Dental Anthropology

Volume 19, Number 3, 2006

Dental Anthropology is the Official Publication of the Dental Anthropology Association.

Editor: Edward F. Harris

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Paramolar tubercle in the left maxillary second premolar: a case report.

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ABSTRACT: This is a case report describing a paramolar tubercle occurring on the buccal surface of left upper second premolar (tooth 25). From the perspective of dental anthropology, this morphological feature, though uncommon, may be useful for classification and identification. Dental Anthropology 2006;19(3):65-69.

Dental anthropology can be viewed as the collaborative effort of anthropology, clinical dentistry, biology, paleontology, and paleopathology. The resulting knowledge base permits the study, analysis, interpretation, and understanding of information derived from the human dentition through their morphological, evolutionary, pathological, cultural and therapeutic variations. These structural considerations are viewed against a people’s culture, notably the conditions of life, diet, and adaptation processes. The varied sorts of data studied include nonmetric traits, metric traits, oral and dental diseases, and structural modifications of the teeth. Dental morphology, particularly the study of nonmetric dental traits (NDT), involves genetically-modulated trait expressions that can be used for comparisons within and among populations (Scott and Turner, 1997, 1998; Rodríguez CD, 2003, 2005; Rodríguez JV, 2000; Rodríguez JV, 2003).

More than 100 NDT of dental crowns and roots have been described and standardized internationally using various methodologies. Their study and investigation have demonstrated that: (a) they possess high taxonomic value; (b) they can be used to estimate biological relationships among diverse populations (Scott and Turner, 1997, 1998; Rodríguez CD, 2003, 2005; Rodríguez and Delgado 2000; Rodríguez JV, 2003).

PARAMOLAR TUBERCLES

One NDT that has been described as an accessory or supernumerary cusp, was defined by A. A. Dahlberg in 1950 as a paramolar tubercle, a term applied nonspecifically to a style or cusp of supernumerary character that is developed on the buccal or lingual surfaces of the upper and low teeth (Turner and Harris, 2004).

Developmentally, dental cusps begin their formation during the early bell stage, well before calcification of the tooth has begun. The cells of the internal epithelium proliferate and produce activators and inhibitors while they are being deposited in sequential layers from the

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cusp apex toward the neck of the crown starting from an enamel knot. The activator produces a primary enamel knot until the concentration reaches a threshold that induces an inhibitor that neutralizes the activator. Once a primary enamel knot has developed, it subsequently disappears by means of apoptosis and secondary enamel knots may appear. Molecular biologists are beginning to understand the genes that code and control the expression of the activator and the inhibitor that modulate the rhythm and quantity of enamel deposition. These transient gene expressions modulate the formation and elevation of the peaks and crests leaving among them furrows and grooves.

Consequently, the formation of a NDT (a cusp, for example) begins with primary or secondary enamel knot. The form of the NDT is influenced by the amount (thickness) of enamel deposited, size of the crown, its relationship with other NDT, and its internal relationship with the dentine. The NDT’s configuration depends, on one hand, on the molecular patterns that are genetically determined and, on the other hand, on the trait’s relationship with other morphological features (Butler, 1995; Jernvall et al., 1994; Jernvall and Jung, 2000; Jernvall and Thesleff, 2000; Line, 2001; Thesleff and Sharpe, 1997).

Dental studies in the field of the molecular biology derive in part from the work of Thesleff et al. (e.g., 2001). Research demonstrates that the primary enamel knot configures the occlusal table of premolars and molars, while secondary enamel knots individually constitute the cusps during amelogenesis (Thesleff, 2003; Turner and Harris, 2004).

In the case of the paramolar tubercle, Turner and Harris (2004) suggest that such cusps arise during the morphogenesis process starting from an accessory enamel knot developed at the surface where the feature’s apex forms. It seems that these tubercles do not provide any functional adaptation, such as enlarging the occlusal (masticatory) surface, because these tubercles do not enter into function; they do not occlude against any cusp or groove of the antagonist tooth.
To date, there is very little information about racial differences in the frequencies of paramolar tubercles, primarily because of their apparently low occurrence overall. Likewise, no pedigree analysis seems to have been conducted, though their mode of inheritance seems to be complex. Alternatively, their expression may suggest a genetic relationship between individuals. For instance, if the tubercle were found in two coeval individuals in a population, this increases the likelihood that the persons are genetically related, which can be useful for forensic identification (Zoubov, 1997; Edgar, 2005).

CASE REPORT

The subject is an eleven-year-old girl attending the orthodontic clinic at the School of Dentistry of the University of the Valley, Colombia.

Assessment of the maxillofacial skeleton disclosed a slight Class II sagittal molar relationship; upper and low arches were of an oval form; there was slight mandibular retrognathism; the facial form was mesofacial and there was a vertical growth pattern. Diagnosis of the soft tissue showed a convex facial profile, a moderate mentolabial furrow, a normal nasolabial angle, protrusion of both the upper and lower lips, and an increased height of the inferior third of the face. The stomatognathic functional diagnosis disclosed bruxism and a preference for unilateral right mastication. The dental diagnosis
showed that the girl presents a complete permanent dentition (omitting the third molars), a Class I molar malocclusion, a Class II canine relationship, proclination of the mandibular incisors, moderate crowding in both arches, deviation of the dental midlines, and traumatic occlusion.

This NDT of interest here is a unilateral paramolar tubercle that on the buccal surface of the upper left second premolar. Viewed in the frontal plane (Figs. 1, 5), the tubercle presents a free cusp apex that does not reach the occlusal plane. Indeed, the tubercle is out of function since there is no occluding anatomical structure on the opposing mandibular teeth. In buccal view (Figs. 3, 6, 9), the tubercle constitutes a triangular prominence with its base below the gingival margin and its apex oriented occlusally. This cusp is aligned with that of the premolar’s buccal cusp. From the occlusal view (Figs. 4, 7, 8), one can appreciate the symmetrical prominence of the tubercle, which is centered mesiodistally along the tooth’s buccal surface. The longitudinal furrow is evident here, and it runs mesial to distal, separating the tubercle from the premolar’s primary cusp.

Other NDTs that can be appreciated in the patient are: (A) Crowding of the upper incisors (Figs. 4, 7), where the lateral incisors are lingually displaced and there is a consequent tooth-size to arch-size discrepancy (Rodriguez, 1989; Bernabé and Flores, 2006). (B) Slight incisor winging (Figs. 4, 7), where both upper central incisors are slightly rotated distolingually relative to the midline; in this case, winging probably is secondary to inadequate arch space for correct incisor alignment (Peck and Peck, 1975; Rodriguez JV, 1989, 2003; Turner et al., 1991; Nandini et al., 2005; Bernabé and Flores, 2006). (C) Cusp 7 (grade 5) occurs bilaterally, which is an NDT characteristic of Negroid populations (Zoubov, 1997). (D) Cusp 6 (grade 2) occurs bilaterally. (E) A deflecting wrinkle (grade 3) can be seen on the first molars. (F) The molar cusp arrangement yields a Y6 groove pattern (mesiolingual cusp contacts with the distobuccal cusp at the central groove). (G) A protostylid pit occurs bilaterally (Fig. 10), which is a common NDT in mixed population from Colombia (Moreno et al., 2004; Moreno and Moreno, 2005; Aguirre et al., 2006).

