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Maxillary Canine Ectopia and Maxillary Canine-Premolar Transposition are Associated with Deviations in the Maxilla

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ABSTRACT The purpose was to analyze the direction of the infraorbital canal and the palatal width in cases with maxillary ectopic canines, all oriented horizontally and erupted labially, and with canine transposition and to compare findings with normal values. Eight anthropological human skulls, four with these horizontally oriented ectopic canines and four with canine-premolar transposition comprised the study. A radiopaque marker was placed in the infraorbital canal and frontal and profile radiographs were taken of each skull. Cephalometric measurements evaluated the canal direction (IOt angle). Interorbital (IO) and palatal widths (PW) were measured directly on the skulls. A general linear model was used for statistical analysis. Maxillary canine ectopia: IOt ($\bar{x}$ = 8.54; 95% CI of -3.95 and 21.04; P = 0.18) was larger, PW ($\bar{x}$ = 3.37; 95% CI of 0.51 and 6.23; P = 0.022) was significantly smaller and IO ($\bar{x}$ = 1.49; 95% CI of -2.62 and 5.61; P = 0.47) was also smaller. Maxillary canine-premolar transposition: IOt ($\bar{x}$ = 17.27; 95% CI of 4.78 and 29.76; P = 0.008) and PW ($\bar{x}$ = 3.34; 95% CI of 0.48 and 6.21; P = 0.023) were significantly smaller and IO ($\bar{x}$ = 2.94; 95% CI of -1.17 and 7.06; P = 0.16) was smaller, but not significantly. Eruptional deviations in the maxillary canines-premolars are associated with maxillary deviations expressed as the direction of the infraorbital canal and the transpalatal width. Accordingly, dental and osseous deviations within the maxillary developmental field are interrelated *Dental Anthropology* 2010;23(2):37-41.

A previous study on 42 normally developed anthropological skulls demonstrated that the direction of the infraorbital canal changes with age in the frontal view (Caspersen *et al.*, 2009). This study also indicated that the direction of the infraorbital canal reflects the transversal growth of the maxilla.

Previous cephalometric studies have shown that the pterygoid canal and the mandibular canal are stable structures useful for superimposing of profile radiographs and therefore valuable when evaluating craniofacial growth patterns (Björk and Skieller, 1977, 1983). It is assumed that the infraorbital canal also is a stable structure during growth.

The infraorbital canal is located in the region of the maxilla, which has developed from the maxillary developmental field (Kjær, 2009). The palatal processes of the maxilla influencing the palatal width and the maxillary canines and premolars are also located within this field (Fig. 1). It is hypothesized that osseous deviations involving shape and width are expected in the maxilla in cases with dental deviations in the canine-premolar area. Such deviations are ectopic maxillary canine anomalies occurring with a frequency of 0.8 to 2.8% (Aydin *et al.*, 2004) and maxillary canine transpositions occurring with a frequency below 0.4% (Yilmaz *et al.*, 2005). A dental transposition (or transmigration) occurs when teeth emerge in the wrong sequences in the dental arch, and the most common situation is when the maxillary canine emerges distal to the first premolar.

The purpose of the present study was to analyze the direction of the infraorbital canal and the palatal width in cases either with (A) ectopic maxillary canines or (B) maxillary canine transpositions and to compare the findings with normal values. The ectopic canines were selected as possessing a horizontal orientation in the bone and these teeth had erupted labially into what would have been the subject's buccal vestibule.

MATERIALS AND METHODS

Skulls

Eight anthropological human skulls were analyzed, four with maxillary canine ectopia, all of which were oriented horizontally and had erupted labially (2 bilateral and 2 unilateral), and four with maxillary canine-premolar transposition (2 bilateral and 2 unilateral). In the ectopia cases, the canines were malpositioned and had failed to follow the normal eruption path (Fig. 2a). The skulls came from Björk's skull collection at the Department of Orthodontics, Copenhagen School of Dentistry, Denmark. The results from a previous study of 42 anthropological skulls from the same collection were used as normal

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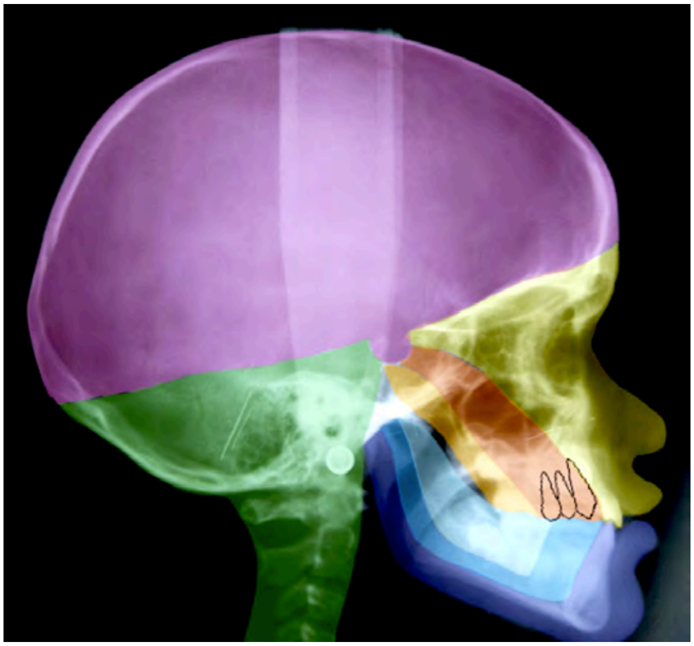

Fig. 1. On a profile radiograph of a 9 year-old girl different colored regions are marked indicating the embryological developmental fields defined by Kjær (2009). The maxillary field is the focus of the present study.

Yellow	The frontonasal field
Red	The maxillary field (canines and premolars are in this field)
Orange	The palatal field
Blue	Different fields in the mandible
Purple	The theka field
Green	The occipital field

[Color figure can be viewed in the electronic (PDF) version of the journal.]

controls (Caspersen *et al*., 2009).

Registration of the infraorbital canal

A radiopaque marker was placed in the infraorbital canal in the side where the maxillary canine ectopia (Fig. 2a) or the maxillary canine-premolar transposition (Fig. 2b) occurs. In the skulls with bilateral expressions, a marker was placed in both infraorbital canals.

Radiography

Frontal radiographs were taken of each skull as illustrated in Figure 3. The radiographs were taken at the Department of Orthodontics, School of Dentistry, Copenhagen, Denmark, in a Philips/Valmet BR 2002 cephalostat (Tagarno A/S, Horsens, Denmark) with a film-to-focus distance of 195 cm. The linear enlargement was 8.3%. The radiographic film used was LifeRay XDA Plus UTLG (Ferrania Technologies S.p.A., Cairo Montenotte, Italy). The films were exposed with 65-67kv and 5-7 mA. The radiographs were taken with the skulls oriented in the Frankfort Horizontal plane.

Cephalometric analysis

This analysis was performed according to the method developed by Caspersen *et al*. (2009). Tracing paper was placed on each frontal radiograph, and the outer contour of the skull, the orbital rim and piriform aperture were marked. Two lines were drawn: line 1 connecting the two bilateral orbital landmarks (lo) (Fig. 4) and line 2 expressing the direction of the infraorbital canal (Fig. 4). The bilateral orbital landmarks (lo) were defined according to Svanholt and Solow (1977). The angle between lines 1 and 2 (Fig. 4) was named the infraorbital transversal angle (IOt) (Caspersen *et al*., 2009).

Direct skull measurements

Two widths (one anterior and one posterior) were measured on the skulls according to Caspersen *et al*. (2009). The interorbital width (IO) was the length between the left and right infraorbital foramen; this is the anterior width. The palatal width (PW) was the maxillary cross-arch transversal palatal width (from first maxillary molar; left, to first maxillary molar, right); this is the posterior width.

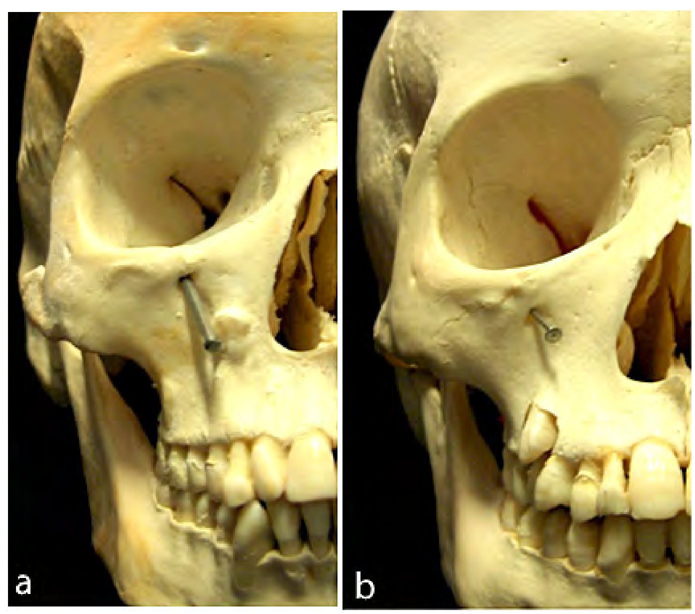

Fig. 2. Photographs of two anthropological skulls. (***Left***) Maxillary canine ectopia in the right side. The canine is oriented horizontally and has erupted labially. In this specimen, the permanent canine is lateral to the piriform plate, near the base of the nose, and the primary canine is still in occlusion. A radiopaque marker is placed in the infraorbital canal indicating the direction of the canal. (***Right***) Maxillary canine-premolar transposition in the right side. A radiopaque marker is placed in the infraorbital canal indicating the direction of the canal.

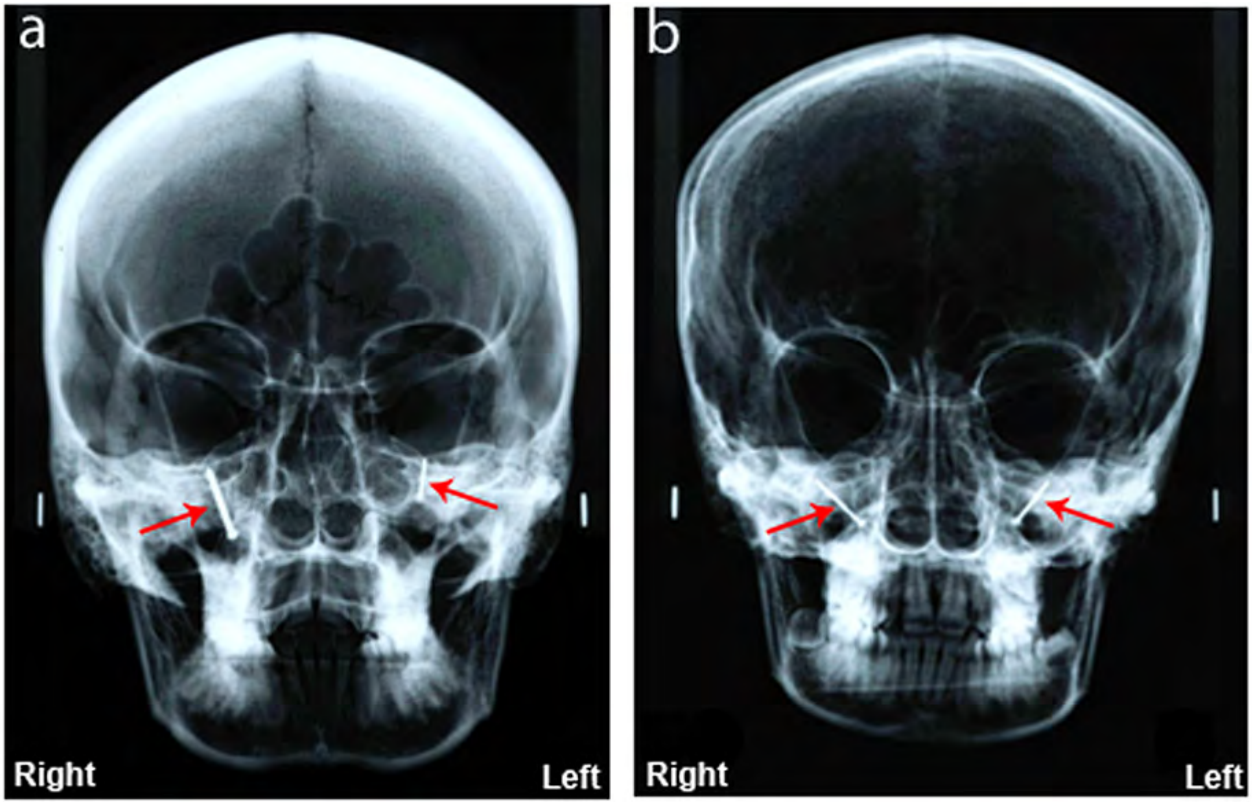

Fig. 3. Frontal radiographs of two anthropological skulls. (a) A skull with bilateral maxillary canine ectopia with a radiopaque marker in each infraorbital canal, visualized and marked by arrows. (b) A skull with bilateral maxillary canine-premolar transposition with a radiopaque marker in each infraorbital canal, visualized and marked by arrows.

Statistical analysis

A general linear model was used for statistical analysis of the three variables (IOt, PW, and IO). When the results from the ectopic and the transposition groups were compared with those of the control group, IOt, PW and IO were the dependent variables and the three different groups of skulls were the explanatory variables.

For all explanatory variables the mean level was subtracted. The results were presented by P-values and the estimates with 95% Confidence Interval (CI). P-values less than 5% were considered significant. The analyses were performed using SAS (version 9.1, SAS Institute Inc., Cary, N.C., USA).

Further, in cases with bilateral registration the skulls were tested for differences between the sides. This test showed no significant difference (P = 0.21 for IOt; P = 0.91 for PW; P = 0.98 for IO) and the mean value was used. This resulted in eight observations, namely four cases of maxillary labial canine ectopia (E) and four cases of maxillary canine-premolar transposition (T).

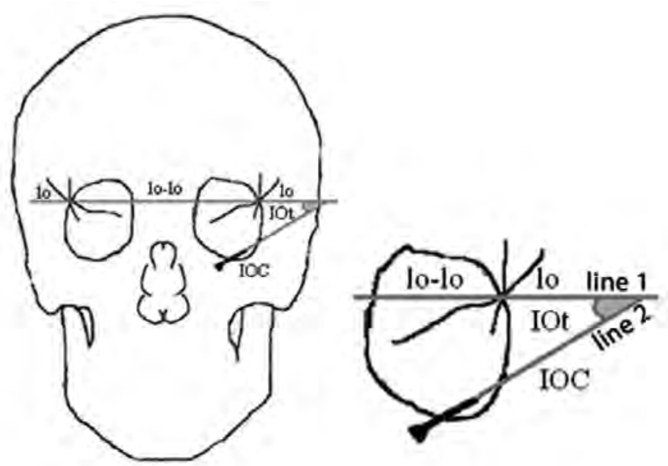

Fig. 4. The figure illustrates the tracing on the frontal cephalometric film of an anthropological cranium from a normal human adult. Line 1 represents the line through the contour of the bilateral orbital points (lo) and line 2 represents the direction of the infraorbital canal. The intersection between line 1 and line 2 forms the infraorbital transversal angle (IOt), which represents the inclination of the infraorbital canal.

RESULTS

The measurements of the three variables (IOt, IO, and PW) for the cases with canine ectopia (E) and canine-premolar transposition (T) are shown in Table 1. When all eight cases were evaluated a weak correlation was seen

TABLE 1. Descriptive statistic of the three variables

Group	Variable†	n	mean	sd
E	IOt (degrees)	4	74.63	12.33
E	PW (mm)	4	34.05	1.11
E	IO (mm)	4	50.30	2.01
T	IOt (degrees)	4	48.81	7.22
T	PW (mm)	4	34.08	1.77
T	IO (mm)	4	48.85	1.60

†IOt: Infra orbital transversal angle
PW: Palatal width
IO: Inter orbital width.
The mean value and the standard deviation are given for the four skulls with maxillary canine ectopia (E) and for the four skulls with maxillary canine/premolar transposition (T).
For comparison normal values according to Caspersen *et al*. (2009) are:
IOt: mean 66.08, sd 12.11
PW: mean 37.42, sd 2.85
IO: mean 51.79, sd 4.13

between IOt and IO (P = 0.20), whereas no correlation was seen between IOt and PW or between PW and IO (Table 2).

Analysis showed that the infraorbital transversal angle (IOt) (= 8.54; 95% CI of -3.95 and 21.04; P = 0.18) was larger and that the palatal width (PW) ($\bar{x}$ = 3.37; 95% CI of 0.51 and 6.23; P = 0.022) was significantly smaller than the mean value for the normal skulls. The interorbital width (IO) ($\bar{x}$ = 1.49; 95% CI of -2.62 and 5.61; P = 0.47) was also smaller.

The infraorbital transversal angle (IOt) ($\bar{x}$ = 17.27; 95% CI of 4.78 and 29.76; P = 0.008) and the palatal width (PW) ($\bar{x}$ = 3.34; 95% CI of 0.48 and 6.21; P = 0.023) were significantly smaller compared with the normal skulls. Also, the interorbital width (IO) ($\bar{x}$ = 2.94; 95% CI of -1.17 and 7.06; P = 0.16) was smaller than the mean value in normal skulls, though not significantly.

This suggests that IOt and PW can be used as parameters expressing the maxillary complex in cases with maxillary canine ectopia and maxillary canine-premolar transposition. The infraorbital transversal angle (IOt) may be larger and the palatal width (PW) smaller in skulls with maxillary canine ectopia compared with normal skulls, whereas the infraorbital transversal angle (IOt) and the palatinal width are both smaller in skulls with maxillary canine-premolar transposition compared with normal skulls.

TABLE 2. Pearson correlations among the three variables

Variable	IOt (degrees)	PW (mm)	IO (mm)
IOt (degrees)	1.000	0.13	0.51
		0.77	0.20
PW (mm)	0.13	1.000	0.01
	0.77		0.99
IO (mm)	0.51	0.01	1.000
	0.20	0.99	

Correlation coefficients: n = 4; Prob > |r| under H_0: Rho = 0
Correlation between the three variables (IOt, PW and IO) in the 8 skulls with canine ectopia and canine/premolar transposition by Pearson correlation coefficients. The table shows a weak correlation between IOt and OI (P = 0.20), whereas the other variables are not significantly correlated.

DISCUSSION

Two sorts of maxillary dental deviations were studied, namely (A) canine ectopia (where the canines are oriented horizontally and erupted labially) and (B) canine transposition. Analysis shows that both conditions are associated with skeletal deviations in the maxillary developmental field. This is a new observation. Meanwhile, the present study cannot explain the association between dental and osseous deviations. The question is whether the dental deviations are a result of regional developmental deviations in the field or whether the regional developmental deviations in the skeleton are a result of dental deviations. This question is closely associated with the etiology of the dental deviations, which cannot be explained by the present findings.

