Chinese (Sinodonty). Despite the absence of archaeological evidence that the Rotuma dental sample should be considered Polynesian, oral tradition, cemetery location, island location, dating, and dental characteristics strongly suggest that it is Polynesian. Hence, it provides yet another Polynesian isolate that supports the local evolution hypothesis for the origin of Sundadonty.

CONCLUSION

A small but geographically rare sample of archaeologically-derived teeth from Rotuma Island shares more crown and root morphological resemblances with teeth from Polynesian and Southeast Asian dental samples than it does with teeth from the Melanesian island of New Britain. On the basis of these comparisons, it is concluded that this Rotuma dental sample originated from a population that had a greater epigenetic relationship with Polynesians than with Melanesians. Being relatively near the border zone between Melanesia and Polynesia, Rotuma Island may have had chronologically or geographically both Melanesian and Polynesian occupants; however, the sample discussed herein can easily be hypothesized as having been Polynesian. Dental morphology, linguistic classification, and oral traditions independently favor a Polynesian affiliation for these Rotuma human remains. The Rotuma teeth also help reconfirm the local evolution hypothesis for the origin of Sundadonty.

ACKNOWLEDGMENTS

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Regional Differences of Dental Microwear on the Occlusal Surface of an M2 from Neolithic Japan: A Case Study

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ABSTRACT Regional differences of dental microwear among four small areas on the heavily worn occlusal surface of a mandibular M2 of an adult male from Neolithic Japan were investigated using a scanning electron microscope (SEM). The M2 specimen was cast using a high-resolution epoxy resin under low pressure for SEM, and the cast specimen was sputter-coated with gold. Among the four regions of the M2, two (facets 3 and 9) showed higher proportions of pits (78.6% and 75.0%, respectively), and the two others (lingual marginal facet 7n, and the inner side of facet 7n) showed lower proportions of pits (5.6% and 33.3%, respectively). The two pitted regions seem to reflect the processing of hard foods, and the two other regions with higher frequencies of striations might reflect exposures to less gritty, softer foods. The variation of these pits and striations suggests that the Jomon subsisted on stone-processed hard foods, with coarse grain sizes of sand in foods that included tuberous roots, animal meats with bones, and clams. The analyses of regional differences of dental microwear will develop important ways to study tooth use and past diets. *Dental Anthropology* 2005;18(2):61-64.

Macroscopic tooth wear has been investigated with relation to tooth use and diets among numerous different cultures, and various tooth-wear scoring systems have been devised to record the range and pattern of variation (*e.g*., Bullington, 1991; Hinton, 1981; Molnar 1971; Scott, 1978; Walker, 1978). Such scoring systems depend on overall observations of the occlusal surfaces. But, it also is informative to examine the patterns of tooth wear microscopically because dental microwear reveals that different small regions of a crown are used for processing different foods—and processing food in different ways. Thus, the patterns of microwear differ among various animals corresponding to their diets (Walker *et al*., 1978). Subsequent to Walker's investigation of microwear of mammalian teeth as an indicator of diet, the assessment of dental microwear on facets has been applied to the study of tooth use and diets of non-human primates and of humans (*e.g*., Gordon, 1982; Hojo, 1991, 1996; Teaford, 1988; 1994, 1996).

While my previous study reported overall observations on dental microwear of late stone age (Neolithic age) and early modern people (Hojo, 1989), the present study identifies regional difference of dental microwear features on four small occlusal areas of a heavily worn occlusal surface of an M_2 of Neolithic Japan using Microwear Image Analyzing Software Version 2.2β (Ungar, 1996).

Pits on the heavily worn surfaces of teeth have been found in hard-diet eaters (Hojo, 1991; Teaford, 1994, 1996). In the present study, the high frequency and various sizes of pits on an M_2 of Neolithic Japan suggest a variety of hard foods and hard fine sand grains in the foods of Japanese Neolithic people.

Direct evidence of the use of wild vegetables, such as wild yams for grinding, was not found in this Neolithic site, but evidence of wild yams, wild chestnuts and other wild vegetables often are found in Neolithic sites. Also, their foods would become hard through dehydration for preservation. Furthermore, smooth stones and Jōmon style pottery were found in the present archaeological site. Such worked stones could be used for grinding and cutting hard foods (animal meats, bones, and clams), and fragments of pottery may have been used for food processing. The various sizes of pits and striations recorded in this study could be related to the size of grains that were incorporated into foods from stone tools as part of the people's hunter-gathering economy.