RECOMMENDATIONS

It is important to recognize that although some NDTs, including the paramolar tubercles, only occur in low frequencies, they should not be classified as anomalous (a perspective common in clinical dentistry) since they are normal morphological features of the dentition. This morphological variation is evidenced by the diverse trait frequencies among world populations. Of course, this variability often is capitalized on in the processes of an individual’s forensic identification.

It should be noted that, during orthodontic treatment, paramolar tubercles often are removed by ameloplasty (i.e., the selective removal of enamel by grinding) because they interfere with cementation of the brackets and correct alignment of orthodontic archwires. However, this clinical procedure should be considered a last option, since it involves the mutilation of an epigenetic variant of the dental morphology.

It is important that NDTs are described systematically (by form and position) in each person’s clinical dental history because these variants are of discriminatory value and because of their usefulness in the identification processes carried out during the technical and scientific exercise of forensic dentistry.

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Brief Communication: Rotation of the Maxillary Premolars: Evidence in Support of Premolar Morphogenetic Field

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ABSTRACT: The presence of an individual tooth, axially rotated within the maxillary and/or mandibular dental arcade is not an uncommon occurrence in the human dentition. Far rarer is the axial rotation of two or more adjacent teeth, rotated together as a “unit” within the dental arcade. Two rare cases are presented here, each case possessing a maxillary P3-P4 unit that has been axially rotated. This event is in and of itself interesting and important, yet it also potentially provides support for the concept of a “premolar” morphogenetic field. Dental Anthropology 2006;19(3):70-73.

Dental morphological variation can be considered to fall within two broad categories: (1) those that involve major deviations from the basic dental blueprint and (2) those that involve minor, subtle variations in crown and/or root morphology (Hillson, 1996; Scott and Turner, 1997). Included within the first category are such dental anomalies as supernumerary teeth (polygenesis or polydontia), missing one or more teeth (agenesis or hypodontia), fusion of adjacent teeth, transposition of teeth, rotation of teeth, malposition of teeth, deviations from the “normative” crown morphology (e.g., conical lateral incisors, 3-cusped upper premolars, “mulberry” molars) and other sundry anomalies. The second category of dental variation includes minor variations in secondary cusps, fissure patterns, marginal ridges, supernumerary roots, and so forth (Scott and Turner, 1997:3). Many of the dental anomalies in the first category involve developmental errors in the number and/or positions of individual tooth germs or tooth morphogenic fields. However, the existence of dental morphogenic fields has been debated (Henderson and Greene, 1975). Evidence illustrating an extremely rare form of dental rotation, as well as supporting the presence of a premolar morphogenetic field is discussed below.

SPECIMENS

Within the skeletal collection of the American Museum of Natural History, New York, are two specimens displaying a unique rotation of a maxillary P3-P4 unit.

CASE 1: AMNH 99.1/1395

The first case consists of well-preserved maxillary and mandibular dental arches of a specimen from the collection of Marquesas Island crania collected by H. L. Shapiro during the Templeton Crocker Pacific Expedition in 1934 or possibly during his participation in the B. P. Bishop Museum Tuamotu Expedition in 1929. This specimen possesses a unique dental anomaly in which both the maxillary left P3 and P4 were mesially rotated 90°, as a unit (Figs. 1-2). Crown morphology of the premolars is completely normal. Also evident in the specimen’s dentition is moderate shoveling of the central and lateral incisors, as well as a small expression of Carabelli’s trait on the first maxillary molars. No other dental anomaly was noted.

CASE 2: AMNH 99/8478

The second case consists of well-preserved maxillary and mandibular dental arches of a specimen from the collection of Cañon del Muerto, Arizona crania collected by Earl H. Morris during an American Museum of Natural History expedition in 1923 and 1924. This specimen also possesses a unique dental anomaly in which both the maxillary right P3 and P4 were distally rotated ~80°, as a unit (Figs. 3-4). However, unlike the P4 of the AMNH 99.1/1395 specimen, the P4 of this specimen appears to have distally rotated an additional 180°. Crown morphology of the premolars is normal otherwise, though with a relatively large carious lesion on the distal surface on the P4 crown and root. Also evident in the specimen’s dentition is shoveling of the central incisors, as well as the medial rotation of the central incisors. No other dental anomaly was noted.
Fig. 1. Occlusal view of AMNH 99.1/1395 maxillary dentition.

Fig. 2. Close-up view of left maxillary premolars of AMNH 99.1/1395.
DISCUSSION

Minor-to-pronounced axial rotation has been noted of individual teeth of the maxillary and mandibular dental arcade. The direction of this axial rotation can be either mesial or distal. Winging and counter-winging, either unilateral or bilateral, of the maxillary central incisors, seen predominantly in Native American Indians, is one example of a minor rotation of a tooth (Dahlberg, 1963; Escobar et al., 1976). More pronounced axial rotation of an individual tooth typically involves a 90 to 180 degree rotation (Lui, 1980; Tay, 1968; van Nievelt and Smith, 1997). Normally, these cases of extreme axial rotation are also characterized by either unilateral or bilateral rotation of individual teeth.

However, the rare cases discussed above represent an even smaller sub-category of dental rotation, an occurrence where two adjacent teeth are rotated as a “unit” within the dental arcade. This type of dental rotation, to the author’s knowledge, has not been documented or reported in the literature. These cases each possess a maxillary P3-P4 unit that has been either medially or distally rotated, an event in and of itself very interesting and important. Yet, these examples of P3-P4 unit rotation also potentially support the concept of a premolar morphogenic field.

Butler (1937; 1939) presented the concept that the gradients in mammalian dentition was due to morphogenic fields. He proposed that each tooth germ in the maxilla or mandible possessed the same genetic information, which would allow any single tooth germ to develop into any type of tooth. It was only the tooth germ’s position in the maxilla or mandible that determined what type of tooth the tooth germ would ultimately develop into, directed by some field substance or morphogen (Scott and Turner, 1997). Butler hypothesized three morphogenic fields, namely incisor, canine and molar, and variations within each field were due to “pattern genes” operating at a secondary level on different tooth germs within a morphological field (Butler, 1937, 1939; Scott and Turner, 1997:82).

Butler’s morphogenic field theory was applied to humans by Dahlberg (1945). In addition to Butler’s three morphogenic dental fields, Dahlberg defined a fourth, “premolar” dental field. Dahlberg’s separation of premolars from the molar morphogenic field into its own field, resulting in the definition of four morphogenetic dental fields, nicely corresponded to the four morphological classes of teeth present in humans. Debate currently exists as to whether premolars should be distinguished as a dental field, separate from the molar field (Scott and Turner, 1997; Suarez and Williams, 1973; Townsend and Brown, 1981). Many dental anthropologists argue that premolars are an anterior extension of the molar dental field, while others note crown and root morphology that support the existence of a distinct premolar dental field (Scott and Turner, 1997:84-85; Wood and Engleman, 1988; Wood et al., 1988). Scott and Turner (1997:85) state, “To summarize, the evidence is equivocal regarding a separate premolar field…”

These cases with their rotated maxillary P3-P4 units and perfectly formed premolar and molar crowns tentatively support the existence of a separate premolar morphogenic field, making the evidence slightly less equivocal.

