ANTHROPOLOGIE • XXXVIII/1 • pp. 101–107 • 2000

SHELLEY R. SAUNDERS, ROBERT D. HOPPA, ROBERTO MACCHIARELLI, LUCA BONDIOLI

INVESTIGATING VARIABILITY IN HUMAN DENTAL DEVELOPMENT IN THE PAST

ABSTRACT: An initial comparison of long bone size between a nineteenth century Canadian skeletal sample and an Imperial Roman sample used the dental formation standards of Moorrees, Fanning, and Hunt (1963a,b) to estimate chronological age. The two samples appear similar until 8 years when the Roman sample falls below the Canadian one. This method of comparison assumes that the patterns of dental formation are the same in the two samples. But there is a body of research which shows either genetic or environmental effects on dental development. The two samples were compared using tooth pairs at various stages of formation, independent of any other population standards. No significant differences were found. However, sampling problems may mimic patterned differences in dental development and be affected by biases in archaeological mortality samples. The absence of differences in patterns of dental formation between these two samples suggests that there are no micro-level genetic differences between them or environmental differences that might affect dental formation, despite the considerable evidence for skeletal stress in the Roman sample. Shorter stature in the Roman sample, manifested in later childhood, reflects expectations for population differences in skeletal size.

KEY WORDS: Tooth formation – Dental development – Population variability – Skeletal growth

Careful age at death estimation is critical to the investigation of immature human skeletons whether they are fossil specimens or come from more recent archaeological sites. In 1984, the nearly complete juvenile skeletal remains of an early hominid (KNM-WT 15000) were found at the site of Nariokotome in northern Kenya. This discovery accelerated research into comparative primate (and specifically hominid) dental and skeletal development. Shortly after, considerable debate was generated around the evolutionary timing and appearance of the extended growth period seen in modern humans (Bromage, Dean 1985, Bromage 1987, Mann *et al.* 1987, 1990, Lampl *et al.* 1993). Palaeoanthropology researchers recognised at that time that there was a need for an independent, chronological, and numerative method for judging the age at death of fossils so that comparative growth and development could be evaluated and compared between specimens and species.

The desired method has been found in microscopic methods for calculating the timing and duration of production of dental tissues, both before and after birth (Fitzgerald *et al.* 1999, Antoine *et al.* 1999). These methodologies have almost entered the mainstream of dental anthropology research. But the microscopic approach is invasive, still time consuming, and currently restricted to relatively small samples. In the field of bioarchaeology, or, the skeletal biology of more recent human populations, the radiographic assessment of the developing dentitions of subadults has become the accepted approach to evaluating age in large samples (Ubelaker 1989, Saunders 1992, Saunders, in print). While radiographic studies have been criticised and considered limited in their ability to precisely determine dental developmental events for fossils (Macho, Wood 1995) it will be some time before histological sampling of teeth from human populations in the present and in the past