MATERIALS AND METHODS

An M_2 from Neolithic Japan was of an adult male excavated from the Kakiwara shell mound in western Kyusyu Japan (Matsuno *et al*., 1967). To avoid damage to the tooth, a high-resolution cast specimen was used. This is because of the risk during the dehydration process or in the specimen chamber of the SEM (scanning electron microscope) that teeth can easily be broken. The high-

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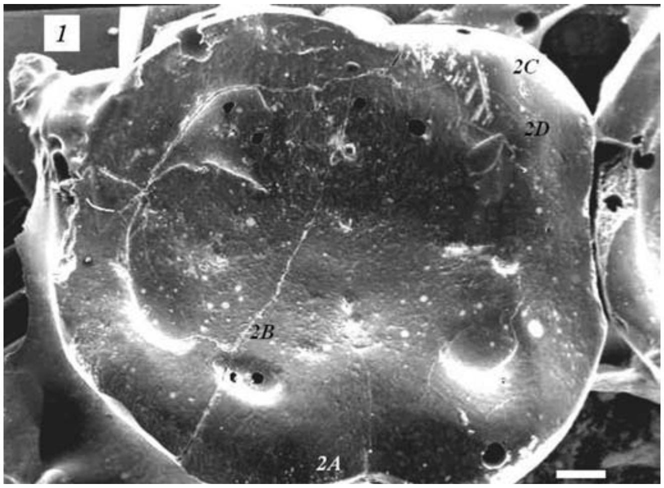

Fig. 1. A heavily worn surface of an M_2 from Neolithic Japan in overall view using SEM. Four small regions are labeled (2A, 2b, 2C, 2D). The lingual side is up, and the mesial side is right. Bar = 1,000 microns.

resolution cast of the M_2 was made with a standard technique (*e.g.*, Hojo, 1989, 1991, 1996; Teaford, 1994): First, an impression was taken using a polysiloxane impression material (Coltene, "Light-Body"). Second, a low-viscosity epoxy resin (Ciba-Geigy, "Araldite") was used to make the positive cast. Then, the high-resolution specimen cast was sputter-coated and inspected with an ABT SX-40A SEM (Akashi-Beam Technology, Tokyo Japan) at magnifications ranging from 7X to 500X at 25kV. The four regions noted in Figure 1 were closely scanned by SEM as follows: the site labeled 2A was on facet 3; 2B was on facet 9; 2C was on the lingual marginal facet 7n, and 2D was on the inner side of facet 7n. Facets 3, 9, and 7n were labeled following Kay (*e.g.*, Kay, 1977; Gordon, 1982). The lengths and widths of pits and striations were measured at the magnification of 500X using Microwear Image Analyzing Software Version 2.2β (Ungar, 1996).

RESULTS AND DISCUSSION

The macroscopic scoring system of Scott (1979) was applied to the heavily worn occlusal surface of the M_2 from Neolithic Japan. This specimen was from an adult male, and the attrition score was 8 as can be seen in Figure 1.

Measurements of pits and striations on the four regions of the M_2 (Fig. 1) were analyzed through digitization of the wear marks (Ungar, 1996), and the percentages of pits were high in two regions 2A and 2B (Table 1, Fig. 3). Region 2C showed the highest proportion of striations (94.4%; Table 1, Fig. 3). Region 2D showed a higher proportion of striations (66.7%; Table 1, Fig. 3) than regions 2A or 2B. All measurements were computed using a 4:1 ratio of length to width as a cut-off between pits and striations just as suggested by Teaford (1988) and Ungar (1996).

The mean breadth of the pits of the region 2C was the smallest (Table 1; Fig. 4). As for the mean breadth of the pits, the difference between the region 2C and 2D was not statistically significant, but the difference between the region 2B and 2C was highly statistically significant by t-test ($P < 0.001$), and between regions 2B and 2D also was significant (t-test, $P < 0.001$).

Two regions (2A and 2B) showed higher proportions of pits (78.6% and 75.0%, respectively) and broader pits (17.0 microns and 16.4 microns, respectively). The two other regions (2C and 2D) showed lower proportions of pits (5.6% and 33.3%, respectively) and smaller pits (6.8 microns and 8.0 microns, respectively).