ACKNOWLEDGEMENTS

I would like to acknowledge the following individuals for their assistance and access to the skeletal material examined in this study and for their permission to photograph the specimens presented in this report: Dr. Ian Tattersall, Dr. Kenneth M. Mowbray, and Gary Sawyer, American Museum of Natural History, New York, New York.

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Fig. 3. Occlusal view of AMNH 99/8478 maxillary dentition.

Fig. 4. Close-up view of right maxillary premolars of AMNH 99/8478.

Wood BA, Abbott SA, Uytterschaur H. 1988. Analysis of

the dental morphology of Plio-Pleistocene hominids.
Dr. Stefan’s interesting description of two archeological cases with severely malposed premolars (Dental Anthropology 2006;19(3):70-73) prompted me to review two comparable cases I have encountered. I present these here in hopes that their description will stimulate discussion from the readership.

CASE 1

Figure 1 shows an occlusal view of the mandibular dental arch of a 24-year-old American black male. All 16 permanent mandibular teeth are erupted into functional occlusion, and, as shown in this figure, there is appreciable anterior dental crowding. The notable feature, of course, is the buccolingual juxtaposition of the left first and second premolars, where the second premolar is erupted ectopically to the lingual (with ~40° distolingual rotation) and the first premolar is rotated with the lingual aspect ~40° to the mesial. The canine is ectopically positioned to the labial in the corresponding right quadrant, but the two right premolars are arranged normally in the midarch. There is good gingival height around both ectopic premolars, with normal crown-root ratios as viewed from radiographs. Premolar alignment is normal in the maxillary arch.

CASE 2

This is a 14-year-old American white girl. Figure 2 shows the buccal-lingual arrangement of her maxillary right premolars. The second premolar is displaced to the lingual with mesial rotation of the tooth’s lingual aspect. The first premolar is deviated less transversely, but the lingual aspect is rotated ~80° to the lingual (lingual rotation of the second premolar is ~60°). Gingival contours are healthy around all teeth. Premolar arrangement is normal in the other three quadrants. All 32 permanent teeth are present on X-ray, though the third molars have not yet emerged.

PERSPECTIVE

It is tenuous to speculate on the etiology of these rotations and displacements just from examination of the completed dentition because several different factors may have been contributory. One possibility, of course, is that the premolars’ tooth crypts formed in the wrong positions and these teeth’s erupted malpositions reflect this developmental anomaly. Figure 3 shows a panoramic radiograph of a young boy with such a problem. Instead of the premolar crypts being located in the root bifurcations of the primary molars, the crypts of both the first and second premolar are beneath (apical to) the primary first molar. In this boy, the same malposition occurs in all four quadrants rather than just one quadrant as seen in the four older cases presented by Dr. Stefan and myself.

Alternatively, the permanent first molar (that emerges well before the premolars) could be the culprit. If this molar’s eruptive path were deflected to the mesial, it would have compromised the arch space available for normal premolar eruption. With inadequate space, the premolars would remain trapped within the bone, or would have erupted along whatever pathway of least resistance presented itself. One can speculate that compromised space forced the premolars into the odd positions seen in the cases presented here. This situation occasionally occurs in the maxilla because of the upper molar’s normal mesial-occlusal eruptive trajectory (e.g., van der Linden and Duterloo, 1976; Duterloo, 1991). It is much less common in the mandible because the lower molar normally has an essentially vertical path of eruption. Figure 4 shows the panoramic radiograph of a case where the maxillary first molars are mesially inclined and are actively lysing through the distal root of the primary second molars. In contrast, the mandibular first molars have erupted normally, distal to the primary second molars. Several clinicians have reported on the occlusal consequences of first-molar ectopia, notably in the maxilla (e.g., Kurol and Bjerklin, 1986; Bjerklin, 1994; Barberia-Leache et al., 2005). The scenario would be that the early-erupting first molar erupts in to the space that should be held by the primary second molar, leading to this primary tooth’s premature loss, and the space for the normal emergence of the premolar is compromised, leading to failure to erupt (impaction) or, conceivably as seen in
Fig. 1. Case of a young adult American black male with buccal-lingual juxtaposition of the mandibular left premolars. **Top:** Intraoral photograph of the mandibular arch, showing the ectopic premolars and appreciable anterior crowding. **Bottom:** Occlusal view of the same subject’s dental cast.

Fig. 2. Case of an adolescent American white female with buccal-lingual juxtaposition of the maxillary right premolars. **Top:** Intraoral photograph of the maxillary arch. Aside from the ectopic premolars in the right quadrant, there is little crowding. The absence of space mesial to the first or second molar on the right illustrates the effect of mesial drift. **Bottom:** Occlusal view of the same subject’s dental cast.

Figures 1 and 2, ectopia of one or both premolars in a quadrant.

Another possibility is caries: Indeed, historically, caries was the greatest single cause of malocclusion (e.g., Weinberger, 1926). The two primary molars in a quadrant can be viewed as space holders for the later-emerging premolars. If one or both primary molar is lost prematurely because of caries, the permanent first molar will drift forward, diminishing the space available for normal eruption of one or both premolars. An example of an impacted second premolar is shown in Figure 5; here the failure of eruption was due to caries and premature loss of the primary second molar, followed by mesial drift of the permanent first molar before the second premolar could erupt. Contemporary dentists have a variety of appliances that can be used to preserve the arch space of an extracted primary tooth (e.g., Ngan et al., 1999; Choonara, 2005), but, of course, this was not an option in the past—when caries also was a more prevalent health problem.
A quick review of the literature shows that premature loss of a primary tooth affects the eruption tempo of its successor, but the effects reported are contradictory, some stating that premature loss accelerates eruption of the replacement tooth, others that loss delays eruption (reviewed, e.g., by Ronnerman, 1977, Loevy, 1989). Fanning (1962), though often overlooked, was among the first to make sense of the situation, and my elaboration of her findings is this: When a primary tooth is lost at an early age, the supporting alveolar bone has plenty of time to heal and remodel (often atrophying to a narrow ridge) and the successor’s root is too immature to initiate eruption (though the true “initiator” of eruption is poorly understood). Eruption of the successor is delayed in such cases, which increases the opportunity and extent of drift of teeth adjacent to the extraction site (e.g., Ronnerman, 1977; Ronnerman and Thilander, 1978; Northway, 2000). In contrast, if the primary tooth is lost at an older age, the successor is more mature and closer to its normal eruption age, so the alveolar bone remains less remodeled and more cancellous (Boyne, 1995; Diedrich and Wehrbein, 1997; Hasler et al., 1997), and eruption is hastened. When the successor erupts soon into the extraction space, there is little opportunity for drift of the adjacent teeth, thus enhancing chances of normal occlusal position.