The etiology of canine ectopia and canine-premolar transposition is not known, but is assumed to be associated with multifactorial disorders involving genetic factors (Feichtinger *et al*., 1977; Peck *et al*., 1994). Whether a difference in the infraorbital canal direction exists between the type of ectopia described in this study where the canines are oriented horizontally and erupted labially and other types of canine ectopia cannot be determined from the data in this study. Also, inadequate space has been mentioned as a causative factor (Al-Nimri and Gharaibeh, 2005). Several studies have documented differences in the dentition in palatally and labially displaced ectopic canines (Chaushu *et al*., 2002; 2003; Sørensen *et al*., 2008).

The infraorbital canal and the maxillary canine are both located in the maxillary developmental field defined by Inger Kjær (2009). The deviated direction of the infraorbital canal discloses a deviation in the maxilla, which may influence the tooth eruption seen in cases with canine ectopia and canine-premolar transposition. A similar comparison of tooth development and bone development within a developmental field has previously been shown in the frontonasal field of the maxilla. The present material comprising four crania with ectopia and four crania with transposition may seem small, but considering the very low prevalence of both conditions (ectopia 0.8 to 2.8% and transposition below 0.4%) the material represents a considerable population. Furthermore, among the types of ectopia, horizontally oriented and labially erupted canines are considered rare.

Regarding the frontonasal field, the tooth deviation seen in SMMCI (Single Median Maxillary Central Incisor) has been associated with regional osseous deviations within the frontonasal field including the anterior wall of the sella turcica (Kjær *et al*., 2001; Becktor *et al*., 2001). The extension of the frontonasal field is demonstrated in Figure 1 (yellow color). It is recommended that the morphology of the sella turcica be investigated systematically in all cases of dental deviations in future studies.

The sagittal and vertical growth of the cranium can also affect the direction of the infraorbital canal, but in the present study only the frontal view was investigated because canine ectopia is often diagnosed in the frontal view on a panoramic radiograph. In the present study, the transverse width of the palate has been measured as an indicator of transverse growth in the mid-palatal suture. Under normal circumstances, palatal expansion is characterized by more extensive growth in the posterior region than anteriorly (Iseri and Solow, 1990). It seems that this usual pattern of growth does not occur in the cases evaluated in the present study.

The present study documents a statistically significant correlation between the direction of the infraorbital canal, maxillary morphology, and deviations in tooth eruption in the maxilla. It can be concluded that the maxillary dimensions are different in ectopia and transposition, and that the maxillary dimensions differ from normal findings.

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LITERATURE CITED

Al-Nimri K, Gharaibeh T. 2005. Space conditions and dental and occlusal features in patients with palatally impacted maxillary canines: an aetiological study. Eur J Orthod 27:461-465.

Aydin U, Yilmaz HH, Yildirim D. 2004. Incidence of canine impaction and transmigration in a patient population. Dentomaxillofac Radiol 33:164-169.

Becktor KB, Sverrild L, Pallisgaard C, Burhøj J, Kjær I. 2001. Eruption of the central incisor, the intermaxillary suture, and maxillary growth in patients with a single median maxillary central incisor, SMMCI. Acta Odontol Scand 59:361-366.

Björk A, Skieller V. 1977. Growth of the maxilla in three dimensions as revealed radiographically by the implant method. Br J Orthod 4:53-64.

Björk A, Skieller V. 1983. Normal and abnormal growth of the mandible: a synthesis of longitudinal cephalometric implant studies over a period of 25 years. Eur J Orthod 5:1-46.

Caspersen LM, Christensen IJ, Kjær I. 2009. Inclination of the infraorbital canal studied on dry skulls expresses the maxillary growth pattern—a new contribution to the understanding of change in inclination of ectopic canines during puberty. Acta Odontol Scand 17:1-5.

Chaushu S, Sharabi S, Becker A. 2002. Dental morphologic characteristics of normal versus delayed developing dentitions with palatally displaced canines. Am J Orthod Dentofacial Orthop 121:339-346.

Chaushu S, Sharabi S, Becker A. 2003. Tooth size in dentitions with buccal canine ectopia. Eur J Orthod 25:485-491.

Feichtinger C, Rossiwall B, Wunderer H. 1977. Canine transposition as autosomal recessive trait in an inbred kindred. J Dent Res 56:1449-1452.

Iseri H, Solow B. 1990. Growth displacement of the maxilla in girls studied by implant method. Eur J Orthod 12:389-398.

Kjær I. 2010. Orthodontics and foetal pathology: a personal view on craniofacial patterning. Eur J Orthod 32:40-47.

Kjær I, Becktor KB, Lisson J, Gormsen C, Russell BG. 2001. Face, palate and craniofacial morphology in patients with a solitary median maxillary central incisor. Eur J Orthod 23:63-73.

Peck S, Peck L, Kataja M. 1994. The palatally displaced canine as a dental anomaly of genetic origin. Angle Orthod 64:249-256.

Svanholt P, Solow B. 1977. Assessment of midline discrepancies in the postero-anterior cephalometric radiograph. Trans Eur Orthod Soc 25:261-268.

Sørensen HB, Artmann L, Larsen HJ, Kjær I. 2008. Radiographic assessment of dental anomalies in patients with ectopic maxillary canines. Int J Paediatr Dent 19:108-114.

Yilmaz HH, Türkkahraman H, Sayin MÖ. 2005. Prevalence of tooth transpositions and associated dental anomalies in a Turkish population. Dentomaxillofac Radiol 34:32-35.

Residential Mobility and Dental Decoration in Early Medieval Spain: Results from the Eighth Century Site of Plaza del Castillo, Pamplona

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ABSTRACT Excavations at Plaza del Castillo in Pamplona (northern Spain) revealed a large Islamic necropolis dating to the eighth century A.D., including the skeleton of an adult female showing intentional dental modification (PLA-159). While the practice of dental decoration was virtually absent in Medieval Spain, it is common in Africa and suggests that this individual was born in Africa and brought to Spain later in life. The historically documented occupation of Pamplona by Muslim groups from northern Africa between ca. 715 and 799 A.D. also supports an African origin. As an additional line of evidence, we investigated the geographic origins of two individuals from the cemetery, including PLA-159, via radiogenic strontium and stable oxygen isotope analyses on enamel hydroxyapatite. The human isotopic signatures were measured following established methodologies and compared to the local geochemical composition and modern precipitation values. The data analysis showed a non-local isotopic signature for both individuals, suggesting that they moved to Pamplona following childhood, probably from northern Africa, during the Islamization of the city. Stable carbon isotope analysis revealed a diet heavily based on C_3 terrestrial plants. Overall, this preliminary data set exemplifies the use of biogeochemistry as an analytical tool, and provides unique insight about the diffusion of Muslim groups into the Early Medieval Iberian Peninsula.
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The Muslim conquest of the Iberian Peninsula in the Early Middle Ages constitutes an important part in the history of Spain, known from historical sources yet archaeologically unexplored. Excavations at Plaza del Castillo in the city of Pamplona in northern Spain (Fig. 1) recovered a large Islamic cemetery dating to the eighth century A.D. The identification of intentional dental modification in the cemetery, a practice virtually absent in Medieval Spain but common in African groups, may suggest an African origin for part of the burial sample, a hypothesis also supported by the historically documented arrival of Berbers from North Africa during the time of Muslim occupation. Hence, the reconstruction of the geographic origins of the individuals interred at Plaza del Castillo will afford unique insight about the Islamic occupation of the city of Pamplona, as well as about the diffusion of Muslim groups in Iberian Peninsula during the eighth century A.D.

Here we report the results of the preliminary study on migration in Early Medieval Pamplona using biogeochemical analysis. In the last decade, the use of biogeochemistry to address past residential mobility and migration has provided an invaluable new line of evidence and a growing field in archaeological science. The methodology, introduced to archaeology from environmental and ecological studies, has been successfully applied to numerous studies in a variety of historic and prehistoric contexts with a wide geographic range. Mobility and migration via isotopic analysis have been examined, for example, in the American Southwest (*e.g.*, Ezzo *et al*., 1997; Ezzo and Price, 2002; Price *et al*., 1994), Mesoamerica (*e.g.*, Price *et al*., 2006; White *et al*., 2004), south central Andes (*e.g.*, Knudson and Buikstra, 2007; Knudson and Price, 2007; Knudson and Torres-Rouff, 2009), South Africa (Cox and Sealy, 1997), and Thailand (*e.g.*, Bentley *et al*., 2007). In Europe, isotopic studies of geographic origins have been conducted in England (*e.g.*, Montgomery *et al*., 2005), Central Europe (*e.g.*, Bentley *et al*., 2004; Bentley and Knipper, 2005; Price *et al*., 1998; 2001),

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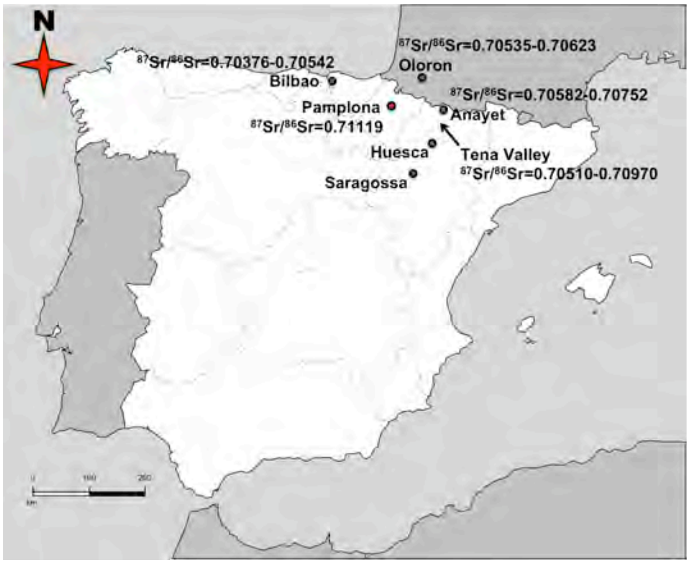

Fig. 1. Map of Iberian Peninsula showing the location of Pamplona with observed radiogenic strontium isotope signatures in bedrock and soil.

Iceland (*e.g.*, Price and Gestsdóttir, 2006), the Alps (*e.g.*, Müller *et al*., 2003), Spain (Díaz-Zorita Bonilla *et al*., 2009; Prevedorou *et al*., 2009), and Greece (*e.g.*, Nafplioti, 2008; Richards *et al*., 2008).

In this paper, we use biogeochemistry to test hypotheses explicitly formed by the bioarchaeological and historical evidence. We begin by presenting the site of Plaza del Castillo, along with the history of the region. We provide an analytical description of the typology, technique, and origin of the case of dental decoration observed in the Islamic cemetery, and we present our research objectives. We continue by introducing biogeochemistry as an analytical tool to address human behavior, and we then describe the materials and laboratory methodology for this study. Finally, we present our results and discuss the interpretation of this preliminary data set, as well as future research.

ARCHAEOLOGICAL AND HISTORICAL BACKGROUND: THE SITE OF PLAZA DEL CASTILLO

The cemetery of Plaza del Castillo, located in the city of Pamplona, came to light in 2002 during the construction of an underground parking lot (Fig. 2a). The large Islamic necropolis, *maqbara* in Arabic, was located outside the city walls covering an area of 4000 m^2; however, the total area of the cemetery is not yet known. Of the 160 undisturbed burials recovered in total, 50% were juveniles, while the adult burials consisted of approximately equal numbers of male and female individuals. Following the Islamic funerary traditions, the burials were single inhumations that lacked grave goods; bodies were placed in a simple pit lying on their right sides, with head towards south-southeast facing the holy city of Mecca (Casal, 2003; Faro Carballa *et al*., 2007; de Miguel Ibáñez, 2007) (Fig. 2a,b). The date of the Islamic cemetery corresponds with the emergence of the Islamic control in the Iberian Peninsula in eighth century A.D. and constitutes the first definite archaeological evidence for the Muslim occupation of the city of Pamplona.

According to historic sources, Pamplona came under Islamic authority around 715 A.D. with the arrival of Muslim groups, mostly Berbers, from North Africa (Maghreb). The city remained under Muslim control until 799 when the ruler Mutarrif ibn Musa was assassinated (Faro Carballa *et al*., 2007-2008). Radiocarbon dating conducted thus far in one of the skeletons from Plaza del Castillo (Burial 32) yielded a date between 660 and 770 cal. A.D. (Beta-218654). Hence, the onset of the Muslim authority in Pamplona in 715, and the radiocarbon date of Burial 32 suggest that at least part of the Plaza del Castillo cemetery was in use during the initial Islamization and the ensuing expansion of the Muslim community in the city.

The discovery of the *maqbara* is of great significance for the reconstruction of the historical trajectory of Pamplona and northern Spain in general. Despite the belief that the conquest of the city took place with a pact between the conquerors and those conquered, it appears that the Islamic occupation went through several crises that necessitated military intervention. Arabic sources report that during Uqba's rule (probably in 734 A.D.), he had to suppress his opponents and take over their cities and that he was the one who conquered the city of Arbona, subjugated Galicia and Pamplona, and brought in Muslim people (Al-Marrakusi, 1999). Thus, the individuals buried at Plaza del Castillo could in fact represent the Muslims first arriving in Pamplona, coming to suppress the continuous revolutions of the time in the name of Emir.

DENTAL DECORATION IN PLAZA DEL CASTILLO

Skeletal analysis of the human remains from the Islamic necropolis has identified the presence of intentional dental modification in the anterior dentition of Burial 159 (PLA-159), an adult female (Fig. 2b) (Romero *et al*., 2009). The modified teeth were classified following the typology established by Romero Molina (1986), which constitutes the most complete classification system based on earlier revisions (Saville, 1913; Romero Molina, 1958; Rubín De la Borbolla, 1940). Scanning electron microscopy (SEM) was performed on casts and replicas of the teeth to examine in detail the modified surfaces. Silicon Coltène® President Plus Jet and epoxy transparent resin Araldite 2020® were used for the dental casts and replicas respectively, following established methodologies (Galbany *et al*., 2006; Romero and De Juan, 2003). The dental replicas were analyzed with a SEM Hitachi S3000N at a magnification of 30X (Servicios Técnicos Investigación, Universidad de Alicante).

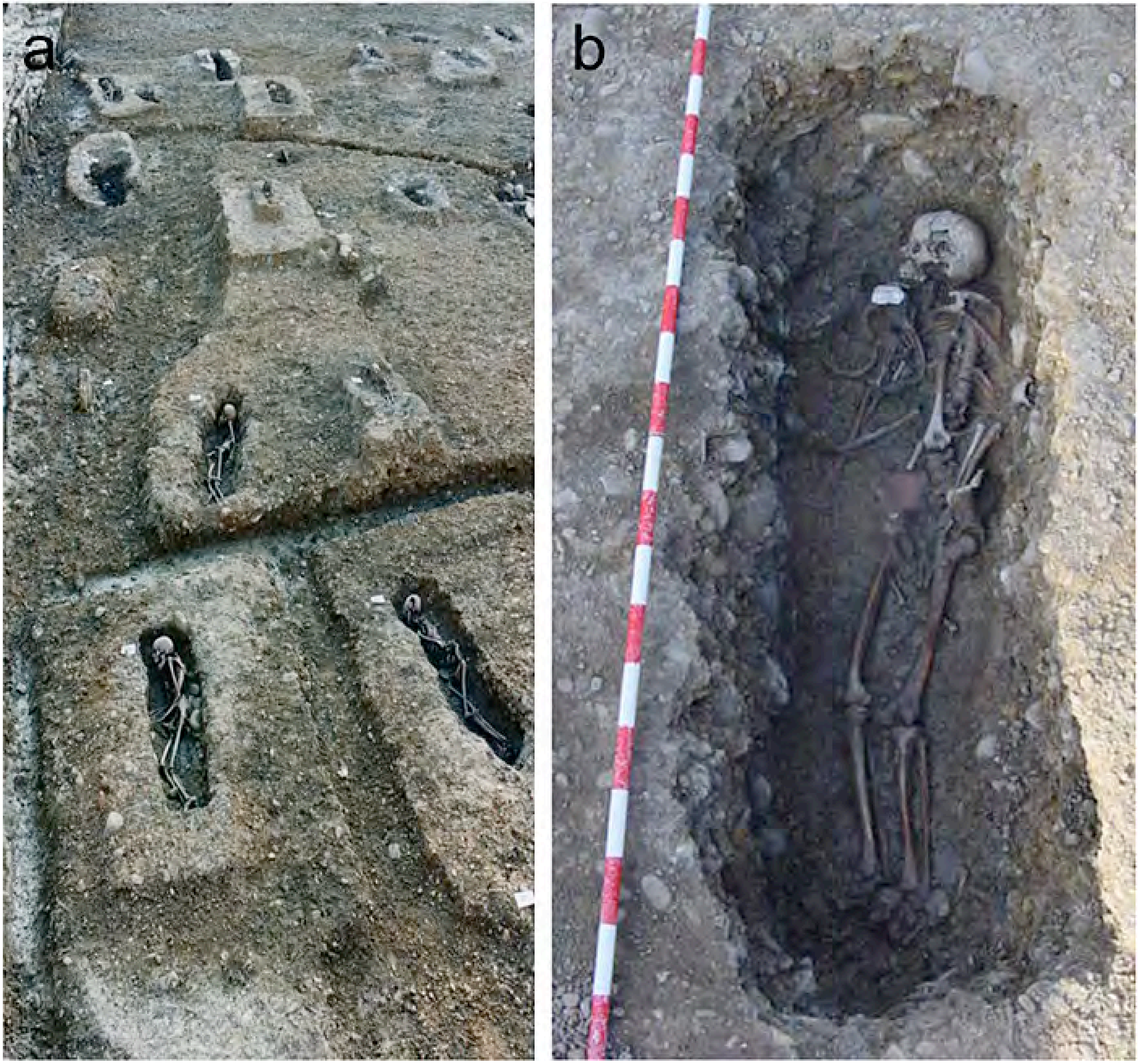

Fig. 2. View of the Islamic cemetery of Plaza del Castillo in Pamplona during excavation, showing the uniformly oriented burials (***a***) and individual PLA-159 in situ (***b***) (photo courtesy of Gabinete Trama de Arqueología, Pamplona) [Color figure can be viewed in the electronic (PDF) version of the journal.].

Individual PLA-159 showed dental modifications in 5 out of the 27 preserved teeth. Missing teeth included agenesis of the mandibular right third molar; the maxillary left first and second incisors and canine were lost post-mortem. Modifications were identified on the mesial and distal surfaces of the maxillary right first incisor; the mesial and distal surfaces of the maxillary right second incisor; the mesial surface of the maxillary right canine; the mesial surface of the manbibular left first incisor; and the mesial surface of the mandibular right second incisor (Fig. 3a,b). The mandibular right first incisor was not intentionally modified and thus it was used for biochemical analysis.