Because pits are considered to be related to the processing of hard foods (Hojo, 1991; Teaford, 1994, 1996), such numerous and broad pits in the two regions (2A and 2B) suggest that big sand grains might be adhered to the foods in everyday life of the Neolithic age (Figs. 3 and 4). Surprisingly, the highest percentage of pits, 78.6% in region 2A, is higher than that of the hard-diet primate, *Cercocebus albigena*, with 55.2% pits (Teaford, 1988). And as for mean pit breadths, region 2A

TABLE 1. M_2 microwear in Neolithic Japanese (microns)

	Striations			Pits			
	n	Mean	sd	n	Mean	sd	% of Pits
2A Length	3	75.6	15.0	11	24.2	12.8	78.6
Breadth	3	3.5	1.5	11	17.0	8.0	
2B Length	5	39.3	17.4	15	28.9	13.2	75.0
Breadth	5	5.5	3.1	15	16.4	8.8	
2C Length	51	55.6	28.8	3	18.1	14.4	5.6
Breadth	51	1.9	0.9	3	6.8	5.6	
2D Length	16	40.3	18.4	8	23.3	9.9	33.3
Breadth	16	5.0	1.6	8	8.0	3.0	

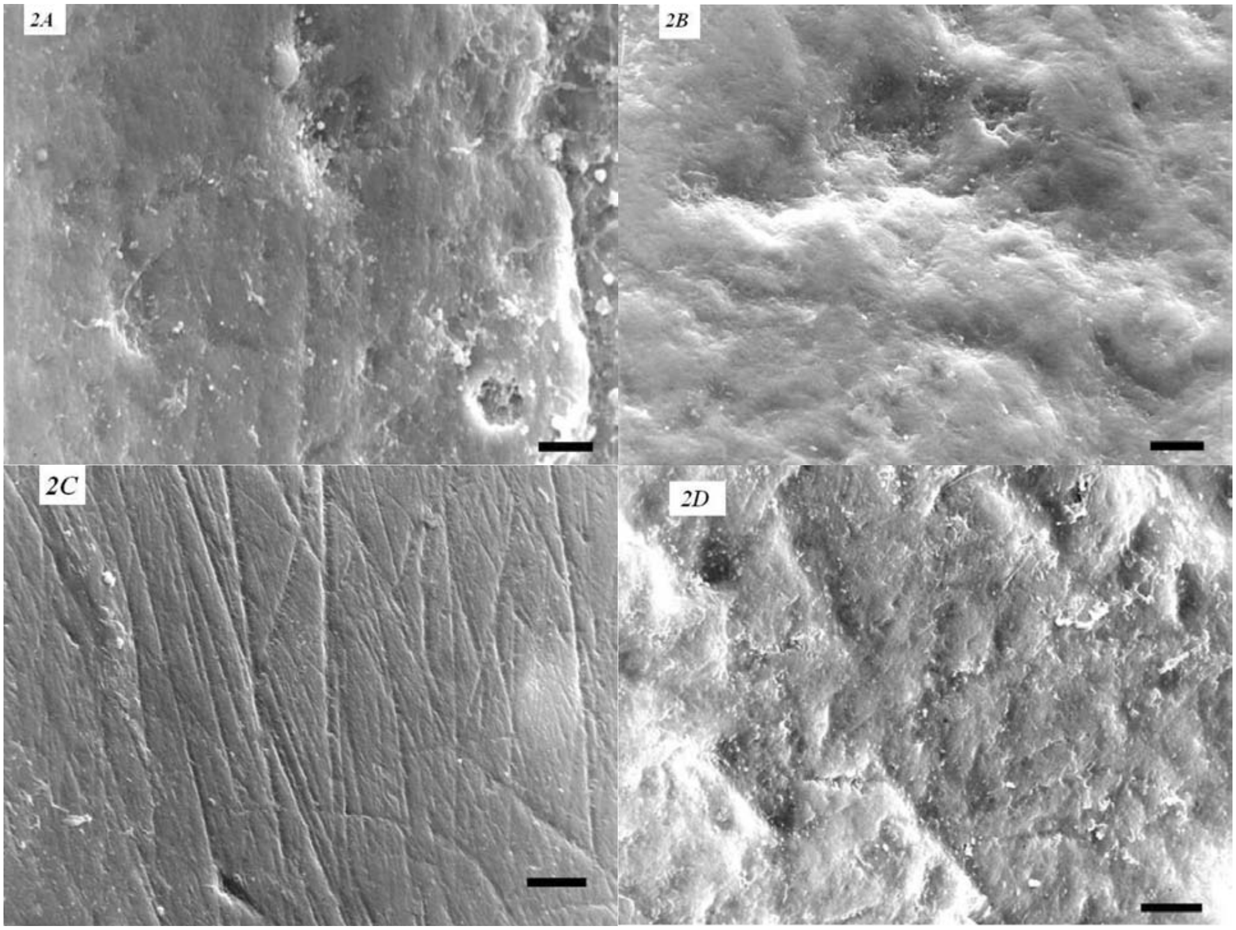

Fig. 2. Figures of four regions (2A, 2B, 2C, and 2D) of SEM that are identified in Figure 1. Pits are preponderant in 2A, and 2B, and the broadest pits are seen in 2B. Many thin striations and a few pits are observed in 2C, and in 2D. Pits in 2C and in 2D are less common than those in 2A and in 2B. Bar = 20 microns.

and 2B exhibited mean breadths of 17.0 microns and 16.4 microns, respectively, (Table 1; Fig. 4), but the mean for *Cercocebus albigena* was just 9.9 microns (Teaford, 1988). This suggests that the two regions (2A and 2B) of this Neolithic M_2 had been abraded by harder and bigger sand grains and substances than the extreme hard-diet primate *Cercocebus albigena*.

The difference of the mean breadth of striations (Table 1) between regions 2A and 2B was not statistically significant, but the mean breadth of striations of 2B was significantly broader than that of 2C by t-test ($P < 0.001$). The mean breadth of striations was thinnest in region 2C (Fig. 4). The image of the region 2C looks like those of soft-food eaters, *Colobus guereza* (that has a mean breadth of striations of 1.2 microns; Teaford, 1988). The region 2C may represent the processing of soft food.