Although uncommon, it is useful to mention pathological conditions that can retard exfoliation (of the primary tooth) and/or eruption (of the succedaneous tooth). An odontoma—a generally benign developmental hamartomatous lesion often coronal to an unerupted tooth—consists of tissues that resist tooth eruption as well as the normal migration of the successor.
of erupted teeth. Some odontomas form enamel and dentinal structures that look like miniature teeth (“toothlets”), but others leave no readily-discernible skeletal evidence of their existence. Morning (1980) reviewed tooth impactions secondary to odontomas (also see Amado Cuesta et al., 2003; Tomizawa et al., 2005). The case reported by Kupietzky and coworkers (2003) is relevant here because it details the ectopic displacement of a second molar consequent to an odontoma. In a similar vein, molecular biologists have discovered genes that influence tooth eruption, notably, mutant alleles that interfere with the normal lysis of bone ahead of an erupting tooth, which can lead to impaction (e.g., Tiffee et al., 1999; Nishino et al., 2001; Ida-Yonemochi et al., 2004).

The commonality of these various scenarios involves the similarity of developmental timing of the first and second premolars (and canine) in each quadrant. These three teeth erupt during what van der Linden and Duterloo (1976) term the “second transition” — roughly 10 to 12 years of age (Fig. 6). Hurme (1949, 1951, 1957) published syntheses of eruption studies, and his classic works are still among the most common citations on the subject. Hurme (1951) found that, modestly, the second premolar erupts roughly 9 months later than the first premolar, though there is some inter-individual variation (Kent et al., 1978; Smith ad Garn, 1987; Diamanti and Townsend, 2003). Liversidge recently (2003) has collated the extensive literature from the 20th century. The data (based on various collection strategies and various statistical methods) show that the second premolars characteristically emerge later than the first, but, again, these averages hide the considerable variability among individuals. Inspection of the four cases reported by Dr. Stefan and myself show that, in each instance, the second premolar’s position is more aberrant than the first—and this is consistent with the later-emerging second premolar moving into a more-constrained space (because, statistically, the first premolar probably emerged slightly earlier and commandeered space for itself). It may be relevant too that in all four cases presented by Dr. Stefan and myself, the malposed premolars are restricted to one quadrant—suggesting that the etiology generally is anatomically localized rather than systemic.

Importantly, modal eruption ages can camouflage the variability in eruption sequences, though published reports of just the former are far more common. Sato and Parsons (1990) documented the appreciable variation seen in eruption sequences, particularly when the subjects can be followed longitudinally. The first premolar emerges ahead of the second (P1→P2) in most children (80% in maxilla; 96% in mandible), which agrees with the findings of Smith and Garn (1987) who, using cross-sectional data, found P1→P2 in about 90% of their children. Diamanti and Townsend (2003) also assessed data cross-sectionally, and found somewhat higher frequencies for P1→P2, about 97% in both arches. The relevant point here is that the data agree that the first premolar is quite likely to emerge before the second, thus putting P2 at greater risk for impaction or malposition—and this is what is seen in all four of the cases reviewed here.

These comments do not detract from Dr. Stefan’s presentation. Instead, they are meant to emphasize the dynamic sequence of events that, gone awry, can lead to the observed malplacements of later-forming teeth. Indeed, in addition to the broad criteria developed by Butler (1939) and Dahlberg (1945), a premolar field can be assessed by a variety of other measures, such as crown and root size and morphology, and similarities in formation, eruption, and emergence times and sequences.

ACKNOWLEDGEMENTS

I extend my thanks to Dr. Robert Turner and Dr. Jerome Burr who provided the orthodontic records of my case 1 and case 2, respectively. Dr. Betsy Barcroft provided the records for Figure 3, and Dr. Woodrow Powell provided the records for Figure 4.
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Boyne PJ. 1995. Use of HTR in tooth extraction sockets to maintain alveolar ridge height and increase concentration of alveolar bone matrix. Gen Dent 43:470-473.


ABSTRACT: This study describes a Byzantine cranium from an archaeological site in Jordan (Khirbit Yajuz). This case study illustrates severity of the multiple dental pathologies encountered and speculates on the cause of death. The 21-yers-old female of this study suffered multiple dental abscesses, where the accumulated pus reached the nasal cavity and the maxillary sinuses through a large fistula, probably causing septicemia that may have caused her early death. This case was selected from among similar cases from the site, and it illustrates an extreme, progressive state of caries and the absence of dental hygiene. Dental Anthropology 2006;19(3):79-82.

The study of the total collection of the human teeth from the archaeological site of Khirbit Yajuz has revealed striking results, notably conspicuous oblique dental wear on the first lower molars, premortem and perimortem tooth loss, dental abscesses in the maxilla, and progressive periodontal disease (Al-Shorman, 2003). The frequency of dental caries among the recovered skeletons (n = 120 individuals) is 13.3%, which is within the range of the other Byzantine sites in the region (Smith et al., 1992; Williams et al., 2004). These and other archaeological results suggest a population of low social status whose primary occupation was weaving (Al-Shorman and Khalil, 2006). In the upper jaw, most of the sites of tooth decay had developed into dental abscesses. In contrast, the low frequency of caries and the absence of dental abscesses in the lower jaw might have been triggered by the use of teeth as tools (Al-Shorman, 2003) that frequently polished the occlusal tooth surface, thereby removing sticky food particles and reducing depths of the fissures. In other words, the rate of dental wear was high enough to inhibit the development of dental caries on the occlusal surfaces of teeth (Powell, 1985). The frequency of dental abscesses among the Byzantine people of Khirbit Yajuz was extraordinarily high compared to similar sites; most of the investigated carious lesions had periapical abscesses.

A periapical abscess develops when the area surrounding the tip of the root is invaded by bacteria; fluids and dead bacteria accumulate in the periapical region, forming a pocket as part of the phagocytic defense process (Scott and Turner, 1988). Abscesses develop as the fluids break through the alveolar bone. An untreated case may develop a fistula either on the buccal or the lingual side (Alexandersen, 1967). A periapical abscess typically is the result of pulp exposure due to rapid attrition, caries, trauma, or periodontal disease (Hillson, 1996); all of these factors were present among the Yajuz people. The present study presents one of the progressive cases of acute periapical abscesses and periodontal disease. This analysis also extracted the demographic variables of age and sex based on morphology of the cranium and development of the teeth. Dealing with the case from a forensic perspective, the study elucidates the probable cause of death.

MATERIALS AND METHODS

The study deals with the remains of one individual represented by a cranium that is dated to the Byzantine period, ca. 5th-8th century AD (Khalil, 1998, 2001). This cranium was visually assessed for the presence of periapical abscesses, caries, dental wear, and periodontal disease. The sex was estimated after Ascádi and Nemeskéri (1970), aging after Ubelaker (1989), wear according to Smith (1984), and abscesses and caries after Buikstra and Ubelaker (1994).

RESULTS AND DISCUSSION

The supraorbital margins are very sharp with only minor prominence of Glabella, indicating that the specimen was female. The third right upper molar is not in complete occlusion; it is below the level of the adjacent right second molar. This situation suggests an age of about 21 years (Ubelaker, 1989).

The maxilla retained five teeth, namely the right canine, right first premolar, right second molar, right third molar, and left first premolar. The other teeth were lost before death (premortem) or around death (perimortem).

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The teeth that are present in occlusion exhibit minor dental wear, suggesting that the woman had a less abrasive diet and/or the teeth did not have enough time to be abraded because she died at a young age. The second right molar possesses two large caries, one on the mesial and the other on the distal cervical margin of the crown. The left second premolar also has a moderate lingual surface caries. Periodontal disease is prominent along the tooth arcade, with significant horizontal alveolar bone loss.

