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Correlations Among New Dental and Cranial Measurements

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ABSTRACT Cranial and dental anthropometry is commonly used in many areas of research, e.g., in forensic anthropology and paleoanthropology. We propose new craniometric and dental landmarks and distances that may have important applications in physical anthropology. Furthermore, a classical anthropometrical approach was applied to quantify the correlation between dental and cranial measurements, which were taken on 30 Middle Ages adult crania from Sardinia (Italy).

Principal components analysis was performed to explore the correlations among inter-landmark distances. The first component showed correlations between the cranial base and maxillary inter-landmark distances (the 'cranial base' system). The second component exclusively demonstrated correlations among maxillary and dental inter-landmark distances (the 'oral cavity' system). The third component showed positive correlations between the zygomatic and midline maxillary inter-landmark distances, and high negative loadings that include the bilateral styloid process and midline maxillary landmarks (the 'upper cranium' system).

The inter-landmark dental distances correlate with inter-landmark cranial distances that have not been described previously. These data can be applied in other research and clinical areas.

In the past, anthropologists generally studied the human skull from a purely descriptive point of view, and only in relatively recent times have they began to study skulls through comparisons of skull morphologies. This applies not only to the class of Primates, but for the whole series of Vertebrates, to highlight specific and different morphological characteristics in relation to the biological species or sub-species, or to the sex and age, or other such characteristics. The first attempts were made by Louis-Jean-Marie Daubenton (1716-1799), Johann Friedrich Blumenbach (1752-1840), Petrus Camper (1722-1789) and James Cowles Prichard (1786-1848). Their comparative anatomical studies were resumed and continued in France by Étienne Geoffroy Saint-Hilaire (1772-1844), Georges Cuvier (1769-1832), and other researchers, who gave them a very special impulse, so that it can be said that they established a new science: cranial anthropometry. Some years before, Anders Retzius (1796–1860) was the first to use the cephalic index in physical anthropology to classify ancient human remains from Europe. Soon after, Paul Pierre Broca (1824-1880) developed new anthropometric methods and coined a technical terminology that had hitherto been unknown (Spencer, 1997).

In 1906, the Convention of Monaco established international standards for cephalometric and craniometric data collection, which were listed in the *Lehrbuch der Anthropologie* (Martin and Saller, 1957-1966). In 1908, Aldobrandino Mòchi (1875-1931), and later Raffaello Parenti (1907-1977) (Parenti, 1955), observed that certain cranial forms, such as

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those listed by Giuseppe Sergi (1841-1936) and Paolo Mantegazza (1831-1910), corresponded to particular values of the cephalic index of Retzius (Capasso, 2015). Then during the twentieth century, several anthropometric indices were proposed and applied to describe the ranges of variability of morphometrical cranial features, to classify skulls into categories, and to evaluate the distribution patterns within modern and ancient human populations (e.g., Perez et al., 2007; Hanihara et al., 2003; Relethford, 2002; Ngeow and Aljunid, 2009).

The contributions of classical cranial anthropometry to the study of the evolutionary scenarios of hominin cranial shapes and sizes have been well demonstrated, and in archaeological and forensic anthropology, measures and indices are still commonly used to reconstruct a biological profile of an individual (e.g., Kimbel and Rak, 2010; Gapert et al, 2013; Veroni et al., 2010; Gonzalez, 2012). At the same time, metrics are usually employed in dental anthropology for sex determination (Viciano et al., 2015) and estimation of age (Irurita et al., 2014).

The aim of this article is to propose new craniometric and dental landmarks and inter-landmark distances. The landmarks represent anatomical, muscular, vascular and neuronal structures that are involved in physiological and biomechanical functions, and they delimit anthropometric linear measurements, which we have experienced to be particularly useful in clinical practice. The clinical data available to us strongly suggest that the proposed measurements are extremely useful for treating cases of malocclusion and incorrect posture of the skeleton. We treat malocclusion clinical cases by acting on the distances between the proposed anthropometric landmarks, bringing them back to values in healthy individuals (Moyers et al., 1996). Our clinical results suggest the existence of a correlation between the proposed dental and craniometric measurements.

The new dental and craniometric landmarks and measurements may have important applications in other fields of research of physical anthropology because they (i) supplement the landmarks and the anthropometric distances previously published, (ii) suggest new correlations between dental and cranial measurements and, more generally, (iii) may contribute to better clarify relations between the various anatomical regions of the skull.
For these reasons a classical anthropometrical approach was applied to quantify the correlation between the new dental and cranial measurements.

MATERIALS AND METHODS

Materials

The skeletal remains used in the present study were dated to the Middle Ages and were part of a large well-preserved ossuary that was discovered during the restoration works on the San Lucifero Church in Sardinia (Italy). It is believed that these skeletal remains are those of the monks and the people of a small community that lived in the vicinity of the church. Due to the provenance of these remains, some of their anthropological data are limited (e.g., sex, age estimation) (Sarigu et al., 2016).

A total sample of 30 adult crania without mandibles and of individuals of unidentified sex was analyzed in the present study. These specimens were selected from the osteological collection housed in the Sardo Museum of Anthropology and Ethnography, at the University of Cagliari (Sardinia, Italy). The vaults of these crania were open, and a series of hinges provided access to the endocranial structures and allowed direct collection of the cranial and dental measurements. Only well-preserved specimens were used in the present study (i.e., without pathological signs or taphonomic alterations). Thanks to their excellent state of preservation, it was possible to localize the deepest landmarks accurately, otherwise difficult to detect by X-ray or other imaging studies.

Data acquisition and analysis

A MicroScribe portable digitizer (Model MX, Immersion Corporation, San Jose, CA, USA) and the integrated MicroScribe Utility Software were used to collect the data for the distances between the anatomical landmarks with an accuracy of 0.05 mm, considered for the midline and both sides of the skull (Table 1, Figure 1). The spatial position of the landmarks and the related measurements were collected with the skull oriented according to the Frankfurt horizontal plane. Many standard craniometric landmarks were included, with the remaining landmarks chosen to represent the overall size of the maxilla. In addition, with the bilateral dental landmarks, a number of constructed landmarks were calculated that were established as the midpoints of the distances between these bilateral dental landmarks. As a merely descriptive classification, the landmarks were divided into three anatomical regions: (i) the oral cavity, which included the *pr*, *sta*, *D4*, *D5*, *D6*, *D7*, *pt4*, *pt5*, *pt6* and *pt7* landmarks; (ii) the base of the cranium, which included the *pht*, *ba*, *o*, *gfb*, *stl* and *bms* landmarks; and (iii) the upper cranium, which included *n*, *stb*, *zm* and *op* landmarks (see Table 1 and Figure 1). Subsequently, a series of virtual triangles were constructed that had at least the central vertex on a landmark of the maxilla. The inter-landmark distances were calculated from the raw data of the landmarks of these virtual triangles on the left or right side, depending on the availability. As it is assumed that an ideal skull is symmetrical, if both sides were available, the mean was calculated to adjust values, to avoid the use of more sophisticated techniques for the analysis of asymmetry (Figure 2).

The statistical analysis was performed using the IBM® SPSS® Statistics 22.0 software. A descriptive analysis was performed to calculate the minimum, maximum, mean and standard deviation for each inter-landmark distance. This analysis characterized the study sample and allowed detection of any major errors in the database collection or the data processing. Principal component analysis (PCA)

TABLE 1. Description of landmarks used in this study

Anatomical region	Source	Landmark	Location	Code	Definition
Oral cavity	Direct acquisition	Prosthion[a]	Midline	pr	Most anterior point on the alveolar process between the two upper central incisors, in the midsagittal plane
		Staphilion[a]	Midline	sta	The point on the posterior hard palate where the palatal suture is crossed by a line drawn tangent to the curves of the posterior margin of the palatal bones
		Distal surface first premolar[b]	Bilateral	D4	Most occluso-distal point of the crown
		Distal surface second premolar[b]	Bilateral	D5	Most occluso-distal point of the crown
		Distal surface first molar[b]	Bilateral	D6	Most occluso-distal point of the crown
		Distal surface second molar[b]	Bilateral	D7	Most occluso-distal point of the crown
	Calculated landmarks	Point 4[b]	Midline	pt4	Midpoint of the distance between the distal points of the first premolars
		Point 5[b]	Midline	pt5	Midpoint of the distance between the distal points of the second premolars
		Point 6[b]	Midline	pt6	Midpoint of the distance between the distal points of the first molars
		Point 7[b]	Midline	pt7	Midpoint of the distance between the distal points of the second molars
Base of the cranium	Direct acquisition	Pharyngeal tubercle[b]	Midline	pht	Bone tubercle on the lower surface of the basilar part of occipital bone, about 1 cm. anterior to the *foramen magnum*, which gives attachment to the fibrous raphe of the pharynx
		Basion[a]	Midline	ba	Point on the anterior margin of the *foramen magnum* in the midsagittal plane.
		Opisthion[a]	Midline	o	Most posterior point on the posterior margin of the *foramen magnum* in the midsagittal plane
		Base of the glenoid fossa[b]	Bilateral	gfb	The more medial and caudal point of the glenoid fossa
		Styloid process[b]	Bilateral	stl	Posterior point of the base of the styloid process
		Base of mastoid process[b]	Bilateral	bms	Posterior point of the base of mastoid process
Upper cranium	Direct acquisition	Nasion[a]	Midline	n	Point at junction of internasal suture and nasofrontal suture, in midsaggital plane
		Base of sella turcica[a]	Midline	stb	The midpoint of the hypophyseal fossa
		Zygomaxillare[a]	Bilateral	zm	Point located externally at the lowest extent of the zygomaticomaxillary suture
		Opisthocranion[a]	Midline	op	Instrumentally determined point marking maximum skull length, as measured from glabella. This point is in the midsagittal plane

[a] Landmarks described by Martin and Knuβmann (1988).
[b] Modified definitions from Martin and Knuβmann (1988) or new landmarks used in the current study.

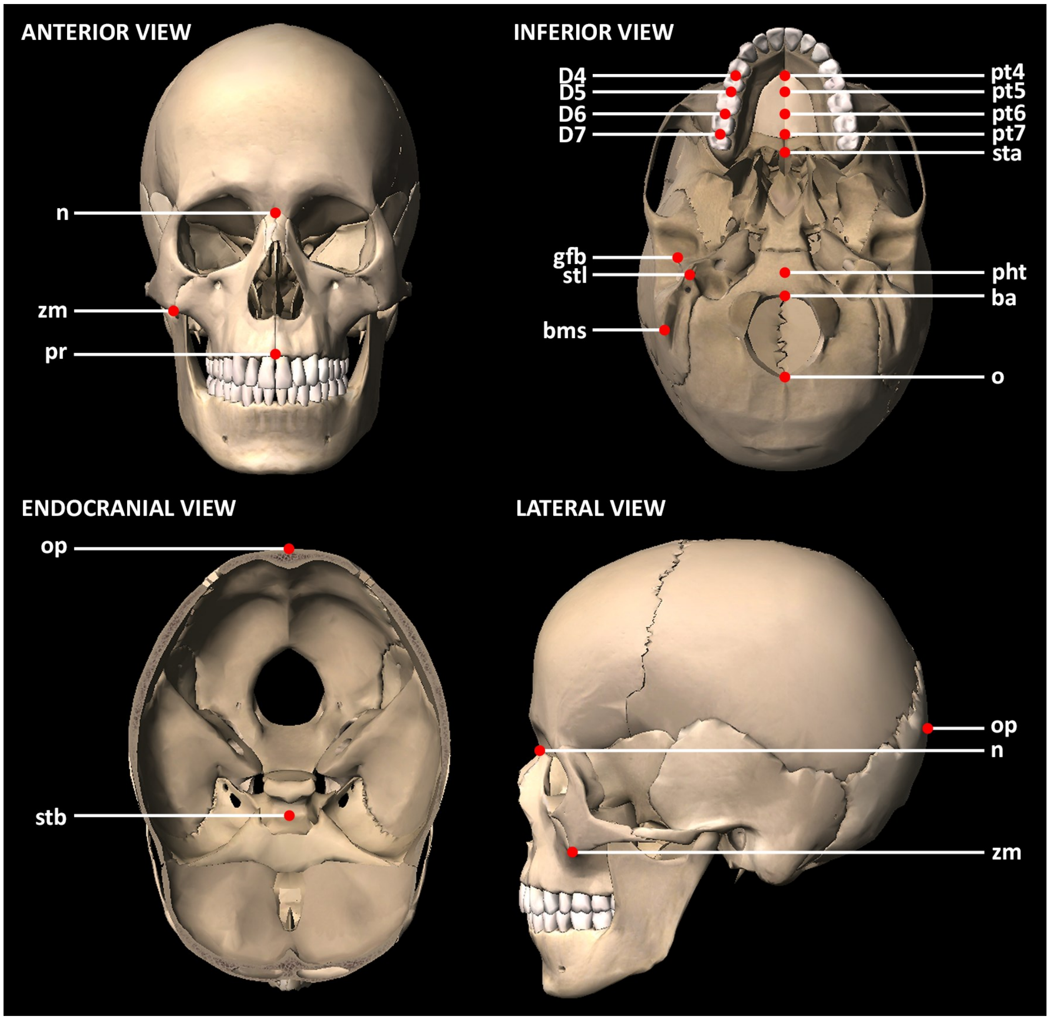

Figure 1. Anatomical landmarks used for measurements recorded

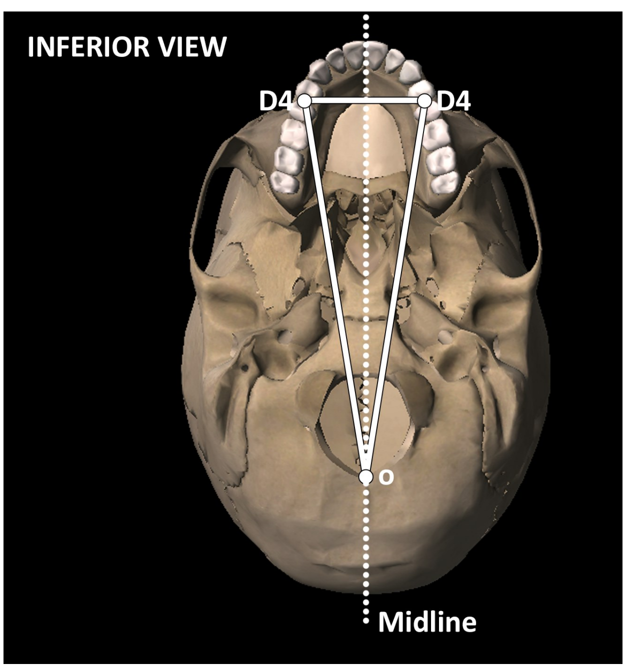

Figure 2. Example of one virtual triangle constructed in this study: triangle *D4 – o – D4* (all 62 virtual triangles are specified in Table 2). Three inter-landmarks distances were calculated from the raw data: *D4 – o* (to the right side from the midline), *D4 – o* (to the left side from the midline), and *D4 – D4*. Then, the mean was calculated to adjust the values for the bilateral inter-landmark distances *D4 – o*

was carried out to explore the relative relationships and particular features among these inter-landmarks distances. Data were first assessed for normality using the Kolmogorov–Smirnov one-sample test. Next, a PCA was performed, generating a small number of principal components that can be used to explain most, if not all, of the variation of a sample. Orthogonal varimax rotation of these components with eigenvalues greater than 1.0 was used to simplify the component structure. The relationships between the different inter-landmark distances were then investigated through Pearson product-moment correlations. Significance was set to $p < 0.05$.

RESULTS

The sample consisted of 30 skulls, with 28 landmarks identified and collected (24 anatomical, four calculated) (see Table 1). A total of 62 virtual triangles were also obtained, with at least the central vertex located on the midline of the skull or maxilla (Table 2). Table 2 shows the descriptive analysis of the inter-landmark distances. The results of Kolmogorov–Smirnov test indicated that all of the inter-landmark distances were normally distributed.

Principal component analysis returned ten components that explained 94.6% of the variation. Here, only the first three components were considered to facilitate the interpretation of the data, and these explained 67.1% of the variation in the data set (Table 3). The loadings of the original variables on these three rotated principal components are illustrated in Figure 3.