The differences of the lengths of striations (Table 1) among the four regions were statistically insignificant in multivariate analysis.

In brief, measurements of dental microwear for various primate species (Teaford, 1988) suggest that these human four patterns of dental microwear reflect the processing of foods that have incorporated different grain sizes. The grains that abraded the regions 2C and 2D are suggested to be smaller than the two others.

Among recent microscopic analyses of tooth wear, there have been interesting experimental studies of diet-induced changes of human tooth wear, for instance, a case of stone-ground maize populations was reported by Teaford (1996). The variation in microwear features in the present study may be related to various kinds of foods. In the environment of this Neolithic human, the foods probably included wild tuberous roots, clams, fish, and animal meat and bones. Even now, in southwestern Japan, both cultivated and wild yams and other wild tuberous roots commonly are eaten. In Japan, stone-ground flour has been used widely. Until now, the flour of traditional noodles has been made by stone grinding.

Additionally, in Neolithic Japan (late stone age) some wild vegetables, chestnuts and walnuts were dried for preservation for use out of season, and these would later be stone-ground as were other vegetable roots just as in

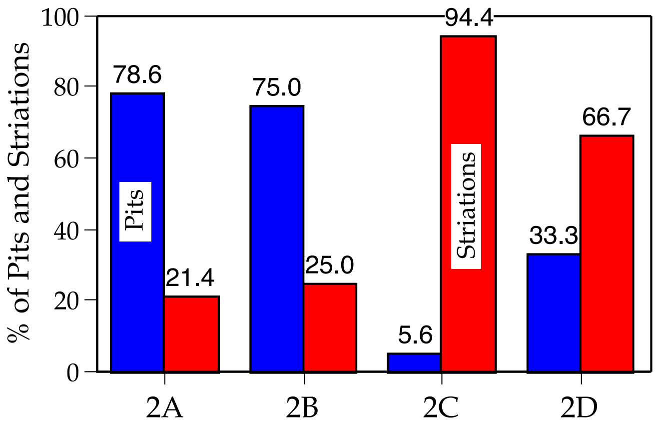

Fig. 3. Frequencies of pits and striations on the four regions of the M_2 were analyzed through digitization of the wear marks (Ungar, 1996). Pits of two regions (2A and 2B) showed higher proportions than the two other regions (2C and 2D), which, in turn, showed higher frequencies of striations than the other two regions (2A and 2B).