The pattern of dental modification in individual PLA-159 matches the general types of B and C (following Romero Molina, 1986). According to anthropological and ethnographical literature on Mesoamerica and Africa, dental modification was preferentially performed on the six maxillary anterior teeth (Goose, 1963; Romero Molina, 1958). However, modification of the mandibular dentition is also reported (*e.g.*, this study; Fastlicht, 1976; Lagunas and Karam, 2003; Romero Molina, 1958). Intentional modification primarily of the maxillary incisors and canines, with extraction of the mandibular anterior teeth has been documented in various modern and ancient

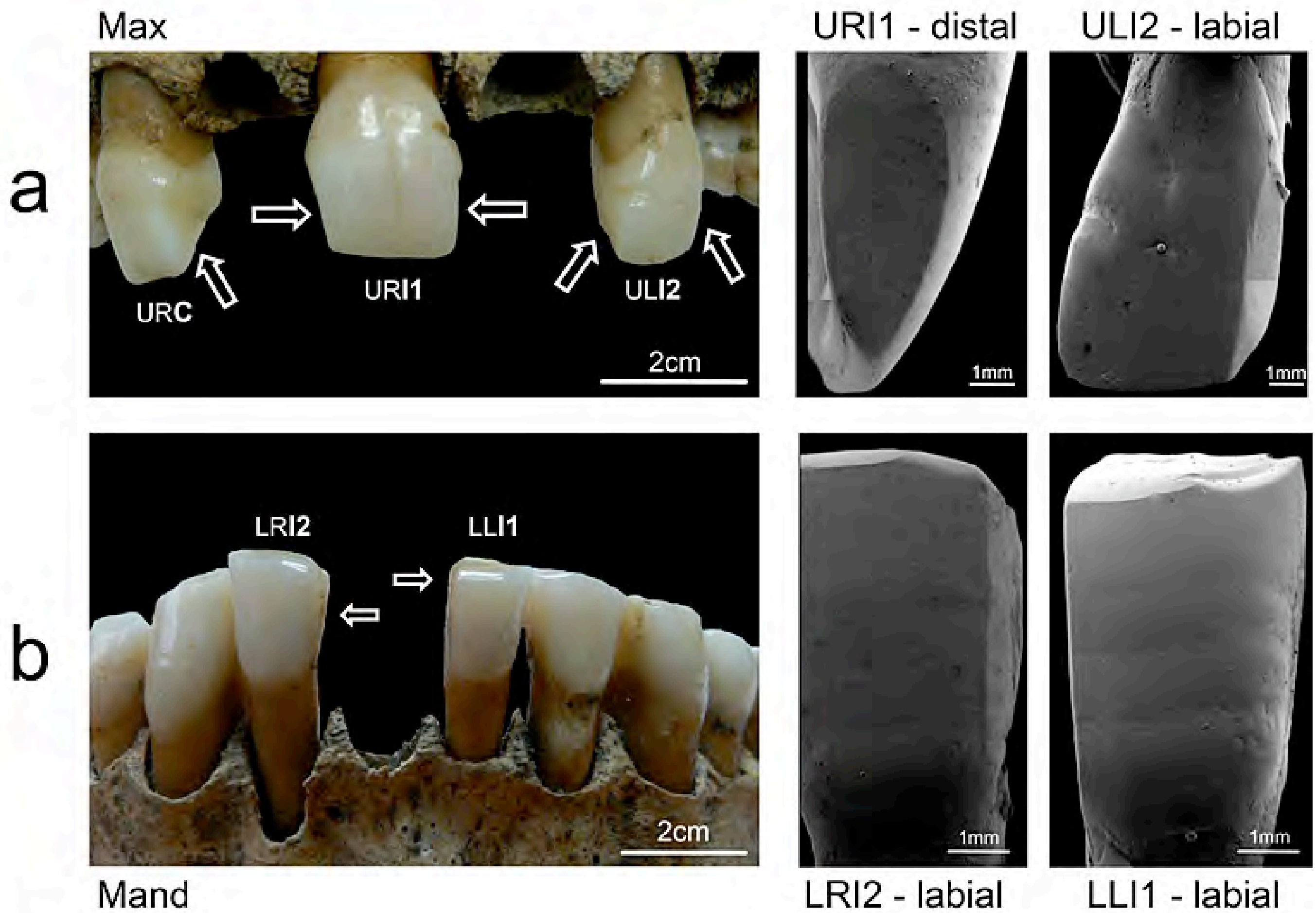

Fig. 3. Macroscopic and microscopic (SEM) views of the dental modifications present in individual PLA-159 in maxillary (a) and mandibular dentition (b) (photo by A. Romero). Abbreviations are: upper right first incisor (URI1); upper left second incisor (ULI2); upper right canine (UCR); lower right second incisor (LRI2); lower left first incisor (LLI1). [Color figure can be viewed in the electronic (PDF) version of the journal.]

African groups (Lagunas and Karam, 2003; Muwazi *et al*., 2005; Pindborg, 1969; Van Rippen, 1918). Typological analyses places the dental modifications of PLA-159 among the ones reported for African groups (Haour and Pearson, 2005; Tiesler, 2002). Primarily in western, central, and southern Africa, intentional dental modification of the anterior teeth in some cases consists of filing one or both interproximal sides, thereby destroying the incisal axis (Finucane *et al*., 2008; Gould *et al*., 1984; Jones, 1992; Reichart *et al*., 2007). This is similar to the modifications observed in African individuals resettled in the Americas during the period of colonization (Tiesler, 2002; Price *et al*., 2006) and in Iberian Peninsula during 13th to 15th centuries A.D. (Gonzalo *et al*., 2001). Among the types closest to the modifications observed in Plaza del Castillo are the ones reported for western Africa regions such as the Niger (Haour and Pearson, 2005:431), wherein the shape of the tooth was modified without affecting the occlusal surface. However, no parallel types have yet been found for the removal of the enamel up to the cervical area as observed in individual PLA-159 (Fig. 3b).

Documentation of the practice of dental decoration in the Iberian Peninsula is scarce. Dental modifications have been observed as part of post-mortem ritual in prehistoric Spain (Campillo *et al*., 2001). One case of an adult male of a possible sub-Saharan origin with intentional dental modification is documented from a more recent Islamic cemetery (13th to 15th centuries A.D.) in Spain (Gonzalo *et al*., 2001). A number of examples of dental modification are reported in Portugal in later periods, associated with the trade of slaves, mostly unpublished. Thus, the occurrence, as well as the typology of intentional dental modification at Plaza del Castillo suggest an African origin for PLA-159 and argue for the presence of first-generation immigrants in the cemetery.

RESEARCH OBJECTIVES

The presence of the Islamic cemetery in Pamplona coincides with the conquest of the city by Muslim groups in eighth century A.D. In particular, the identification of the adult female PLA-159 showing dental decoration in Plaza del Castillo raises significant questions regarding the geographic origins of the individuals buried in the *maqbara*. While the practice of dental modification was generally absent in Early Medieval Spain, it is commonly documented in African groups suggesting that PLA-159 was not part of the indigenous population. The historically documented episodic arrival of Muslim groups, mostly Berbers, from North Africa (Maghreb) in the Iberian Peninsula during the eighth century A.D. also supports an African origin for the individuals buried in Plaza del Castillo. Nevertheless, during the Muslim occupation part of the local population did convert to Islam, and interaction between the two religious groups is suggested by the recovery of rings with Arabic inscriptions in Kufic script in two contemporaneous Christian cemeteries in Pamplona (Faro Carballa *et al*., 2007-2008).

Hence, the question raised by the bioarchaeological evidence is whether the individuals buried in the *maqbara* were born in Pamplona or alternatively in Africa, brought in Spain later in life as part of the first generation of the incoming Muslim groups during the Islamization of the city. Specifically, determining the youthful residence of PLA-159 reveals important information regarding the nature of dental modification and its presence in Medieval Spain. To test the hypothesis of a non-local geographic origin and to begin exploring the residential histories of the individuals buried in Plaza del Castillo radiogenic strontium and stable oxygen isotope analyses were performed in a preliminary data set: the female PLA-159 showing dental decoration, and the adult PLA-28 of indeterminate sex without evidence of dental decoration. In addition, stable carbon isotope analysis was conducted to reconstruct paleodiet.

HUMAN BEHAVIOR THROUGH BIOGEOCHEMISTRY: GENERAL PRINCIPLES

Radiogenic strontium isotope analysis

Strontium is an alkaline earth element, and occurs naturally in four isotopes, the radiogenic ^{87}Sr (7.04%) and the stable isotopes ^{84}Sr (~0.56%), ^{86}Sr (~9.87%) and ^{88}Sr (~82.53%) (Bentley, 2006). Given that the radiogenic ^{87}Sr is formed over time by the radioactive decay of ^{87}Rb (rubidium), strontium isotope ratios in a geological region are a function of the geochemical composition and the age of rocks (Bentley, 2006). The abundances of ^{87}Sr are normalized to the non-radiogenic ^{86}Sr and are reported as the ^{87}Sr/^{86}Sr ratio in order to allow for comparison among different samples (Bentley, 2006); the ^{87}Sr/^{86}Sr ratio in different geological terrains ranges roughly between 0.700 and 0.750 (Price *et al*., 2002).

Strontium moves from bedrock into the food chain via soil and groundwater. It ultimately is incorporated into the human skeleton by substituting for calcium in the crystalline lattice of hydroxyapatite of skeletal tissues due to the similar chemical structure of the two elements (Bentley, 2006; Ezzo, 1994; Price *et al*., 2002). Contrary to strontium elemental concentrations which vary according to trophic level, radiogenic strontium isotope ratios are not substantially fractionated by biological processes. The radiogenic strontium isotopic composition of human bone and teeth therefore reflect the isotopic composition of the individual's diet and water sources, which in turn reflect the bioavailable strontium of the geological region and habitat from which the food and water sources were obtained (Price *et al*., 2002). Specifically, dental enamel reflects the composition of the strontium sources consumed during infancy and childhood because it forms during this period and does not remodel. In consequence, differences between the isotopic signature of tooth enamel and the isotopic signature of the region in which the individual died can reveal changes in the residence history of the individual, as long as local food and water sources were consumed (Price *et al*., 2002). However, due to the vast variability of geological formations, different locations can have similar geochemical signatures; therefore, possible mobility between geochemically similar regions will not be expressed in the skeletal elements (Burton *et al*., 2003).

Stable oxygen isotope analysis

Oxygen occurs in three stable isotopes, ^{16}O (99.765%), ^{18}O (0.1995%) and ^{17}O (0.0355%), and it is the most abundant chemical element in the earth's oceans and the second most abundant in the atmosphere (Kendall and Caldwell, 1998). Oxygen isotope data ($\delta^{18}O_{c(V\text{-}PDB)}$) are reported relative to the V-PDB (Vienna PeeDee belemnite) carbonate standard and are expressed in per mil (‰) using the following standard formula: $\delta^{18}O = (((^{18}O/^{16}O_{sample})/(^{18}O/^{16}O_{standard})) - 1) \times 1{,}000$ (Coplen, 1994; Craig, 1961).

Oxygen is incorporated into the minerals of the human skeleton mainly via the ingestion of water ($\delta^{18}O_w$) (Luz and Kolodny, 1985). Due to the isotopic equilibrium between ingested water and bioapatite when the body temperature is constant, hydroxyapatite carbonate and phosphate will reflect meteoric water values (Balasse and Ambrose, 2002; Longinelli, 1984). Oxygen isotope signatures in water sources vary according to a number of environmental factors, including altitude, latitude, distance from the coast, precipitation, temperature and humidity (*e.g*., Craig, 1961; Kohn, 1996; Kohn *et al*., 1996; Luz and Kolodny, 1985; Sponheimer and Lee-Thorp, 1999). Thus, given that local water sources were used, oxygen isotope values from hydroxyapatite will reflect the isotopic composition of the local environment during tooth and bone formation. Several studies have shown that the correlation of the $\delta^{18}O_c$ with meteoric water makes it useful for assessing residence and mobility across different environmental zones (Land *et al*., 1980; Kohn and Law, 2006). However, a number of factors, including utilization of a variety of drinking water sources, storage and preparation of drinking water, as well as enrichment in ^{18}O due to breastfeeding, can affect human δ^{18}O values (Knudson, 2009).

Stable carbon isotope analysis

Carbon occurs in two stable isotopes, ^{12}C representing 99% of the element, and ^{13}C representing the remainder 1% (Smith, 1972). Carbon isotope ratios ($\delta^{13}C_{c(V\text{-}PDB)}$) are reported relative to the V-PDB (Vienna PeeDee belemnite) carbonate standard and are expressed in per mil (‰) using the following standard formula: $\delta^{13}C = (((^{13}C/^{12}C_{sample})/(^{13}C/^{12}C_{standard})) - 1) \times 1000$ (Coplen, 1994).

During the process of photosynthesis, plant tissues incorporate ^{12}C preferentially relative to ^{13}C, such that the atmospheric $^{13}C/^{12}C$ ratio is greater than the one in plant tissues; a process termed fractionation. Plants are categorized relative to the different photosynthetic pathways that they use to fix atmospheric CO_2: briefly, plants as maize, millet, and other tropical grasses use the C_4 (or Hatch-Slack) pathway, whereas most plants, including grass, woody shrubs and trees, use the C_3 (or Calvin) pathway (Smith and Epstein, 1971). In general, C_4 plants demonstrate less negative $\delta^{13}C$ values with an average of -12.5‰, contrary to C_3 plants that exhibit more negative $\delta^{13}C$ values with an average of -26.5‰ (Smith, 1972; Smith and Epstein, 1971; Vogel, 1978). Furthermore, the carbon isotopic composition of the diet is represented in the consumer's tissue; thus animals that consume C_3 plants will have more negative $\delta^{13}C$ values than ones that consume C_4 plants (*e.g.*, Ambrose *et al.*, 1997; Ambrose and Norr, 1993; van der Merwe and Vogel, 1978). Finally, carbon isotopic values from bone collagen reflect the dietary protein, whereas carbon isotopic values from bone carbonate represent the isotopic composition of the whole diet; in humans, $\delta^{13}C$ values from apatite reflect an average of the whole diet offset by 9.4‰ (Ambrose and Norr, 1993).

MATERIALS AND LABORATORY METHODOLOGY

Our sampling strategy was designed to provide isotopic data from tooth enamel that formed early in an individual's life. The maxillary left first incisor and the mandibular right first incisor were used for isotopic analysis from the individuals PLA-28 and PLA-159, respectively (Table 1). Radiogenic strontium and stable carbon and oxygen isotope analyses were performed on hydroxyapatite in enamel for both teeth. Tooth enamel is considered to be generally resistant to post-depositional chemical alteration (Budd *et al.*, 2000; Lee-Thorp and Sponheimer, 2003; Sillen, 1989). However, it should be noted that since contamination results from the local post-depositional environment, it may cause a false local signal, but not the reverse, making non-local signatures significant (Price *et al.*, 2006). In order to characterize the local strontium isotopic signature, burial soil from Plaza del Castillo was also sampled and analyzed.

The enamel and soil samples were prepared at the Archaeological Chemistry Laboratory at Arizona State University. Teeth were first cast and photographed, and they were mechanically cleaned by abrasion in order to remove any adhering organic matter or contaminants, as well as the outermost layers of tooth which are most susceptible to diagenetic contamination (Budd *et al.*, 2000; Montgomery *et al.*, 1999; Waldron, 1981, 1983; Waldron *et al.*, 1979). Approximately 10 milligrams of tooth enamel were then removed with a Dremel Minimite-750 cordless drill equipped with an engraving cutter. The type and the color of the soil sample were first characterized according to Munsell soil color charts. Approximately two grams were first dried at 120°C for 48 hours, and then ashed at 800°C for 10 hours.

Radiogenic strontium isotope analysis was performed at the W.M. Keck Foundation Laboratory for Environmental Biogeochemistry at Arizona State University. Eight milligrams of tooth enamel powder were dissolved in 0.50 mL of 5M HNO_3. The dissolved tooth enamel was evaporated and further dissolved in 0.25 mL of 5M HNO_3. One hundred milligrams of soil were dissolved in 5.0 mL of 5M HNO_3 and in 1.0 mL of HF. The soil sample was evaporated and further dissolved in 1.0 mL of 5M HNO_3, 3.0 mL of HCl and 0.5 mL of HF. Following this procedure the sample was again evaporated and further dissolved in 1.0 mL of 5M HNO_3. Strontium was separated from the sample matrix using EiChrom SrSpec resin, a crown-ether Sr-selective substance (100-150 μm diameter), and then loaded into the tip of a glass column. Total resin volume was approximately 50 μL. Resin was used once for sample elution and discarded. The SrSpec resin was pre-soaked and flushed with H_2O to remove strontium present from the resin manufacturing process. The resin was further cleaned in the column with repeated washes of deionized H_2O and conditioned with 750 μL of HNO_3. The dissolved sample was loaded in 250 μL of 5M HNO_3, washed in 500 μL of 5M HNO3, and then the strontium was eluted with 1000 μL of H_2O.

TABLE 1. Heavy and light isotope data for archaeological human enamel and soil from Plaza del Castillo, Pamplona

Laboratory Number	Specimen Number	Material[a]	Corrected $^{87}Sr/^{86}Sr$	$\delta^{13}C_{c(V\text{-}PDB)}$ (‰)	$\delta^{18}O_{c(V\text{-}PDB)}$ (‰)	$\delta^{18}O_{dw(V\text{-}SMOW)}$ (‰)
ACL-0400	PLA-28	ULI1	0.70797	-16.33	-9.65	-16.1
ACL-0401	PLA-159	LRI1	0.70817	-13.57	-5.64	-9.8
ACL-0439	PLA-0001	Soil	0.71119	NA	NA	NA

[a]Tooth abbreviations are: ULI1= upper left first incisor; LRI1= lower right first incisor.

The enamel and soil samples were analyzed in a Neptune multi-collector inductively coupled plasma mass spectrometer (MC-ICP-MS) at the W.M. Keck Foundation Laboratory. On April 14, 2007, when the human enamel samples were analyzed, $^{87}Sr/^{86}Sr$ analyses of strontium carbonate standard SRM-987 yielded a value of $^{87}Sr/^{86}Sr$= 0.71031 ± 0.00003 (2σ, n = 18). On December 7, 2007, when the soil sample was analyzed, $^{87}Sr/^{86}Sr$ analyses of strontium carbonate standard SRM-987 yielded a value of $^{87}Sr/^{86}Sr$ = 0.71028 ± 0.00003 (2σ, n = 14). These data can be compared to analyses of SRM-987 using a thermal ionization mass spectrometer (TIMS), where $^{87}Sr/^{86}Sr$ = 0.710263 ± 0.000016 (2σ) (Stein *et al*., 1997), and analyses of SRM-987 using an identical MC-ICP-MS, where $^{87}Sr/^{86}Sr$ = 0.710251 ± 0.000006 (2σ) (Balcaen *et al*., 2005).