Component one (PC1) accounts for 42.9% of the sample variance and demonstrates positive loadings for all inter-

TABLE 3. Ten components of the principal components analysis of the interlandmark distances

Principal component	Eigenvalue	Explained variance (%)	Cumulative variance (%)
PC1	30.052	42.932	42.932
PC2	9.137	13.052	55.985
PC3	7.792	11.131	67.116
PC4	5.432	7.759	74.875
PC5	3.723	5.319	80.194
PC6	3.346	4.779	84.973
PC7	2.233	3.190	88.163
PC8	1.993	2.847	91.010
PC9	1.370	1.957	92.967
PC10	1.159	1.655	94.623

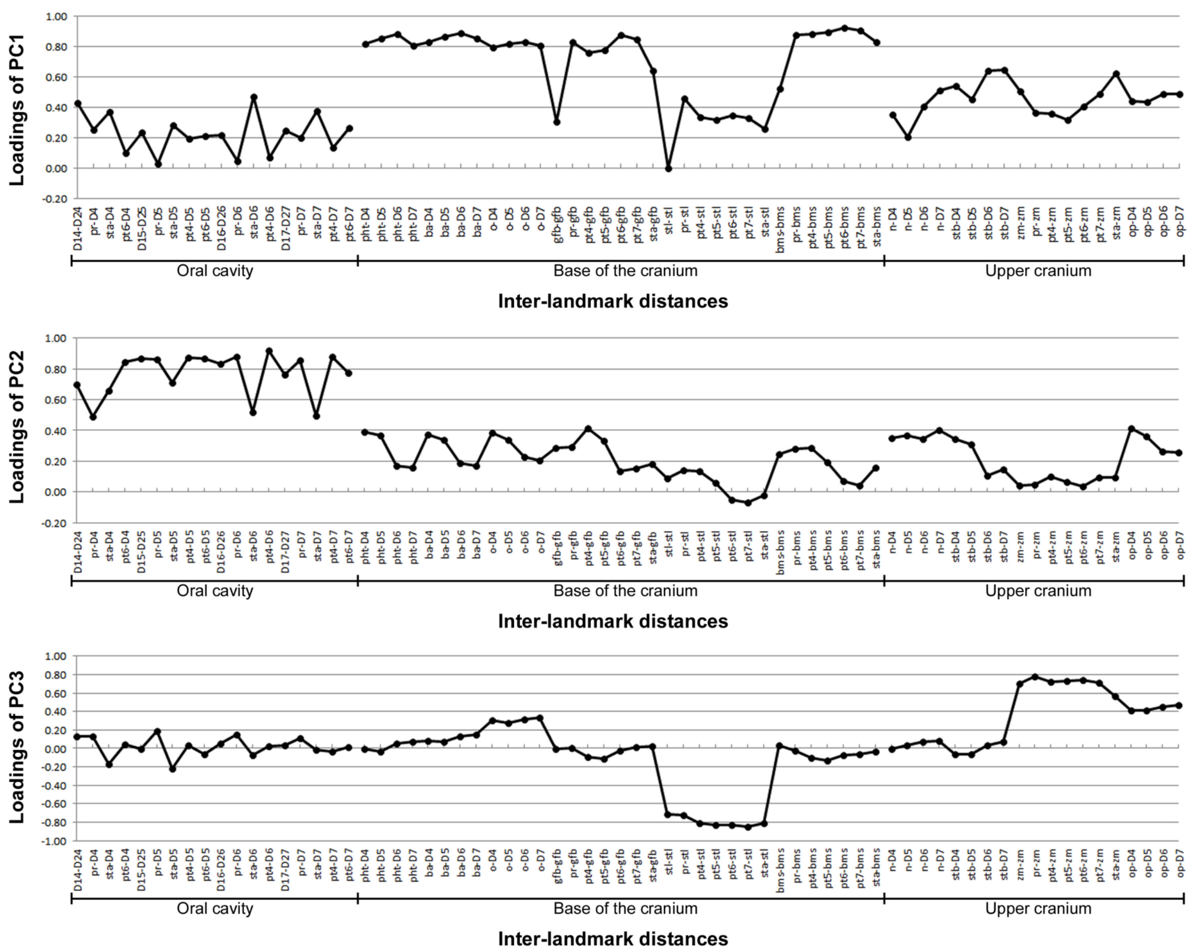

Figure 3. The loadings of the original variables on the three rotated principal components

TABLE 2. *Descriptive statistics of inter-landmark distances*

Triangle	Inter-landmark distance	N	Minimum	Maximum	Mean	SD
D4 – op – D4	D4 – D4	30	36.28	44.92	39.432	2.015
	op – D4	30	163.92	197.865	180.923	7.989
D4 – o – D4	D4 – D4	30	36.28	44.92	39.432	2.015
	o – D4	30	103.24	128.505	115.071	6.289
D4 – ba – D4	D4 – D4	30	36.28	44.92	39.432	2.015
	ba – D4	29	72.285	88.895	82.475	4.753
D4 – n – D4	D4 – D4	30	36.28	44.92	39.432	2.015
	n – D4	30	65.295	84.675	75.557	5.122
D4 – pr – D4	D4 – D4	30	36.28	44.92	39.432	2.015
	pr – D4	28	24.71	31.235	27.407	1.678
D4 – sta – D4	D4 – D4	30	36.28	44.92	39.432	2.015
	sta – D4	28	40.13	47.88	43.701	2.12
D4 – pht – D4	D4 – D4	30	36.28	44.92	39.432	2.015
	pht – D4	29	67.4	81.695	75.378	3.847
D4 – stb – D4	D4 – D4	30	36.28	44.92	39.432	2.015
	stb – D4	30	71.915	84.265	78.653	3.664
D4 – pt6 – D4	D4 – D4	30	36.28	44.92	39.432	2.015
	pt6 – D4	30	22.95	28.39	25.66	1.31
D5 – op – D5	D5 – D5	30	37.3	52.23	43.126	3.34
	op – D5	30	160.52	197.09	176.646	8.237
D5 – o – D5	D5 – D5	30	37.3	52.23	43.126	3.34
	o – D5	29	98.275	122.63	109.509	5.983
D5 – ba – D5	D5 – D5	30	37.3	52.23	43.126	3.34
	ba – D5	29	68.43	86.74	78.101	4.785
D5 – n – D5	D5 – D5	30	37.3	52.23	43.126	3.34
	n – D5	30	70.26	88.395	79.087	4.966
D5 – pr – D5	D5 – D5	30	37.3	52.23	43.126	3.34
	pr – D5	29	29	37.035	33.022	1.896
D5 – sta – D5	D5 – D5	30	37.3	52.23	43.126	3.34
	sta – D5	28	38.415	46.115	40.953	2.082
D5 – pht – D5	D5 – D5	30	37.3	52.23	43.126	3.34
	pht – D5	29	64.505	79.67	71.493	3.816

Triangle	Inter-landmark distance	N	Mini-mum	Maxi-mum	Mean	SD
D5 – stb – D5	D5 – D5	30	37.3	52.23	43.126	3.34
	stb – D5	30	67.265	86.195	76.724	3.627
D5 – pt4 – D5	D5 – D5	30	37.3	52.23	43.126	3.34
	pt4 – D5	30	19.21	26.61	22.685	1.732
D5 – pt6 – D5	D5 – D5	30	37.3	52.23	43.126	3.34
	pt6 – D5	30	20.75	28.375	23.824	1.746
D6 – op – D6	D6 – D6	30	44.37	57.56	49.66	2.841
	op – D6	30	153.525	189.135	168.369	8.257
D6 – o – D6	D6 – D6	30	44.37	57.56	49.66	2.841
	o – D6	29	90.735	114.67	100.758	6.154
D6 – ba – D6	D6 – D6	30	44.37	57.56	49.66	2.841
	ba – D6	30	62.055	80.225	70.731	5.204
D6 – n – D6	D6 – D6	30	44.37	57.56	49.66	2.841
	n – D6	30	74.405	94.35	83.014	4.727
D6 – pr – D6	D6 – D6	30	44.37	57.56	49.66	2.841
	pr – D6	29	38.23	46.325	42.476	1.963
D6 – sta – D6	D6 – D6	30	44.37	57.56	49.66	2.841
	sta – D6	29	33.14	40.735	36.907	1.755
D6 – pht – D6	D6 – D6	30	44.37	57.56	49.66	2.841
	pht – D6	29	57.19	73.695	64.491	4.067
D6 – stb – D6	D6 – D6	30	44.37	57.56	49.66	2.841
	stb – D6	30	65.27	83.66	72.358	3.795
D6 – pt4 – D6	D6 – D6	30	44.37	57.56	49.66	2.841
	pt4 – D6	30	26.1	33.615	29.77	1.617
D7 – op – D7	D7 – D7	30	45.9	60.54	52.994	3.044
	op – D7	30	145.725	179.07	160.094	8.051
D7 – o – D7	D7 – D7	30	45.9	60.54	52.994	3.044
	o – D7	29	82.235	105.79	92.806	5.969
D7 – ba – D7	D7 – D7	30	45.9	60.54	52.994	3.044
	ba – D7	30	53.32	72.83	63.315	5.147
D7 – n – D7	D7 – D7	30	45.9	60.54	52.994	3.044
	n – D7	30	73.645	96.69	84.384	5.154

TABLE 2. Descriptive statistics of inter-landmark distances, cont'd

Triangle	Inter-landmark distance	N	Minimum	Maximum	Mean	SD
D7–pr–D7	D7–D7	30	45.9	60.54	52.994	3.044
	pr–D7	29	45.53	53.895	49.778	2.196
D7–sta–D7	D7–D7	30	45.9	60.54	52.994	3.044
	sta–D7	28	25.99	37.68	33.313	2.281
D7–pht–D7	D7–D7	30	45.9	60.54	52.994	3.044
	pht–D7	29	47.46	65.59	57.455	4.238
D7–stb–D7	D7–D7	30	45.9	60.54	52.994	3.044
	stb–D7	30	57.04	78.035	66.932	4.115
D7–pt4–D7	D7–D7	30	45.9	60.54	52.994	3.044
	pt4–D7	30	32.765	41	36.169	1.89
D7–pt6–D7	D7–D7	30	45.9	60.54	52.994	3.044
	pt6–D7	30	25.57	31.495	27.99	1.443
zm–pr–zm	zm–zm	30	83.66	124.93	95.985	7.478
	pr–zm	30	51.791	78.83	58.854	5.456
zm–pt4–zm	zm–zm	30	83.66	124.93	95.985	7.478
	pt4–zm	30	47.208	72.99	54.61	5.204
zm–pt5–zm	zm–zm	30	83.66	124.93	95.985	7.478
	pt5–zm	30	48.233	72.38	54.425	4.895
zm–pt6–zm	zm–zm	30	83.66	124.93	95.985	7.478
	pt6–zm	30	48.193	70.998	54.239	4.442
zm–pt7–zm	zm–zm	30	83.66	124.93	95.985	7.478
	pt7–zm	30	47.755	69.667	54.283	4.051
zm–sta–zm	zm–zm	30	83.66	124.93	95.985	7.478
	sta–zm	30	48.284	64.307	53.373	3.08
gfb–pr–gfb	gfb–gfb	30	81.02	98.37	90.007	5.126
	pr–gfb	30	90.305	106.91	99.063	4.057
gfb–pt4–gfb	gfb–gfb	30	81.02	98.37	90.007	5.126
	pt4–gfb	30	79.67	96.359	88.442	3.824
gfb–pt5–gfb	gfb–gfb	30	81.02	98.37	90.007	5.126
	pt5–gfb	30	77.783	92.833	85.235	3.655

Triangle	Inter-landmark distance	N	Minimum	Maximum	Mean	SD
gfb–pt6–gfb	gfb–gfb	30	81.02	98.37	90.007	5.126
	pt6–gfb	30	72.338	86.557	78.967	3.702
gfb–pt7–gfb	gfb–gfb	30	81.02	98.37	90.007	5.126
	pt7–gfb	30	64.986	80.248	72.662	3.682
gfb–sta–gfb	gfb–gfb	30	81.02	98.37	90.007	5.126
	sta–gfb	30	52.848	96.005	59.842	7.346
stl–pr–stl	stl–stl	30	61.18	82.92	73.589	5.822
	pr–stl	30	87.066	110.219	96.866	5.465
stl–pt4–stl	stl–stl	30	61.18	82.92	73.589	5.822
	pt4–stl	30	71.497	95.088	82.623	6.019
stl–pt5–stl	stl–stl	30	61.18	82.92	73.589	5.822
	pt5–stl	30	66.62	90.169	78.031	6.028
stl–pt6–stl	stl–stl	30	61.18	82.92	73.589	5.822
	pt6–stl	30	57.788	82.064	69.951	5.952
stl–pt7–stl	stl–stl	30	61.18	82.92	73.589	5.822
	pt7–stl	30	50.497	74.686	62.674	5.75
stl–sta–stl	stl–stl	30	61.18	82.92	73.589	5.822
	sta–stl	30	43.62	83.549	53.431	7.002
bms–pr–bms	bms–bms	30	90.67	109.89	98.825	3.941
	pr–bms	30	104.919	125.308	114.227	5.088
bms–pt4–bms	bms–bms	30	90.67	109.89	98.825	3.941
	pt4–bms	30	91.216	108.945	99.601	4.827
bms–pt5–bms	bms–bms	30	90.67	109.89	98.825	3.941
	pt5–bms	30	86.896	104.009	94.804	4.8
bms–pt6–bms	bms–bms	30	90.67	109.89	98.825	3.941
	pt6–bms	30	79.231	95.879	86.658	4.76
bms–pt7–bms	bms–bms	30	90.67	109.89	98.825	3.941
	pt7–bms	30	72.511	88.059	79.636	4.497
bms–sta–bms	bms–bms	30	90.67	109.89	98.825	3.941
	sta–bms	30	62.802	106.875	72.287	7.39

landmark distances. PC1 includes the bilateral dental landmarks and the midline landmarks of the base of the cranium. The loadings of the distances that include the *o*, *ba*, *pht* midline landmarks with all of the dental bilateral landmarks (*D4*, *D5*, *D6* and *D7*) are slightly higher than the others. Also, the distances that include the *pr*, *pt4*, *pt5*, *pt6*, *pt7* and *sta* maxillary midline landmarks with the *gfb* and *bms* bilateral landmarks show high shared variance for PC1. Thus, PC1 is interpreted as representing the 'cranial base system', as all of these inter-landmark distances load in a positive direction, with similar eigenvector coefficients.

Component two (PC2) accounts for 13.05% of the sample variance, and exclusively contrasts the landmarks of the oral cavity (the 'oral cavity system'), with lower shared variance for the other landmarks of the base and upper cranium.

Component three (PC3) is attributable to the vertical dimension (the 'upper cranium system'), and consists of compensatory relationships among high positive loadings that include the *zm* bilateral landmark and the midline maxillary landmarks (*pr*, *pt4*, *pt5*, *pt6*, *pt7*, *sta*) and high negative loadings that include the *stl* bilateral landmark and the same midline maxillary landmarks. Thus, individuals with large transversal distances (i.e., bizygomatic breadth) are predisposed to lower distances that include the *stl* bilateral landmark. The PC3 component explains 11.13% of the variation.

The bivariate Pearson product-moment correlations between the selected inter-landmark distances derived from the first three PCs are given in Tables 4 to 6. For PC1, all of the selected pairwise correlations are positive and are highly correlated between themselves. For PC2, the selected bivariate correlations are also positive, and generally with high-intermediate values. Finally, for the correlations of PC3, the distances that include the *zm* landmark are positively highly correlated between themselves. The distances that include the *stl* landmark are also positively correlated between themselves, although with lower values than for the *zm* landmark. However, both of these groups of inter-landmark distances are generally not correlated between each other, with negative values that are close to zero.

DISCUSSION

New dental and cranial landmarks and craniometric measurements related to one another have been proposed. They may have interesting applications in physical anthropology and in other research areas such as craniofacial clinic and surgery.

In the principal component analysis, PC1 shows correlations between the cranial base and the maxillary distances. The landmarks of the cranial base system refer to muscle insertions, articular joints, and vascular and neuronal areas. *Basion*, which is the midpoint on the anterior margin of the *foramen magnum* on the occipital bone, provides insertion for the apical occipital odontoid ligament. The *medulla oblongata* continues into the spinal cord through the *foramen magnum*, which also provides a passage to accessory nerves and the vertebral arteries, the posterior and anterior spinal arteries, the tectorial membrane of the atlanto-axial joint, and the alar ligaments that connect the sides of the odontoid process on the axis to tubercles on the medial side of the occipital condyle. Approximately 1 cm from *basion*, there is the *pharyngeal tubercle*, on which there are the occipito-pharyngeal ligament, the *constrictor pharyngis superior* muscle, and the anterior longitudinal ligament. The glenoid fossa of the temporal bone receives the mandibular condyles, and it is an important component of the temporomandibular joint. The mastoid process is a point of attachment for several muscles: the *splenius capitis*, *longissimus capitis*, digastric posterior belly, and sternocleidomastoid occipital condyle (Testut, 1943; Latarjet and Ruiz Liard, 2008).