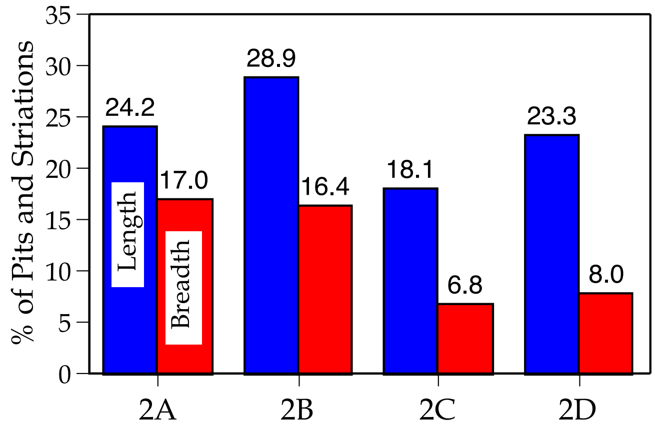

Fig. 4. Measurements of pits and striations on the four regions of the M_2 were analyzed through digitization of the wear marks (Ungar, 1996). The mean breadth of the pits of the region 2C was the most narrow. Pits of two regions (2A and 2B) were broader with higher proportions.

modern Japan. Worked stones in this Neolithic site might have been used for grinding and cutting hard foods, and small grains from these stones would be incorporated into the food, just as stone-ground maize was part of the diets of various prehistoric populations (Hinton, 1981). Characteristic changes of dental microwear would be induced by stone-ground maize (Teaford, 1996).

It is anticipated that the further analyses of regional differences of dental microwear will develop important insights into tooth use and prehistoric dietary practices.

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Kazuro Hanihara
1927–2004

Fig. 2. Kazuro Hanihara: 1924–2004.

Kazuro Hanihara, born in Fukuoka Prefecture on the southernmost Japanese island of Kyushu, was one of the major figures in biological anthropology in Japan. He was especially prominent among Japanese anthropologists for his work in dental anthropology, and he regularly voiced his gratitude to that legendary embodiment of dental anthropology, Albert A. Dahlberg of Chicago, for contacts, encouragement, and access to dental collections. Among his many contributions was his construction of a measuring device that allowed the researcher to give precise figures for the depth of the lingual fossa in a shovel-shaped incisor.

Hanihara gained both his undergraduate, 1948-1951, and his graduate, 1951-1956, training in anthropology at the School of Science of the University of Tokyo. Early in his graduate career, he worked for the American military forces at Kokura Camp in Fukuoka Prefecture at the task of identification of American soldiers who had died during the Korean War. This not only gave him practical experience in forensic anthropology and in the recognition of anatomical features of people of largely European ancestry but, at least as important, it made him comfortable with communicating in the English language. Not only was he able to discuss matters in effective English, he could lecture in the language with comfort and ease. Much of his anthropological work was published in English, and much of the writing was primarily done by himself and needed only minor editing by a native English speaker. This quickly earned him international recognition that he was to retain for the rest of his life.

Fig. 1. Kazuro Hanihara (*right*); his wife, Kazuko (*center*); and Keiichi Omoto (*left*) at a dinner gathering in the Hanihara home following the end of a workshop titled "The Origin and Past of *Homo sapiens sapiens* as Viewed from DNA—Theoretical Approach" that took place on December 14-17, 1993, in the International Institute for Advanced Studies, Kyoto, Japan. Dr. Hanihara was the workshop convenor and IIAS Vice-Director. (Photograph courtesy of Christy G. Turner II.)

In 1956, he became an assistant professor in the Department of Legal Medicine at the Sapporo Medical College on the northern island of Hokkaido. His use of Mahalanobis D^2 distances, discriminant functions, and Q-mode correlation coefficients gave the cachet of statistical sophistication to his work, and in 1958, the year he earned his Doctor of Science degree from the University of Tokyo, he was promoted to Associate Professor at the Sapporo Medical College. The very next year, as a Fulbright Exchange Scholar, he served as a Visiting Professor at the University of Chicago, a role he filled again in 1968. In 1969, aided by a Leverhulme Visiting Fellowship, he was a Visiting Professor at the University of Adelaide in Australia where he studied the dentition of the northern Australian Aborigines. He also served as a Visiting Professor at Arizona State University in 1984.