For oxygen and carbon isotope analysis, approximately 5 milligrams of powdered tooth enamel were treated with 0.24 mL of 2% NaOCl and then 0.24 mL of 0.1 M CH_3COOH. Carbonate isotopic analyses were performed on a Finnigan MAT 253 stable isotope ratio mass spectrometer (IRMS) at the W.M. Keck Foundation Laboratory. Replicates of NBS-19 resulted in a reproducibility of ±0.2‰ for $\delta^{18}O$ and ±0.2‰ for $\delta^{13}C$. When necessary, the following conversion equations were used: $\delta^{18}O_{VSMOW} = (1.03091 \times (\delta^{18}O_{VPDB})) + 30.91$, $\delta^{18}O_{VPDB} = (0.97002 \times \delta^{18}O_{VSMOW}) - 29.98$, $\delta^{18}O_{c(VSMOW)} = (8.5 + (\delta^{18}O_p))/0.98$, and $\delta^{18}O_{p(VSMOW)} = (0.64 \times (\delta^{18}O_{dw})) + 22.37$ (Coplen *et al*., 1983; Iacumin *et al*., 1996; Müller *et al*., 2003; Wolfe *et al*., 2001).

RESULTS

The enamel sample from individual PLA-28 exhibits $^{87}Sr/^{86}Sr$ = 0.70797, $\delta^{18}Oc$ =-9.7‰, and $\delta^{13}C_c$ = -16.3‰ (Table 1). The enamel sample from individual PLA-159 exhibits $^{87}Sr/^{86}Sr$ = 0.70817, $\delta^{18}O_c$ = -5.6, and $\delta^{13}C_c$ = -13.6‰ (Table 1). Using the previously-discussed conversion equations the $\delta^{18}O_c$ values from the enamel were converted to likely drinking water values $\delta^{18}O_{dw(V\text{-}SMOW)}$ = -16.1‰ for PLA-28, and $\delta^{18}O_{dw(V\text{-}SMOW)}$ = -9.8‰ for PLA-159 (Table 1). The soil sample shows a ratio of $^{87}Sr/^{86}Sr$ = 0.71119 (Table 1).

DISCUSSION

Before we turn to the interpretation of the biogeochemical results, we will briefly examine the geochemical setting of the study area. Pamplona basin is located in the western part of the Southern Pyrenean Foreland Basin, and consists of geologic transitional marine and terrestrial deposits that formed in the Lower to Middle Eocene (Payros *et al*., 1999). The Valle de Tena in Huesca province, located to the northeast of Pamplona, is characterized by Silurian to Permian and Cretaceous carbonate and detrital sedimentary rocks, with the Paleozoic limestones showing isotopic values of $^{87}Sr/^{86}Sr$ = 0.70510-0.70970 (Subías *et al*., 1998) (Fig. 1). The deposits of fluorites and calcites in the area exhibit isotopic ranges of $^{87}Sr/^{86}Sr$ = 0.70850-0.71083 in Portalet, $^{87}Sr/^{86}Sr$ = 0.70858-0.71036 in Lanuza, and $^{87}Sr/^{86}Sr$ = 0.70911-0.71010 in Tebarray (Subías *et al*., 1998). Furthermore, the andesites in Anayet exhibit a ratio of $^{87}Sr/^{86}Sr$ = 0.70582-0.70752 (Innocent *et al*., 1994) (Fig. 1). The volcanic and intrusive alkaline rocks in Oloron in southern France show an isotopic range of $^{87}Sr/^{86}Sr$ = 0.70535-0.70623 (Rossy *et al*., 1992) (Fig. 1). To the west of Pamplona, basalts from the region of Bilbao in the Spanish Basque Country give an isotopic range of $^{87}Sr/^{86}Sr$ = 0.70376-0.70542 (Rossy *et al*., 1992) (Fig. 1).

In order to control for the wide petrographic diversity and intraregional bedrock variation, soil from Plaza del Castillo was used to determine the local isotopic baseline of the area for this preliminary study. When radiogenic strontium isotopic signatures from both enamel samples are compared to the local geochemical signal for the soil, they prove to be considerably lower (Table 1). This may indicate that both individuals were born and spent at least early childhood in a different location and moved to Pamplona later in life, assuming local dietary and water sources were consumed.

In an attempt to trace the geographic origins of both individuals and thus test the hypothesis of a North African provenance, isotopic signatures from enamel were compared to radiogenic strontium isotopic ratios reported for Africa. In northeastern Morocco, the region approximately 100 km southwest to the city of Oujda shows a series of granodiorites with ratios of $^{87}Sr/^{86}Sr$ = 0.70693-0.70972 (Ajaji *et al*., 1998). Groundwater sampled across numerous locations along the Continental Intercalaire aquifer system, spanning from the Saharan Atlas of Algeria to the Chotts region of southern Tunisia, yields isotopic ratios of $^{87}Sr/^{86}Sr$ = 0.707826-0.70939 (Edmunds *et al*., 2003). Furthermore, cumulate rock sequences at Laouni, Hoggar, in southern Algeria exhibit a range of $^{87}Sr/^{86}Sr$ = 0.70305-0.70669 (Cottin *et al*., 1998). Finally, soil samples and modern faunal samples collected in the Gobero area in central Niger show average ratios of $^{87}Sr/^{86}Sr$ = 0.71290 ± 0.00064 (1σ) and $^{87}Sr/^{86}Sr$ = 0.71261 ± 0.00116 (1σ), respectively (Sereno *et al*., 2008). Hence, the radiogenic strontium isotopic signatures of the two individuals analyzed from Plaza del Castillo generally match the radiogenic strontium isotopic ratios from northeastern Morocco, thus supporting a North African origin of Berber groups, such as those who colonized Medieval Pamplona during the early Medieval period.

The enamel radiogenic strontium isotope signatures from Plaza del Castillo are also consistent with some marine strontium sources, averaged with strontium from a geologic zone or zones with lower strontium isotope signatures. Since seawater is characterized by $^{87}Sr/^{86}Sr$ = 0.7092 (Veizer, 1989), these individuals may have obtained some, though not all, of their strontium in the first years of life from marine sources. However, according to the results from stable carbon isotope analysis discussed below this interpretation is unlikely, given that marine food consumption was not a major component of the diet of the two individuals.

Given that the climate in northern Spain is considered to be relatively stable since the eighth century A.D., modern $\delta^{18}O_{V\text{-}SMOW}$ values from precipitation were used to determine the local range of $\delta^{18}O_{V\text{-}SMOW}$. Due to the lack of available precipitation values for Pamplona, precipitation $\delta^{18}O_{V\text{-}SMOW}$ values measured in Saragossa (Fig. 1) were used to determine the probable $\delta^{18}O_{V\text{-}SMOW}$ values in Pamplona (IAEA/WMO, 2006). Oxygen isotope signatures in precipitation collected in the Saragossa station in 2000-2001, showed a range from $\delta^{18}O_{V\text{-}SMOW}$ = -10.8‰ to $\delta^{18}O_{V\text{-}SMOW}$ = 1.67‰, with an average value of $\delta^{18}O_{V\text{-}SMOW}$ = -5.9 (n = 24) (IAEA/WMO, 2006), which was used as the probable local range of $\delta^{18}O_{V\text{-}SMOW}$ for Pamplona. When the drinking water values from Plaza del Castillo are compared to the modern precipitation values from Saragossa, the $\delta^{18}O_{V\text{-}SMOW}$ value for individual PLA-28 (-16.1‰) falls outside the range of the observed precipitation values. The $\delta^{18}O_{V\text{-}SMOW}$ value for PLA-159 (-9.8‰) appears within the local precipitation range; however, it is very close to the lower limit. Thus, analysis of $\delta^{18}O_{V\text{-}SMOW}$ values may indicate that these two individuals lived outside of the Pamplona region during enamel formation, paralleling results from the strontium analysis.

As mentioned, bone carbonate reflects the isotopic composition of the diet plus 9.4‰ (Ambrose and Norr, 1993). Therefore, subtracting 9.4‰ from the measured archaeological human enamel $\delta^{13}C_{c(V\text{-}PDB)}$ values shows that they correspond to a diet based heavily on C_3 plants and/or animals that consumed C_3 plants (Table 1). The reconstruction of a diet based on terrestrial C_3 plants, like cereals, is consistent with either African or Spanish early childhood residence.

CONCLUSIONS

Overall, the presence of two first-generation immigrants at the Islamic cemetery of Plaza del Castillo was successfully identified through isotopic analyses. The two individuals (PLA-28, PLA-159) showed non-local isotopic signatures suggesting movement to Pamplona from a different geographic location sometime after early childhood. An origin from northern Africa, as suggested by the typological analysis of the dental modifications in PLA-159, is consistent with the isotopic results. Dental decoration, the apparent early date for at least part of the cemetery and these isotopic results suggest that the individuals included in the study may have come to Pamplona from North Africa, perhaps as part of the military expedition to control the local revolutions of the time against the recently established Muslim authority. The fact that individual PLA-159 is a female further indicates that the incoming Muslim population was not formed exclusively by men with a military function, but rather by family groups and/or camp followers.

Given the promising results of this preliminary study, future research consisting of isotopic analysis of a larger sample size, representative of the *maqbara*, will allow for a complete examination of the residential histories of the individuals buried in Plaza del Castillo and will inform our understanding of the migration of African groups in eighth century A.D. Pamplona during the initial Islamization of the city. In addition, a vital direction for further research is the continued characterization of baseline isotopic and elemental data from Pamplona and the surrounding region, including the bioavailable strontium isotope ratios in the study region and paleoenvironmental reconstructions. Detailed data on strontium isotope ratios in exposed bedrock samples from the geological literature should be supplemented with strontium isotope analysis of modern and archaeological small mammals from the study region. This will facilitate characterization of local strontium isotope signatures and a more informed interpretation of the geographic origin of the individuals interred in Plaza del Castillo. In conclusion, the present study exemplifies the use of biogeochemistry as an analytical tool, and provides a new perspective to the Muslim diaspora in northern Spain.

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LITERATURE CITED

Ajaji T, Weis D, Giret A, Bouabdellah M. 1998. Coeval potassic and sodic calc-alkaline series in the post-collisional Hercynian Tanncherfi intrusive complex, northeastern Morocco: geochemical, isotopic and geochronological evidence. Lithos 45:371-393.

Al-Marrakusi II. 1999. Historia de Al-Andalus. Trans. F. Fernández González (1860) Málaga: Aljaima.

Ambrose SH, Butler BM, Hanson DB, Hunter-Anderson RL, Krueger HW. 1997. Stable isotopic analysis of human diet in the Marianas Archipelago, western Pasific. Am J Phys Anthropol 104:343-361.

Ambrose SH, Norr L. 1993. Experimental evidence for the relationship of carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In: Lambert JB, and Grupe G, editors. Prehistoric human bone: Archaeology at the molecular level. Berlin: Springer-Verlag. p 1-38.

Balasse M, Ambrose SH. 2002. The seasonal mobility model for prehistoric herders in the south-western Cape of South Africa assessed by isotopic analysis of sheep tooth enamel. J Archaeol Sci 29:917-932.

Balcaen L, Schrijver ID, Moens L, Vanhaecke F. 2005. Determination of the 87Sr/86Sr isotope ratio in USGS silicate reference materials by Multi-Collector ICP–Mass Spectrometry. Int J Mass Spectrom 24:251-255.
Bentley RA. 2006. Strontium isotopes from the earth to the archaeological skeleton: a review. J Archaeol Method Th 13:135-187.
Bentley RA, Knipper C. 2005. Geographical patterns in biologically available strontium, carbon and oxygen isotope signatures in prehistoric SW Germany. Archaeometry 47(3):629-644.
Bentley RA, Price DT, Stephan E. 2004. Determining the "local" 87Sr/86Sr range for archaeological skeletons: A case study from Neolithic Europe. J Archaeol Sci 31:365-375.
Bentley RA, Tayles N, Higham C, Macpherson C, Atkinson TC. 2007. Shifting gender relations at Khok Phanom Di, Thailand: Isotopic evidence from the skeletons. Curr Anthropol 48:301-314.
Budd P, Montgomery J, Barreiro B, Thomas RG. 2000. Differential diagenesis of strontium in archaeological human dental tissues. Appl Geochem 15:687-694.
Burton JH, Price DT, Wright LE. 2003. The use of barium and strontium abundances in human skeletal tissues to determine their geographic origins. Int J Osteoarchaeol 13:88-95.
Campillo D, Pérez-Pérez A, Rovira J. 2001. Analyse microscopique de mutilations dentaires posthumes dans la Préhistoire de la Péninsule Ibérique. In: Hadjouis D, and B. M, editors. La Paléo-Odontologie Analyses et Méthodes d´étudeCollection Paléoanthropologie et Paléopathologie osseuse: Éditions Artcom. p 171-180.
Casal MT. 2003. Los cementerios musulmanes de Qurtuba. Universidad de Córdoba.
Coplen TB. 1994. Reporting of stable hydrogen, carbon, and oxygen isotopic abundances. Pure Appl Chem 66:273-276.
Coplen TB, Kendall C, Hopple J. 1983. Comparison of stable isotope reference samples. Nature 302:236-238.
Cottin JY, Lorand JP, Agrinier P, Bodinier JL, Liégeois JP. 1998. Isotopic (O, Sr, Nd) and trace element geochemistry of the Laouni layered intrusions (Pan-African belt, Hoggar, Algeria): evidence for post-collisional continental tholeiitic magmas variably contaminated by continental crust. Lithos 45:197-222.
Cox G, Sealy J. 1997. Investigating identity and life histories: Isotopic analysis and historical documentation of slave skeletons found on the Cape Town foreshore, South Africa. Int J Hist Archaeol 1:207-224.
Craig H. 1961. Isotopic variations in meteoric waters. Science 133:1702-1703.
De Miguel Ibáñez MP. 2007. La maqbara de la Plaza del Castillo (Pamplona, Navarra): avance del estudio osteoarqueológico. In: Senác P, editor. Villes et campagnes de la Tarraconaise et d'Al-Andalus (VIe-XIe siècle): la transition: CNS-Université de Toulouse-Le Mirail. p 183-197.
Díaz-Zorita Bonilla M, Waterman AJ, Knudson KJ. 2009. Explorando la movilidad y los patrones dietarios durante la Edad del Cobre en el Suroeste de la Península Ibérica: estudio preliminar bioarqueológico del Tholos de Palacio III (Almadén de la Plata, Sevilla). Actas del IX Congreso Nacional de Paleopatología Morella (Castellón) 26-29 de Septiembre de 2007. p 669-674.
Edmunds WM, Guendouz AH, Mamou A, Moulla A, Shand P, Zouari K. 2003. Groundwater evolution in the Continental Intercalaire aquifer of southern Algeria and Tunisia: trace element and isotopic indicators. Appl Geochem 18:805-822.
Ezzo JA. 1994. Putting the "chemistry" back into archeological bone chemistry analysis: modeling potential paleodietary indicators. J Anthropol Archaeol 13:1-34.
Ezzo JA, Johnson CM, Price DT. 1997. Analytical perspectives on prehistoric migration: a case study from east-central Arizona. J Archaeol Sci 24:447-466.
Ezzo JA, Price DT. 2002. Migration, regional reorganization, and spatial group composition at Grasshopper Pueblo, Arizona. J Archaeol Sci 29:499-520.
Faro Carballa JA, García-Barberena Unzu M, Unzu Urmeneta M. 2007. La presencia islámica en Pamplona. In: Senác P, editor. Villes et campagnes de la Tarraconaise et d'Al-Andalus (VIe-XIe siècle): la transition: CNS-Université de Toulouse-Le Mirail. p 97-138.
Faro Carballa JA, García-Barberena Unzu M, Unzu Urmeneta M. 2007-2008. Pamplona y el Islam. Nuevos testimonios arqueológicos. Trabajos de Arqueología Navarra 20:229-284.
Fastlicht S. 1976. Tooth mutilation and dentistry in Pre-Columbian Mexico. Berlin: Quintessenz.
Finucane BC, Manning K, Touré M. 2008. Prehistoric dental modification in Western Africa–Early evidence from Karkarichinkat nord, Mali. Int J Osteoarchaeol 18:632-640.
Galbany J, Estebaranz F, Martínez LM, Romero A, De Juan J, Turbón D, Pérez-Pérez A. 2006. Comparative analysis of dental enamel polyvinylsiloxane impression and polyurethane casting methods for SEM research. Microsc Res Tech 69:246-252.
Gonzalo J, Trancho GJ, Robledo B. 2001. Modificaciones intencionales de la corona dental: la mutilación dentaria. In: Campo Martín M, and Robles Rodríguez F, editors. ¿Dónde estamos? Pasado, presente y futuro de la Paleopatología. Madrid: UAM and AEP. p 359-366.
Goose DH. 1963. Tooth-mutilation in West Africans. Man 63:91-93.
Gould AR, Farman AG, Corbitt D. 1984. Mutilations of the dentition in Africa: a review with personal observations. Quintessence Int Dent Dig 1:89-94.
Haour A, Pearson JA. 2005. An instance of dental modification on a human skeleton from Niger, West Africa. Oxford J Archaeol 24:427-433.

Iacumin P, Bocherens H, Mariotti A, Longinelli A. 1996. Oxygen isotope analysis of co-existing carbonate and phosphate in biogenic apatite: a way to monitor diagenetic alteration of bone phosphate? Earth Planet Sci Lett 142:1-6.

IAEA/WMO. 2006. Global Network of Isotopes in Precipitation. The GNIP Database. Accessible at http://isohis.iaea.org.

Innocent C, Briqueu L, Cabanis B. 1994. Sr-Nd isotope and trace element geochemistry of late Variscan volcanism in the Pyrenees: magmatism in post-orogenic extension? Tectonophysics 238:161-181.

Jones A. 1992. Tooth mutilations in Angola. British Dent J 173:177-179.

Kendall C, Caldwell EA. 1998. Fundamentals of isotope geochemistry. In: Kendall C, and McDonell JJ, editors. Isotope tracers in catchment hydrology: Elsevier. p 51-86.

Knudson KJ. 2009. Oxygen isotope analysis in a land of environmental extremes: The complexities of isotopic work in the Andes. Int J Osteoarchaeol 19:171-191.

Knudson KJ, Buikstra JE. 2007. Residential mobility and resource use in the Chiribaya polity of Southern Peru: Strontium isotope analysis of archaeological tooth enamel and bone. Int J Osteoarchaeol 17:563-580.

Knudson KJ, Price DT. 2007. Utility of multiple chemical techniques in archaeological residential mobility studies: Case studies from Tiwanaku- and Chiribaya-affiliated sites in the Andes. Am J Phys Anthropol 132:25-39.

Knudson KJ, Torres-Rouff C. 2009. Investigating cultural heterogeneity in San Pedro de Atacama, Northern Chile, through biogeochemistry and bioarchaeology. Am J Phys Anthropol 138:473-485.

Kohn MJ. 1996. Predicting animal $\delta^{18}O$: Accounting for diet and physiological adaptation. Geochim Cosmochim Acta 60:4811-4829.

Kohn MJ, Law M. 2006. Stable isotope chemistry of fossil bone as a new paleoclimate indicator. Geochim Cosmochim Acta 70:931-946.

Kohn MJ, Schoeninger MJ, Valley JW. 1996. Herbivore tooth oxygen isotope compositions: Effects of diet and physiology. Geochim Cosmochim Acta 60:3889-3896.