All of the midline and lateral landmarks that are distributed in the cranial base system appear to be the nodes of a network that includes both the anterior and posterior legs of the skull base (Andria et al., 2004). The cranium has a complex architecture that is characterized by 'frames and trusses' that can withstand various mechanical stresses. At the same time, the skull is an efficient engineering solution to numerous functional requirements (which are often in conflict which each other), and the result of biological compromises; e.g., it protects the brain and the organs of sense that it contains, including the airways and the entrance to the digestive tract (Dubrul, 1988). The masticatory system is deeply integrated into this cranial architecture. In this context, the statistical correlations between the inter-landmark distances can be interpreted from a biodynamic and functional point of view.

The growth of the cranial base, the position and size of the cervical system (i.e., vertebral column), and the hyoid bone all have an influence on the morphogenesis and growth of the maxillofacial complex (Bedoya et al., 2014; Arntsen and Sonnesen, 2011). This integrated functional and anatomical system is well known, and it has important applications in dentistry, not only at the macroscopic level (Andria et al., 2004), but also histologically. The bone cells behave like a network of neurons, and the vascular and neural channels appear to be part of a complex biological system (Bhangu et al., 2001). The correlations of the linear distances among these demonstrate their inter-

TABLE 4. Bivariate product-moment correlations for inter-landmark distances included in PC1

	o-D4	ba-D4	pht-D4	o-D5	ba-D5	pht-D5	o-D6	ba-D6	pht-D6	o-D7	ba-D7	pht-D7	pr-gfb	pt4-gfb	pt5-gfb	pt6-gfb	pt7-gfb	sta-gfb	pr-bms	pt4-bms	pt5-bms	pt6-bms	pt7-bms
o-D4	–																						
ba-D4	**0.883**	–																					
pht-D4	**0.839**	**0.940**	–																				
o-D5	**0.988**	**0.876**	**0.837**	–																			
ba-D5	**0.865**	**0.978**	**0.920**	**0.887**	–																		
pht-D5	**0.808**	**0.902**	**0.958**	**0.841**	**0.942**	–																	
o-D6	**0.971**	**0.852**	**0.812**	**0.986**	**0.862**	**0.811**	–																
ba-D6	**0.869**	**0.947**	**0.894**	**0.879**	**0.974**	**0.914**	**0.892**	–															
pht-D6	**0.786**	**0.866**	**0.918**	**0.827**	**0.910**	**0.957**	**0.845**	**0.948**	–														
o-D7	**0.965**	**0.832**	**0.809**	**0.969**	**0.829**	**0.787**	**0.988**	**0.864**	**0.828**	–													
ba-D7	**0.867**	**0.932**	**0.900**	**0.865**	**0.942**	**0.898**	**0.887**	**0.983**	**0.946**	**0.887**	–												
pht-D7	**0.764**	**0.829**	**0.900**	**0.790**	**0.853**	**0.910**	**0.819**	**0.906**	**0.971**	**0.833**	**0.950**	–											
pr-gfb	**0.795**	**0.832**	**0.804**	**0.789**	**0.853**	**0.815**	**0.764**	**0.847**	**0.780**	**0.734**	**0.817**	**0.718**	–										
pt4-gfb	**0.711**	**0.765**	**0.774**	**0.666**	**0.762**	**0.754**	**0.609**	**0.734**	**0.668**	**0.577**	**0.704**	**0.607**	**0.862**	–									
pt5-gfb	**0.655**	**0.675**	**0.678**	**0.636**	**0.734**	**0.756**	**0.576**	**0.711**	**0.669**	**0.529**	**0.664**	**0.584**	**0.835**	**0.939**	–								
pt6-gfb	**0.684**	**0.694**	**0.705**	**0.675**	**0.750**	**0.765**	**0.665**	**0.784**	**0.766**	**0.631**	**0.758**	**0.708**	**0.852**	**0.912**	**0.954**	–							
pt7-gfb	**0.715**	**0.718**	**0.736**	**0.690**	**0.746**	**0.752**	**0.695**	**0.797**	**0.774**	**0.690**	**0.809**	**0.773**	**0.839**	**0.886**	**0.889**	**0.967**	–						
sta-gfb	0.247	**0.374**	**0.385**	0.338	**0.505**	**0.548**	0.318	**0.491**	**0.548**	**0.258**	**0.437**	**0.467**	**0.538**	**0.517**	**0.652**	**0.649**	**0.556**	–					
pr-bms	**0.847**	**0.859**	**0.845**	**0.838**	**0.861**	**0.834**	**0.812**	**0.848**	**0.787**	**0.795**	**0.831**	**0.741**	**0.894**	**0.773**	**0.721**	**0.736**	**0.753**	0.286	–				
pt4-bms	**0.822**	**0.836**	**0.830**	**0.797**	**0.833**	**0.822**	**0.762**	**0.811**	**0.756**	**0.746**	**0.793**	**0.707**	**0.785**	**0.808**	**0.767**	**0.758**	**0.753**	0.246	**0.931**	–			
pt5-bms	**0.795**	**0.801**	**0.802**	**0.794**	**0.832**	**0.834**	**0.765**	**0.820**	**0.783**	**0.739**	**0.792**	**0.719**	**0.789**	**0.786**	**0.779**	**0.780**	**0.761**	0.322	**0.931**	**0.985**	–		
pt6-bms	**0.792**	**0.780**	**0.780**	**0.793**	**0.809**	**0.803**	**0.795**	**0.835**	**0.804**	**0.776**	**0.817**	**0.755**	**0.767**	**0.740**	**0.726**	**0.777**	**0.773**	0.289	**0.916**	**0.963**	**0.984**	–	
pt7-bms	**0.777**	**0.754**	**0.766**	**0.766**	**0.765**	**0.764**	**0.771**	**0.800**	**0.768**	**0.778**	**0.806**	**0.749**	**0.736**	**0.710**	**0.676**	**0.737**	**0.765**	0.214	**0.906**	**0.951**	**0.964**	**0.986**	–
sta-bms	**0.376**	**0.503**	**0.521**	**0.466**	**0.634**	**0.682**	**0.446**	**0.619**	**0.677**	**0.391**	**0.568**	**0.596**	**0.616**	**0.564**	**0.683**	**0.683**	**0.593**	**0.953**	**0.462**	**0.438**	**0.514**	**0.484**	**0.415**

Significant correlations ($p < 0.05$) are in **bold**.

TABLE 5. Bivariate product-moment correlations for inter-landmark distances included in PC2

	D14-D24	pr-D4	pt6-D4	D15-D25	pr-D5	pt4-D5	pt6-D5	D16-D26	pr-D6	pt4-D6	D17-D27	pr-D7	pt4-D7	pt6-D7
D14-D24	–													
pr-D4	**0.613**	–												
pt6-D4	**0.682**	0.254	–											
D15-D25	**0.723**	**0.454**	**0.699**	–										
pr-D5	**0.684**	**0.761**	**0.617**	**0.705**	–									
pt4-D5	**0.666**	**0.366**	**0.758**	**0.966**	**0.651**	–								
pt6-D5	**0.678**	**0.431**	**0.699**	**0.985**	**0.690**	**0.945**	–							
D16-D26	**0.718**	**0.397**	**0.629**	**0.939**	**0.621**	**0.893**	**0.914**	–						
pr-D6	**0.686**	**0.735**	**0.637**	**0.665**	**0.958**	**0.592**	**0.682**	**0.624**	–					
pt4-D6	**0.591**	0.232	**0.870**	**0.878**	**0.607**	**0.907**	**0.878**	**0.876**	**0.622**	–				
D17-D27	**0.484**	0.282	**0.544**	**0.725**	**0.463**	**0.757**	**0.705**	**0.764**	**0.452**	**0.733**	–			
pr-D7	**0.645**	**0.654**	**0.587**	**0.621**	**0.840**	**0.560**	**0.639**	**0.612**	**0.904**	**0.592**	**0.588**	–		
pt4-D7	**0.427**	0.179	**0.766**	**0.726**	**0.496**	**0.762**	**0.747**	**0.721**	**0.528**	**0.876**	**0.830**	**0.672**	–	
pt6-D7	**0.473**	0.237	**0.543**	**0.726**	**0.422**	**0.745**	**0.723**	**0.768**	**0.433**	**0.738**	**0.972**	**0.619**	**0.882**	–

Significant correlations ($p < 0.05$) are in **bold**.

TABLE 6. Bivariate product-moment correlations for inter-landmark distances included in PC3

	zm-zm	pr-zm	pt4-zm	pt5-zm	pt6-zm	pt7-zm	sta-zm	stl-stl	pr-stl	pt4-stl	pt5-stl	pt6-stl	pt7-stl	sta-stl
zm-zm	–													
pr-zm	**0.955**	–												
pt4-zm	**0.946**	**0.966**	–											
pt5-zm	**0.944**	**0.953**	**0.975**	–										
pt6-zm	**0.966**	**0.947**	**0.964**	**0.987**	–									
pt7-zm	**0.965**	**0.921**	**0.935**	**0.950**	**0.980**	–								
sta-zm	**0.908**	**0.816**	**0.801**	**0.821**	**0.878**	**0.923**	–							
stl-stl	-0.275	-0.322	-0.213	-0.257	-0.300	-0.284	-0.249	–						
pr-stl	-0.187	-0.263	-0.222	-0.236	-0.207	-0.120	0.051	**0.556**	–					
pt4-stl	-0.220	-0.322	-0.229	-0.233	-0.225	-0.167	-0.036	**0.645**	**0.943**	–				
pt5-stl	-0.255	-0.354	-0.272	-0.263	-0.255	-0.204	-0.070	**0.648**	**0.935**	**0.988**	–			
pt6-stl	-0.245	-0.356	-0.284	-0.278	-0.257	-0.201	-0.053	**0.632**	**0.926**	**0.973**	**0.988**	–		
pt7-stl	-0.279	**-0.389**	-0.319	-0.321	-0.299	-0.241	-0.088	**0.666**	**0.918**	**0.964**	**0.973**	**0.990**	–	
sta-stl	-0.180	-0.210	-0.207	-0.169	-0.170	-0.159	-0.092	0.061	**0.400**	**0.406**	**0.486**	**0.460**	**0.385**	–

Significant correlations ($p < 0.05$) are in **bold**.

dependence and might reflect the complex and combined ontogenetic development of this anatomical region (Gazi-Coklica et al., 1997; Ranly, 2000). Moreover, the cranial base and its component parts appear to have influences on the alveolar and dental positions in the maxillary bone (Andria et al., 2004; Arntsen and Sonnesen, 2011).

Healthy development of the cranial base might be in compliance with the proportions and balance between the parties concerned; i.e., the correlations between malocclusion and anthropometric measures outside the normal range of variability appear to confirm this assumption (Simoes, 2010). PC1 (i.e., the 'cranial base system') suggests that the development and mechanical actions of the masticatory and suprahyoid muscles can influence the morphology of the maxillary dental arch, although they do not insert into the alveolar bone (Xuguang, 2005; Deshayes, 2006).

PC2 depicts the oral cavity as a well-circumscribed system (i.e., the 'oral cavity system'), where the distances between the landmarks are related to each other. The correlations between the maxillary anterior teeth and the facial landmarks have been described in the literature, whereby the intercanine tip width and the width of the distal surface of the canine have a relationship with the intercommissural width and the distance between left and right projection lines drawn from the inner canthus of the eyes to the *alae* of the nose (Kini and Angadi, 2013; Sinavarat et al., 2013). Proportional relationships between the bizygomatic width and the width of the maxillary central incisor, the intercanine distance, and the interalar width have also been observed in women (Hasanreisoglu et al., 2005). Furthermore, in an indirect way, clinical trials have suggested that there is interdependence between the morphology and the size of the palate and the maxillary dental arch (Toro-Ibacache et al., 2014; Liu et al., 2011).

In any case, previous studies have not considered the palatal landmarks and did not evaluate the possible relationships among the palatine and maxillary dental inter-landmark distances. These data in the present study show correlations among the dental and palatal inter-landmark measures, and the close anatomical and functional connections between the maxillary teeth and the palate.

PC3 shows a relationship between the measures delimited by the bilateral landmarks (i.e., *zm*, *stl*) and the midline maxillary landmarks (i.e., *pr*, *pt4*, *pt5*, *pt6*, *pt7*, *sta*). We have defined the PC3 component as the 'vertical dimension system' because it includes the *zm* landmark in the *splanchnocranium*, which is is the most prominent point of the zygomatic bone, and which participates in the formation of the temporal and infratemporal fossae, and also forms part of the lateral wall and floor of the orbital cavity.

The cranial base consists of two legs (Andria et al., 2004). For cephalometric measurement purposes, the maxilla is attached to the anterior leg, which extends from the *sella turcica* (*s*) to the frontal-nasal suture (*n*). The mandible is attached to the posterior leg, and extends from the *sella turcica* (*s*) to the anterior border of the *foramen magnum*, which is defined as the *basion* (*ba*). Andria et al. (2004) demonstrated that the angular *ba–s*/FH (FH, Frankfurt Horizontal plane), the linear *ba–s* (in mm), and the proportional length of *ba–s*/*ba–n* are all statistically negatively correlated to the facial angle. They thus concluded that the posterior cranial base leg is the controlling factor in relating the cranial base to mandibular prognathism. Our data are similar in some ways, and complete their study by suggesting that the posterior leg of the cranial base can affect the maxilla relationship to the other facial structures.

The three components, PC1, PC2 and PC3, which refer to the 'cranial base', the 'oral cavity' and 'upper cranium' systems, respectively, include linear measurements that are statistically correlated to each other. In other words, even if the three components are independent, a large number of landmarks that were used in the anthropometric analysis of the skulls are recurrent in each of these three components; e.g. *pr*, *pt4*, *pt5*, *pt6*, *pt7* have important roles in describing the anthropometric characteristics of all three of these systems, and they are correlated with the other lateral and midline landmarks that are distributed in the PC1, PC2 and PC3 components.

For each of these three systems described by the PC1, PC2 and PC3 components, it is possible to draw various correlated linear distances that demonstrate that there are connections between the different anatomical regions. We analyzed the skulls of adult individuals, although our data suggest that the normal ontogenetic development of the cranium (and its legs) takes place according to anthropometric measures and proportions, which need to be further investigated. Moreover, the clinical data show the conservation of reports of the balanced relationship among the anatomical structures of the complex cranial, maxillary and mandibular anatomical regions during development, which are essential for growth harmonics (Mcnamara and Brudon, 1993).

The correlations between the lateral (dental and facial) and midline (*pr, ptz, ptg, sta, pht, ba*) landmarks of the skull appear to be within the more general context of the symmetry that characterizes the entire human body (Weyl, 1952; Gardner, 1990). In terms of their application in the near future, the correlations shown in this study suggest that we can calculate the position of a landmark starting from known anthropometric distances; e.g., the correlation between dental landmarks and landmarks placed on the midline near the foramen magnum (*pht, ba, o*) can provide new and very interesting information on the relationships between dental occlusion disturbances and the curvature of the vertebral spine (Ramirez-Yanez et al., 2014; Shimazaki et al., 2003).

Moreover, the results could contribute to comprehension of the phenomenon described by Gould as *allometry* (Gould, 1966), who suggested that variation in the absolute size of the total organism or specific parts can generate proportional changes in the dimensions of particular anatomical traits, as well as correlated physiological and behavioral changes.

CONCLUSIONS

We propose new dental (*D4*, *D5*, *D6*, *D7*, *pt4*, *pt5*, *pt6*, *pt7*) and craniometric (*pht*, *gfb*, *stl*, *bms*) landmarks that may have important application in physical anthropology and clinical dentistry.

Our data show correlations among anthropometric linear measurements that are distributed in different anatomical regions of the skull. We have defined these as the cranial base, the oral cavity, and the upper cranium systems. They open questions into the existence of mathematical laws useful to calculate the position of a landmark starting from known anthropometric distances. The same laws could describe normal/healthy ontogenetic development of the entire cranium. To verify this hypothesis, the next stages of this research will be to increase the sample size and to include skulls of individuals of different sex, developmental age and ethnic groups.

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Dental Caries as a Measure of Diet, Health, and Difference in Non-Adults from Urban and Rural Roman Britain

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ABSTRACT Dental disease in childhood has the potential to inform about food availability, social status, and feeding practices, in addition to contributing to a child's overall health status. This paper presents the first comprehensive overview of carious lesion frequencies in 433 non-adults (1-17 years), and 6,283 erupted permanent and deciduous teeth from 15 urban and rural Romano-British settlements. Pooled deciduous and permanent caries rates were significantly higher in major urban sites (1.8%) compared to rural settlements (0.4%), with children from urban sites having significantly higher lesion rates in the deciduous dentition (3.0%), and in younger age groups with mixed dentitions. The differences in dental caries between urban and rural populations suggest disparities in maternal oral health, early childhood feeding practices, food preparation and access to refined carbohydrates. A richer, perhaps more 'Roman', cuisine was eaten in the urban settlements, as opposed to a more modest diet in the countryside. The effect of early childhood stress on caries frequency was explored using evidence for enamel hypoplasia. Co-occurrence of caries and enamel hypoplasia was highest in the major urban cohort (5.8%) and lowest in the rural sample (1.3%), suggesting that environmental stress was a contributing factor to carious lesion development in Romano-British urban children.