Because of his initial professional location on Hokkaido, he became involved in questions concerning the identity of the Ainu and their relations to the prehistoric inhabitants of Japan and to the majority of the non-Ainu Japanese. He clearly recognized the similarity of the Ainu to the prehistoric Jōmon. Despite his use of sophisticated statistics, however, his conclusions savored more of preconceived notions than of anything that derived from the actual metric data. Without actually using odontometric data to test the idea, he debunked the old suggestion that there was a "Caucasoid" element in the Ainu. As with so many Japanese who want to believe that they are descended from the prehistoric inhabitants of the archipelago, he tried to push the idea that the Jōmon played a role in the ancestry of the Japanese which they did to a varying extent. He recognized the fact that most Japanese looked more like mainland East Asians than Jōmon-Ainu people, and he suggested, in the absence of archaeological support, that massive population movements from that mainland had been responsible. His estimate was that more than a million people moved from Northeast Asia to Japan during the time between 300 BCE and 700 CE, a guess that has made more than a few prehistorians uneasy and doubtful.

In 1972 he returned to the University of Tokyo as Professor of Anthropology in the School of Science where he remained until reaching the mandatory retirement age of 60. Starting in 1987, he began what was to be a lifelong affiliation with the International Research Center for Japanese Studies in Kyoto. Actually, he was one of the major figures involved in setting up that Research Center in the first place. In order to make the case to Japanese Prime Minister Nakasone for the establishment of that Center, Hanihara traveled to America in the spring of 1985 and visited a series of Universities to gather expressions of support for the project. His efforts were highly successful, and this points out one of the most prominent aspects of Kazuro Hanihara. He was a marvelous organizer and administrator and was a successful chairman of a Museum and Department as well as a long series of committees. Not only was he admirably well-organized, but he exuded a manifestation of graciousness and charm that clearly nurtured his success.

Hanihara was probably most known for his proposal of a "Dual structure model for the population history of the Japanese" first published in 1991. In this, he proposed that the prehistoric Jōmon of Japan were derived from Southeast Asia which he sometimes referred to as "South Asia" although this did not mean the Indian sub-continent as that designation has usually implied. He suggested that a mixture of Jōmon and Northeast Asians gave rise to the Ainu on the one hand and the modern Japanese on the other. The difference between the two, he proposed, was the result of microevolution in situ. The Jōmon themselves he regarded as qualifying as perfectly good "Mongoloids" although this was not supported by any kind of metric demonstration. The idea that the Ainu represent the continuity of the Jōmon with a bit of input from eastern Asia is indeed supported by an analysis of common variance, and the idea that the Japanese largely represent the morphology of eastern Asia tempered by a trace of Jōmon form in increasing amounts the farther east one goes in the archipelago is also supported by the variance figures. However, the role of microevolution in leading to the Ainu/Japanese differentiation has no basis, and there is no evidence supporting a Southeast Asian locus of origin for the Jōmon themselves.

Last but not least, Kazuro Hanihara was enormously helpful to visiting scholars who knew little or no Japanese. Whether he agreed with the interpretation of the results of their work or not, he was unfailingly gracious and supportive. He figured out bus and train schedules, helped people get to the right stations, he met planes, and made hotel reservations, and many more much appreciated acts of generosity and assistance. For those of us who counted him as a friend, his passing leaves a real sense of loss.

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Book Review

DENTAL FUNCTIONAL MORPHOLOGY: HOW TEETH WORK. By Peter W. Lucas. New York: Cambridge University Press, 2004. 372 pages, 7 chapters, 2 appendices. $130.00 £75.00

Occasionally in science a novel treatment of a familiar subject opens new vistas for exploration and thought. This is the case with *Dental Functional Morphology* by Peter W. Lucas. Part dental anthropology and part physics, this book challenges long held paradigms regarding the morphology of mammalian teeth. Viewed from the perspective that physical characteristics of food drive selection of tooth form, Lucas presents a well thought argument revolving around how dental morphology has evolved in response to the fracture properties of food.

The adage "if you don't eat, you die" can be altered using Lucas' view to "if your teeth don't efficiently fracture foods and reduce particle size to that which is optimal for energy extraction, you die." As this implies, this volume is really an exploration of the mechanics of eating from the perspective of how biological material is broken down so that as much energy as possible is derived from that which is ingested. Here I will attempt to elucidate the main points that Lucas brings forth and pique the reader's interest enough that you will obtain a copy; although it is not an easy read, it is certainly thought provoking.

The nine sections (seven chapters and two appendices) of *Dental Functional Morphology* can be distilled into two groups, namely the core of chapters 4-6 and the periphery. The periphery sets up understanding of the core. Chapters 1-3 present a good background to the anatomy and functions of mastication, Chapter 7 provides insight into the evolution of mammalian teeth, and the appendices present an introduction to the mechanics of fracture in solids and the mechanical properties of teeth and foods.