Lagunas Z, Karam CE. 2003. Cráneos africanos de la época colonial con mutilación dentaria, procedentes del ex Hospital Real de San José de los Naturales de la ciudad de México, D. F. Estudios de Antropología Biológica 11:967-981.

Land LS, Lundellius EL, Valastro S. 1980. Isotopic ecology of deer bones. Paleogeogr Paleoclimatol Paleoecol 32:143-151.

Lee-Thorp J, Sponheimer M. 2003. Three case studies used to reassess the reliability of fossil bone and enamel isotope signals for paleodietary studies. J Anthropol Archaeol 22:208-216.

Longinelli A. 1984. Oxygen isotopes in mammal bone phosphate: A new tool for paleohydrological and paleoclimatological research? Paleogeogr Paleoclimatol Paleoecol 32:143-151.

Luz B, Kolodny Y. 1985. Oxygen isotope variations in phosphate of biogenic apatites, IV. Mammal teeth and bones. Earth Planet Sci Lett 75:29-36.

Montgomery J, Budd P, Cox A, Krause P, Thomas RG. 1999. LA-ICP-MS evidence for the distribution of lead and strontium in Romano-British, Medieval and modern human teeth: Implications for life history and exposure reconstruction. In: Young SMM, Pollard AM, Budd P, and Ixer RA, editors. Metals in Antiquity BAR International Series No 792. Oxford: British Archaeological Reports. p 290-296.

Montgomery J, Evans JA, Powlesland D, Roberts CA. 2005. Continuity or colonization in Anglo-Saxon England? Isotope evidence for mobility, subsistence practice, and status at West Heslerton. Am J Phys Anthropol 126:123-138.

Müller W, Fricke H, Halliday AN, McCulloch MT, Wartho J-A. 2003. Origin and migration of the Alpine Iceman. Science 302:862-866.

Muwazi LM, Charles M, Rwenyonyi CM, Francis J, Tirwomwe FJ, Ssali C, Kasangaki A, Nkamba ME, Ekwaru P. 2005. Prevalence of oral diseases/conditions in Uganda. Afr Health Sci 5:227-233.

Nafplioti A. 2008. 'Mycenean' political domination of Knossos following the Late Minoan IB destructions on Crete: negative evidence from strontium isotope analysis (87Sr/86Sr). J Archaeol Sci 35:2307-2317.

Payros A, Pujalte V, Orue-Etxebarria X. 1999. The South Pyrenean Eocene carbonate megabreccias revisited: new interpretation based on evidence from the Pamplona Basin. Sediment Geol 125:165-194.

Pindborg JJ. 1969. Dental mutilation and associated abnormalities in Uganda. Am J Phys Anthropol 31:383-390.

Prevedorou EA, Díaz-Zorita Bonilla M, Buikstra JE, Gordon G, Anbar A, Knudson KJ. 2009. Residential mobility and dietary patterns at the prehistoric site of Gatas, southeastern Spain. Am J Phys Anthropol 138(S48):330.

Price DT, Bentley AR, Lüning J, Gronenborn D, Wahl J. 2001. Prehistoric human migration in the Linearbandkeramik of Central Europe. Antiquity 75:593-603.

Price DT, Gestsdóttir H. 2006. The first settlers of Iceland: An isotopic approach to colonisation. Antiquity 80:130-144.

Price DT, Grupe G, Schroter P. 1998. Migration and mobility in the Bell Beaker period in Central Europe. Antiquity 72:405-411.

Price DT, Tiesler V, Burton JH. 2006. Early African diaspora in colonial Mexico: Strontium isotopic evidence. Am J Phys Anthropol 130:485-490.

Price TD, Burton JH, Bentley RA. 2002. The characterization of biologically available strontium isotope ratios for the study of prehistoric migration. Archaeometry 44:117-135.

Price TD, Johnson CM, Ezzo JA, Ericson J, Burton JH. 1994. Residential mobility in the prehistoric Southwest United States: a preliminary study using strontium isotope analysis. J Archaeol Sci 21:315-330.
Reichart P, Cruetz U, Scheifele C. 2007. Dental mutilations and associated alveolar bone pathology in African skulls of the anthropological skull collection, Charité, Berlin. J Oral Pathol Med 37:50-55.
Richards M, Harvati K, Grimes V, Smith C, Smith T, Hublin J-J, Karkanas P, Panagopoulou E. 2008. Strontium isotope evidence of Neanderthal mobility at the site of Lakonis, Greece using laser-ablation PIMMS. J Archaeol Sci 35:1251-1256.
Romero A, De Juan J. 2003. Microscopic features on enamel incisor surfaces: implications as regards feeding behavior in bio-archaeological groups. Int J Dent Antrhopol 4:1-9.
Romero A, De Miguel Ibáñez MP, Buikstra JE, Knudson KJ, Prevedorou EA, Díaz-Zorita Bonilla M, De Juan J. 2009. Mutilación dentaria en la necrópolis islámica de Plaza del Castillo (Siglo VIII DC) de Pamplona (Navarra). Revista Española de Antropología Física 29:1-14.
Romero Molina J. 1958. Mutilaciones dentarias prehispánicas de México y América en general. México: Instituto Nacional de Antropología e Historia.
Romero Molina J. 1986. Catálogo de la colección de dientes mutilados prehispánicos. IV parte. Colección Fuentes. México: Instituto Nacional de Antropología e Historia.
Rossy M, Azambre B, Albarède F. 1992. REE and Sr-Nd isotope geochemistry of the alkaline magmatism from the Cretaceous North Pyrenean Rift Zone (France-Spain). Chem Geol 97:33-46.
Rubín de la Borbolla DF. 1940. Types of tooth mutilation found in Mexico. Am J Phys Anthropol 26:349-366.
Saville MH. 1913. Precolumbian decoration of the teeth in Ecuador. With some account of the occurrence of the custom in other parts of North and South America. Am Anthropol 15:377-394.
Sereno PC, Sereno PC, Garcea EAA, Jousse H, Stojanowski CM, Saliège JF, et al. 2008. Lakeside cemeteries in the Sahara: 5000 years of Holocene population and environmental change. PLoS ONE 3 e2995. doi:2910.1371/journal.pone.0002995.
Sillen A. 1989. Diagenesis of the inorganic phase of cortical bone. In: Price DT, editor. The chemistry of prehistoric bone: Cambridge University Press. p 211-229.
Smith BN. 1972. Natural abundances of the stable isotopes of carbon in biological systems. BioScience 22:226-231.
Smith BN, Epstein S. 1971. Two categories of $^{13}C/^{12}C$ ratios for higher plants. Plant Physiology 47:380-384.
Sponheimer M, Lee-Thorp JA. 1999. Oxygen isotopes in enamel carbonate and their ecological significance. J Archaeol Sci 26:723-728.
Stein M, Starinsky A, Katz A, Goldstein SL, Machlus M, Schramm A. 1997. Strontium isotopic, chemical, and sedimentological evidence for the evolution of Lake Lisan and the Dead Sea. Geochim Cosmochim Acta 61:3975-3992.
Subías I, Moritz R, Fernández-Nieto C. 1998. Isotopic composition of strontium in the Valle de Tena (Spanish Central Pyrenees) fluorite deposits: relevance for the source of elements and genetic significance. Mineralium Deposita 33:416-424.
Tiesler V. 2002. New cases of an African tooth decoration from colonial Campeche, Mexico. Homo 52:277-282.
van der Merwe NJ, Vogel JC. 1978. ^{13}C Content of human collagen as a measure of prehistoric diet in woodland North America. Nature 276:815-816.
van Rippen B. 1918. Practices and customs of the African natives involving dental procedure. Am Anthropol 20:461-463.
Veizer J. 1989. Strontium isotopes in seawater through time. Ann Rev Earth Planet Sci 1:141-167.
Vogel JC. 1978. Isotopic assessment of the dietary habits of ungulates. S Afr J Sci 74:298-301.
Waldron HA. 1981. Postmortem absorption of lead by the skeleton. Am J Phys Anthropol 55:395-398.
Waldron HA. 1983. On the post-mortem accumulation of lead by skeletal tissues. J Archaeol Sci 10:35-40.
Waldron HA, Khera A, Walker G, Wibberly G, Green CJS. 1979. Lead concentrations in bones and soil. J Archaeol Sci 6:295-298.
White CD, Spence MW, Longstaffe FJ, Law KR. 2004. Demography and ethnic continuity in the Tlailotlacan enclave of Teotihuacan: the evidence from stable oxygen isotopes. J Anthropol Archaeol 23:385-403.
Wolfe BB, Aravena R, Abbott MB, Seltzer GO, Gibson JJ. 2001. Reconstruction of paleohydrology and paleohumidity from oxygen isotope records in the Bolivian Andes. Paleogeogr Paleoclimatol Paleoecol 176:177-192.

Relationship Between Width of Maxillary Anterior Teeth and Interalar Distance

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ABSTRACT There are few guides to estimate the size of denture teeth. The purpose of this observational cross sectional study of Iranian adults was to evaluate the relationship between interalar width compared to intercanine tip distance and to the summed width of the maxillary anterior teeth in adults. The samples were selected from dental students in Isfahan University. Interalar width was measured with calipers. Maxillary inter-canine distance was measured between cusp tips on dental casts. Mesiodistal widths of the six anterior teeth also were measured. Independent t-tests, Pearson's correlation coefficients, and linear regression were used for statistical analysis. Mean interalar width was 36.38 mm (sd = 3.81), intercanine tip distance was 34.15 mm (sd = 2.05), and mean width of maxillary anterior teeth was 48.23 mm (sd = 2.07). There were significant associations between interalar width and summed widths of the maxillary anterior teeth and with intercanine distance. In addition, predictive equations for estimation of tooth sizes using interalar width were calculated by regression. These statistical relationships may also be useful forensically. *Dental Anthropology* 2010;23(2):53-56.

One of the confusing and difficult aspects of complete denture prosthodontics is the selection of appropriately sized maxillary anterior denture teeth (Hoffman *et al*., 1986). The anterior teeth are primarily selected to satisfy esthetic concerns. The esthetic restoration of edentulous patients has an important psychological effect (Sellen *et al*., 1999; Al-Wazzan, 2001; Frush and Fisher, 1955). Patients who receive their dentures expect them to appear similar to their previous natural teeth (Gomes *et al*., 2009). The mesiodistal width of teeth is a harder aspect to estimate than the proper height of the anterior artificial teeth (McArthur, 1985). Various guidelines have been suggested for determining the maxillary anterior teeth when pre-extraction records are not available, but different opinions have been reported regarding their usefulness (Sellen *et al*., 1999; Verjao and Nogueira, 2005). One of the methods for selecting artificial anterior teeth is using certain guides (Keng, 1960). Several anatomic measurements have been suggested, including bizygomatic width (BZW), interpupillary distance (IPD), interalar width (IAW), and intercommisural width (ICW) (Zlatarić *et al*., 2007). Different views have been reported on the significance of the interalar width in selection of anterior tooth sizes. Picard (1958) found that interalar width could be used to estimate widths of the maxillary anterior teeth. This was substantiated by Wehner *et al*. (1967) who suggested extending parallel lines from the lateral margins of the alae of the nose onto the labial surface of the maxillary occlusal rim to estimate positions of the inter-canine cusp tips.

Hoffman *et al*. (1986) stated that there is a correlation of 0.413 between IAW and intercanine tip distance (ICTD). A weaker correlation coefficient of 0.217 was observed between IAW and width of maxillary anterior teeth (WMAT). ICTD was 3% greater than IAW and WMAT was 31% greater than IAW. Aleem *et al*. (1997) reported that WMAT is 26% greater than IAW. Al-El–Sheikh and Al-Athel (1998) found significant associations between IAW with (1) ICTD and (2) WMAT, and WMAT was 56% greater than IAW. Mavroskoufis and Ritchie (1981) found a positive association between nasal width and ICTD, which promotes its use in establishing the width of the anterior teeth. Latta *et al*. (1991) reported significant differences in the IAW and IPD between races and sexes.

The aims of the present study were to compare IAW, ICTD, and WMAT between males and females and to derive predictive equations from a group of Iranian adults.

MATERIALS AND METHODS

This was a cross-sectional study of Iranian young adults. The sample of convenience consists of dental students from Isfahan University. A total of 120 cases were analyzed (60 males; 60 females). Inclusion criteria were: at least 18 years old of Iranian descent; normal nose morphology without a history of rhinoplasty; intact maxillary six anterior teeth without history of orthodontic therapy; a Class I normal occlusion without a diastema, spacing or crowding; and well aligned teeth in the maxillary arch (Al-El–Sheikh and

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Fig. 1. Measurement of interalar width.

Al-Athel, 1998; Hasanreisoglu *et al*., 2005).

Sliding calipers were used with an accuracy of 0.1 mm. Each distance was measured 3 times and the average was recorded (Gomes *et al*., 2009). IAW (Fig. 1) was measured from the widest point on either nostril (Zlatarić *et al*., 2007).

Irreversible hydrocolloid impressions (Cavex CA37, Cavex Holland, BV, Haarlenm, Holland) of the maxillary teeth were made and poured with hard dental stone (Begostone, BEGO, Bremen, Germany). The straight-line distance between canine tips (Fig. 2) was measured (Hoffman *et al*., 1986). The maximum mesiodistal width of each anterior tooth was measured, and these widths were summed (coded as WMAT) (Gomes *et al*., 2009; Hasanreisoglu *et al*., 2005).

Descriptive statistics, independent t-tests, Pearson's correlation coefficient, and linear regression analysis were used for statistical analyses using the Statistical Package for Social Sciences (SPSS Inc., Chicago, IL, USA).

RESULTS

Descriptive data are listed in Table 1. Results of independent t-tests show that the values of IAW, ICTD and WMAT were significantly greater in males than females. Pearson's r disclosed significant associations between IAW and ICTD in females ($r = 0.457$; $P < 0.05$) and in males ($r = 0.442$; $P< 0.05$) and between IAW and WMAT in females ($r = 0.473$; $P < 0.05$) and in males ($r = 0.481$; $P < 0.05$). The predictive equations for estimating tooth sizes from interalar width are summarized in Tables 2 and 3.

DISCUSSION

In earlier studies, measurements were made using extracted teeth. Recent studies measured tooth dimensions on casts or using computer-based images or intraoral evaluations (Hasanreisoglu *et al*., 2005). It is generally agreed that selection of the width of anterior teeth should be based on facial measurements and proportions (Al-El–Sheikh and Al-Athel, 1998). It has been reported that the width of the nose may be used for selecting the size of the anterior teeth, for positioning the maxillary canines and for registering the curve of the anterior arch (Hoffman *et al*., 1986).

Sex differences in the dimensions of the anterior teeth have been noted for most racial groups, with men exhibiting mesiodistally wider teeth than women (*e.g*., Hasanreisoglu *et al*., 2005; Strett *et al*., 1992; Lavelle, 1972; Richardson and Malhotra, 1975).

The mean of IAW was 36.37 mm in the present study. It was smaller than the means reported by Mosharraf *et al*. 36.6 mm (2006), Latta and Weaver 43.9 mm (1991), Dharap and Tanuseputro (1997) 39.8 mm and was greater than the mean reported by Hoffman *et al*. (1986) at 34.28 mm and Al-El-Sheikh and Al-Athel (1998) at 33.27 mm.

In the present study the mean of ICTD was 34.15 mm, which is smaller than means reported by Dharap and

Fig. 2. Measurement of straight-line distance between the canine tips (intercanine tip distance)

Fig. 3. Measurement of maximum mesiodistal width of maxillary incisor.

TABLE 1. Descriptive statistics

Sex	n	Mean	Max	Min	sd
		IAW†			
Female	60	34.32	40.4	27.6	2.863
Male	60	38.43	47.5	30.8	3.549
Total	120	36.38	47.5	27.6	3.816
		ICTD			
Female	60	33.25	36.3	29.1	1.735
Male	60	35.05	40.2	31.2	1.962
Total	120	34.15	40.2	29.1	2.052
		WMAT			
Female	60	47.67	52.7	41	2.367
Male	60	48.78	54.6	40	2.873
Total	120	48.23	54.6	40	2.679

†IAW, interalar width; ICTD, intercanine tip distance; WMAT, width of maxillary anterior teeth.

Tanuseputro (1997) 36.7 mm or Hoffman *et al*. (1986) 35.35 mm or Gomes *et al*. (2009) 37.44 mm.

The mean of WMAT in this study 48.23 mm was smaller than the mean reported by Gomes *et al*. (2009) 53.67 and Al-El-Sheikh (1998) 52.22 mm and was greater than means reported by Hoffman *et al*. (1986) 44.85 mm, Al-Wazzan (2001) 45.23 mm and Shillingburg *et al*. (1972) 45.80 mm.

The differences among studies would seem to be due to ethnic differences or, possibly, different measurement techniques. Some studies used digital photography and obtained facial measurement from them, so they may have some errors because of the effect of the third dimension of anteroposterior length (Gomes *et al*., 2009; Hasanreisoglu *et al*., 2005), while others took measurements on the face (Hoffman *et al*., 1986; Al-El–Sheikh and Al-Athel, 1998; Mosharraf *et al*., 2006). Al-El-Sheikh and Al-Athel (1998) and Mosharraf *et al*. (2006) measured dental dimensions intraorally and Hoffman *et al*. (1986) used wax rim indices. Hasanreisoglu *et al*. (2005) and Gomes *et al*. (2009) measured dimensions from dental casts.

Genetic heritage would seem to be the main cause of variation between different groups (McArthur, 1985; Mavroskoufis and Ritchie, 1981). Participants in the current study were Iranian, and this is one source of the observed differences among groups.

There was a significant association between IAW and ICTD in females ($r = 0.457$; $P < 0.05$) and in males ($r = 0.442$, $P < 0.05$), which agrees with the studies of Hoffman *et al*. (1986) ($r = 0.49$, $P < 0.05$), Mavroskoufis and Ritchie (1981), and Dharap and Tanuseputro (1997) ($r = 0.31$, $P < 0.05$).

In the current study there was a significant relation between IAW and WMAT in females ($r = 0.473$; $P < 0.05$) and in males ($r = 0.481$; $P < 0.05$). Hoffman *et al*. (1986), Mosharraf *et al*. (2006), and Al-El-Sheikh and Al-Athel (1998) reported similar associations in their studies ($P < 0.05$).

Concerning the estimation of ICTD from IAW, Hoffman *et al*. (1986) found the ratio of 1.31 between IAW and WMAT, this ratio was 1.30 in Gomes *et al*.'s study (2009) and 1.26 in a study conducted by Aleem *et al*. (1997) and 1.56 in Al-El-Sheikh and Al-Athel's study (1998). Other studies calculated the ratio of means, whereas we provide regression equations for estimating WMAT from IAW, which is more useful. Different results in this study are assumed to be due to different measurement methods, to ethnic differences, and to different methods of analyzing the data statistically.

From a clinical perspective, we promote the predictive equations in Tables 2 and 3 for estimating tooth sizes in Iranians. These equations will help dentists provide Iranian patients the best esthetics relative to their previous natural teeth and in harmony with their facial dimensions.