Five teeth exhibit periapical abscesses in advanced stages (Table 1). The most noticeable and advanced

---

**Table 1. Maxillary tooth inventory**

<table>
<thead>
<tr>
<th>Tooth type</th>
<th>Side</th>
<th>Occlusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>First incisor</td>
<td>Right</td>
<td>Premortem loss</td>
</tr>
<tr>
<td>Second incisor*</td>
<td>Right</td>
<td>Perimortem loss</td>
</tr>
<tr>
<td>Canine</td>
<td>Right</td>
<td>Complete occlusion</td>
</tr>
<tr>
<td>First premolar</td>
<td>Right</td>
<td>Complete occlusion</td>
</tr>
<tr>
<td>Second premolar*</td>
<td>Right</td>
<td>Perimortem loss</td>
</tr>
<tr>
<td>First molar*</td>
<td>Right</td>
<td>Perimortem loss</td>
</tr>
<tr>
<td>Second molar</td>
<td>Right</td>
<td>In full occlusion</td>
</tr>
<tr>
<td>Third molar</td>
<td>Right</td>
<td>Below full occlusion</td>
</tr>
<tr>
<td>First incisor</td>
<td>Left</td>
<td>Postmortem loss</td>
</tr>
<tr>
<td>Second incisor</td>
<td>Left</td>
<td>Postmortem loss</td>
</tr>
<tr>
<td>Canine</td>
<td>Left</td>
<td>Postmortem loss</td>
</tr>
<tr>
<td>First premolar</td>
<td>Left</td>
<td>Postmortem loss</td>
</tr>
<tr>
<td>Second premolar</td>
<td>Left</td>
<td>In full occlusion</td>
</tr>
<tr>
<td>First molar</td>
<td>Left</td>
<td>Premortem loss</td>
</tr>
<tr>
<td>Second molar*</td>
<td>Left</td>
<td>Perimortem loss</td>
</tr>
<tr>
<td>Third molar*</td>
<td>Left</td>
<td>Perimortem loss</td>
</tr>
</tbody>
</table>

*Tooth exhibits a periapical abscess.
The presumed large amount of pus in the nasal cavity and the maxillary sinuses might have been absorbed by the epithelial tissues lining them. The pus probably infiltrated the bloodstream causing septicemia. Since the person died during the active stage of the disease, septicemia is the probable cause of her death. The progress of the disease was from the root of the first molar to the palatine bone, followed by the nasal cavity, and then involvement of the maxillary sinus. Finally, the orbit was involved, all of which took a considerable amount of time, probably weeks. This extensive invasion stresses the woman’s physiological ability to tolerate and cope with the disease, especially in the absence of medical intervention.

CONCLUSION

The multiple dental pathologies in this case involve a clear-cut situation of poor dental hygiene in the presence of a rich carbohydrate diet. Comparable multiple pathologies were common among the people of Khirbit Yajuz, especially among skeletal remains of the low social classes. Our case is from the Yajuz people; the woman belonged to a low social class and probably died of septicemia at around 21 years of age.

LITERATURE CITED

Dental morphology trait expressions have been used in anthropology and forensic sciences for determination of biological and geographical affiliations. Variations in morphology of crowns may be manifest in the primary and/or permanent dentitions. Dental variation is heritable, is caused by multiple genes, and is little influenced by environmental factors. Traditionally, three, four, five, six or seven cusps, specifically the protoconid, metaconid, hypoconid, rntoconid, hypoconulid, entoconulid and metaconulid, have been reported in morphological descriptions of lower molars for various human groups (Axelsson and Kirverskari, 1979; DeVoto and Perroto, 1972; Hanihara, 1967; Harris and Bailit, 1980; Morris, 1965; Sciulli, 1977; Schroeder et al., 1983; Scott and Turner 1997; Suzuki and Sakai, 1973). This brief communication reports on the presence and asymmetry of a possible eighth cusp on mandibular primary second molars of a contemporary Argentinean boy.

**MATERIALS AND METHODS**

The teeth of a racially mixed boy five years of age from Cordoba City, Argentina, were examined in situ and on a plaster cast. An unusually shaped accessory occlusal cusp was observed on both the left and right mandibular primary second molars. Size of this eighth cusp was measured with sliding calipers. This case report is part of an anthropological study carried out on material provided by the Departamento de Ortodoncia, Facultad de Odontología, Universidad Nacional de Córdoba, Argentina.

**RESULTS**

Figures 1 and 2 illustrate the presence and bilateral asymmetry observed on mandibular primary second molars. A small additional cusp occurs between hypoconulid and entoconulid cusps. The anomalous cusp is larger on the right molar (diameter: 0.245 mm) than the left (diameter: 0.165 mm).

**DISCUSSION**

This accessory, eighth cusp has been not reported previously. This rare variant on anomalous lower primary molars provides an interesting record of eighth cusp in human dental morphology. Bilateral presence and asymmetrical appearance of the eighth cusp suggest a possible factor of heritability in the expression of this infrequently human molar form. Brabant suggests that primary second mandibular molars with five cusps are most common. Six cusps are less frequent (2% to 30%), and the seven-cusp molar—with a cusp of Jørgensen (metaconulid)—is found in less than 10% of cases (Brabant, 1967). Kallay’s (1966) classification

Grant Sponsor: Facultad de Odontología, Universidad Nacional de Córdoba, Argentina.

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**ABSTRACT:** The presence and asymmetry of an eighth cusp observed on the primary second mandibular molars of an Argentinean boy is described. *Dental Anthropology* 2006;19(3):83-85.
could be used to label this eighth cusp, perhaps the Protuberantio apulparis sited in the distal occlusal area of primary second lower molars. As mentioned by Brothwell (1967), the phenomenon of increasing world contact, immigration, and interbreeding between previously more isolated communities can produce new forms that enrich the variation observed in the human dentition.

**LITERATURE CITED**

Fig. 2. Occlusal view of the mandibular second molars as seen on the plaster cast.

The Albert A. Dahlberg Prize is awarded annually to the best student paper submitted to the Dental Anthropology Association (DAA). Dr. Dahlberg was a professor at the University of Chicago, one of the founders of the International Dental Morphology Symposia, and among the first modern researchers to describe variations in dental morphology and to write cogently about these variations, their origins, and importance. The prize is endowed from the Albert A. Dahlberg Fund established through generous gifts by Mrs. Thelma Dahlberg and other members of the Association.

Papers may be on any subject related to dental anthropology. The recipient of the Albert A. Dahlberg Student prize will receive a cash award of $200.00, a one-year membership in the Dental Anthropology Association, and an invitation to publish the paper in Dental Anthropology, the journal of the Association.

Students should submit three copies of their papers in English to the President of the DAA. Manuscripts must be received by January 31, 2007. The format must follow that of Dental Anthropology, which is similar to the style of the American Journal of Physical Anthropology. The Style Guide for Authors is available at the web site for the AJPA (http://www.physanth.org) or by e-mail from the AJPA editor (ajpa@osu.edu).