Child health is an understudied subject in the archaeology of Roman Britain. Most of what we know about growing-up in the province is derived from the Classical literature. While archaeological research has mainly focused on the architectural grandeur of the towns and high status villa settlements (Parkins, 1997; Millett, 2005; Mattingly, 2006; Pearce, 2008; Holbrook, 2015), rural settlements and their inhabitants have received scant attention ,preventing a more holistic view of life in Britannia (Taylor, 2007; McCarthy, 2013; Breeze, 2014; Fulford and Holbrook, 2014). Contrary to the long-held belief in the detrimental effects of the urban environment, recent bioarchaeological research has demonstrated that living in the Romano-British countryside also negatively affected health (Pitts and Griffin, 2012; Redfern et al., 2015). The late Romano-British villa economy may have provided health challenges for its workers, a subject yet to be fully explored. While non-adult skeletons are widely acknowledged to provide an intricate measure of population fitness in the past (Mensforth et al., 1978), comparisons of the morbidity and mortality of urban and rural Romano-British children have yet to be carried out. A child's diet would have reflected the cultural beliefs and social standing of his or her family. Carious lesion frequency can therefore provide valuable information on access to resources, eating habits, and food preparation practices.

In children, calcified plaque (calculus), and pathological conditions of the dentition such as periapical lesions, periodontal disease, and antemortem tooth loss are rare. Carious lesion frequencies in the deciduous and permanent teeth, therefore, provide the most effective measure for discussing past dental health during childhood (Halcrow et al., 2013). The presence of dental caries in children not only indicates the levels of carbohydrates consumed, but also informs on cultural practices such as pre-mastication, and sharing of foods or utensils (Nield et al., 2008). Carious lesions can cause considerable discomfort, resulting in intense pain, difficulty eating, reduced efficiency of the immune system (Baqain et al., 2004), and can affect speech development (Aligne et al., 2003). Dental studies that focus on children are rare in the palaeopathological literature and tend to focus on individual sites or have small sample sizes (e.g. Moore and Corbett, 1973; Whittaker et al.,

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1981; O'Sullivan et al., 1993; Clough and Boyle, 2010; Redfern et al., 2012). This study will provide an overview of carious lesion frequency in non-adults from 1st to early 5th century AD urban and rural settlements in Roman Britain. Due to the general absence of periodontal disease, periapical lesions, antemortem tooth loss, and calculus in the dentitions of children, this study relies on dental caries as the sole measure of childhood dental health. The aim of the study is to assess whether an urban or rural living environment impacted childhood dental health through the investigation on lesion frequencies of dental caries in the deciduous and permanent dentition.

Pathogenesis of dental caries in children

Dental caries is a progressive infectious disease of the deciduous and permanent dentition, with localised demineralisation of the dental hard tissues by organic acids (Larsen, 1997). *Streptococcus* and *Lactobacillus* bacteria in the oral cavity metabolise sugars and starches, which create an acidic environment and demineralise tooth enamel (Byun et al., 2004). Teeth are remineralised as soon as pH levels are restored to neutral. If, however, the pH is low for a prolonged period, the dynamic between de- and re-mineralisation is upset, resulting in a cavity (Gussy et al., 2006). *Streptococcus mutans*, the main cariogenic bacterium, is normally transmitted from the mother or other caregiver to the child through kissing or sharing implements (Nield et al., 2008). Colonisation with *S. mutans* can commence as early as six months old, although the highest risk for infection is at two years old. It takes around 13-16 months from colonisation for a lesion to develop (Kawashita et al., 2011).

'Early Childhood Caries' defined as caries in children aged 0-5 years, is a serious chronic condition in the modern world (Afroughi et al., 2010). Newly erupted deciduous teeth are particularly susceptible to dental caries due to incomplete maturation, large dental tubules and thinner enamel, which is insufficient in preventing the progression of carious lesions (Aligne et al., 2003; Schuurs, 2013). The area around the erupting tooth also provides favourable conditions for bacterial colonisation (Schuurs, 2013). Child saliva flow rate is slower than in adults, and has lower levels of secretory immunoglobin A (IgA) concentrations. While IgA begins to be produced after one month of life, its formation can be impaired by high levels of cortisol in the blood through stress. Stress could therefore have a caries-promoting function. It may manifest as enamel defects, i.e. hypoplasia, which in turn may increase the risk of dental caries (Boyce et al., 2010). Enamel hypoplasias may cause dental caries to progress more quickly due to higher acid solubility of defective enamel, and greater adhesion of cariogenic bacteria at the site of a defect (Hong et al., 2009). The presence of enamel hypoplasias in individuals with dental caries may therefore be a valuable indicator of early childhood stress in relation to dental decay, and it is of interest to evaluate their co-occurrence.

Using the jaws of modern children, Afroughi and colleagues (2010) showed that once a tooth is infected, dental caries continues to spread to the teeth on either side or above, often in a symmetrical pattern. Risk of lesion development was greater for maxillary posterior teeth than for anterior or mandibular teeth. Early childhood caries may take on a rampant virulent form, known as 'Severe Early Childhood Caries' (SECC), 'Nursing Caries' or 'Milk Bottle Syndrome'. The condition is characterised by rapid lesion development and dental decay primarily in the maxillary anterior dentition (Berkowitz, 2003; Azevedo et al., 2005). A probable case of SECC has recently been identified by Bonsall and colleagues (2015) in a 3-4 year old child from Roman Ancaster, Lincolnshire.

Diet is a crucial factor in the onset and proliferation of dental caries. Refined foods with a high carbohydrate and/or sugar content encourage the metabolic activity of oral bacteria and acid production, increasing the risk of lesion development (Powell, 1985; Prowse et al., 2008). A tough and fibrous diet has a cleaning effect, and vigorous mastication stimulates salivary flow, which is alkaline, buffering against plaque acids (Duray, 1992; Moynihan, 2000). Soft sticky foods and prolonged snacking or sipping of sweetened fluids pose a greater risk for acid development (Hallet and O'Rourke, 2003). Dental disease is usually described by the different surfaces of the tooth that are affected: the occlusal surfaces, smooth surfaces of the crown including the interproximal areas, or the root (Moore and Corbett, 1973). Each of these surfaces has different cariogenic potential, therefore, the location of carious lesions on the tooth may provide insight into changes in diet (Ortner, 2003). With the intensification of cereal agriculture, carious lesions at the root and cemento-enamel junction rise, and with the introduction of refined sugars, interproximal and fissure carious lesions increase, especially in children (Hillson 1996, 283).

The Romano-British diet

There are a number of historical sources that make reference to 'Roman' food and drink, including Apicius' collection of recipes, Pliny the Elder's Naturalis Historia or Galen's medical writings (Grocock and Grainger, 2006; Alcock, 2010). These sources reflect Mediterranean practices of the literate upper classes in the 1st and 2nd centuries AD, and it remains unknown how these are relevant for exploring diet in Roman Britain. When comparing literary evidence on diet to recent isotopic and osteological studies of populations from Rome (Rutgers et al. 2009; Killgrove and Tykot 2013), Velia (Craig et al. 2009), and Portus Romae

(Prowse et al. 2008), it transpires that a 'typical' Roman diet as described in Classical sources may not have been followed, or in fact existed.

Cereal products such as bread and porridge may have been the staple foods in Britain, although variation across the social and geographical strata is expected (Cool, 2006). Sugars would have been available as fructose from fruits, fruit juices, honey and syrups, or glucose in the carbohydrates consumed (Moore and Corbett, 1973; Bowman and Thomas, 1994; Cool, 2006; Bogdanov et al., 2008; Nassar et al., 2012). More advanced farming and plant cultivation techniques, alongside larger scale animal breeding, would have ensured a stable food supply for the army and non-producing urban population, whilst also putting increasing demands on the workers in the countryside (Mattingly, 1997; Dobney, 2001; Taylor, 2001; Pitts and Griffin, 2012; McCarthy, 2013; Redfern et al., 2015).

Studies by King (1984; 1999; 2001) and Cummings (2009) have demonstrated that access to meat and animal products was dependent on site type and status. Overall, marine and freshwater fish became increasingly fashionable, probably as a result of following Roman tastes (Locker, 2007). Isotopic studies on human bones (Richards et al., 1998; Redfern et al., 2010; Cheung et al., 2012; Müldner, 2013) and archaeobotany (van der Veen, 2008; van der Veen et al., 2007; 2008) have revealed temporal, cultural, social and sex differences in the consumption of terrestrial, plant, and aquatic foods at an inter-site and intra-site level. Richard and colleagues' (1998) study of Poundbury Camp in Dorset showed that animal protein and marine foods were only available to the few. Children are thought to have enjoyed more marine foods, and diet was more varied for the inhabitants of the towns (Redfern et al., 2010; Müldner, 2013). It also appears that marine and freshwater foods were primarily consumed in the urban environment rather than the surrounding villages, and that the male and female diet, at least within Roman Gloucester, differed (Cheung et al., 2012). To the benefit of Britons, a variety of new plant foods were introduced following the Roman conquest, improving the nutritional value of the Romano-British diet. Examples include cherries, carrots, or plum, also beet and cabbage, which are high in nutrients and vitamins (van der Veen et al., 2008). As a general pattern, plant foods were widely accessible and eaten in both town and country (van der Veen et al., 2007). It is of note that some areas of the province differed. Access to new plant foods was more restricted, or perhaps opposed, in the southwest (van der Veen et al., 2008).

In children, dietary experiences would have started at weaning with the gradual introduction of solid foods to supplement breastmilk. Galen's writings and Soranus' Gynaecology, both dating to the 2nd century AD, recommend the introduction of supplementary foods from around six months (Fildes, 1986; Temkin, 1991). Weaning would have been complete by 2-4 years old, a practice that has been supported by isotopic analysis of non-adults from England and Italy (Fildes, 1986; Fuller et al., 2006; Prowse et al., 2008; Prowse, 2011; Nehlich et al., 2011; Redfern et al., 2012; Powell et al., 2014). The Roman weaning diet comprised mainly of cereal foods, such as porridge, or bread mixed with milk, wine or honey (Temkin, 1991; Garnsey, 1999). Pre-mastication of foods for weanlings was warned to be harmful; however, the fact that the practice needed to be discouraged suggests it was a known method of infant feeding (Bradley, 1986; Temkin, 1991). Honey was also used as a popular medicinal aid. Soranus suggests rubbing honey on the gums of teething infants to soothe their pain (Temkin, 1991). Once weaned, the contents of the Roman early childhood diet are unknown. If diet was influenced by location and status, children would have been subjected to differential food allocation. Child dental disease rates may then also differ, depending on urban and rural site types, or high versus low status settlements. A large scale investigation of dental caries rates may therefore provide the first detailed evidence for cultural practices and dietary habits of children in Roman Britain.

MATERIALS AND METHODS

Site classification

The terms 'urban' and 'rural' are used to characterise the nature of the settlement rather than its geographic locale. In order to allow for a comparison of carious lesion frequencies between settlements under different levels of Roman influence, sites were divided into major urban (coloniae, civitates), minor urban (nucleated/small towns) and rural settlements (villages, farmsteads, villa estates). A common denominator for Romano-British towns, whether large or small, is the dependence on the hinterland for agricultural surplus to feed the non-producing urban population (Mattingly, 1997; Morley, 1997). 'Major urban' sites were defined as large legal and administrative settlements with a series of features including a grid layout for the street system and organised planning throughout, with public buildings, a forum and a spiritual focus (Wacher, 1974; Burnham and Wacher, 1990; Millett, 1990; Laurence et al., 2011). 'Minor urban' centres displayed some urban aspects, such as evidence for town planning and a market to facilitate local trade (Hingley, 1989; Burnham, 1993; 1995; Millett, 1995; Wilson, 2011). Rural sites were defined as undefended farmsteads, villages, or villa estates with a predominantly agricultural focus (McCarthy, 2013). Depending on their location, rural sites would have exhibited varying economic and socio-cultural dependence on nearby towns (Laurence et al., 2011; White, 2014). However, their agricultural focus still rendered them as rural in character and urbanisation of the countryside to the extent seen in Italy was not apparent in Roman Britain (Laurence, 2011). Current models on life in the Romano-British countryside consider villa economies as estates managed by landowners, with a peasant population that cultivates the land as tenants or freeholders, living either on the estate or surrounding villages (Taylor, 2001; Mattingly, 2006; McCarthy, 2013; Breeze, 2014).

There is a growing awareness of the difficulty in classifying Romano-British settlements (Mattingly, 1997; Millett, 1999; Burnham et al., 2001; Millett, 2001; Pearce, 2008; Rogers, 2011), and it is important to bear in mind that power in Roman Britain was not exclusively urban, as the elite often resided in the countryside or a town's immediate hinterland (Parkins, 1997; Pitts and Perring, 2006). In addition, not all urban cemeteries would have contained those living and dying exclusively within these large settlements, as many individuals may have been derived from the "urban periphery" (Goodman, 2007:1-2), or represent rural migrants (Griffin and Pitts, 2012; Redfern et al., 2015).

Materials

Dental caries was recorded in 433 non-adults (aged 1.1-17.0 years) and a total of 6,283 erupted teeth (deciduous n=2910; permanent n=3373) from 15 Romano-British sites dating from the 1st-5th centuries AD (Table 1, Figure 1). Infants (birth to 1.0 year) were excluded from analysis due to the scarcity of erupted teeth within this age group. The following age categories defined by Lewis (2002) were used: 1.1-2.5 years, 2.6-6.5 years, 6.6-10.5 years, 10.6-14.5 years, 14.6-17.0 years. Age ranges serve to minimise age estimation error, and allow for cross-site comparison while corresponding with developmental milestones (Lampl and Johnston, 1996; Scheuer and Black, 2004; Lewis, 2010).

Methods

Individuals were aged based on their dental development either through macroscopic assessment or, wherever possible, using radiographs (Moorres et al., 1963a,b). As non-adults were not sexed, male and fe-

TABLE 1. Study sites by settlement date and type

Site	Date (AD)	Type	Total non-adults	TPR by tooth count a/p (%)	CPR by Individual a/p (%)	Reference
Winchester (North, West, East)	1-4th century	Major Urban	39	11/559 (2.0)	6/39 (15.4)	Ottaway et al. (2012)
Kingsholm, Gloucester	2-4th century	Major Urban	9	9/135 (6.7)	4/9 (44.4)	Hurst (1985), (1986)
Gambier-Parry Lodge, Gloucester	2-4th century	Major Urban	6	0/76 (0.0)	0/6 (0.0)	Heighway (1980); Mullin (2006)
Trentholme Drive, York	3-4th century	Major Urban	17	2/262 (0.8)	2/17 (11.8)	Wenham (1968); Ottaway (2009)
Bath Gate, Cirencester	4th century	Major Urban	38	5/483 (1.0)	4/38 (10.5)	Viner and Leech (1982)
Butt Road, Colchester	4-5th century	Major Urban	80	22/1209 (1.8)	12/80 (15.0)	Crummy and Crossan (1993)
Baldock, Hertfordshire	2-4th century	Minor Urban	25	2/414 (0.5)	2/25 (8.0)	Stead and Rigby (1986); Burleigh and Fitzpatrick-Matthews (2010)
Queenford Farm/ Mill, Oxfordshire	3-4th century	Minor Urban	51	8/729 (1.1)	3/51 (5.9)	Durham and Rowley (1972); Chambers (1987)
Ancaster, Lincolnshire	3-4th century	Minor Urban	34	13/480 (2.7)	5/34 (14.7)	Todd (1975); Cox (1989)
Great Casterton, Rutland	3-4th century	Minor Urban	27	7/383 (1.8)	4/27 (14.8)	McConnell et al. (2012)
Ashton, Northamptonshire	4th century	Minor Urban	17	0/265 (0.0)	0/17 (0.0)	Dix (1983)
Dunstable, Bedfordshire	3-5th century	Minor Urban	12	7/201 (3.5)	4/12 (33.3)	Matthews (1981)
Owslebury, Hampshire	1-4th century	Rural	3	0/42 (0.0)	0/3 (0.0)	Collis (1968), (1977)
Cannington, Somerset	3-4th century	Rural	69	4/977 (0.4)	3/69 (4.3)	Rahtz et al. (2000)
Catsgore, Somerset	2-5th century	Rural	1	0/6 (0.0)	0/1 (0.0)	Leech (1982)
Bradley Hill, Somerset	4-5th century	Rural	5	0/62 (0.0)	0/5 (0.0)	Leech et al. (1981)
Total non-adults			**433**	**90/6283 (1.4)**	**49/433 (11.3)**	

Figure 1. Distribution of study sites (black: major urban, dark grey: minor urban, light grey: rural)

male tooth development stages were averaged. The cut-off point of 17.0 years was assigned when the roots of the third mandibular molar were complete but the apex remained open, giving an average age of 16.9 years old (Smith, 1991). When the apices of the available teeth were closed, an upper age estimate was derived using skeletal maturation and diaphyseal lengths (Ubelaker, 1989; Scheuer and Black, 2000; 2004). Individuals were excluded once the femoral head was fully fused, with completion estimated between 14-17 years in females and 16-19 years for males (Scheuer and Black, 2000; 2004). It is recognised that the cut-off age of 17.0 years reflects a biological rather than chronological age; however, it is based on the oldest, most accurate age estimate we currently have for non-adults (Lampl and Johnston, 1996). It is of course recognized that a biological age of 17.0 years would not necessarily have marked the end of childhood in Roman Britain. The lifecourse of Romano-British children is not fully explored; we therefore cannot use skeletal ages or age groups according to chronological ages that marked transitions in the lifecourse we are yet to define.