Chapter 1, "How To Get Excited About Teeth," briefly outlines what Lucas is up to and begins one thinking of food in terms of how it breaks into smaller particles through the forces of mastication. As stated on page 10 the aim of the book is to consider "the function of teeth in relation to the ingestion, chewing, and swallowing of food. It attempts to elucidate the principles that underlie the evolution of tooth shape and size and those mechanisms by which the dentition can be maintained." The basic point is that teeth need to be viewed as anatomical structures in which selection for shape and size are a result of the physical properties of the material they come in contact with. Ergo, how teeth deal with two aspects of food, the external physical attributes and the internal mechanical properties, influences the evolution of their structure. Lucas puts this in context for the salient aspects of the book in stating, "The chance of hitting a food particle with the teeth is enhanced by making the tooth bigger, *i.e*. by changing tooth size. In contrast, the effects of the force that the tooth exerts on that particle depend on the contours of its working surface–*i.e*. on its tooth shape" (p. 12).

Chapters 2 and 3 offer very good review of the anatomy and function of the mouth, respectively. Included in Chapter 2 is an in depth overview of the micro- and macro-structures of the teeth and masticatory apparatus with excellent lateral head and neck drawings. The last lines of the chapter allow an introduction to Lucas' writing style, which is best described as 'humorously quirky' at times. This last section deals with the muscles of the neck, which he closes thusly, "However, humans have an habitual upright bipedal stance in which the head is balanced only by continuous active contraction of posterior neck muscles such as the longissimi. Without this action, the head falls forward —such as when dozing over a book like this. That is enough about structure" (p. 54). Chapter 3 is a very in depth treatment of the mechanisms of mastication. Jaw movement, food particle breakdown, food movement in the mouth, the mechanics of swallowing, taste, and the role of saliva are all addressed. This chapter begins the process of getting the reader thinking about teeth as processors of organic matter and is a building block for Lucas' argument concerning tooth size and shape developed in the following chapters.

In most books, appendices are sections that supplement the main text and are meant to be perused, or ignored, as the reader sees fit. That is not the case with Appendix A. Before delving into the core of the book, Chapters 4-6, this is necessary reading. As a primer on mechanical properties and their measurement, Appendix A covers material important to understanding the concepts Lucas presents. He suggests the reader at least "skim" this section, I suggest that a careful reading is important particularly if your knowledge of the mechanics of fracture in solids is limited. Pay particular attention to the sections explaining Young's Modulus (E), a measurement of stiffness (elasticity) of materials, and derivations for R (toughness) and K_{IC} (fracture toughness) as a comprehension of these and other formulae is important for following Lucas' logic trail.

Study of tooth shape (Ch. 4), size (Ch. 5), and wear (Ch. 6) is integral to the study of dental anthropology. The importance of shape and size, in particular, transcends the relatively narrow confines of our specialty to encompass the much broader study of the evolution of terrestrial life forms. Since, as we all know, teeth are the most often recovered portions of once living beings, paleospecies rise and fall based on characteristics relating to the size and shape of their teeth. Therefore, a better understanding of possible selective forces impacting dental evolution will lead to a better understanding of evolution in general. These three chapters offer readers the opportunity to reevaluate what they think they know about the evolution of the dentition and gain new insight into the microevolutionary forces at play in the evolutionary give-and-take between the eaters and that which they eat.

It is difficult to explain Lucas' exploration of the properties of food particle fracture and their effect on dental form without detailed description and the repetition of formulae that would expand this review beyond acceptable limits.

The basic premise of Chapter 4, Tooth Shape, is the assumption "that the shape of teeth is an evolved response for overcoming the toughening mechanisms inside foods that frustrate their fracture and that these mechanisms lie at the heart of the diversity of dental form" (p. 96). This focus on the complex structural properties of food is in direct response to the classic, simplistic, view of tooth function that lumps teeth into two broad, ill defined, categories; shearing and grinding. By understanding the true mechanics of fracture in solids, how cracks are initiated and progress, it becomes apparent that "shear" and "grinding" are not what is happening at all during mastication. Force, applied through the teeth by the muscles of mastication, initiates cracks that lead to fracture and thence, to reduction in size of solid organic matter. The geometry of this fracture (how easily and in what manner it fractures) is controlled by the food particles and not by the teeth since being structurally sound is selectively advantageous. Understanding how foods prevent fracture is important for understanding tooth form. Lucas spends what seems like a great deal of time discussing cusp shape (pointedness) and how this affects fracture propagation, cell toughness, and the fracture characteristics of various foods. However, in the end, one is left with a better understanding of how the structural characteristics of food can influence tooth shape so that structures such as marginal ridges are no longer perceived as accessory features of crown anatomy but as structures that facilitate fracture continuation.