The manuscript should be accompanied by a letter from the student’s supervisor indicating that the individual is the primary author of the research and the paper. Multiple authorship is acceptable, but the majority of the research and writing must be the obvious work of the student applying for the prize. Send enquiries and submissions to the President of the DAA:

Professor Simon Hillson
Institute of Archaeology
University College London
31-34 Gordon Square
London WC1H 0PY
United Kingdom
e-mail: simon.hillson@ucl.ac.uk

The DAA reserves the right to select more than one paper, in which case the prize money will be shared equally among the winners. They also reserve the right to not select a winner in a particular year.

The winner of the Albert A. Dahlberg Student Prize will be announced at the Annual Meeting of the DAA, which is held in conjunction with the annual meeting of the American Association of Physical Anthropologists. In 2007, the meeting will be held in Philadelphia, Pennsylvania, March 27 - April 1.
The Relative Sexual Dimorphism of Human Incisor Crown and Root Dimensions

Edward F. Harris* and W. Max Couch, Jr.

Department of Orthodontics, University of Tennessee, Memphis, TN 38163

ABSTRACT: Teeth are unusual structures in that their dimensions are sexually dimorphic even though they form early in life, several years before steroid-mediated adolescence. These size differences make teeth attractive as indicators of a specimen’s sex. Alternatively, the magnitude of sexual dimorphism in humans is low, so there is considerable overlap in sizes between the two sexes. Prior studies suggest that tooth root dimensions are more dimorphic than crown dimensions, so roots would be more useful for sex determination. To explore this, we measured the four incisor tooth types from standardized periapical radiographs in a sample (n = 148) of living American white adolescents. Root lengths are somewhat more dimorphic than crown sizes in this sample (ca. 6% vs. 2%), and this translates into somewhat higher discriminatory power. The hindrance, however, is that all crown and root sizes are positively intercorrelated, so there is effectively just one dentition-wide axis of “tooth size” variation. Statistically, at least for these incisor tooth types, there is no added discriminatory power in the crown sizes once root dimensions have been accounted for, though the addition of data from other tooth types might improve discrimination somewhat. Dental Anthropology 2006;19(3):87-95.

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Full-mouth dental casts were taken along with the periapical radiographs, and we measured the maximum mesiodistal crown dimensions of the teeth using sliding calipers, which provide an absolute measure of tooth size as well as an internal check of the radiographic method. Four dimensions are evaluated here, (1) mesiodistal crown width, (2) overall tooth length, (3) crown height, and (4) root length.

Overall tooth length was measured from the root apex coronally to the mediolateral midpoint of the tooth’s incisal edge (Fig. 1). Root length—from the root apex to the cementoenamel junction (CEJ)—is not an invariant distance because the CEJ undulates around the tooth’s periphery (Zeisz and Nuckolls, 1949), with the CEJ higher (more occlusal) on the tooth’s mesial and distal aspects than labially or lingually. We measured the straight-line distance from the root apex separately to the mesial and the distal margins of the CEJ. For the present study, the average of these two distances was used as root length. This distance was subtracted on an individual basis from tooth length to yield crown height. In sum, tooth length equals crown height plus root length.

Sexual dimorphism was assessed statistically using factorial analysis of variance (Winer et al., 1991) and stepwise multivariate discriminant functions analysis (Cooley and Lohnes, 1971). Principal components analysis (Gorsuch, 1983) was performed to evaluate the statistical associations among the variables. Statistics were calculated using the JMP software package (SAS Institute Inc., Cary, NC).

**RESULTS**

**Tooth Dimensions**

Of the four incisor tooth types, mesiodistal crown diameter of just the upper central incisor (U1) exhibits

<table>
<thead>
<tr>
<th>Tooth Code</th>
<th>Males</th>
<th>Females</th>
<th>% Sex Dimorphism</th>
<th>Adjusted r²</th>
<th>Analysis of Variance</th>
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<td>x</td>
<td>sd</td>
<td>sem</td>
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<td>0.01</td>
<td>91</td>
</tr>
</tbody>
</table>

1 Tooth codes are maxillary central (U1) and lateral (U2) incisor and mandibular central (L1) and lateral (L2) incisor. Sexual dimorphism is calculated from the means, ((M-F)/F) times 100. Adjusted r² is the variation in the tooth dimension accounted for by sexual dimorphism (the independent variable) in the analysis of variance.

#The r² is close to zero, and the adjustment caused the estimate to be negative, though this has no statistical interpretation (and should be set to zero).
TABLE 2. Matrix of Pearson correlation coefficients for the 16 incisor dimensions studied

<table>
<thead>
<tr>
<th>U1 CW</th>
<th>U2 CW</th>
<th>L1 CW</th>
<th>L2 CW</th>
<th>U1 TL</th>
<th>U2 TL</th>
<th>L1 TL</th>
<th>L2 TL</th>
<th>U1 CH</th>
<th>U2 CH</th>
<th>L1 CH</th>
<th>L2 CH</th>
<th>U1 RL</th>
<th>U2 RL</th>
<th>L1 RL</th>
<th>L2 RL</th>
</tr>
</thead>
<tbody>
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<td>0.44</td>
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<td>0.38</td>
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<td>0.11</td>
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</tbody>
</table>

1Variable codes are crown width (CW), tooth length (TL), crown height (CH), and root length (RL). Sample size was 148 individuals for all correlations, so coefficients above 0.16 are statistically significant (P < 0.05; Rohlf and Sokal, 1981).

TABLE 3. Results of principal components analysis on 16 incisor dimensions, without rotation

<table>
<thead>
<tr>
<th>Tooth</th>
<th>Eigenvectors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Crown Width</td>
</tr>
<tr>
<td>U1</td>
<td>0.061 0.044 0.038 0.177</td>
</tr>
<tr>
<td>U2</td>
<td>0.038 -0.019 -0.010 0.198</td>
</tr>
<tr>
<td>L1</td>
<td>0.034 0.048 0.029 0.112</td>
</tr>
<tr>
<td>L2</td>
<td>0.028 0.042 0.029 0.116</td>
</tr>
<tr>
<td></td>
<td>Tooth Length</td>
</tr>
<tr>
<td>U1</td>
<td>0.418 -0.405 0.497 0.108</td>
</tr>
<tr>
<td>U2</td>
<td>0.382 -0.276 -0.535 0.248</td>
</tr>
<tr>
<td>L1</td>
<td>0.367 0.409 0.027 0.000</td>
</tr>
<tr>
<td>L2</td>
<td>0.371 0.423 0.073 0.065</td>
</tr>
<tr>
<td></td>
<td>Crown Height</td>
</tr>
<tr>
<td>U1</td>
<td>0.083 -0.015 0.144 0.427</td>
</tr>
<tr>
<td>U2</td>
<td>0.063 -0.026 0.006 0.313</td>
</tr>
<tr>
<td>L1</td>
<td>0.087 0.182 0.094 0.361</td>
</tr>
<tr>
<td>L2</td>
<td>0.086 0.121 0.063 0.330</td>
</tr>
<tr>
<td></td>
<td>Root Length</td>
</tr>
<tr>
<td>U1</td>
<td>0.335 -0.390 0.353 -0.320</td>
</tr>
<tr>
<td>U2</td>
<td>0.319 -0.250 -0.542 -0.065</td>
</tr>
<tr>
<td>L1</td>
<td>0.280 0.228 -0.067 -0.361</td>
</tr>
<tr>
<td>L2</td>
<td>0.285 0.302 0.010 -0.265</td>
</tr>
<tr>
<td>Eigenvalue</td>
<td>21.164 5.475 2.785 1.836</td>
</tr>
<tr>
<td>Percent</td>
<td>61.847 16.000 8.138 5.365</td>
</tr>
<tr>
<td>Cumulative Percent</td>
<td>61.847 77.847 85.986 91.351</td>
</tr>
</tbody>
</table>