CONCLUSIONS

Within the limitations of the present study, the following conclusions were drawn:

1. The dimensions of IAW, ICTD and WMAT were larger in males.
2. There were significant relationships between IAW and ICTD and WMAT in each sex.

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LITERATURE CITED

Aleem, MA, Stipho HD, Talic YF, Khan N. 1997. The significance of inner canthal distance in prosthodontics. Saudi Dental J 9:36-39.

Al-El–Sheikh HM, Al-Athel MS. 1998. The relationship of inter pupillary width and maxillary anterior teeth width in Saudi population. Odonostomatol tropicale 21:7-10.

TABLE 2. Predictive equation for estimation of ICTD and WMAT from IAW in males ($Y = a + bX$)

Y	X	r	P value	Predictive equation
ICTD	IAW	0.442	<0.0001	ICTD = 26.143 + 0.216 × IAW
WMAT	IAW	0.481	0.0080	WMAT = 43.807 + 0.129 × IAW

TABLE 3. Predictive equation for estimation of ICTD and WMAT from IAW in females (Y = a + bX)

Y	X	r	P value	Predictive equation
ICTD	IAW	0.457	0.016	ICTD = 28.187 + 0.145 × IAW
WMAT	IAW	0.473	0.000	WMAT = 42.194 + 0.159 × IAW

Al-Wazzan KA. 2001. The relationship between intercanthal dimension and width of maxillary anterior teeth. J Prosthet Dent 88:608-612.

Dharap AS, Tanuseputro H. 1997. A comparison of interalar width and intercanine distance in Malay males and females. Anthropol Anz 55:63-68.

Frush JP, Fisher DR. 1955. Introduction to dentogenic restorations. J Prosthet Dent 5:586–595.

Gomes VL, Gonçalves LC, Costa MM, Lucas Bde L. 2009. Interalar distance to estimate the combined width of the six maxillary anterior teeth in oral rehabilitation treatment. J Esthet Restor Dent 21:26-35.

Hasanreisoglu U, Berksun S, Aras K, Arsalan I. 2005. An analysis of maxillary anterior teeth: facial and tooth proportions. J Prosthet Dent 94:530-538.

Hoffman W Jr, Bombery TJ, Hatch RA. 1986. Interalar width as a guide in denture tooth selection. J Prosthet Dent 55:219-221

Keng SB. 1960. Nasal width dimension and anterior teeth in prosthodontics. Ann Acad Med Singapore 15:311-314.

Latta GH Jr, Weaver JR, Conkin JE. 1991. The relationship between the width of the mouth, interalar width, bizygomatic width and interpupillary distance in edentulous patients. J Prosthet Dent 65:250-254.

Lavelle CL. 1972. Maxillary and mandibular tooth size in different racial groups and in different occlusal categories. Am J Orthod 61:29-37. Young HA (1954) . Selecting anterior tooth mold. J Prosthet Dent 4:748-760.

Mavroskoufis F, Ritchie GM. 1981. Nasal width and incisive papilla as guides for the selection and arrangement of maxillary anterior teeth. J Prosthet Dent 45:592-597.

McArthur DR. 1985. Determining approximate size of maxillary anterior artificial teeth when mandibular anterior teeth are present. Part I: size relationship. J Prosthet Dent 53:216–218.

Mosharraf R. Sadeghian S, Farzan A, Malekzadeh F. 2006. The relationship between the mesiodistal width of maxillary incisors and width of the mouth, interalar width, Bizygomatic width and intercanthal distance. Int J Dental Anthropology 8:22-30.

Picard JR. 1958. Complete denture esthetics. J Prosthet Dent 8:252-259.

Richardson ER, Malhotra SK. 1975. Mesiodistal Crown dimension of the permanent dentition of American Negroes. Am J Orthod 68:157-164.

Sellen PN, Phil B, Jagger DC, Harrison A. 1999. Methods used to select artificial anterior teeth for the edentulous patient: a historical overview. Int J Prosthodont 1999;12:51-58.

Shilllingburg HT Jr, Kaplan MJ, Grace SC. 1972. Tooth dimension, a comparative Study. J So Calif Dent Assoc 40:830-839.

Strett JD Oliver T, Robinson F, Fortson W, Knaak B, Russel CM. 1992. Width/length ratios of normal clinical crowns of the maxillary anterior dentition in men. J Clin Periodontol 26:153-157.

Verjao FM, Nogueira SS. 2005. Intercommisural width in 4 racial groups as a guide for selection of maxillary anterior teeth in complete dentures. Int J Periodontol 18:513-515.

Wehner PJ, Hickey JC, Boucher CO. 1967. Selection of artificial teeth. J Prosthet Dent 18:222-232.

Zlatarić DK, Kristek E, Celebić A. 2007. Analysis of width/length ratios of normal clinical crowns of the maxillary anterior dentition: correlation between dental proportions and facial measurements. Int J Prosthodont 20:313-315.

Mesiodistal Crown Dimensions of the Permanent Dentition in a Nigerian Population

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ABSTRACT Mesiodistal crown dimensions of the permanent dentition were assessed in a Nigerian population. The study sample consisted of 54 dental casts of Nigerian subjects (33 males; 21 females) with a mean age of 26.6 (sd = 2.1) years. The subjects had their permanent teeth present and fully erupted from first molar to first molar, no interproximal caries or restorations and no abnormal tooth sizes or shapes. Descriptive statistics are provided. Sex differences in the means and comparisons with the means from other population were evaluated using t-tests. Results revealed no statistically significant difference in mesiodistal crown dimensions between the sexes and no left to right side tooth size discrepancy in the sample. The study provides normative data on the mesiodistal crown dimensions of Nigerian subjects. Compared to African Americans, crown dimensions tended to be smaller in these Nigerians, especially in males. *Dental Anthropology* 2010;23(2):57-60.

The availability of information about the size of individual tooth types and groups of teeth in the maxillary and mandibular arches is of importance in clinical orthodontics as it facilitates orthodontic diagnosis and treatment planning (Richardson and Malhotra, 1975). The desire to achieve stable occlusion during and after orthodontic treatment also necessitates the need for knowledge about tooth crown dimensions and ratios since without coordination between the sizes of the upper and lower teeth, it would not be possible to have correct intercuspation of the teeth, overjet, overbite and optimal occlusion (Andrews, 1972; Ballard, 1944; McLaughlin, 2001; Smith *et al*., 2000).

An early study on the mesiodistal widths of teeth was conducted by Black (1902) who also provided data on mean tooth dimensions. Presently, a lot of data are available in the literature for tooth dimensions of different populations and some variations in tooth sizes between gender and among different racial and ethnic groups have been reported (Richardson and Malhotra, 1975; Moyers *et al*., 1976; Moorrees *et al*., 1957; Santoro *et al*., 2000; Bishara *et al*., 1989; Merz *et al*., 1991; Singh and Goyal, 2006).

There is dearth of information on mesiodistal tooth size in Nigerians and the few studies available were conducted in the southwestern region of the country (Mack, 1981; Otuyemi and Noar, 1996; Adeyemi and Isiekwe, 2003). Presently, there are no data on mesiodistal crown dimensions of the permanent dentition of Nigerians in the southern and eastern regions of Nigeria. It is therefore desirable to determine standards for mesiodistal tooth size for the Nigerian population who invariably constitute the largest congregation of Black people in the world.

The purposes of this study were to establish normative data on the mesiodistal crown dimensions of the permanent dentition in a Nigerian population, identify any gender differences, and compare their mean mesiodistal crown dimensions to other racial groups.

MATERIALS AND METHODS

The sample for this study consisted of 54 Nigerian students made up of 33 males (61%) and 21 females (39%) with a mean age of 26.6 years (sd = 2.1) selected among the 74 final year students at the School of Dentistry of University of Benin, Benin City. The selection criteria included being a Nigerian, permanent teeth present and fully erupted, particularly from the first molar to first molar, no missing teeth, no teeth with abnormal sizes or shapes, no interproximal caries or excess tooth material as a result of restorations, and no presence of dental attrition. The 54 subjects who met the selection criteria were born of Nigerian parents and they predominantly belong to the major ethnic groups of the southern and southeastern regions of Nigeria.

Impressions of the upper and lower arches were taken for each subject in alginate and poured immediately in dental stone to prevent dimensional changes. The dental casts were measured with a digital vernier caliper. The

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TABLE 1. Comparison of mean, range and standard deviation for mesiodistal crown dimension of permanent dentition of Nigerian males and females

Tooth†	Males (n = 33)			Females (n = 21)			P-Value
	mean	range	sd	mean	range	sd	
			Maxillary				
I1	8.80	7.38 - 10.48	0.70	8.81	7.10 - 9.98	0.67	ns‡
I2	7.21	5.66 - 8.46	0.58	7.16	5.64 - 8.18	0.55	ns
C	8.07	7.18 - 9.12	0.43	7.85	7.05 - 9.10	0.51	ns
P1	7.51	6.92 - 8.38	0.40	7.43	6.68 - 8.08	0.35	ns
P2	7.01	6.04 - 8.12	0.46	7.13	6.10 - 8.18	0.52	ns
M1	10.55	9.60 - 12.1	0.61	10.37	9.60 - 10.92	0.36	ns
			Mandibular				
I1	5.58	4.62 - 6.37	0.38	5.62	4.70 - 6.18	0.35	ns
I2	6.19	5.18 - 6.98	0.42	6.08	5.18 - 6.66	0.37	ns
C	7.24	6.15 - 8.24	0.45	7.04	6.00 - 7.66	0.43	ns
P1	7.57	6.82 - 8.30	0.43	7.43	7.06 - 8.30	0.33	ns
P2	7.54	6.74 - 8.32	0.39	7.39	6.62 - 8.10	0.33	ns
M1	11.24	10.36 - 12.1	0.32	11.13	10.68 - 11.80	0.26	ns

†I1 - central incisor, I2 - lateral incisor, C - canine, P1 - first premolar, P2 - second premolar, M1 - first molar
‡ns, not significant; *significant difference at P < 0.05

maximum mesiodistal widths of the incisors, canines, premolars, and first molars were measured. The caliper was placed parallel to the occlusal plane of each tooth with its sharp points at the greatest distances between the contact points on the proximal surface of each tooth and measurement taken and rounded to the nearest 0.1 mm. Each tooth was measured twice by a single investigator and intra-examiner precision was set at 0.2 mm. Differences greater than this limit caused a new set of measurements to be taken, and the nearest two measurements were averaged.

TABLE 2. Descriptive statistics for mesiodistal crown dimension of permanent dentition of Nigerian sample

Tooth	Mean	Range	sd	CV
		Maxillary		
I1	8.80	7.10 - 10.48	0.68	7.75
I2	7.19	5.64 - 8.46	0.56	7.85
C	7.99	7.05 - 9.12	0.47	5.92
P1	7.48	6.68 - 8.38	0.38	5.08
P2	7.06	6.04 - 8.18	0.48	6.79
M1	10.48	9.60 - 12.1	0.53	5.05
		Mandibular		
I1	5.60	4.62 - 6.37	0.36	6.51
I2	6.15	5.18 - 6.98	0.40	6.52
C	7.16	6.00 - 8.24	0.45	6.29
P1	7.52	6.82 - 8.30	0.40	5.30
P2	7.48	6.62 - 8.32	0.37	5.00
M1	11.20	10.36 - 12.10	0.30	3.00

Data analysis was carried out with the Statistical Package for Social Sciences software version 16 (SPSS, Chicago, Illinois). Descriptive statistics including means, standard deviation, range, and coefficient of variation were calculated for each tooth dimension. The possibility of significant statistical differences in the tooth dimensions between the left and right side of the arch in the maxilla and mandible was evaluated using paired t-tests. Existence of a statistical difference between the sexes or between this sample and another racial group was evaluated with unpaired t-tests. Statistical significance was regarded when $P < 0.05$.

RESULTS

There was no statistical difference in the tooth dimensions between left and right sides of the arches ($P > 0.05$). The means, range, standard deviation, and statistical comparison of crown size dimensions in male and females are shown in Table 1. There was no statistically significant difference for mesiodistal crown dimensions between males and females ($P > 0.05$), so statistics for the combined data are provided in Table 2.

The sex-specific mean mesiodistal measurements obtained for these Nigerian subjects were compared with the mean values of African Americans. Table 3 shows that there were similarities in tooth sizes of the maxillary lateral incisor and canine and mandibular central incisor, lateral incisor and canine between Nigerian and African American males while the other 7 dimensions were statistically different ($P < 0.05$). There was a greater similarity in maxillary tooth sizes of Nigerian and African American females as shown in Table 4, except the

TABLE 3. Comparison of mean, range and standard deviation of Nigerian males with African American males

	Nigerian subjects		African Americans†		
Tooth	mean	sd	mean	sd	P-value
			Maxillary		
I1	8.80	0.70	9.12	0.67	<0.05
I2	7.21	0.58	7.26	0.64	ns‡
C	8.07	0.43	8.19	0.53	ns
P1	7.51	0.40	7.66	0.49	<0.05
P2	7.01	0.46	7.25	0.49	<0.01
M1	10.55	0.61	11.04	0.64	<0.001
			Mandibular		
I1	5.58	0.38	5.53	0.39	ns
I2	6.19	0.42	6.13	0.44	ns
C	7.24	0.45	7.37	0.57	ns
P1	7.57	0.43	7.76	0.51	<0.05
P2	7.54	0.39	7.85	0.55	<0.001
M1	11.24	0.32	11.76	0.72	<0.001

†From Richardson and Malhotra (1975).
‡ns, not significant

maxillary first molar that was highly significantly larger in African American females (P < 0.001). The mandibular central incisor, second premolar, and first molar also were statistically different (P < 0.05) between the two groups.

DISCUSSION

The university students evaluated in this study provide a suitable sample of Nigerian subjects who belong to the predominant ethnic groups in the southern and southeastern regions of Nigeria where there were no normative data on the mesiodistal crown dimensions of the permanent dentition. There was no significant gender difference in the mesiodistal crown dimensions of permanent teeth in this sample of Nigerians. Mean values of the males were, however, slightly larger than females in both the maxillary and mandibular arches, and this observation was consistent with findings in African American (Richardson and Malhotra, 1975), Dominican American (Santoro *et al*., 2000), and Indian populations (Singh and Goyal, 2006).

In the maxilla, mean width of the central incisor was larger than lateral incisor and, similarly, mean width of the first premolar was larger than the second premolar, which was consistent with findings in an earlier Nigerian study (Adeyemi and Isiekwe, 2003) and in other populations (Richardson and Malhotra, 1975; Santoro *et al*., 2000; Singh and Goyal, 2006; Uysal and Sari, 2005). In the mandibular arch, the mean width of the central incisor was smaller than the lateral incisor while mean width of the first premolar was also smaller than the second premolar as reported elsewhere (Richardson and Malhotra, 1975; Uysal and Sari, 2005).

The maxillary and mandibular first molar show least variability in mesiodistal tooth size in this sample. The variability of central and lateral incisors in the mandible are similar but show less variability than the maxillary incisors. The lateral incisor has the highest variability in the maxillary arch and should be of interest during clinical examination because of its location in the anterior maxillary segment and the possibility of crowding or spacing.

The normative mesiodistal crown dimensions of the maxillary and mandibular permanent teeth for these Nigerians were only similar to a few of those of African American sample reported by Richard and Malhotra (1975). For males, the sex-specific measurements for the Nigerians compared to those of African Americans revealed statistically significant differences in 7 of the 12 variables, with the African Americans being larger. However, there was greater similarity between Nigerian and African American females with the exception of the maxillary first molar, mandibular central incisor, second premolar, and first molar, which were significantly larger in the Nigerian sample. These group differences in tooth sizes could be attributed to racial differences as previously observed in another comparative study of tooth sizes (Bishara *et al*., 1989), but it is also important to note that the African American population is an admixture of multiple racial groups.

This study re-emphasizes the importance of evaluation of mesiodistal tooth dimensions in different populations. A previous study involving Nigerian children reported that the mesiodistal crown dimensions of the Nigerian sample were significantly larger than a British Caucasian sample (Otuyemi and Noar, 1996). Also, some other studies have

TABLE 4. Comparison of mean, range and standard deviation of Nigerian females with African American females

	Nigerian adults		African Americans†		
Tooth	mean	sd	mean	sd	P-value
			Maxillary		
I1	8.81	0.67	8.72	0.58	ns‡
I2	7.16	0.55	7.08	0.56	ns
C	7.85	0.51	7.74	0.38	ns
P1	7.43	0.35	7.37	0.43	ns
P2	7.13	0.52	6.94	0.39	ns
M1	10.37	0.36	11.04	0.64	<0.001
			Mandibular		
I1	5.58	0.38	5.38	0.39	<0.01
I2	6.08	0.37	5.99	0.46	ns
C	7.04	0.43	6.86	0.42	ns
P1	7.43	0.33	7.41	0.50	ns
P2	7.54	0.39	7.61	0.50	<0.01
M1	11.13	0.26	11.28	0.62	<0.05

†From Richardson and Malhotra (1975).
‡ns, not significant

shown that American blacks have significantly larger tooth crowns and arch dimensions than American whites (Richardson and Malhotra, 1975; Merz *et al*., 1991; Burris and Harris, 2000). It is important that ethnic and individual variations and treatment needs be taken into consideration in the evaluation of patients, diagnosis, and treatment planning in order to achieve desired treatment objectives and optimal occlusion.

CONCLUSION

The study provided normative data on the mesiodistal crown dimensions of Nigerian subjects. The males and females exhibited similar patterns of tooth size even though the mean values of the tooth size of the males were slightly larger. The mean tooth sizes of Nigerian and African American population were only comparable for a few teeth in the maxilla and mandible.

LITERATURE CITED

Adeyemi TA, Isiekwe MC. 2003. Mesio-distal crown dimensions of permanent teeth in a Nigerian population. Afr J Med Med Sci 32:23-25.

Andrews LF. 1972. The six keys to normal occlusion. Am J Orthod 62:296-309.

Ballard ML. 1944. Asymmetry in tooth size: a factor in the etiology, diagnosis and treatment of malocclusion. Angle Orthod 14:67-71.

Bishara SE, Jakobsen JR, Abdallah EM, Garcia AF. 1989. Comparisons of mesiodistal and buccolingual crown dimensions of the permanent teeth in three populations from Egypt, Mexico and the United States. Am J Orthod Dentofacial Orthop 96: 416-422.

Black GV. 1902. Descriptive anatomy of human teeth, 4th edition. Philadelphia: S S White.

Burris BG, Harris EF. 2000. Maxillary arch size and shape in American blacks and whites. Angle Orthod 70:297-302.

Mack PJ. 1981. Maxillary arch and central incisor dimensions in a Nigerian and British population sample. J Dent 9:67-70.

McLaughlin RP, Bennett JC, Trevisi HJ. 2001. Systemised orthodontic treatment mechanics. St Louis: Mosby, p 285.

Merz ML, Isaacson RJ, Germane N, Rubenstein LK. 1991. Tooth diameters and arch perimeters in a black and a white population. Am J Orthod Dentofacial Orthop 100:53-58.