Only erupted teeth were included in the analysis, reflecting their susceptibility to dental caries. For teeth within the jaw, eruption was defined as those teeth in occlusion. The identification of loose teeth as erupted involved an assessment of root development stages (Moorrees et al., 1963a,b) and eruption patterns (Ubelaker, 1989), in addition to any evidence of wear or dental calculus (Buikstra and Ubelaker, 1994). As different teeth have varying degrees of susceptibility to dental caries, they were defined by type: deciduous or permanent, posterior (deciduous and permanent molars, permanent premolars) or anterior (deciduous and permanent incisors and canines) and location (i.e. root or crown). Carious lesion frequencies were reported accordingly. A lesion was recorded macroscopically when it perforated the tooth enamel. Statistical analysis was performed using a Pearson's chi-square test to evaluate the prevalence of lesions between the urban and rural sites, with a confidence limit set at 99.5% (p=0.005). Percent caries rates are presented as both crude prevalence rates (CPR) for the number of individuals observed and affected, or more precisely as true prevalence rates (TPR) determined by the number of teeth observed over those affected. The caries correction factor advocated by Lukacs (1995) was not applied as antemortem tooth loss is low in non-adult samples and loss of teeth through attrition was unlikely.

Enamel hypoplasia was recorded macroscopically when the tooth enamel was disrupted by circular or linear defects on two or more teeth on opposite sides of the dentition (Goodman and Armelagos, 1985; Goodman and Rose, 1990). This was done to avoid recording defects that may have resulted from localised trauma. The relationship between enamel hypoplasia and caries was quantified by Yule's Q.

RESULTS

Entire sample

The prevalence of dental caries for each site is listed in Table 1. For all sites and in the deciduous and permanent dentition combined, 11.3% (n=49/433) of individuals displayed caries, with a TPR of 1.4% (n=90/6283 teeth). Overall, 2.1% of posterior teeth were affected (n=79/3678 teeth) compared to only 0.1% (n=2/2586 teeth) of the anterior teeth, a significant difference (X^2=51.29, p<0.001, d.f.=1). No lesions at the cemento-enamel junction (or 'root caries') were reported. Carious lesions were predominantly found on the occlusal surface of posterior teeth (TPR 1.1%, n=39/3678 teeth). Fissure caries accounted for 49.4% (n=39/79 teeth) of lesions in posterior teeth.

When the deciduous and permanent caries rates were compared, TPR was marginally higher in the deciduous dentition at 1.5% compared to 1.1%, but not significantly so (X^2=1.58, d.f.=2) (Table 2).

Inter-settlement comparisons

Nine carious teeth in the minor urban cohort were derived from the Ancaster toddler with SECC (Bonsall et al., 2015). To prevent skewing of the data, this individual was removed from analysis. The prevalence of caries was highest in the major urban sites (CPR 14.8%, TPR 1.8%), followed by minor urban (CPR 10.3%, TPR 1.1%) and rural settlements (CPR 3.8%, TPR 0.3%). The rural TPR is significantly lower than those reported from the urban settlements (X^2=13.66, p<0.005, d.f.=2).

Lesion frequency in posterior teeth was significantly lower in the rural sites at TPR 0.6% (n=4/659 teeth; X^2=12.34, p<0.005, d.f.=2) compared to both the major and minor urban sites. Lesions in the anterior dentition were only found in two non-adults, both from a major urban site, affecting the deciduous canine in the maxillary dentition of a 2.6-6.5-year old from Kingsholm, Gloucester, and the mandibular deciduous canine of a 6.6-10.5-year old from the northern cemetery at Winchester (see Table 2).

In the deciduous teeth, significantly more lesions were recorded in the major urban cohort (n=32/1075 teeth) at TPR 3.0% (X^2=27.03, p<0.001, d.f.=2). Whereas no significant differences were observed for caries in the permanent teeth (see Table 2).

Interproximal caries affecting the crown surface, either mesially or distally, was observed in 29 posterior teeth or 1.0% of the total sample (n=29/3019 teeth), but only in the major and minor urban sites with a revised prevalence rate of 38.7% (n=29/75 teeth). Again, buccal caries was only observed in these urban cohorts with a prevalence of 10.7% (n=8/75 teeth).

Age differences

The prevalence of caries increased with age, albeit with a slight decrease in the 10.6-14.5 year age group (CPR 16.7%, TPR 1.3%), probably as a result of the shedding of the primary dentition. Caries was not apparent until 10.6 years in the rural sample, whereas lesions were observed in the youngest cohort (1.1-2.5 years) in the major urban sample. In the 6.6-10.5-year cohort, the frequency of carious lesions was statistically higher in the major urban sample at TPR 3.7% (n=20/539 teeth; X^2=11.36, p<0.005, d.f.=2) compared to both the minor urban and rural sites. Out of the total of 20 carious teeth within this major urban group, 17 (85.0%) were deciduous molars (Table 3).

Stress and caries

In the major urban group, 11.4% of teeth (n=309/2700 teeth) had dental enamel defects, compared to 9.6% (n=236/2460 teeth) in the minor urban cohort, and 4.5% (n= 49/1087 teeth) in the rural sample. The rural rate was significantly lower than those from both urban contexts (X^2=43.66, p<0.001, d.f.=2). The higher rates of enamel hypoplasia observed in major urban non-adults (TPR 11.4%) also matched the elevated rates of caries in these settlements. Overall, 39.6% (n=19/48) of the children with caries also had enamel hypoplasia. The Yule's Q statistic of 0.75 indicates that a moderate to strong relationship between the two conditions existed. This co-occurrence was highest in major urban sites at 5.8% (n=11/189) and lowest in rural children at 1.3% (n=1/78), although these differences were not significant (X^2=3.26, d.f.=2) (Table 4).

TABLE 2. Carious lesion frequencies by tooth type and individual

		Major Urban		**Minor Urban**		**Rural**		**Total**	
		Tth	Ind	Tth	Ind	Tth	Ind	**Tth**	**Ind**
Total	a/p	49/2724	28/189	28/2453* (37/2472)	17/165* (18/166)	4/1087	3/78	**81/6264* (90/6283)**	**48/432* (49/433)**
	%	**1.8**	**14.8**	**1.5* (1.5)**	**10.3* (10.4)**	**0.3**	**3.8**	**1.3* (1.4)**	**11.1* (11.3)**
Deciduous teeth	a/p	32/1075	14/125	10/1335	7/127	1/481	1/54	**43/2891**	**22/306**
	%	**3.0**	**11.2**	**0.7**	**5.6**	**0.2**	**1.9**	**1.5**	**7.2**
Permanent teeth	a/p	17/1649	14/124	18/1118	10/86	3/606	2/43	**38/3373**	**26/253**
	%	**1.0**	**11.3**	**1.6**	**11.6**	**0.5**	**4.7**	**1.1**	**10.3**
Anterior teeth	a/p	2/1100	2/171	0/1058	0/152	0/428	0/69	**2/2586**	**2/392**
	%	**0.2**	**1.2**	**0**	**0**	**0**	**0**	**0.08**	**0.5**
Posterior teeth	a/p	47/1624	28/185	28/1395	17/164	4/659	3/78	**79/3678**	**48/427**
	%	**2.9**	**15.1**	**2.0**	**10.4**	**0.6**	**3.8**	**2.1**	**11.2**

Tth = tooth count; Ind=individual count; a/p = number affected/number present; *corrected rates for the Ancaster child with SECC, uncorrected rates in brackets

TABLE 3. Carious lesion frequencies by age group and site type

Age (years)		Major Urban Tth	Major Urban Ind	Minor Urban Tth	Minor Urban Ind	Rural Tth	Rural Ind	Total Tth	Total Ind
1.1-2.5	a/p	1/394	1/38	0/571	0/49	0/193	0/21	**1/1158**	**1/108**
	%	0.3	2.6	0.0	0.0	0.0	0.0	**0.1**	**0.9**
2.6-6.5	a/p	12/555	7/50	7/774	4/56	0/254	0/22	**19/1583**	**11/128**
	%	2.2	14.0	0.9	7.1	0.0	0.0	**1.2**	**8.6**
6.6-10.5	a/p	20/539	8/35	4/393	4/27	0/112	0/8	**24/1044**	**12/70**
	%	3.7	22.9	1.0	14.8	0.0	0.0	**2.3**	**17.1**
10.6-14.5	a/p	11/883	8/44	11/520	5/25	1/315	1/15	**23/1718**	**14/84**
	%	1.3	18.2	2.1	20.0	0.3	6.7	**1.3**	**16.7**
14.6-17.0	a/p	5/213	4/20	6/195	4/8	3/351	2/12	**14/759**	**10/40**
	%	2.4	20.0	3.1	50.0	0.9	16.7	**1.8**	**25.0**

Tth = tooth count; Ind=individual count; a/p= number affected/number present

TABLE 4. Prevalence rates of enamel hypoplasia and co-morbidity

		Major Urban Tth	Major Urban Ind	Minor Urban Tth	Minor Urban Ind	Rural Tth	Rural Ind	Total Tth	Total Ind
Total	a/p	309/2700	54/214	236/2460	43/192	49/1087	12/105	**594/6247**	**109/511**
	%	11.4	25.2	9.6	22.4	4.5	11.4	**9.5**	**21.3**
Co-morbidity	a/p		11/189		7/165		1/78		**19/432**
	%		5.8		4.2		1.3		**4.4**

Tth = tooth count; Ind=individual count; a/p = number affected/number present

DISCUSSION

This study provides the first large-scale examination of carious lesion frequencies in non-adults from urban and rural settlements in Roman Britain. Dental caries is age-progressive and multifactorial, but can provide valuable insights into the cultural habits that affected non-adult diet, particularly where the characteristics of eating and drinking in childhood across Roman Britain are still largely unknown. This study is limited by the scarcity of skeletal and dental material from rural sites, a common problem within Romano-British bioarchaeology, and due to limited sample sizes it was also not possible to analyse variations in diet over time.

However, caries affected 11.3% of the Romano-British children, or 1.4% of all erupted teeth. Lesions were more frequent in children from major urban sites, where 14.8% of non-adults presented with caries. This is substantially higher than the non-adult rate reported at the Dorchester civitas (CPR 3.6%, Lewis pers. comm.), which is thought to represent a major urban settlement. Instead, the Dorchester rates are more comparable to the rural pattern (CPR 3.8%) (see Table 2, Table 5). The major urban TPR of 1.8% is, however, similar to that reported from the Lankhills cemetery for the Winchester civitas (TPR 1.7%) (Clough and Boyle, 2010).

When the deciduous teeth were examined, lesions were statistically more frequent in the major urban sample (TPR 3.0%), the only cohort to show individuals with caries in the anterior deciduous dentition. Higher rates of lesions in the deciduous compared to permanent dentition might be expected due to reduced enamel hardness and longer exposure to the oral environment (Hunter et al., 2000; Halcrow et al., 2013), although soft and carbohydrate-rich weaning foods further elevate early childhood caries (Temkin, 1991; Garnsey, 1999). Hence, the greater frequencies of deciduous caries in the major urban group suggest a prolonged exposure to cariogenic foods during early childhood (Veerkamp and Weerheijm, 1995; Berkowitz, 2003; Freeman and Stevens, 2008), while the presence of anterior deciduous caries may hint at the use of pacifiers (Azevedo et al., 2005). The significantly lower rate of deciduous caries in the rural settlements suggests a different early childhood diet or

TABLE 5. Previously reported caries rates in Romano-British non-adults

Study	Site and context	Date (AD)	CPR (%)	TPR (%)	Comments
Moore and Corbett (1973)	Various unknown Major urban, military	1st-5th century		4.2	Deciduous teeth
O'Sullivan et al. (1993)	Various unknown Not stated	1st-5th century		16.0	Deciduous molars
Redfern et al. (2012)	Various (Dorset) Major urban, rural	1st-5th century		0.3/1.5	Deciduous/ permanent teeth
Lewis (pers. comm.)	Poundbury Camp Dorchester Civitas	3rd-5th century	3.6	0.7/0.7	Deciduous/ permanent teeth
Clough and Boyle (2010)	Lankhills Winchester Civitas	4th century		1.7	Deciduous and permanent teeth
Caffell (2007)	Horncastle, Lincolnshire, Fort/minor urban	4th century		12.5/0.0	Deciduous/ permanent teeth

food processing techniques. Fewer carious lesions in the rural cohort may suggest that this part of the population was restricted in its consumption of agricultural products, which are high in carbohydrates. Perhaps this reflects the primary role of rural inhabitants in this period, who were expected to produce a surplus to provide for urban dwellers, the army, and the elite (de la Bédoyère 1993, 86; Jones 1996, 208; MacMullen 1987; Whittaker and Garnsey 1997), where rural families would have been hesitant to consume their primary source of income. In turn, rural weaning foods may have been chosen that were less economically important and also less cariogenic. Differences in the archaeobotanical record between rural sites, particularly in the southwest where the sample sites of the current study are located, and urban settlements across Roman Britain were observed by van der Veen and colleagues (2008), and strengthen the argument for biased food allocation between producer and consumer. A diet high in grit, with hard and abrasive fibrous foods or contaminants may have also been consumed in rural areas, limiting dental caries development (Duray, 1992; Moynihan, 2000). Further research into dental wear in the urban and rural groups may help elucidate this pattern.

While it is important to compare the results from this study with those that have gone before, this is challenging. Many of the studies that have discussed caries rates in Romano-British non-adults have very small sample sizes, and merged data without specifying which sites they included (Table 5). However, data for carious lesion frequency in non-adults is available for Rome itself. Killgrove (2010) reported true prevalence rates for 0-10 year olds, and 11-20 year olds. At Casal Bertone, a cemetery located close to the walls of the city of Rome, caries prevalence rates were 3.2% (0-10 year olds) and 2.9% (11-20 year olds), compared to 2.2% (n=33/1488 teeth in 1.1-10.5 year olds) and 1.5% (n=16/1096 teeth in 10.6-17.0 year olds) in the major urban cohort of the current study. Lesions were less frequent at the cemetery at Castellia Europarco which was located in an agricultural area of the suburbs of Rome. Just as in this study, no dental caries was reported in children under 10 years old; however, the sample was small (n=2/121 teeth) (Killgrove 2010). Although we cannot make inferences on the specific foods eaten in Rome and the major urban towns of Roman Britain from this comparison, dental disease rates from both locations highlight the pertinent differences in oral health between residents of the towns and country at the centre and the fringes of the Empire. Prowse and colleagues (2008) reported a TPR of 3.8% for carious lesions in the deciduous teeth of 1-12 year olds from the necropolis at Isola Sacra at urban Portus. Although the deciduous caries rates for major urban settlements (3.0%) in the current study are significantly higher than elsewhere in Roman Britain, it is below that of children living in Italy, even outside of Rome. Additional data for child caries rates comes from Kellis II in Egypt, where Shukrum and Molto (2009) reported a TPR of 8.9% for deciduous teeth and TPR 3.8% for the permanent dentition, again substantially higher than seen in the British province. Overall, refined carbohydrates and a more fortified diet may have been more readily available to major urban residents in Roman Britain, compared to those living in the countryside. Yet, access to rich foods was more restricted than in Rome, the Italian urban centres and other provinces closer to the centre of the Empire. However, we also have to assume that genetic and geographic factors, such as immunity and fluoride exposure may have influenced dental caries susceptibility between these different populations.