Fig. 1. Labial view of a maxillary right central incisor showing measurements of root length determined separately on the medial and lateral aspects (from root apex to CEJ) and tooth length (from root apex to midpoint of incisal edge). Crown height was operationalized as tooth length minus root length (i.e., average of medial and lateral distances), which yields a longer root length (and shorter crown height) than if the labial or lingual level of the CEJ had been used.
significant sexual dimorphism (Table 1). Percentage-wise, mean size for males is only 1-2% larger than for females. The other crown dimension assessed here, crown height, comparably exhibits little sexual dimorphism. Just the mean size difference for U2 is significant statistically (a 4% difference), and crown heights of the mandibular incisors are virtually identical in the two sexes.

It seems noteworthy that overall tooth lengths of all four incisors are appreciably more dimorphic. All four ANOVA tests are significant (Table 1). Percent sexual dimorphism is lower but not trivial in the mandible (ca. 3%) and higher (ca. 5 to 8%) in the upper arch. This greater sexual dimorphism is likely reflected in the coefficients of determination ($r^2$) that can be read as the percentage of the variation in tooth length accounted for in the statistical sense by “sex.” Percentages are lower for the two mandibular incisor types than in the maxilla, or, perhaps more correctly, the maxillary lateral incisor tooth length is comparatively highly dimorphic ($r^2 = 14\%$).

It is evident that tooth length is composed of crown height and root length and, since sex differences in crown height are minor, most of the dimorphism obviously is due to sex differences in root length (Table 1). Indeed, sexual dimorphism in incisor root lengths is in the range of 5 to 8%, which is noticeably higher than for crown widths or heights. Also, unlike crown dimensions, percentage sex differences are not smaller for the mandibular root dimensions.

Crown-Root Ratios

Incisor crown-root ratios (Table 1) were here assessed for completeness. The ratio is simply crown height divided by root length, so the larger the ratio the more crown height contributes to overall tooth length. Ratios are 50% or less, showing that incisor root lengths characteristically are more than twice their crown heights. Mean crown-root ratios are slightly larger in the mandible because the mandibular root lengths are proportionately shorter. Sexual dimorphism for these ratios is trivial in the maxillary incisors, whereas both tests are significant for the mandibular incisor types. These mandibular differences are due to longer roots in males (whereas the crown heights are very similar in men and women).

Correlation Matrix

Several studies have shown that tooth crown diameters are positively intercorrelated (reviewed, e.g., in Henderson, 1975), and Garn et al. (1978a) showed that root lengths within individuals likewise covary in a positive fashion. These expectations are evident in the present data (Table 2) where all 120 pairwise correlations are positive and most are significantly different from zero statistically. Given the uniform sample size of 148 cases, correlations above 0.16 are significant ($P < 0.05$) and those above 0.21 are highly significant ($P < 0.01$).

Scanning the matrix, the weakest correlations are between crown widths and root lengths, and the strongest are between tooth lengths and root lengths. These latter are predictable, however, because root length is the major constituent of tooth length. Pearson and Davin (1924; also see Solow, 1966) term these sorts of correlations of a dimension plus part of itself “spurious” in the sense that they are correlated simply because of their geometric association, which need not be biological.

Ideally, one would like to find statistically independent axes of variation so that the sexual dimorphism exhibited by some tooth dimensions is not duplicative of that of other dimensions. Separate “axes” of variation would provide greater statistical power for discriminating between the sexes using multiple tooth dimensions. Given the consistently positive, generally high correlations here (Table 2) suggests that there is effectively just a single statistical (and, by inference, biological) axis of sexual dimorphism.

Principal Components Analysis

PCA (Gorsuch, 1983) was used to assess the relationships among the crown and root dimensions. Four dimensions for each of the four incisor tooth types were used in the analysis, namely (1) crown width, (2) tooth length, (3) crown height, and (4) root length. Four components were extracted with eigenvalues exceeding
Fig. 2. Plots of the variable weights on the first four principal components extracted from the covariance matrix of 16 crown and root dimensions. These “weights” of variables with each canonical axis can be interpreted as the correlation coefficient of the variables with the axis.
one (Kaiser, 1970), and these were evaluated without matrix rotation (Table 3). These four axes account for most (91%) of the variation, and, within these, just the first axis is responsible for most (62%) of the total variance.

PC I is controlled by tooth length, with slightly higher weightings on the two maxillary dimensions (Fig. 2). Probably because root lengths are major constituents of tooth length (Fig. 1), root lengths also have comparatively high weights on this component.

PC II reflects the high loadings of tooth lengths and root lengths, but here there are polarities (opposite signs) for variables in the maxilla and the mandible. As with the first component, crown widths and heights have only minor loadings (correlation coefficients) with PC II.

PC III is a further orthogonal axis of variation for root length and, by association, tooth length. Here just the maxillary variables exhibit high loadings, with polarities between the central and lateral incisors. In other words, having accounted for the variances of PC I and II, the remaining major axis of variation is a contrast between root lengths of the two maxillary incisor types.

Highly weighted variables for PC IV are restricted to crown heights and root lengths (Fig. 2). Within a variable (crown height or root length), all four weights are of the same sign.

When tested for sexual dimorphism (Table 4), PC I scores, which depend primarily on root lengths, are highly significant. In contrast, none of the other three axes seems to be of any value for sex discrimination.

Discriminant Analysis

When the eight crown size variables (4 widths, 4 heights) were subjected to stepwise linear discriminant function analysis, just one variable—crown width of U1—was significantly predictive. Correct allocation was 47% overall, though somewhat higher in girls (56%) than boys (37%).

When the other eight variables were analyzed (4 tooth lengths, 4 root lengths), again there was just one significant predictor because of the considerable

Fig. 3. Sequenced arrays of the probabilities of group assignment. Probabilities above 50% are the cases correctly assigned; cases with probabilities below 50% were allocated to the wrong sex. The height of the symbol above the 0.5 line is a measure of how confident the researcher can be that the case is correctly classified. The shallow slope of the distributions illustrates the weak sexual dimorphism even of these selected variables. Top. Arrays using U1 crown width, which is the one statistically significant crown size predictor of sex from among the 8 tested. Bottom. Arrays using mandibular I1 root length, which is the one significant root size predictor of sex in this sample from among the 8 tested.
statistical redundancy of these dimensions. Here, mandibular central incisor (L1) root length was most discriminating, with 60% correct assignment (54% for males; 64% for females). This is an improvement over using crown widths alone, but the increase in correct assignment (60% vs. 49%) is modest. One can see from the very gradual slope of probabilities of correct assignment (Fig. 3) that there is considerable overlap in crown and in root dimensions between the two sexes.