Moyers RE, Van Der Linden FPGM, Riolo ML, McNamara JA Jr. 1976. Standards of human occlusal cevelopment. Monograph 5. Ann Arbor, MI: Center for Human Growth and Development, University of Michigan.

Moorrees CFA, Thomsen SO, Jensen E, Yen PK. 1957. Mesiodistal crown diameter of the deciduous and permanent teeth in individuals. J Dent Res 36:39-47.

Otuyemi OD, Noar JH. 1996. A comparison of crown size dimensions of the permanent teeth in a Nigerian and a British population. Eur J Orthod 18:623-628.

Richardson RE, Malhotra SK. 1975. Mesiodistal crown dimension of the permanent dentition of American Negroes. Am J Orthod 68:157-164.

Santoro M, Ayoub ME, Pardi VA, Cangialosi TJ. 2000. Mesiodistal crown dimensions and tooth size discrepancy of the permanent dentition of Dominican Americans. Angle Orthod 70:303-307.

Singh SP, Goyal A. 2006. A mesiodistal crown dimensions of the permanent dentition in North Indian children. J Indian Soc Pedod Prev Dent 24:192-196.

Smith SS, Buschang PH, Watanabe E. 2000. Interarch tooth size relationships of 3 populations: 'Does Bolton's analysis apply? Am J Orthod Dentofacial Orthop 117:169-174.

Uysal T, Sari Z. 2005. Intermaxillary tooth size discrepancy and mesiodistal crown dimensions for a Turkish population. Am J Orthod Dentofacial Orthop 128:226-230.

Technical Note: Primary Tooth Mineralization and Exfoliation Ages Calculated from the Moorrees-Fanning-Hunt Study

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ABSTRACT Staging of the formation of teeth and shedding of the primary teeth are particularly useful for age estimation of archaeological and forensic specimens, as well as for gauging whether a child's tempo of maturation is progressing within normal limits. Staging can be done using radiographs or with direct inspection of dental remains. Standards for the primary dentition are scarce, but obviously needed for young children. This note provides tables, by sex, of the normative ages of the mineralization of three mandibular tooth types (c, m1, m2) as well as of root resorption and times of shedding of these tooth types. The data are transformed from charts developed by Moorrees, Fanning and Hunt (1963 *Am J Phys Anthropol* 21:99-108). Conversion to numeric form is intended to aid in using these data for statistical comparisons. *Dental Anthropology* 2010;23(2):61-65.

Tooth-formation standards for the primary teeth are quite scarce, largely because these teeth begin developing *in utero* where analysis is complicated and because dental researchers have avoided dealing with very young children, especially where irradiation is involved. A singular exception, due in large part to the tireless efforts of Arthur B. Lewis, is the analysis of primary tooth mineralization in children between birth and about 16 years of age (Moorrees *et al.*, 1963a).

While data from the earliest-forming teeth, the incisors, are unavailable, Moorrees, Fanning and Hunt (1963a) reported on the formative stages and the later exfoliation of three primary tooth types, specifically the canine, first and second molars in the mandible. This report, in the *American Journal of Physical Anthropology*, accompanies these authors' better-known study of the permanent dentition (Moorrees *et al*., 1963b). Their study of the primary teeth has been useful in several studies, but the authors chose to present their data in graphical form only, which has been an impediment to using the data statistically. In hopes that these tabulated data will be more useful to others, I have converted the graphical data into more applicable tables of medians and standard deviations.

To my knowledge, these are the only published data on the tooth mineralization of primary teeth that span the relevant postnatal age interval (neonates up to school age). Comparable radiographic data were collected in the Bolton-Brush Study (Cleveland, Ohio) as reviewed by Behrents (1985) and in the Child Research Council (Denver, Colorado) as reviewed by McCammon (1970), but these radiographs do not seem to have been analyzed to develop tooth-formation data. Demirjian and colleagues (*e.g.*, Demirjian *et al*., 1982) also collected the needed data from their longitudinal study of French-Canadian children in Montreal, though these data do not seem to be published.

In contrast, there are several studies that report on the *eruption* ages of the primary teeth (*e.g.*, Falkner, 1957; Infante, 1974; Delgado *et al*., 1975; Tanguay *et al*. 1986), based either on direct intraoral examinations or on serial dental casts (Moorrees, 1959).

TABLE 1. The stages of tooth formation and resorption developed by Moorrees and coworkers

Stage	Code
Tooth Mineralization	
Coalescence of cusp	C co
Cusp outline complete	C oc
Crown ½ complete	Cr ½
Crown ¾ complete	Cr ¾
Crown complete	Cr c
Initial root formation	R i
Initial cleft formation	Cl i
Root length ¼	R ¼
Root length ½	R ½
Root length ¾	R ¾
Root length complete	R c
Apex ½ closed	A ½
Apex closure complete	A c
Tooth Exfoliation	
One-fourth root reorption	Res ¼
One-half root resorption	Res ½
Three-Fourths root resorption	Res ¾

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TABLE 2. Median ages (years), by sex, for stages of mandibular primary tooth formation[1]

Formation Stage	Girls median	sd	Boys median	sd
Primary canine				
C co	•	•	•	•
C oc	0.1	0.09	0.2	0.09
Cr ½	0.3	0.10	0.3	0.10
Cr ¾	0.5	0.12	0.5	0.12
Cr c	0.7	0.14	0.7	0.14
R i	0.9	0.15	0.8	0.16
R ¼	1.1	0.17	1.0	0.17
R ½	1.3	0.20	1.3	0.20
R ¾	1.8	0.25	1.9	0.25
R c	2.1	0.27	2.0	0.26
A ½	2.5	0.32	2.5	0.32
A c	3.0	0.36	3.1	0.37
Primary first molar				
C co	•	•	•	•
C oc	•	•	•	•
Cr ½	0.1	0.09	0.2	0.09
Cr ¾	0.2	0.10	0.3	0.09
Cr c	0.3	0.11	0.5	0.12
R i	0.6	0.12	0.6	0.13
Cleft	0.6	0.12	0.7	0.14
R ¼	0.6	0.14	0.8	0.15
R ½	0.9	0.16	0.9	0.16
R ¾	1.1	0.18	1.2	0.19
R c	1.3	0.19	1.3	0.20
A ½	1.5	0.22	1.7	0.24
A c	1.8	0.25	2.0	0.26
Primary second molar				
C co	•	•	•	•
C oc	•	•	0.2	0.09
Cr ½	0.2	0.10	0.3	0.10
Cr ¾	0.5	0.12	0.5	0.12
Cr c	0.7	0.14	0.7	0.14
R i	0.9	0.16	0.9	0.16
Cleft	1.0	0.16	1.0	0.16
R ¼	1.3	0.20	1.3	0.21
R ½	1.6	0.22	1.9	0.23
R¾	1.9	0.26	2.0	0.21
R c	2.0	0.27	2.0	0.27
A ½	2.4	0.30	2.4	0.31
A c	2.8	0.35	3.1	0.37

[1]Statistics are the median chronologic age and its standard deviation (sd). These norms were developed from serial x-rays taken on 136 boys and 110 girls from among those enrolled in the Fels Longitudinal Study, Yellow Springs, Ohio.

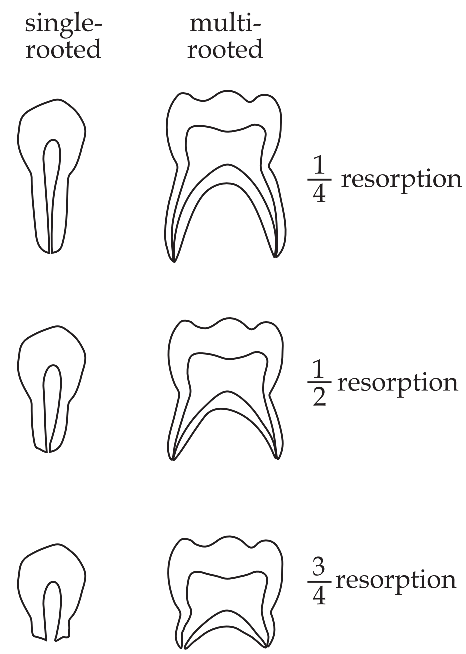

Fig. 1. Sketches of the 3 stages of primary tooth root resorption used byMoorrees, Fanning and Hunt (1963a).

THE DATA

As stated in their article, Moorrees *et al*. (1963b) collected data from the Fels Longitudinal Study located in Yellow Springs, Ohio (Roche, 1992). This is one of the premiere longitudinal growth studies in the world, following children from birth into biological adulthood. The Fels study had its inception in 1929, and from then until the early 1960s (when Moorrees and coworkers collected their data), between 500 and 600 children had been enrolled (Roche, 1992). Lateral and oblique headfilms (radiographs) were taken at 3-month intervals during the first year of life and at 6-month intervals thereafter (Moorrees *et al*., 1963a). These planar radiographs were an efficient means of visualizing all of the teeth with one or two films; this was in the era before panoramic films were available (Graber, 1966). Experience suggests that the researchers focused on the mandibular teeth because the tooth images are clearer in this arch, whereas the maxillary images are overlain with complex bony shadows. Strong intercorrelations between stages of homologous teeth in the two arches (Moorrees and Reed, 1954; Kent *et al*., 1978) can be used as an argument for restricting attention to just one arch.

Moorrees *et al*. state that their standards are based on the serial radiographic records of 136 boys and 110 girls.

Moorrees and coworkers thought the charts that they developed were most useful for clinical application. For a single case, this might be true. I used Photoshop CS3 to measure high-quality scans of he charts and then transformed these measurements back to decimal years. (Comparable tabulations of permanent tooth formation

TABLE 3. Median ages (years), by sex, for stages of mandibular primary tooth resorption and exfoliation

Stage	Girls median	Girls sd	Boys median	Boys sd
Canine				
Res ¼	4.93	0.45	6.08	0.55
Res ½	7.26	0.65	8.41	0.74
Res ¾	8.73	0.76	9.79	0.84
Exfoliation	9.53	0.83	10.64	0.92
First molar, mesial root				
Res ¼	4.90	0.45	5.45	0.49
Res ½	7.25	0.64	7.58	0.68
Res ¾	8.85	0.77	9.41	0.82
Exfoliation	10.12	0.87	10.79	0.93
First molar, distal root				
Res ¼	5.17	0.48	6.39	0.58
Res ½	7.68	0.66	8.35	0.73
Res ¾	9.75	0.81	10.01	0.87
Exfoliation	10.12	0.87	10.79	0.93
Second molar, mesial root				
Res ¼	6.09	0.55	6.65	0.59
Res ½	8.31	0.73	8.61	0.74
Res ¾	10.02	0.87	10.42	0.90
Exfoliation	11.13	0.96	11.67	1.00
Second molar, distal root				
Res ¼	6.95	0.62	7.45	0.65
Res ½	8.61	0.76	9.51	0.82
Res ¾	9.95	0.87	11.08	0.95
Exfoliation	11.12	0.96	11.64	1.00

standards [Moorrees *et al*., 1963b] are available in Harris and Buck, 2002.)

THE RESEARCHERS

As an aside, it is interesting to note the serendipity (synergism) of Moorrees, Fanning, and Hunt's collaboration. Moorrees (b. 1916 – d. 2003) certainly had a knowledgeable interest in development of the dentition (see, *e.g*., Moorrees, 1959), and he was in a position at the Forsyth Dental Infirmary (Harvard School of Dental Medicine) to coordinate the study (Moorrees, 1993; Peck and Will, 2004). Elizabeth Fanning (b. 1918 – d. 2007) was trained in Australia as a dentist (Townsend, 2007), and she brought her expertise in scoring tooth-mineralization stages. Beginning with her thesis (Fanning, 1960), Fanning developed elaborate grading systems; these have generally been eschewed by subsequent workers as too detailed to allow high intraobserver reliability in their hands. However, if mastered, these stages of short duration provide fine-grained analysis. Ed Hunt (b. 1922 – d. 1991) a physical anthropologist at Harvard University had research interests in growth and development, but he also had a strong background in quantitative methods (Baker, 1992), and he was the team member who actually calculated the probit analyses (*e.g*., Finney, 1971) that yielded the median ages at each stage of tooth formation and of exfoliation. The collaboration involved Moorrees overseeing the study, Fanning scoring the tooth stages from the films, and Hunt calculating the statistics.

The unsung hero in this scenario is Arthur B. ("Buzz") Lewis, a dental specialist in orthodontics, who maintained a private practice as well as an appointment on the orthodontic faculty at Ohio State University throughout his professional life. Lewis also was a research associate at the Fels Research Institute for a full half-century (Mayerson, 1996), and most dental anthropologists will recall his numerous publications with Stanley Garn. Lewis is the man responsible for taking the dental radiographs of the participants at Fels, with X-rays taken every 3 months for the first year, then at 6-month intervals after that. Without the radiographs of these infants—a considerable undertaking in itself—there would have been no data to collect.

PRIMARY TOOTH FORMATION

The original charts record two sequential processes, one is the formation of these three primary teeth (c, m1, m2) that begin mineralization as early as the second trimester (Lunt and Law, 1974) and continue till about 3 years of age. The second process, some years later, occurs during the "second transition" of dental development (van der Linden and Duterloo, 1976), when these primary teeth are exfoliated and replaced by the permanent canine and premolars in each quadrant. Shedding of these primary teeth occurs between 9 and 11 years of age, with subsequent emergence of the successors.

Moorrees *et al*. used the same 12 stages of tooth mineralization as they used elsewhere to score the permanent teeth (Moorrees *et al*. 1963b). One additional stage (cleft formation) was used to note the interradicular area of multi-rooted teeth.

The interval from about 2 ½ years (when all 20 primary teeth have emerged into occlusion) to about 6 years of age (when the permanent first molar emerges) is viewed as the interval of the intact primary dentition. These data (Tables 1, 2) show that these three teeth begin their resorptive processes by about 5 years of age (somewhat later in boys) when the canines and first molars initiate root resorption. This is, of course, some years before exfoliation.

Histologically, osteoclasts are congregated and mature ahead of the successor's dental sac (Wise *et al*., 1999, 2002, 2008), and these multinucleated cells remove the bone and deciduous tooth roots ahead of the replacement tooth. Timely resorption of the primary tooth's root is necessary for normal eruption of the permanent tooth. The biochemical signaling for lysis is from the dental follicle of the permanent successor. This is why, when the successor is congenitally absent, exfoliation of the primary tooth is delayed, often for many years though roots still tend to

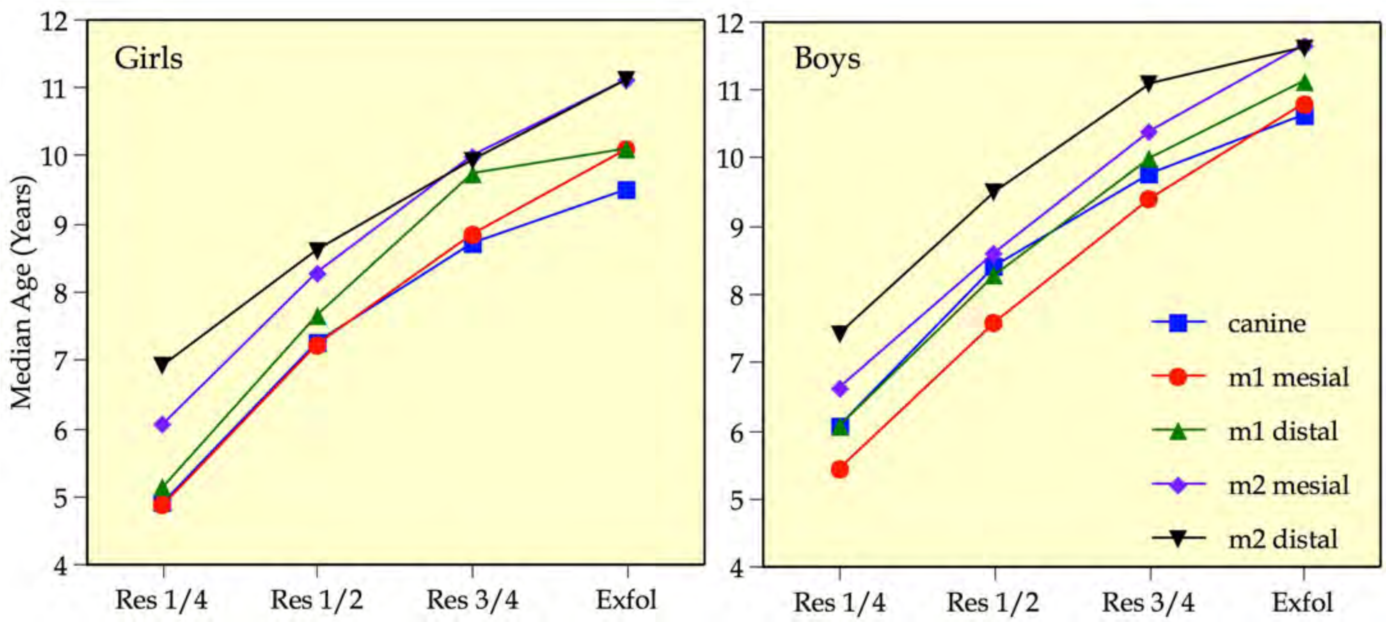

Fig. 2. Plots of the median ages of primary tooth resorption. Girls tend to be developmentally ahead of boys, though the patterns of change and the sequencing are similar in the two sexes. Mesial root of m1 tends to be the first of these three teeth to exhibit resorption, while the distal root of m2 is the last to resorb. Sequencing coincides with the high prevalence of cases where m1 exfoliates earlier than m2 (and the first premolar emerges earlier than the second).

resorb albeit slowly (*e.g.*, Haselden *et al.*, 2001; Nordquist *et al*. 2005; Bjerklin *et al*., 2008).

Primary tooth mineralization progresses more rapidly than in the permanent successors, and this is reflected in smaller overall sizes, thinner tissue components, and lower enamel and dentin densities (*e.g.*, McDonald, 1978; Wilson 1989; Hunter, 2000). The Moorrees charts (Table 2) show that about half of the crowns are mineralized *in utero*, so their staging is missed even when radiographs are taken at birth.

Results show that girls progress faster than boys. Differences are small and not significant statistically (based on univariate comparisons of 95% confidence limits), but younger median ages in girls are widespread across the data. Parenthetically, this raises the interesting question of ethnic and environmental influences on rates of development. Assessed multivariately, Tanguay and coworkers (1986) found earlier tooth primary emergence for *boys*, though other studies have reported different results, generally no discernible sex difference (Demirjian, 1978).

The first molar is particularly fast-forming. It completes crown formation (amelogenesis) by about 4 months after birth and roots are apexified by 2 years of age. The other two tooth types form more slowly, with average crown completion at about 0.7 years (~ 8 months), and with root completion (A_c) by 3 years of age.