With tooth size, Lucas prods us to view it as something whose variation is tied to the size of the entire orofacial complex, the size of which is, in turn, related to the size of the food that is put into it. Stating that "The overriding philosophy is that physical properties of mammalian diets explain not only tooth size, but also the size of most orofacial structures" (p. 133), he proposes that tooth size should be scaled not to body size as in standard allometric analyses but to the size of the 'food particles' that they encounter. He finds that the size of the anterior teeth and that of the post-canine teeth are affected by different aspects of the diet. On the one hand, jaw and anterior tooth size scale to the size of food as it is put into the mouth while post-canine tooth size is related to external physical properties of the food and how it fractures. Along the way Lucas presents in-depth discussions of the effects of variation in food toughness and tooth size, how food intake speed impacts overall orofacial size, and the differential effects of herbivory and carnivory on structures of the mouth.

Lucas explores tooth wear by examining what actually causes it. From a mechanical standpoint tooth wear is the loss of small fragments from the body of the tooth, therefore, understanding how these fragments are removed is important. Tooth-tooth wear (attrition) and food-tooth wear (abrasion) affect enamel and dentine in different ways resulting in different selective pressures on the structure of teeth. In this view, food-tooth wear impacts tooth size while enamel thickness responds to tooth-tooth wear. The pressures of food-tooth interactions are spread across the whole of the crown and vary from chew to chew. This impacts tooth size because the larger the tooth the more surface comes into contact with food which, in turn, increases the life of the tooth, impacting survival. In contrast, tooth-tooth wear occurs repeatedly, and under high pressure, at very specific points, particularly the cusp tips, resulting in selective response in enamel thickness. While Lucas states that he "did not say much in this chapter" (p. 200), he does present a wide ranging discussion of tooth wear that includes several pages on the response of dentine, an area that is frequently overlooked.

The concluding chapter is self described as "a chapter of ideas, mixing fact with suggestions that, although seemingly logical and based on the previous chapters, might require a lifetime's work to substantiate in any detail" (p. 202). As speculative in nature as it is, this chapter is also a thorough overview at how teeth function and the evolution of the mammalian dentition in light of the emphasis on the fracture properties of food. The last 20, or so, pages deals with diet and human evolution, touching on several areas. An example or two will suffice. On page 238 Lucas anticipates the discovery of *Homo floresiensis* by suggesting that dental reduction, specifically tooth loss, could be tied to dental crowding brought on by dwarfing in small, isolated, mammalian populations. Pages 243-244 cover the molarization of premolars where he ties this trait to the size of the food that is being eaten and postulates that hominids who possess molarized premolars have adapted to eating relatively small objects. In fact it seems that Lucas relates everything in dental evolution to food toughness and particle size. For the most part this appears to work. However, when it comes to applying this theoretical line to dental reduction and the effects of cooking food on tooth size Lucas completely ignores the possible impact agriculture and the resulting foods high in fermentable carbohydrates may have had in the selection for smaller, less complex, molars over the last 10,000 years.

Now for a succinct concluding paragraph. Hopefully this review has given the reader a hint at the complexity and value of *Dental Functional Morphology*. Although "a little thick at times" (reviewer's notes), if taken in the right dosage, with periods of contemplation liberally interspersed, one comes away with a new appreciation for the role food has played in the evolution of teeth. However technical the book may be at times, I think it can also become an important resource for professionals and as a starting point for discussion in graduate seminars. On a theoretical level most of what is proposed within this volume is well supported though it seems that Lucas is, at times, so tied to food particle size and fracture properties that other, simpler, possibilities are overlooked. As in any book of this length there are several nit-picky things that I could address but I'll only attack one. On page 149, line 4, in discussing characteristics of food Lucas says "Fleshy fruits are *designed* for feeding on by vertebrates because these animals can disperse their seeds effectively" (emphasis added). The Darwinian in me recoils at the implications of some unseen hand working its magic in what is otherwise a fine evolutionary synthesis. In the end, whether or not one buys Lucas' premise that the evolution of the mammalian dentition is the result of adaptation to the mechanical properties of food this book is a valuable addition to the dental anthropology literature.

Review by
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