We supposed that there would be enough statistical independence between crown and root dimensions that they could be used in combination to improve sex determination. This was not the case. Once the greater dimorphism of root length was entered (specifically, inclusion of L1 root length at step 1) and statistics of the other variables were adjusted to account for root length, none of the other dimensions had significant independent power to be added. With hindsight, this is because all 16 of the variables studied here are positively intercorrelated, and even the weakest associations (between crown widths and root lengths) are still on the order of 0.1 to 0.2.

**DISCUSSION**

Tooth root size and morphology have been studied far less than crown size (e.g., Kovacs, 1971; Thomas, 1995), largely because of their inaccessibility and, additionally, in archeological specimens, their comparative fragility. So too, little is known about the genetic control of root size and morphology. Most root formation occurs prior to tooth emergence (Carlson, 1944), which may be protective against forces of mastication until teeth are in function. Unlike enamel, a root’s configuration is subject to surface remodeling. Root resorption can be instigated with orthodontic forces (Harris, 2000) or with jiggling forces that are common consequences of pathological loss of supporting crestal bone (Nyman et al., 1978; Harris et al., 1993).

The accretion of cementum, in contrast, increases root dimensions in an age-progressive manner (Wittwer-Backofen et al., 2004), though the annual depositions are too small to be visualized on conventional radiographs. Cementum accumulation typically is thickest in the bifurcations of multirooted teeth, though hypercementosis occasionally occurs periapically (e.g., Halstead and Hoard, 1991).

The normal age-progressive periapical accumulation of cementum needs to be studied in more detail; researchers have reported on an increase in root length—supposedly by cementum apposition—as an age-progressive event. Most such studies have been cross-sectional (Levers and Darling, 1983; Whittaker et al., 1990), though there is some longitudinal evidence for root lengthening with age (Bishara et al., 1999).

The prime focus in the present study was to test whether root lengths exhibit greater sexual dimorphism than crown dimensions, where sex differences are too subtle to be definitive in most cases (Ditch and Rose, 1972; Kieser and Groeneveld, 1989). Precisely because sexual dimorphism is modest in humans, most studies that have developed discriminant functions capitalize on sex differences specific to their own sample; applications to other groups generally exhibit much weaker frequencies of correct sex assignment. The problem is intrinsic to the crown size data, not to sophistication of the statistical techniques. There are two synergistic problems, (1) there is little sexual dimorphism (the canines, especially buccolingually, seem to be the most dimorphic; Sciulli et al., 1977) and (2) even though teeth are numerous within a person, crown sizes all are significantly, positively intercorrelated, so there are few axes of novel information to exploit (e.g., Moorrees and Reed, 1964; Potter et al., 1968; Harris and Bailit, 1988); the sexual dimorphism seen among crown dimensions is statistically redundant.

These observations seem to have motivated Garn and coworkers (1979) and others to look for independent axes of variation. Tooth roots seem to offer two advantages here: (1) the dimensions are at least partially uncoupled from crown size (Fig. 2), so the data are not repetitive (statistically redundant) with crown dimensions, and (2) root lengths are a bit more dimorphic than crown dimensions (Table 1).

The present study has clear precedents in the work of Stanley Garn and colleagues (1978a,b, 1979) who measured root lengths in a sample of living American white teenagers using 45° oblique-jaw radiographs. They measured five mandibular tooth types (C, P1, P2, M1, M2) omitting the incisors that are distorted in this radiographic view. While their methodological details differ from ours, there are some key similarities. One, we examined different teeth than Garn’s group, but our intertooth correlations (Table 2) for tooth lengths are in the same range, about 0.5 to 0.6, and the correlations within an arch are higher than between arches. Two, the correlations between crown size (here we tested mesiodistal incisor crown widths) and root lengths are low (ca. 0.1 to 0.2) but consistently positive. Garn et al. (1978b) found the same low level of crown-root integration.

Garn and coworkers (1979) tested the sex discriminatory power of numerous combinations of crown and root dimensions. Scrutiny of their presentation shows, however, that they made no effort to show that each variable in each discriminant function contributed significant statistically information. Alternatively, the simple addition of more variables typically will improve discrimination of individuals in the sample used to generate the formulae (discriminant functions) because using more variables capitalizes on variation unique to that sample. Unfortunately, amassing variables (1) does not improve the statistical significance of the predictive equation and (2) detracts from the generalizability of the results to other samples (Kieser and Groeneveld, 1989).
In other words, “percentage correct allocation” should not be the driving criterion for developing discriminant functions because that criterion commonly is specific to the sample used to develop the functions—that criterion promotes exploiting male-female differences specific to that sample, not to sex differences in size relationships at large.

Tooth roots serve several functions (Shafer et al., 1983), including the important function of transmitting the forces of occlusion to the supporting alveolar bone. Given the significantly larger bite forces in males than females, especially after the onset of puberty (e.g., Bakke et al., 1990; Julien et al., 1996), the tendency for larger roots (with larger surface areas) in men probably is adaptive. As Garn noted (1978b, p 636):

> It is impressive that the crowns of permanent teeth that begin to form by the second trimester of prenatal life and that complete their size-attainment in the second to fifth year of postnatal life thus “anticipate” the length of still-to-be-completed roots by 10 years or more.

**CONCLUSIONS**

This study of incisor crown-root dimensions in a contemporary American white sample shows that root lengths are somewhat more sexually dimorphic than crown dimensions and, thus, are somewhat more useful for sex determination. The statistical associations are higher among crown dimensions than between crowns and roots, but all correlations are positive. Our discriminant function analysis (that relied just on incisor tooth types) does not support the supposition that combinations of crown and root dimensions are any more useful for sex determination than root dimensions alone—because the dimensions all seem to reflect the same statistical information. Perhaps the use of more tooth types, notably the canine, would somewhat improve correct sex assignment from tooth dimensions.

**LITERATURE CITED**


Tanner JM, Prader A, Habich H, Ferguson-Smith MA. 1959. Genes on the Y chromosome influencing rate of maturation in man: skeletal age studies in children with Klinefelter’s (XXY) and Turner’s (XO) syndromes. Lancet 2:141-144.


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</tr>
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<tbody>
<tr>
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<td>Figure Legends</td>
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<tr>
<td>Text</td>
<td>Figures</td>
</tr>
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## Original Articles

Carolina Rodríguez and Freddy Moreno  
*Paramolar tubercle in the left maxillary second premolar: a case report*  
65

Abdulla Al-Shorman  
*A Byzantine Cranium from Jordan: A Case Study in Dental Anthropology*  
79

Edward F. Harris and W. Max Couch  
*The Relative Sexual Dimorphism of Human Incisor Crown and Root Dimensions.*  
87

## Brief Communication

Vincent H. Stefan  
*Rotation of the Maxillary Premolars: Evidence in Support of Premolar Morphogenetic Field*  
70

*Commentary* by Edward F. Harris  
74

Carlos David Rodríguez Florez, Gabriel Mario Fonseca, and Maria Teresa de Villalba  
*Occurrence of an Eighth Cusp on Primary Second Mandibular Molars of a Contemporary Argentinean Child.*  
83

## DAA News

The Albert A. Dahlberg Competition, 2007  
86

14th International Symposium on Dental Morphology  
Greifswald, Germany, August 20 – 23, 2008  
96