TOOTH EXFOLIATION

Shedding of these teeth occurs between about 10 and 11 years of age (Table 3), which is consistent with conventional mnemonics that these primary teeth are shed and their successors emerge around the 2-year interval of the second transition (van der Linden and Duterloo, 1976)

Interestingly, resorption of the roots of these primary teeth begins several years earlier. Resorption is noted on the canine and first molar by about 5 years of age. Three stages of root resorption were scored, along with exfoliation as the ultimate event (Fig. 1). Initial evidence (R¼) of resorption occurs late, between 6 and 7 years of age, for the second molar. Durations of the exfoliation process can be gauged by comparing the earliest evidence of root loss (R¼) to when the tooth actually is lost. The process takes 4 to 5 years on the average, but somewhat less for the canine (~ 4 years) than the two molars.

Fanning's attention to detail allows us to see that the mesial root of the molars resorb faster than the distal root. This may be due to the mesial crown tip of molars (*e.g.*, Dempster *et al.* 1963), so the mesial root is under greater compression when the molar is under pressure. This cause is speculative, but precocity of the mesial root attaining resorption stages is consistent across the data.

Table 3 also discloses the strong trend for girls to shed these teeth ahead of boys. Normal shedding of a primary tooth involves lysis of the roots and of the bone ahead of the succeeding tooth (Wise and King, 2008), so the female precedence that has long been known for permanent tooth emergence (Hurme 1949) is part and parcel of this process.

OVERVIEW

This note presents tabled statistics for three primary mandibular tooth types (c, m1, m2) with regard to their mineralization (Table 2) and their subsequent resorption (Table 3). Tables are transformed from the graphs produced by Moorrees *et al*. (1963a) with the intent of making the data more usable for statistical applications.

LITERATURE CITED

Baker PT. 1992. Obituary: Edward Eyre Hunt, Jr. (1922-1991). Am J Phys Anthropol 89:123-125.

Bjerklin K, Al-Najjar M, Kårestedt H, Andrén A. 2008. Agenesis of mandibular second premolars with retained primary molars: a longitudinal radiographic study of 99 subjects from 12 years of age to adulthood. Eur J Orthod 30:254-261.

Behrents RG. 1985. In search of truth for the greater good of man: a chronological account of the Bolton-Brush growth studies. Cleveland: Bolton Study Press of Case Western Reserve University.

Delgado H, Habicht JP, Yarbrough C, Lechtig A, Martorell, R, Malina R, Klein R. 1975. Nutritional status and the timing of the deciduous tooth eruption. Am J Clin Nutr 28:216-224.

Demirjian A. 1978. The dentition. In: Human growth, Vol 2. postnatal growth. Falkner F, Tanner JM, eds. New York: Plenum Publishers, p 413-444.

Demirjian A, La Palme L, Thibault HW. 1982. La Croissance staturo-ponde'rale des Enfants Canadiens-Francais de la Naissance a 36 Mois. Union Med Can 112:153-163.

Dempster WT, Adams WJ, Duddies RA. 1963. Arrangement in the jaws of the roots of the teeth. J Am Dent Assoc 67:779-797.

Falkner F. 1957. Deciduous tooth eruption. Arch Dis Child 32;386-391.

Fanning EA. 1960. A longitudinal study of tooth formation and root resorption. D.D.S. thesis, University of New Zealand.

Finney DJ. 1971. Probit analysis, 3rd ed. Cambridge, Great Britain: Cambridge University Press.

Graber TM. 1966. Panoramic radiography. Angle Orthod 36:293-311.

Harris EF, Buck A. 2002. Tooth mineralization: a technical note on the Moorrees-Fanning-Hunt standards. Dental Anthropology 16:15-20.

Haselden K, Hobkirk JA, Goodman JR, Jones SP, Hemmings KW. 2001. Root resorption in retained deciduous canine and molar teeth without permanent successors in patients with severe hypodontia. Int J Paediatr Dent 11:171-178.

Hunter ML. 2000. Erosion of deciduous and permanent dental hard tissue in the oral environment. J Dent 28:257-263.

Hurme VO. 1949. Ranges of normalcy in the eruption of permanent teeth. J Dent Child 16:11-15.

Infante PF. 1974. Sex differences in the chronology of deciduous tooth emergence in White and Black children. J Dent Res 53:418.

Kent RL Jr, Reed RB, Moorrees CF. 1978. Associations in emergence age among permanent teeth. Am J Phys Anthropol 48:131-142.

Lunt RC, Law DB. 1974. A review of the chronology of calcification of deciduous teeth. J Am Dent Assoc 89:599-606.

Mayerson M. 1996. In memoriam: Arthur B. Lewis (1909-1996). Am J Orthod Dentofacial Orthop 110:329.

McCammon RW. 1970. Human growth and development. Springfield: Charles C Thomas, Publisher.

McDonald RE. 1978. Dentistry for the child and adolescent, 3rd ed. St Louis. CV Mosby, p 39-44.

Moorrees CFA. 1959. The dentition of the growing child: a longitudinal study of dental development between 3 and 18 years of age. Cambridge: Harvard University Press.

Moorrees CF. 1993. Reflections on an academic career in teaching and research. Am J Orthod Dentofacial Orthop 104:516-522.

Moorrees CFA, Fanning EA, Hunt EE Jr. 1963a. Formation and resorption of three deciduous teeth in children. Am J Phys Anthropol 21:99-108.

Moorrees CFA, Fanning EA, Hunt EE Jr. 1963b. Age variation of formation stages for ten permanent teeth. J Dent Res 42:1490-1502.

Moorrees CF, Reed RB. 1954. Biometrics of crowding and spacing of the teeth in the mandible. Am J Phys Anthropol 12:77-88.

Nordquist I, Lennartsson B, Paulander J. 2005. Primary teeth in adults—a pilot study. Swed Dent J 29:27-34.

Peck S, Will LA. 2004. In memoriam: Coenraad F.A. Moorrees, 1916-2003. Am J Orthod Dentofacial Orthop 125:396-398.

Roche AF. 1992. Growth, maturation and body composition: the Fels Longitudinal Study, 1929-1991. Cambridge, Great Britain: Cambridge University Press.

Tanguay R, Buschang PH, Demirjian A. 1986. Sexual dimorphism in the emergence of deciduous teeth: Its relationship with growth components in height. Am J Phys Anthropol 69:511-515.

Townsend G. 2007. Comments. Dental Anthropology 20:25-27.

van der Linden FPGM, and Duterloo HS. 1976. Development of the human dentition. Hagerstown: Harper and Rowe Publishers.

Wilson PR. 1989. Mineralization differences between human deciduous and permanent enamel measured by quantitative microradiography. Arch Oral Biol 34:85-88.

Wise GE, Frazier-Bowers S, D'Souza RN. 2002. Cellular, molecular, and genetic determinants of tooth eruption. Crit Rev Oral Biol Med 13:323-334.

Wise GE, Huang H, Que BG. 1999. Gene expression of potential tooth eruption molecules in the dental follicle of the mouse. Eur J Oral Sci 107:482-486.

Wise GE, King GJ. 2008. Mechanisms of tooth eruption and orthodontic tooth movement. J Dent Res 87:414-434.

Short Communication: Intra-Individual Microwear Variation: Deciduous versus Permanent Dentition

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ABSTRACT This study compares microwear patterns on deciduous and permanent dentition within individuals. Number of features, total number of pits, mean pit breadth and mean scratch breadth are compared in 11 individuals aged 6-12 years. For each individual, the second deciduous molar and first permanent molar are used. Paired sample t-tests show no significant difference between deciduous and permanent enamel for any of the microwear features examined. This study suggests that differences in the physical and chemical structures of deciduous and permanent enamel are not sufficient to cause differences in microwear patterning. Any difference between juveniles and adults can be assumed to represent a true dietary difference rather than enamel structural differences. *Dental Anthropology* 23(2):66-68.

Analysis of dental microwear has aided in the interpretation of human diet for a number of populations over the last few decades (*e.g.*, Fine and Craig, 1981; Harmon and Rose, 1988; Hojo, 1989; Laleuze *et al*., 1993; Molleson *et al*., 1991; 1993; Danielson and Reinhard, 1998; Schmidt, 2001; Teaford, 2002; Organ, 2005). The majority of these studies rely on microwear of permanent dentition; only a few have used the deciduous dentition (Bullington, 1991; Greene, 2007). Despite investigations into Gordon's claims (1980, 1982) that microwear varies with age (Teaford and Oyen, 1986, 1988, 1989; Bullington, 1991), no study has compared the microwear of deciduous and permanent teeth. This aim of the present study is to determine if microwear patterns differ between deciduous and permanent molars of the same individual. Given the same diet, can deciduous and permanent enamel be expected to show similar microwear patterns?

We know that the physical and chemical properties of deciduous and permanent enamel differ (LeGeros *et al*., 1983; Kornblit *et al*., 2009). Enamel of deciduous teeth is somewhat softer than that of the permanent dentition. This is due to the spatial organization of the enamel prisms, which is more loosely organized in deciduous enamel. Often, superficial deciduous enamel is aprismatic (Kornblit *et al*., 2009). It also tends to be less mineralized and more porous (LeGeros *et al*., 1983; Kornblit *et al*., 2009). Several studies have shown that deciduous enamel erodes at a faster rate than permanent enamel when exposed to acids (Amaechi *et al*., 1999; Hunter *et al*., 2000; Lippert *et al*., 2004). Lippert and colleagues (2004) show that deciduous enamel is significantly softer after being exposed to acid and therefore at higher risk of abrasion and attrition than permanent enamel. Given a faster rate of wear and higher predisposition of deciduous enamel to abrasion, a greater number of microwear features or larger microwear features might be expected.

MATERIALS AND METHODS

A total of 11 individuals were chosen for the study; five from Hierakonpolis and six from Naqada. Both locations are Predynastic sites in Upper Egypt dating to 3,800-3,650 BC. The two sites have been shown to have similar diets (Greene, 2007). Individuals in this sample fell within the 6 to 12 year age range and had both a deciduous second molar and permanent first molar erupted and in occlusion. While most researchers use the mandibular left second molar (Gordon, 1982; Harom and Rose, 1988; Kay, 1987; Schmidt, 1998), deciduous molars would not be expected to remain in occlusion until the eruption of the second molar.

Casts of the teeth were prepared following Schmidt (1998). Casts were separated and given unique random numbers so the researcher did not know which teeth were a pair during study. Micrographs were taken of the Phase II wear facet (as defined by Kay, 1977). Images were obtained on an International Scientific Instruments (ISI-40) SEM at 500X magnification in the secondary emissions mode (Teaford and Walker, 1984; Teaford, 1984, 1991, 1994; Teaford *et al*., 1996). Images were transferred directly from the SEM to computer via an Iridium Digital Imaging System. A semi-automated computer program, Microwear 4.0 (Ungar, 2000), was used to analyze digital images of the tooth surface. Microwear characteristics examined include total number of features (pits and scratches), total number of pits, mean breadth of pits, and mean breadth of scratches (Table 1). Comparisons were made between the deciduous and permanent molar using paired-sample t-tests.

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TABLE 1. Mean values and standard deviations for deciduous and permanent molars

	Deciduous molars		Permanent molars	
	mean	sd	mean	sd
Total number of features	35.18	24.28	47.73	34.42
Total number of pits	17.45	15.08	22.55	22.56
Mean pit breadth	8.63	5.66	9.46	4.86
Mean striation breadth	3.65	2.53	2.86	1.06

RESULTS AND DISCUSSION

The differences between the deciduous and permanent molar were generally small for all individuals. Figure 1 shows the deciduous and permanent dentitions with the greatest overall differences. The average feature tally differs by 13 features, with the majority differing by less than 10 features. The average pit tally differs by only five pits, with the majority differing by less than five. Mean pit breadth differs by 0.1 µm to 4.44 µm, with the majority differing by less than 2 µm. One individual was not included in the test for mean pit breadth because this individual did not exhibit any pits on the deciduous molar. Mean striation breadth differs by 0.29 µm to 8.58 µm, with the majority differing by less than 1 µm. Paired-samples t-tests showed no significant difference between the deciduous and permanent molars for any of the characteristics examined (Table 2).

The results of this study suggest that, despite some small differences, the deciduous and permanent enamel generally react the same way in regard to microwear features. Although the deciduous and permanent teeth were not identical in each individual, the differences were no greater than intertooth differences between first and second permanent molars of the same individual (Mahoney, 2006). Therefore, subadults with deciduous dentition can reasonably be included in population studies of microwear. Also, any difference in microwear patterns between juveniles and adults within a population should represent actual dietary differences rather than differences in enamel structure.

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TABLE 2. Paired-sample t-tests between deciduous and permanent molars

Variable	t	df	P
Total number of features	-1.315	10	0.218
Total number of pits	-0.741	10	0.476
Mean pit breadth	-0.952	9	0.366
Mean striation breadth	0.886	10	0.396

LITERATURE CITED

Amaechi BT, Higham SM, Edgar WM. 1999. Factors influencing the development of dental erosion in vitro: enamel type, temperature and exposure time. J Oral Rehabil 26: 624–630.

Bullington J. 1991. Deciduous dental microwear of prehistoric juveniles from the lower Illinois River Valley. Am J Phys Anthropol 84:59-73.

Danielson DR, Reinhard KJ. 1998. Human dental microwear caused by calcium oxalate phytoliths in prehistoric diet of the lower Pecos region, Texas. Am J Phys Anthropol 107:297-304

Fine D, Craig GT. 1981. Buccal surface wear of human premolar and molar teeth: a potential indicator of dietary and social differentiation. J Hum Evol 10:335-344.

Gordon KD. 1980. Dental attrition in the chimpanzee (*Pan troglodytes uersus*): a scanning electron microscope study. Ph.D. dissertation, Yale University, New Haven, CT.

Gordon KD. 1982. A study of microwear on chimpanzee molars: Implications for dental microwear analysis.

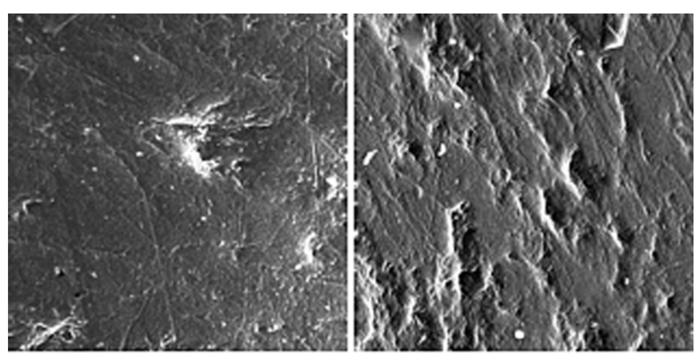

Fig. 1. Microwear images showing the greatest difference between deciduous and permanent dentition represented in this sample: (***left***) deciduous dentition; (***right***) permanent dentition.

Am J Phys Anthropol 59:195-215.

Greene TR. 2007. Diet and dental health in Predynastic Egypt. Berlin: VDM Verlag Dr. Muller.

Harmon AM, Rose JC. 1988. The role of dental microwear analysis in the reconstruction of prehistoric diet. In: Kennedy BV, Le Moine GM, editors. Diet and subsistence: current archaeological perspectives. Calgary, Alberta: Archaeological Association of the University of Calgary. p 267-272.

Hojo T. 1989. Dietary differences and microwear on the teeth of Late Stone Age and early modern people from western Japan. Scan Microsc 3:623-628.

Hunter ML, West NX, Hughes JA, Newcombe RG, Addy M. 2000. Erosion of deciduous and permanent dental hard tissue in the oral environment. J Dent 28:257-263.

Kay RF. 1977. The evolution of molar occlusion in the Cercopithecidae and early Catarrhines. Am J Phys Anthropol 46:327-352.

Kay RF. 1987. Analysis of primate dental microwear using image processing techniques. Scan Microsc 1:657-662.

Kornblit R, Bossu M, Mari D, Rocca JP, Polimeni A. 2009. Enamel and dentine of deciduous teeth Er:YAG laser prepared. A SEM study. Eur J Paed dent 10:75-82.

Lalueza Fox C, Pérez-Pérez A. 1993. The diet of the Neanderthal child Gibralter 2 (Devils' Tower) through the study of the vestibular striation pattern. J Hum Evol 24:29-41.

LeGeros RZ, Piliero JA, Pentel L. 1983. Comparative properties of deciduous and permanent (young and old) human enamel. Gerodontology 2:1-8.

Lippert F, Parker DM, Jandt KD. 2004. Susceptibility of deciduous and permanent enamel to dietary acid-induced erosion studied with atomic force microscopy nanoindentation. Eur J Oral Sci 112:61-66

Mahoney P. 2006. Brief communication: Intertooth and intrafacet dental microwear variation in an archaeological sample of modern humans from the Jordan Valley. Am J Phys Anthropol 129:39-44.

Molleson T, Jones K. 1991. Dental evidence for dietary change at Abu Hureyra. J Archaeol Sci 18:525-539.

Molleson T, Jones K, Jones S. 1993. Dietary change and the effects of food preparation on microwear patterns in the Late Neolithic of Abu Hureyra, northern Syria. J Hum Evol 24:455-468.

Organ JM, Teaford MF, Larsen CS. 2005. Dietary inferences from dental occlusal microwear at Mission San Luis de Apalachee. Am J Phys Anthropol 128:801-811.

Schmidt CW. 1998. Dietary reconstruction in prehistoric humans from Indiana: an analysis of dental macrowear, dental pathology, and dental microwear. Ph.D. dissertation, Purdue University.

Schmidt CW. 2001. Dental microwear evidence for a dietary shift between two nonmaize-reliant prehistoric human populations from Indiana. Am J Phys Anthropol 114:139-145.

Teaford MF. 1984. Molar microwear and diet in the genus *Cebus*. Am J Phys Anthropol 66:363-370.

Teaford MF. 1991. Dental microwear: what can it tell us about diet and dental function? In: Kelley MA, Larsen CS, editors. Advances in dental anthropology. New-York: Wiley-Liss. p 341-356.

Teaford MF. 1994. Dental microwear and dental function. Evol Anthropol 3:17-30.

Teaford MF. 2002. Dental enamel microwear analysis. In: Hutchinson DL, editor. Foraging, farming and coastal biocultural adaptation in late prehistoric North Carolina. Gainesville, Florida: University Press of Florida. p 169-177.

Teaford MF, Oyen OJ. 1986. Dental microwear in vervets raised on different diets. Am J Phys Anthropol 69:270.

Teaford MF, Oyen OJ. 1988. In vivo and in vitro turnover in dental microwear. Am J Phys Anthropol 75:279.

Teaford MF, Oyen OJ. 1989. In vivo and in vitro turnover in dental microwear. Am J Phys Anthropol 80:447-460.

Teaford MF, Walker, A. 1984. Quantitative differences in dental microwear between primate species with different diets and a comment on the presumed diet of *Sivapithecus*. Am J Phys Anthropol 88:347-364.

Teaford MF, Maas MC, Simons E. 1996. Dental microwear and microstructure in early Oligocene primates form the Fayum, Egypt: implications for diet. Am J Phys Anthropol 101:527-543.

Ungar PS. 2000. Microware 4.0.

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