Although the exact pathophysiology of a relationship between enamel hypoplasia and carious lesion development remains to be explored, a total of 39.6% of children with carious lesions also displayed dental enamel hypoplasia. The result was anticipated, and is consistent with the caries-promoting function of stress. Stress may have elevated salivary cortisol levels, which in turn suppressed salivary IgA and enabled cariogenic bacteria to spread (Boyce et al., 2010). Not only will these children have experienced a greater spread of cariogenic bacteria, but the quality of hypoplastic teeth would have exacerbated this effect. In the affected children, bacteria adhere to the site of the defect, and the thinned or defective enamel is more acid soluble, both allowing for dental caries to progress quicker (Hong et al., 2009). Co-occurrence of caries and enamel defects was more frequent in the urban cohorts. More bacteria in the oral cavity, and thinned enamel as a result of non-specific stress may have contributed to the progression of caries in those children. Since hypoplastic enamel defects were more frequent in the major urban cohort than in the rural children, both diet and non-specific stress may have contributed to the significant differences in carious lesion frequencies. This would suggest that higher status of the major urban children was not necessarily a given.

The youngest individual reported with carious lesions was a 1.1-2.5-year old from Butt Road, Colchester with occlusal carious lesions on the deciduous maxillary second molar. The rise in caries TPRs from the youngest age group may reflect the timing of colonisation of the oral cavity with *S. mutans.* Carious lesions usually appear between 13-16 months after initial colonisation (Kawashita et al., 2011), suggesting the children in this study were affected at around one year of age. However, the administration of cariogenic foods and feeding habits may have occurred earlier, for instance between 6-12 months when infants start to sit up, develop better chewing and tasting mechanisms, and are eventually able to self-feed (Sheridan, 1991; Sellen, 2001; 2007; Carruth and Skinner, 2002; Delaney and Arvedson, 2008). Neither human breastmilk nor cow's milk are very cariogenic, but their caries-promoting properties are significantly increased when the infant is fed supplementary foods rich in carbohydrates such as fruits and honey (Moynihan, 2000; Azevedo et al., 2005; Kawashita et al., 2011). Today, *S. mutans* is mainly transmitted from the primary caregiver to the infant as soon as tooth surfaces have erupted (Gussy et al., 2006). In Rome, early child care was not only provided by the mother, but also by a nutrix or paedagogus among richer families (McWilliam, 2013), or by neighbours, friends and relatives for working women (Rawson, 2003a; Golden, 2011). It is likely similar practices were in place in Britain. For example, caries rates in Romano-British females are reported as 5.4% at Cannington (Brothwell et al., 2000), 3.9% at Butt Road, Colchester (Pinter-Bellows, 1993), and 5.4% at Bath Gate, Cirencester (Wells, 1982), higher than those observed in the non-adults from the same sites (TPRs of 0.4%, 1.8% and 1.0% respectively). The mechanism of *S. mutans* transmission may show that Romano-British care givers pre-chewed or tasted their infants' food, and shared utensils with them when administering food or drink (Fildes, 1986). Historical evidence for pre-mastication refers to it as a practice to be avoided (Bradley, 1986; Temkin, 1991), which indicates that it might have indeed occurred, and probably had an influence on the transmission of oral infections from caregiver to child.

Lesion frequencies were higher in major urban and minor urban children from 10.6-17.0 years, at almost four times the rate reported for the rural sites. It is possible that this pattern is reflecting a richer diet of fortified foods for these adolescents. The fact that the majority of carious lesions in both the major urban and minor urban samples were interproximal and occlusal further attests to a softer and more refined diet (Vodanović et al., 2005). There is archaeological evidence for the fine milling of cereals into white flour (Cool, 2006; Alcock, 2010) and following a Roman diet, refined sugar may have been accessed in the form of honey and syrups (Moore and Corbett, 1973; Bowman and Thomas, 1994; Cool, 2006; Carreck, 2008; Crane, 2013). Honey has antibacterial properties which inhibit *S. mutans* growth, but whether honey is primarily cariogenic or cario-protective is debatable (Bogdanov et al., 2008; Nassar et al., 2012). However, it would have been the main sweetener in this time period and therefore frequently consumed. Grape syrup known as defrutum, sapa or caroenum was made in Spain or southern Gaul and was shipped to Britain in distinctive amphorae (Cool, 2006). Evidence for these amphorae in Britain is scarce and dates mainly to the 1st and 2nd centuries AD. These syrups were therefore either imported in different vessels in the later centuries, became even more difficult to get hold of or, alternatively, ceased to be available in Roman Britain (Sealey and Davies, 1984; Sealey and Tyers, 1989; Monfort, 1998). However, defrutum could be made from boiling down any fruit juice in lead vessels, and would therefore have been widely available across Roman Britain (Farwell and Molleson, 1993; Roberts and Cox, 2003). In summary, carious lesion frequencies in children aged older than 10.6 years attest to dietary differences between those living in the towns and country, probably linked with the availability of more refined and softer foods in the urban centres.

CONCLUSIONS

This research has demonstrated the value of reporting carious lesion frequency in non-adults. Its use is further increased by considering the location and type of carious lesions, and the presence of early childhood stress. Higher rates of dental disease in urban environments suggest differences in diet between children in the countryside and the towns of Britannia. Elevated stress, measured as the prevalence of enamel hypoplasia, in the children growing up in urban settlements was accompanied by higher carious lesion frequency. However, we cannot currently estimate how exact the relationship between stress and enamel defects is to the incidence and severity of dental caries. Carious lesions in the deciduous dentition allow for inferences to be made on weaning and feeding practices that promote dental decay, such as the sharing of utensils and food between caregiver and child. The lower frequency of carious lesions in the rural sample suggests a simpler diet consumed by these children, possibly as a result of biased food allocation in response to economic pressures. Urban populations may have had more access to processed and sweetened foodstuffs whereby refined carbohydrates were more readily available.

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Histological Analysis of Dentition in Rockshelter Burials from Two Sites in Central Belize

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ABSTRACT **Objectives:** Investigations of dental health in the Maya region have frequently focused on individuals buried at urban sites rather than in peripheral or intermediary zones. This study presents a dental analysis of a different type of mortuary sample, those persons buried in two non-elite peripheral rockshelters, in Central Belize using a combined dental micro- and macrodefect approach to interpret health experience.

Materials and Methods: A total of 22 teeth (permanent mandibular canines, and mandibular and maxillary third molars) from the two sites were assessed for dental caries, enamel hypoplasias, and Wilson bands. The maximum and minimum ages of microdefect formation for each tooth was calculated.

Results: Carious lesions were infrequently represented in the sample, while linear enamel hypoplasias were expressed in less than half the sample. Wilson bands, conversely, were present in nearly every tooth indicating that the rockshelter populations experienced more acute stress. Individuals interred at Caves Branch Rockshelter were affected earlier in life based on analysis of mandibular canines.

Conclusion: Non-elites buried in rockshelters in Central Belize had similar dental health experiences when compared with individuals buried at elite centers. At least in terms of oral health, peripheral communities in this area were not adversely affected by their distance from urban core sites

The Classic Period Maya (A.D. 250-900) was characterized by social stratification, emergence and expansion of elite classes, and integration of large urban centers (Cucina and Tiesler, 2003). During this period, the Maya incorporated multiple types of burial sites into their mortuary program across the ancient landscape. Traditionally, archaeologists have focused on the excavation of elite structures and tombs in the Maya area, so comparatively little research has been conducted on the bioarchaeological analysis of non-elite Maya burials from mortuary sites outside of civic-ceremonial centers. This study analyzed the dental remains of non-elite individuals distinguished in death by placement in two peripheral locations, Sapodilla (SDR) and Caves Branch (CBR) rockshelters, in Central Belize. Three indicators of stress (dental caries, linear enamel hypoplasia, and Wilson bands) were collected and estimations of age at defect formation were calculated to determine if these peripheral non-elite groups exhibited stress indicators in frequencies comparable to elite groups in the area.

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This study makes two original contributions: 1) the analysis of an understudied Maya mortuary sample using a method (dental histology) that is not widely applied in the regional bioarchaeology literature; and 2) the assignment of age at defect estimation to better interpret episodic health stress events during life. Using these data, rockshelter burials can be compared to two other main mortuary site types in the area, caves and surface sites, to better understand Maya mortuary behavior. Investigations of rockshelter burials, especially those of the highly socially stratified Classic Period, will help to close the gap between the much-studied elite class and those many communities that existed independently or semi-independently from urban site cores. Enamel defects can be seen macroscopically on the enamel crown as hypoplasias, taking furrow or pit forms. Microscopically, the defects present as Wilson bands, which are visualized as areas of disrupted ameloblast activity when the enamel is viewed in cross-

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section. Hypoplasias, observed externally, and Wilson bands, viewed internally, are indelible markers that indicate a generalized systemic response to stress. The etiology of both defect types is not conclusively understood (Hillson 2014), but a combined study of hypoplasias, carious lesions, and Wilson bands allows for more nuanced conclusions about health experience to be drawn from a particular sample. If only macroscopic indicators of health stress were observed, the burial populations may appear to have had a more positive health experience than was their reality. However, by analyzing the teeth for three defect types, it is possible to observe more defects at more age ranges, resulting in a more complete picture of episodic health stress in the individual.

Health experience has historically been measured in human skeletal remains as a physiological disruption resulting in some kind of osteological or dental manifestation of pathology. The physical embodiment of poor health has often been read in the assessment of dental pathology in particular, but a conflation of "health" and "stress" is not intended in this study, but the limitations of interpreting dental pathological conditions are acknowledged here. Recently, bioarchaeologists have made increasing efforts to critically evaluate health studies and stress markers, drawing more conclusions from the incorporation of theoretical models and data from fields of epidemiology, primatology, and clinical biology (Gowland 2015; Temple and Goodman 2014). For this sample, dental pathological conditions are still used as a proxy of health experience, but the complexities of individual well-being cannot possibly be totalized by observable defects. It is recognized that intangible processes and states of emotional being that leave no inscription on the archaeological record and are difficult to measure on the physical body contribute to overall health experience. To mitigate this fact, multiple dental pathological conditions are combined to determine the extent of expression between and among individuals at these rockshelter sites. These baseline data then allow for the proposition of larger anthropological questions of health experience as more archaeological data becomes available.

Specifically, five research questions were asked of this sample: 1) What is the age at defect formation range and mean age at defect formation for each tooth?; 2) How many Wilson bands were observed for each tooth?; 3) How many enamel hypoplasias were observed for each tooth?; 4) How many carious lesions were observed for each tooth?; and 5) What is the relationship, if any, between dental macro- and microdefects?

BIOCULTURAL CONTEXT

The assessment of rockshelter burials in the Maya region is still a relatively new endeavor and certainly part of an ongoing focus on analyzing non-elite burial populations (Dunham et al., 1998; Glassman and Villarejo, 2005; Goldstein and Prufer, 1999; Saul et al., 2005; Scott and Brady, 2005; Wrobel, 2008). The data presented in this paper contribute to the continuing collection of information about the lifeways and social identities of individuals from rural communities. Frequently, archaeologists have posited that cave access was governed in part by social status, whereby elites controlled large darkzone caves for the purposes of ritual activity while non-elite activity was relegated to the smaller, less visually impressive caves and rockshelters (Awe et al., 1998; Graham, 1980; Peterson, 2006; Reents, 1980; Wrobel et al., 2009). The debates over cave and rockshelter use continue in the literature, so the biological data presented here can usefully augment current and future archaeological data collected from these mortuary spaces.

Sapodilla Rockshelter (SDR) is situated near a small tributary of the Caves Branch River system within the northern portion of the Caves Branch River Valley in Central Belize. Over the course of two field seasons of the Central Belize Archaeological Survey (CBAS), the presence of 40 – 50 primary burials, commingled human and faunal bones, ceramics, and lithics was confirmed (Michael and Burbank 2013). Ceramic types recovered at SDR reveal that the use of the site was predominantly limited to the Protoclassic and Early Classic periods (Michael and Burbank 2013). The mortuary patterns and artifact assemblages appear similar to another peripheral site, Caves Branch Rockshelter (CBR), located approximately 1 kilometer away (Glassman and Bonor, 2005; Wrobel, 2008). Some evidence for post-mortem secondary manipulation of remains was noted, as one nearly complete burial was absent the cranium yet the mandible was present, and two isolated skulls were discovered. Burials at SDR were easily individualized since interments were either undisturbed or only slightly commingled. Teeth were mostly retained in the skull or were scattered in close proximity to the body.

Caves Branch Rockshelter, situated in the Caves Branch River Valley east of the present-day Belizean capital of Belmopan, was first excavated by Juan Luis Bonor in the mid-1990s after a number of looting events (Glassman and Bonor, 2005). This salvage operation yielded 32 primary burials, but dense commingling contributed to the countless bone fragments mixed throughout the burial matrix. Following Bonor's work, Wrobel continued excavations at CBR during 2005-2007 with the Belize Valley Archaeological Reconnaissance (BVAR) Project and again in 2015 with CBAS. All CBR excavations demonstrated that the site was unrestricted by sex or age, further suggesting that the mortuary regulations that governed interment in rockshelters were inclusive. Attendant grave artifacts were sparse and utilitarian reflecting use consistent with a rural farming population (Wrobel, 2008). Based on excavations to date, an estimated 400-500 individuals may be interred at the site (Wrobel et al., 2009). The ceramic assemblage spanned a large period of time from the Formative Period to the Terminal Classic (Bonor, 2002; Wrobel et al., 2009; Wrobel, 2008). However, the diagnostic ceramics interred as grave goods were largely from the Late Preclassic, indicating that the most intensive use of the rockshelter likely occurred during this period (Wrobel, 2008a). Two burials were subjected to AMS dating and returned Late Preclassic and Late Classic dates suggesting that use may not have been punctuated, but rather persistent (to varying degrees) through time. During the Late Preclassic, there is no evidence for urban centers in the valley, further underscoring the use of the rockshelter by agrarian communities (Wrobel, 2008a).

MATERIALS AND METHODS

For this study, two tooth classes (permanent and deciduous) mandibular canines, and maxillary and mandibular third molars were selected for analysis following Danforth's (1989) study on pre-Hispanic Maya burials (Tables 1 and 2). Left teeth were preferentially selected, but when not available the antimere was collected for analysis. Due to similarity in enamel formation rates, both the mandibular and maxillary third molars were selected when either was present.

Prior to thin sectioning for microscopic analysis, data were collected on dental caries and enamel hypoplasias following Buikstra and Ubelaker (1994). Enamel hypoplasias were scored using a combination of the "thumbnail" test and taking an impression in putty. The putty records both slighter expressions of horizontal grooves, as well as pit defects that may not be as immediately visible during the thumbnail test. Color and width of the hypoplasias were not recorded, as these data have not been demonstrated to provide any useful biological information (Buikstra and Ubelaker 1994). Fitzgerald and Saunders (2005) also stated that variables other than defect presence do not factor into the threshold level or denote severity of the defect.

TABLE 1. Distribution of teeth in the sample from CBR

Tooth Type	Right	Left
Mandibular canine	4	6
Maxillary third molar	0	0
Mandibular third molar	0	0
Deciduous mandibular canine	3	1
TOTAL	7	7

TABLE 2. Distribution of teeth in the sample from SDR

Tooth Type	Right	Left
Mandibular canine	5	1
Maxillary third molar	1	0
Mandibular third molar	0	1
Deciduous mandibular canine	0	0
TOTAL	6	2

To identify Wilson bands, the parameters advocated by Hillson (2014:174-175) ,which were adapted from Rose et al. (1978:513), and Goodman and Rose (1990:93) were first considered as the standard observation and identification method for this project. Because there is largely no congruent definition in the literature as every author chooses biological criteria and visual representation to prioritize, it was determined that enamel disruptions would be recorded as Wilson bands if two of the three criteria were met, following a recent Wilson band study done by Reeves (2013:42):

1. the stria appears darker and wider than surrounding striae, extending clearly from the dento-enamel junction to the enamel surface
2. the stria exhibits rod disorganization on examination at 1000x magnification
3. the stria has a corresponding darkened stria in the lingual enamel

Other criteria could potentially be added to this list, but the general presentation of disorganized enamel prisms, darkened striae, and bilateral expression are repeated most frequently throughout the literature.

Each sample was impregnated with a resin/hardener mixture and cut in midline. One thin section of approximately 80-100µm (Fitzgerald and Rose, 2000; Hillson, 2014) was created for examination of the internal surface. Thin sections were analyzed using a standard light transmitted binocular LED digital compound microscope with 3D stage and 9MP camera attachment from United Scope. The AmScope 3.7 software included with the microscope was used to image the samples. The digital camera attachment provided a live feed to the computer, as well as an image capture feature. Thin sections were first magnified at 1000x to identify defects, then they were observed and photographed between 400 –

600x.

Following Cook (1981), Danforth (1989) developed a population-specific age-at-defect formation schedule for Maya dental remains (deciduous canines, permanent canines, third molars). Danforth (pers. comm. 2011) stated that it would be reasonable to use these standards for the rockshelter samples. Measurements of the location of the Wilson bands were taken along the DEJ with the CEJ acting at the zero point. For instance, if a Wilson band was recorded at 2.25mm, that means that the defect began 2.25mm from the CEJ. These measurements were matched to the appropriate increment for each tooth class. For example, if a defect in a third molar of a female was noted at 3.1mm from the CEJ, the associated increment would be in Danforth's DEJ zone 5 and the associated age range would be 10.7 – 11.3 years; (Table 3; see Tables 4 and 5 for other tooth classes). In instances where the sex of the individual was estimated, then the male or female age range was used. The majority of the individuals from CBR and SDR do not have sex estimations, and the combined age ranges were employed.

TABLE 3. Age at development for mandibular third molars (adapted from Danforth 1989)*

DEJ Zone	AmScope Measurement (mm from CEJ)	Age in Years (Males)	Age in Years (Females)	Age in Years (Combined Sexes)
1	6.01 – 7.0	9.0 – 9.6	9.1 – 9.6	9.0 – 9.6
2	5.01 – 6.0	9.6 – 10.3	9.6 – 10.2	9.6 – 10.2
3	4.01 – 5.0	10.3 – 10.9	10.2 – 10.7	10.2 – 10.8
4	3.01 – 4.0	10.9 – 11.6	10.7 – 11.3	10.9 – 11.4
5	2.01 – 3.0	11.6 – 12.3	11.3 – 11.8	11.4 – 12.0
6	1.01 – 2.0	12.3 – 13.0	11.8 – 12.3	12.0 – 12.7
7	0.0 – 1.0	13.0 – 13.6		13.0 – 13.6

*The same chart was used for maxillary third molars based on the very similar development times (Logan and Kronfield 1933)

TABLE 4. Age at development for mandibular canines (adapted from Danforth 1989)

DEJ Zone	AmScope Measurement (mm from CEJ)	Age in Years (Males)	Age in Years (Females)	Age in Years (Combined Sexes)
1	11.01 – 12.0	0.7 – 1.1	0.5 – 0.9	0.6 – 1.0
2	10.01 – 11.0	1.1 – 1.5	0.9 – 1.3	1.0 – 1.4
3	9.01 – 10.0	1.5 – 1.8	1.3 – 1.7	1.4 – 1.8
4	8.01 – 9.0	1.8 – 2.2	1.7 – 2.1	1.8 – 2.1
5	7.01 – 8.0	2.2 – 2.6	2.1 – 2.5	2.1 – 2.5
6	6.01 – 7.0	2.6 – 3.0	2.5 – 2.9	2.5 – 2.9
7	5.01 – 6.0	3.0 – 3.4	2.9 – 3.3	2.9 – 3.3
8	4.01 – 5.0	3.4 – 3.8	3.3 – 3.7	3.3 – 3.7
9	3.01 – 4.0	3.8 – 4.1	3.7 – 4.0	3.7 – 4.1
10	2.01 – 3.0	4.1 – 4.5	4.0 – 4.4	4.1 – 4.5
11	1.01 – 2.0	4.5 – 4.9	4.4 – 4.8	4.5 – 4.9
12	0.0 – 1.0	4.9 – 5.3		4.9 – 5.3

TABLE 5. Age at development for deciduous mandibular canines (adapted from Danforth 1989)

DEJ Zone	AmScope Measurement (mm from CEJ)	Age in Months (Combined Sexes)
1	7.01 – 8.0	5 – 6 (in utero)
2	6.01 – 7.0	7 - 8 (in utero)
3	5.01 – 6.0	9 (in utero) – 1 (post -birth)
4	4.01 – 5.0	2 – 3
5	3.01 – 4.0	4 – 5
6	2.01 – 3.0	6 – 7
7	1.01 – 2.0	8 – 9
8	0.0 – 1.0	10 – 11

RESULTS

Table 6 summarizes the data collected for the SDR sample. Six individuals were represented in the sample, but only two of these burials retained more than one desired tooth. Of the eight teeth available, none exhibited carious lesions, three showed linear enamel hypoplasias, and all but one tooth had Wilson bands. The number of Wilson bands in each tooth class and the average age point estimate for each tooth class is summarized in Table 7. With one exception, the teeth were all mandibular canines with Wilson band formation occurring as early as 2.1 years (Burial 17) and as late as 4.9 years (Burials 9 and 13). The number of Wilson bands per tooth was five or under for six of the seven teeth with microdefects. Burial 17, exhibiting 12 Wilson bands, was an outlier. Interestingly, Burial 17 was the only individual in this sample interred in the liminal zone between the rockshelter overhang (where most skeletal remains were found) and the small dark zone cave. This burial was also distinguished by the hundreds of shell tinklers forming a belt and bracelet on the body; no other burial at SDR was as decorated.

Table 8 summarizes the data collected for CBR. Of the fourteen teeth available, all were from different individuals. Only two of these teeth exhibited carious lesions, while six teeth demonstrated at least one linear enamel hypoplasia. Every tooth in the sample expressed at least one Wilson band. The earliest age of Wilson band formation in the deciduous teeth occurred at 0.33 – 0.42 years (Burial 19) and the latest

TABLE 6. Summary of data collected for SDR

Burial	Tooth	No. of Caries	No. of Hypplasias	No. of Wilson bands	Min. Age	Max. Age	Point Estimate Age
Burial 6	RC_	0	2	4	3.7	4.5	4.1
Burial 7	RC_	0	0	5	2.5	3.7	3.1
Burial 9	RC_	0	0	4	3.3	4.9	4.1
Burial 10	RM^3	0	0	0	N/A	N/A	N/A
Burial 10	RC_	0	1	2	3.3	4.1	3.7
Burial 13	LM_3	0	0	3	11.4	12.0	11.7
Burial 13	LC_	0	2	4	2.5	4.9	3.7
Burial 17	RC_	0	0	12	2.1	4.1	3.1

TABLE 7. Summary of SDR sample: Wilson bands and ages

Tooth Class	Number of Wilson Bands in Entire Tooth Class	Point Estimate of Average Affected Age
Mandibular canine (n=6)	31	3.63
Third Molar (mandibular and maxillary) (n=2)	3	11.7
Deciduous mandibular canine (n=0)	N/A	N/A

TABLE 8. Summary of data collected for CBR

Burial	Tooth	No. of Caries	No. of Hypoplasias	No. of Wilson bands	Min. Age	Max. Age	Point Estimate Age
Burial 2	LC_	0	2	1	2.5	2.9	2.7
Burial 9	RC_	0	5	3	2.6	3.4	3.0
Burial 10	LC_	0	3	1	2.1	2.5	2.3
Burial 11	LC_	0	0	3	3.0	3.8	3.4
Burial 19	rc_	1	0	1	0.33	0.42	0.38
Burial 23b	rc_	0	0	1	0.5	0.58	0.54
Burial 36A	rc_	0	0	1	0.5	0.58	0.54
Burial 38	RC_	0	0	3	2.9	3.3	3.1
Burial 46C/42	LC_	0	1	9	1.8	4.5	3.15
Burial 51	RC_	0	2	7	1.3	4.0	2.65
Burial 63	LC_	0	0	3	2.9	3.3	3.1
Burial 71	lc_	0	0	3	0.5	0.75	0.63
Burial 86	RC_	0	1	7	2.2	3.8	3.0
Burial 246	LC_	1	0	6	2.0	4.4	3.2

age at defect formation in the deciduous teeth occurred at 0.5 – 0.75 years (Burial 71). For the permanent teeth, the earliest age at defect formation was 1.3 years (Burial 51) and the latest was 4.5 years (Burial 46C/42). Table 9 summarizes the number of Wilson bands in each tooth class and the average age at defect formation for each tooth class.

TABLE 9. Summary of CBR sample: Wilson bands and ages

Tooth Class	N	Number of Wilson Bands in Entire Tooth Class	Point Estimate of Average Affected Age
Mandibular canine	10	43	2.96
Third Molar (mandibular and maxillary)	0	N/A	N/A
Deciduous mandibular canine	4	6	0.52

DISCUSSION AND CONCLUSIONS

The rockshelter burials investigated in this paper provide baseline data for understanding rural burial populations in Central Belize. Unfortunately, the samples are too small to present statistically significant results, but the descriptive data do demonstrate some patterns. Carious lesions were rarely present at either site, a trend that follows other sites in Central Belize (Slon and Michael, 2013). Hypoplasias were always linear in formation, but at both sites the total frequency of hypoplastic defects was under 50% for the sample. Nearly all teeth expressed at least one Wilson band indicating that these defects, signaling more acute stress events (Wright, 1990), were the norm in these rockshelter burials. The etiology of these microdefects is still not conclusively known, but the disruption of the enamel prisms can, at minimum, be understood to be reflective of some stress event. Of the 22 teeth in the sample, 12 exhibited Wilson bands without presentation of enamel hypoplasias demonstrating that the presence of one defect does not necessarily predict the presence of the other. In fact, the burial with the most microdefects (Burial 17 from SDR) showed no linear enamel hypoplasias.

The average ages at defect formation for each tooth type demonstrate that individuals at CBR were affected by health stress somewhat earlier (2.96 years for the mandibular canine), while health stress occurred later at SDR (3.63 years for the mandibular canine). Deciduous canines, only present at CBR, expressed an average age at defect formation at 0.52 years. Third molars, only present at SDR, expressed an average age of defect formation at 11.7 years.

What can be gleaned from this project is that, largely, the individuals buried at these two rockshelter sites did not experience overwhelming dental health disturbances. These rural communities may once have been assumed to have suffered greater health disparities due to their lower social status, but that hypothesis is proven incorrect here. Previous bioarchaeological research has focused on health experience leading up to (or at the time of) "collapse" when the Maya were re-organizing their political alliances and social structure (Cucina and Tiesler, 2003, 2005; Danforth, 1989, 1997; Gerry, 1997; Storey, 1997; White et al., 2001; White, 1997, 2005; Wright, 1997; 2006), or during the Contact period when the Maya were introduced to new biological and social stresses brought on by the arrival of the Spanish (Danforth, 1989; Wright, 1990). Neither of these periods, in spite of extraordinary cultural change, has been shown to have a significant effect on the development of Wilson bands and/or enamel hypoplasias.

While this study does not focus on periods of social change, the similar results cautiously suggest that residence in peripheral communities (rather than urban centers) did not result in negative biological consequences. Non-elites living in rural settlements both adapted to and acted in concert with their surroundings, responding to both environmental and social pressures. The addition of more health data from rockshelter sites in Central Belize, as well as other Classic Period rockshelters throughout the country, are necessary to determine the extent to which residence in peripheral zones affected health experience. These data indicate that a binary model of health stress (e.g. elites did not suffer, while commoners suffered greatly) likely does not encapsulate the experience of the Classic Period Maya.

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A Rare Case of Congenital Syphilis and a Supernumerary Fourth Molar in an Early 20th Century African American Woman

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Keywords: disease; mercury; mandibular distomolar; morphology; supplemental teeth

ABSTRACT Congenital syphilis is a disease recognized for interfering with odontogenesis, producing specific dental characteristics including Hutchinson's incisor, Moon's molar, Fournier's molar and mulberry molar, while its past treatments including mercury are known to affect amelogenesis. Supernumerary teeth, mainly associated with syndromes, are not commonly found in cases of congenital syphilis. A rare case of congenital syphilis in an individual (P000707) treated with mercury and a mandibular left fourth molar with normal morphology is presented.
Materials and Methods: During a systematic examination of 28 skeletons with treponemal disease at the Smithsonian museum in Washington, DC, a supernumerary mandibular distomolar in one individual (P000707) was revealed.
Results: P000707 was an African American female, 26 years of age. Dentition showed severe enamel hypoplasia of the maxillary and mandibular incisors, left canine, and upper first molars, consistent with the effects of treatment of congenital syphilis by mercurial compounds. Crown of the left mandibular distomolar has typical molar morphology but is smaller in size than other permanent molars. Arrangement of grooves resembles the +4 pattern, but is complex due to crenulation. Oblique x-ray revealed that the fourth molar had one root with a pulp chamber extending towards the apex, suggesting taurodontism. No other distomolar teeth were present.
Conclusions: Congenital syphilis and treatment containing mercury may not influence the development of supernumerary teeth due to: (1) the age at which the development of the fourth molar takes place, (2) the stage of the infection at the time of development and (3) the age at which treatments containing mercury are administered to patients with congenital syphilis.

Congenital syphilis is a disease caused by the transmission of *Treponema pallidum*, from the mother to the fetus during pregnancy or at birth. In the neonate, various systems are affected. Pathological signs appear in two stages of the disease. During the early stage, skeletal manifestations include periosteal reactions, osteochondritis, and osteomyelitis (Hira et al., 1985; McLean, 1931) while during the late stage, signs can include frontal bossing, short maxilla, high palatal arch, saddle nose, Higoumenakis's sign, diaphysitis, metaphysitis and sabre shins (Fiumara and Lessell, 1970; Rasool and Giovender, 1989). However, the disease is most recognized for interfering with tooth formation (odontogenesis), producing certain characteristic teeth including Hutchinson's incisors, Moon's molar, Fournier's molar and the mulberry molar (Fournier, 1886; Hutchinson, 1863; Karnosh, 1926; Moon, 1884). Even though these characteristic dental signs in congenital syphilis are seen in the permanent teeth (upper central incisors and first molars), which erupt approximately at 6-8 years of age, the dental abnormalities in these teeth are produced during the early stages of the disease, that is, once the infection and fever set in around the time of birth affecting initial crown formation. However, these dental abnormalities do not occur in all cases of congenital syphilis. The incidence of Hutchinson's incisors ranges from 30 to 50% (Putkonen and Paatero, 1961), while changes in first permanent molars range between 3 and 37% (Berfield, 1971).

In the past, mercury was used to treat congenital syphilis due to its antibacterial effects (Hutchinson, 1874, 1878; Warner, 1881). Even though mercury was seen to benefit infected individuals, it was also seen to produce dental abnormalities that were different from

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those caused by the disease. Hutchinson recognized that mercury affected amelogenesis resulting in severe enamel hypoplasia (Hutchinson, 1878). Treatments containing mercury were given to infants soon after birth, the time which enamel formation in permanent teeth begins. First permanent molars and incisors begin their formation around birth and this is when they are exposed to disease. Mercury used to treat syphilitic infants continued for months after birth, severely affecting other tooth formation, depending on the length of time the treatment was administered (Hutchinson, 1878). The abnormalities produced by congenital syphilis can be combined with the effects of treatment containing mercury (severe hypoplastic effects) (Hutchinson, 1878; Moon, 1884). Treatment with mercury was commonly used in cases of congenital syphilis until the early 20th century. The whole suite of changes caused by congenital syphilis and treatments containing mercury have been discussed in detail (Ioannou et al., 2016).

Supernumerary teeth have been associated with various syndromes and disorders including Down's and Gardner's, cleidocranial dysostosis, and cleft lip and palate (Kumar and Gopal, 2013; Menezes and Vieira, 2008; Millhon and Stafne, 1941; Panjwani et al., 2011; Sandler, 1951); however, they have not been described in detail in cases of congenital syphilis. Supernumerary teeth are observed when more than 20 deciduous or 32 permanent teeth are present in an individual. They can erupt, remain unerupted, or become impacted (Kara et al., 2012; Mali et al., 2012). Their appearance can be unilateral, bilateral, as a single tooth or in multiples (Brinkmann et al., 2012; Cavalcanti et al., 2011; Harris and Clark, 2008). The morphology of supernumerary teeth can vary in each individual from normal in shape and size, normal shape and reduced in size, conical in shape and abnormal in shape and reduced in size (Harris and Clark, 2008; Kumar and Gopal, 2013; Rahnama et al., 2014).

This paper presents a case of congenital syphilis in an African American woman dating from the early 20th century with a fourth mandibular molar. A focus will be made on the development of the fourth molar in the presence of a disease, which primarily affects dental development.

MATERIALS AND METHODS

During a systematic examination of 28 skeletons held at the Smithsonian museum in Washington, DC, whose documentation stated that they had "treponemal or treponemal congenital" disease, a case of a supernumerary mandibular distomolar in one individual (P000707) was revealed. This individual was an African American female, who was born in 1903 and died of pulmonary tuberculosis in 1929, at 26 years of age. Occlusal and oblique X-rays of the mandible were taken using a Frankenstein unit to see whether a fourth molar was present on the right side. Chemical analysis was performed to detect any levels of mercury. A Bruker Tracer III-V handheld analyser was used on hypoplastic portions of the central and lateral incisors. The initial analysis used an all-elements setting. The settings for the following test were elevated to (0.001" Cu, 0.001" Ti, 0.012" Al filter at 40 keV/16 micro amps for 300 seconds, without vacuum) (Ioannou et al., In press).

RESULTS

All maxillary permanent teeth were present, the central and lateral incisors, canines, premolars and all three molars. The enamel of the central incisors from the incisal third to the middle third of the crown appears mottled and thin (Figure 1). The incisal third of the lateral incisors and left canine demonstrate the same mottled appearance and pitted enamel hypoplasia. Deep pits are apparent toward the middle third of the crown of the central incisors and incisal third of the lateral incisors and canines. In addition to signs caused by mercury on the incisors and canines, other teeth display isolated hypoplastic pits. Maxillary premolars are not affected. First permanent molars have abnormal occlusal surfaces, with cusps reduced in size and pitting hypoplasia, which is also consistent with the side effects of mercury (Figure 2). Diseased enamel is clearly demarcated from the healthy enamel on the cervical third of the crown. The morphology of the second and third permanent maxillary molars is normal with normal groove patterns, but there is some enamel pitting on the occlusal surface.

Mandibular permanent teeth include the central and lateral incisors, left and right canines, first and second premolars, second and third molars and the

Figure 1. The maxillary central and lateral incisors and left canine display hypoplastic enamel seen in patients with congenital syphilis treated with mercury. Signs include thin enamel, pitted enamel hypoplasia (in some places very deep), and distinct demarcation separating diseased from healthy enamel.

Figure 2. Occlusal view of the maxilla. First permanent molars have abnormal surfaces with small cusps and pitting hypoplasia

distomolar. The first permanent molars were lost ante-mortem, possibly by extraction and their alveoli are completely healed. All mandibular incisors have mottled enamel (Figure 3). The left and right second molars and the third left molar do not display severe hypoplasia, save for minor pitting. Their occlusal surfaces are crenulated. The third permanent molar on the right side is represented by its roots only. The crown has broken off probably after its destruction by dental caries. On the left side, in the mandible, there is a fully erupted fourth molar (distomolar). Its crown has normal molar morphology, but is smaller in size in comparison to the other permanent molars present. The arrangement of groves resembles the +4 pattern. However, the groove pattern is complex because of crenulation. Entoconid, metaconid, hypoconid and protoconid are present, and it appears that there may be a narrow metaconulid, but crenulations make it difficult to determine (Figure 4). An oblique X-ray of the mandible shows that the distomolar only has one root with a large pulp chamber extending far down towards its apex, suggesting a taurodont condition (Figure 5). The third molar on the left is large and crowded between the distomolar and adjacent second molar. Its crown is rotated approximately 10 degrees and tilted mesially. Inspection of the X-ray does not reveal the presence of the antimeric distomolar (Figure 6). All molar crowns appear crenulated.

Figure 3. The anterior view of the mandibular incisors displaying enamel defects

Figure 4. Occlusal surface of the mandible. The first permanent molars were lost ante-mortem. Both second molars, the left third molar and left fourth molar are present. The right third molar is represented by its root only. The fourth molar displays normal molar morphology

Figure 5. Oblique X-ray image of the mandible shows that the distomolar has only one root and that there is no antimeric distomolar. Note the large extent of the pulp cavity in the distomolar, suggesting it is a taurodont molar.

In

the

Figure 6. X-ray of the occlusal view of the mandible does not show any evidence of a right fourth molar

post cranial skeleton, limited areas of nodular periosteal reaction were observed on the long bones including the right tibia, fibula, humeri, radius, ulnae, and femora, as well as the lateral surface of the left ilium. The left femur had lytic destruction along the lateral border of the head in the anterior aspect, "classic" striated periosteal reaction is not noticeable.

DISCUSSION

Here we present a case of congenital syphilis with a supernumerary distomolar in an African American woman. Although this condition is very rare during this time, it is probable, as one other case has been documented (Jacobi et al., 1992). However, in this case, the dental abnormalities in P000707 indicate that she was treated with mercury soon after birth. Changes in the morphology of the central maxillary incisors and left canine have enamel malformations that are compatible with dental abnormalities observed by Hutchinson in patients with congenital syphilis administered treatment containing mercury (Figure 7). Crown formation of the central permanent incisors begins at approximately three to four months postnatally and is complete at approximately 4 to 5 years of age (Nelson and Ash Jr, 2010). The specific changes in enamel caused by mercury are seen in one third of the crown, therefore, treatment would have started in the middle of the first year of life and ceased at approximately 2 years of age. Similarly, severe enamel malformations are observed on the lateral incisors and canines that start forming later than the central incisors.

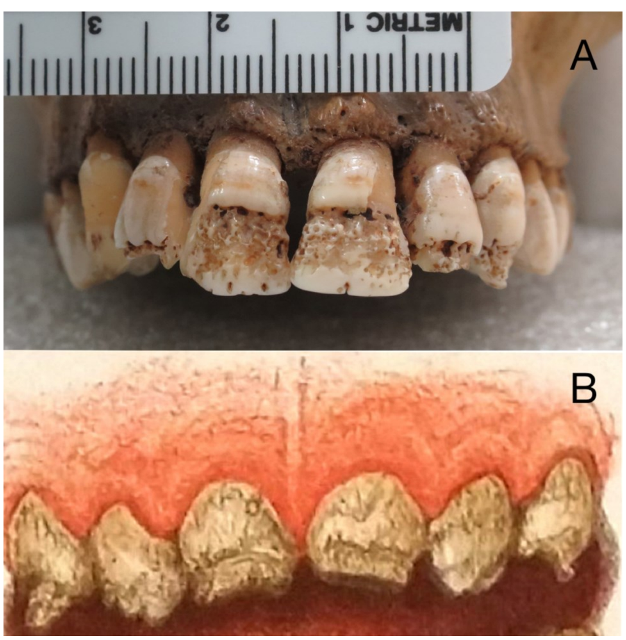

Figure 7. (A) Anterior teeth of P000707 (B) Patient treated with mercury as presented by Hutchinson in 1878 (16 year old boy). Both (A) and (B) display similarities in enamel abnormalities that occur as a result of treatments containing mercury. Mercury would have been administered at a somewhat older age in P000707 than in Hutchinson's patient. Hutchinson, (1878) p. 53, Plate VI, Items I (A)

The morphology of the maxillary first permanent molars demonstrates a normal groove pattern towards the mesial end of the crown, while the rest of crowns' occlusal surfaces are reduced in size and hypoplastic. As the incisal third of the central incisors and a portion of the occlusal surface of the first permanent molars appears to be normal, the rest of the crown is affected, which may be an indication that the onset of the infection was late in relation to tooth development.

Congenital syphilis is known to produce specific dental abnormalities characteristic of the disease. However, it has been noted that in some cases of congenital syphilis, the classic dental changes that are usually observed such as Hutchinson incisors, Moon's molar and Fournier's molars do not occur (Švejda, 1952). Hutchinson also observed and described certain dental abnormalities that occurred as an effect of treatments containing mercury (Hutchinson, 1878). The dental abnormalities produced by the disease itself and treatments containing mercury were so distinct that Hutchinson deemed it worthy to document and illustrate both as separate entities. It is worth noting that the crescentic notch that occurs in the maxillary central incisors of congenital syphilis patients is not observable if they were treated with mercury (Hutchinson, 1878). The features observed in this P000707 are typical signs of teeth treated with mercury in patients with congenital syphilis (Hutchinson, 1878; Ioannou et al., 2016).

While the results of the chemical analysis detected no levels of mercury, this neither confirms nor disproves that mercury was administered to this individual. Various explanations could be considered. It is possible that the low levels of mercury in the enamel could not be detected by the equipment. Another possible explanation for the lack of mercury detected could be due to the quick turnover rate of mercury in the body. The half-life of mercury ranges from 58 days for elemental mercury, 1-2 months for mercuric mercury (e.g. $HgCl_2$), to 70-80 days for methylmercury (National Research Council (US) 2000). Taking into account that this individual was treated with mercury for congenital syphilis in the early stages of life and died at 26 years of age, it is not abnormal to find extremely low levels of mercury. As indicated by Hutchinson, if 648 mg (10 grains) of mercury were introduced in a body of a young individual, after 20 years only a minute quantity of mercury would remain ($2.13*10^{-25}$mg). Thus, it is more likely that a majority of the mercury would be cleared out, making it undetectable.

Other elements considered in the differential diagnosis include lead, zinc, copper and cadmium. High levels of lead can cause a decrease in microhardness of enamel (Gerlach et al, 2002) but cannot cause malformations of the enamel (Gerlach et al, 2002; Youravong et al, 2005). Fosse and Berg-Justesen (1977, 1978, 1978) and Tvinnereim et al. (1999) examined concentrations of zinc, copper, and cadmium in teeth and bone in humans and mice and recorded the difference in concentration of these elements between enamel, dentin, and bone, but did not record any changes or malformations in enamel development.

In relation to changes on the post cranial skeleton of P000707, since the individual died of tuberculosis, it is difficult to say which of those described pathological changes could be due to treponemal infection.

The crown morphology of the distomolar is normal, unaffected by the disease, nor by treatments containing mercury. The smaller size of the distomolar is unlikely to be caused by congenital syphilis. Clinical studies have shown that distomolars can demonstrate normal molar morphology, have as many as three to seven cusps and be reduced in size, in comparison to the other permanent molars (Asrani et al., 2006; Ceperuelo et al., 2015; Kumar and Gopal, 2013; Ohata et al., 2013; Shahzad and Roth, 2012). The normal crown morphology in this case may be due to the time at which the development of the fourth molar began. It is the early stage of the disease that affects dental development. It occurs soon after birth and becomes the tertiary stage after several weeks. Tertiary syphilis does not affect tooth development. The development of the third permanent molar begins at approximately 7 to 10 years of age and the tooth is fully erupted between the ages of 17 and early 20s (Liversidge, 2015). It is possible that the fourth distomolar could have developed at the same age or even later. If the fourth molar had developed soon after the third molar, P000707 would have been in the tertiary stage of the disease; therefore, the disease could be asymptomatic and would not have affected amelogenesis or odontogenesis of the supernumerary fourth molar. However, it is possible that the fourth molar developed sooner. Studies have shown that fourth molars can appear between the ages of 11 and 16 years (Delgado et al., 2014; Menardía-Pejuan et al., 2000; Orhana et al., 2006; Vlaykov et al., 2015).

It also appears common that distomolars demonstrate a single root, unlike the multiple roots observed in the other permanent molars (Ceperuelo et al., 2015; Ohata et al., 2013; Rahnama et al., 2014). However, root formation can vary among individuals (complete with closed apex or incomplete) (Ceperuelo et al., 2015; Kokten et al., 2003; Ohata et al., 2013). Since the distomolar in this case is taurodontic, it is not possible to determine whether it had fused multiple roots or a single root because no separate root canals can be seen. At least formally, the root is a single unit. The cause of taurodontism is unclear. It has been associated with various syndromes (Andersson et al., 2013; Keeler, 1973; Rajić and Mestrović, 1998) and multiple theories have been suggested in the literature (Alvesalo and Varrela, 1991; Witkop Jr et al., 1988). In this case, it should be considered that the proportions of the root to crown size and pulp cavity to root canal volumes may have developed abnormally in the supernumerary, thus not normal, tooth without any special causes.

The development of extra teeth is not fully understood, although multiple theories have been suggested such as hyperactivity within the dental lamina, and dichotomy of the tooth germ and these may be linked to genetic factors (Kokten et al., 2003; Kumar and Gopal, 2013). For instance, Martínez-González et al. (2012) found them in 0.96%, Shahzad and Roth (2012) in 2.2% and Kara et al. (2012) in 0.33%. It has been found that supernumerary molars were also more prevalent in African Americans (6.4%), than in European Americans (0.9%) (Shahzad and Roth, 2012). It has been suggested that African Americans exhibit extra teeth more often than European Americans (Harris and Clark, 2008), which may be related to African Americans having larger dental arches and greater crown and root dimensions. This would increase a probability of the appearance of the distomolar in an African American suffering from congenital syphilis.

CONCLUSION

A systemic infection such as congenital syphilis and its treatment with mercury may not influence the development of supernumerary teeth due to: (1) the age at which the development of the fourth molar takes place, (2) the stage of the infection at the time of development and (3) the age at which treatments containing mercury are administered to patients with congenital syphilis.

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BOOK REVIEW

A Companion to Dental Anthropology. Joel D. Irish and G. Richard Scott., editors. Published in Oxford by Wiley-Blackwell , 2016. pp. xviii + 540. Illus. Indexed. ISBN 978—1-118-84543-1, Price: US$195.00; Can$215.00, Ebook Can$172.99.

As the 29th addition to the book series, "Blackwell Companions to Anthropology", this is a welcome and much needed inclusion to the burgeoning fields of dental anthropology. With an illustrated hard cover depicting the late Christy G. Turner II at work, two Neolithic male crania and dental pathology in a Swazi skull from the renowned Dart Collection at the University of the Witwatersrand, the book's comprehensive encompassment of components of dental anthropology in nine parts and 31 chapters is a tour de force in hominin odontology.

With a list of 41 authors that comprise the "whose who" of the dental anthropology canon, this work is destined to become a cornucopia of odontological inquiry. The contents of this book transcends Brothwell's "Dental Anthropology" (1963), Kelly and Larsen's "Advances in Dental Anthropology" (1991), and Hillson's "Dental Anthropology" (1996) by the incredible advances in instrumentation and imaging techniques, isotopic, DNA and genetic analyses and the paleoanthropological discoveries made in the past quarter century.

The nine parts of the book deal with Context, Dental Evolution, The Human Dentition, Dental Growth and Development, Dental Histology, Dental Morphometrics, Dental Health and Disease and finally, the future of dental anthropology.
Each chapter concludes with an extensive list of references that range from Retzius (1837) to among the most current (Irish JD et al., 2014), constituting an absolute treasury of the odontognathic masticatory literature. The continuing expansion of dental anthropology into related fields is exemplified by the affinity of diets to dentitions (Forshaw, 2014; Morin et al., 2016).

Readers of this tome should be aware that, as much as the contents are current, the rapidly developing expansion of dental relevance in related fields of diets, genetics and paleo-odontology (Hlusko, 2015; Zinc and Lieberman 2016) is mandatory for contemporary study of this discipline. A whole new archeological source of paleodietary investigation of ancient dental calculus allowing for paleogenetic analysis of mitochondrial genomes providing maternal lineage ancestry is being revealed (Ozga et al., 2016).

The book is unreservedly recommended for students and scholars of odontology, dental evolution, masticatory anatomy, forensics, and related fields.

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EDITORS' CORNER

New editorship for Dental Anthropology

This journal has served as a cornerstone for dental anthropologists conducting research over the last 20 years (beginning in 1986 as a newsletter). The journal has been a publication of the Dental Anthropology Association and has been under the editorship of numerous very well-respected scholars within the field: Raymond L .Costa (1986), Susan Loth (1987-1989), A.M Haeussler (1990-2002), Joel D. Irish (1991– 1995), Diane E. Hawkey(1991-1995), Steven R. Street (1991-1992), E.F. Crespo (1991), Liu Wu (1991-1992), Shara Bailey (1993-1997), Korri D. Turner(1993-1995) Esther Morgan (1994), Edward F. Harris (2002-2012) and Christopher W. Schmidt (2012-2016).

As we have reflected on the respected history of this publication, we have begun to outline a new vision for its direction. We hope to continue the tradition of the journal, and develop a format that better serves its readers and those who publish in the journal. Specifically, we would like to solicit more short articles, much like annotations in the *Journal of Dental Research*. We encourage the submission of articles that might not have a place in other larger journals, but are of great interest to dental anthropologists (e.g., articles on methods or editorials). We will include a section on case studies, where interesting morphological or pathological variants of teeth could be discussed and shared. We want to push the technology of the journal to include 3-D PDFs, and allow for the dissemination of databases or datasets to advance scholarly endeavors. Additionally, we plan on creating special volumes centered on topics of interest and debate within the field.

As part of this new vision, we are looking to increase the visibility of the journal. This move includes indexing the journal, ensuring manuscripts are found easily in online databases, and ultimately moving towards acquiring an impact factor. While these are exciting times for the journal, we want to reiterate our commitment to maintaining the open access format we currently have. The free dissemination of the journal has been an important foundation to not only dental anthropological scholarship, but has also been a viewpoint of the Dental Anthropology Association.

We are excited about the future of the journal and hope you help shape its direction over the next several years! We are currently accepting submissions for inclusion in the next volume scheduled to come out in 2017.

MARIN A. PILLOUD and G. RICHARD SCOTT

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