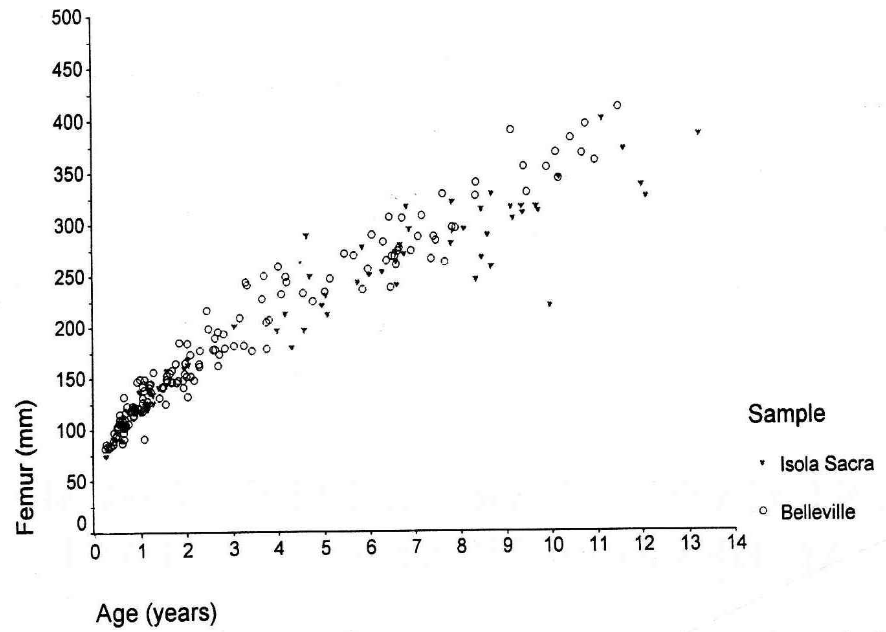

FIGURE 1. Comparisons of distributions of femur diaphyseal length plotted against MFH dental age estimates for Isola Sacra and St. Thomas', Belleville samples.

becomes widespread. Until that time, it is still worthwhile to investigate patterns of biological variability at several observational levels.

It remains to be clearly demonstrated whether inter-population genetic differences in dental development truly exist even for recent human populations. It has become almost paradigmatic to state that the formation of tooth crowns and roots is much less affected by hormonal influences, local and general environmental factors, nutrition, and social factors than is tooth emergence, skeletal development, weight or height (Demirjian 1978, El-Nofely, Iscan 1989, Smith 1991). Several early investigations found empirical support for a buffering of the dentition against environmental and physiological stress (Garn *et al.* 1965, Holz 1959, Green 1961). On the other hand, there are other studies which have firmly concluded that any inter-population differences in development are due to differences in nutritional status and health standards (Shapiro 1939, Niswander 1963, Nanda, Chawla 1966).

Part of the difficulty lies with the problem of obtaining sufficient samples for investigation. Archaeological samples are helpful in this regard because large samples of subadult skeletons can be radiographed without risk.[1)]

They also offer researchers better opportunities for investigating temporal and geographic variability. Comparisons of diaphyseal size in archaeological samples are considered to reflect patterns of skeletal growth. It is believed that inter-sample studies will highlight populations that were experiencing chronic growth stress. But before skeletal size can be compared across samples, chronological age must be estimated. Many previous studies have used ageing standards that were not consistent across samples (Saunders *et al.* 1993). More recently, subadult age estimations have been based on limited formation standards derived mainly from healthy white Europeans and North Americans (Schour, Massler 1940, 1941, Moorrees *et al.* 1963a, 1963b, Haavikko 1970, 1974, Prahl-Andersen, Roede 1979).

In an earlier analysis, we compared a group of subadult skeletons from the Imperial Roman period necropolis of Isola Sacra (SCR) to subadults from the large, 19th century St. Thomas' Anglican Church sample from Belleville, Ontario (Sperduti *et al.* 1997). The St. Thomas' sample has been identified as being close to modern North American standards of growth. Overall distributions plotting diaphyseal length against dental age (using the formation standard provided by Moorrees, Fanning, Hunt 1963a,b – MFH) show the two samples overlapping up to about eight years of age (*Figure 1*). After eight years there is a divergence with the Isola Sacra sample often having smaller-for-age individuals. This comparison assumes that the rate and patterns of dental development are the same between the two populations. Although all of them (MFH, St. Thomas' and Isola Sacra) are European in origin there might still be geographic and temporal differences in dental development between them. It is important to try to compare samples independent of a reference standard such as that provided by the MFH data.

[1)] The authors recognise some of the specific problems associated with radiographic studies. Attainment of a growth stage occurs at a moment in time never observed by an investigator (Smith 1991) and growth stages are artificially created phenomena. In addition, archaeological samples will always be cross sectional and never longitudinal. Nevertheless, the radiographic approach remains as the most accessible, non-destructive approach to investigating dental development.

In the last two decades, there have been some demonstrations of broad population differences in tooth development which are contrary to expected effects from environmental stress. African populations and Aboriginal North Americans (which might be shown to be environmentally disadvantaged) have been found to be advanced in tooth formation compared to Europeans and white North Americans (Chertkow 1980, Owsley, Jantz 1983, Harris, McKee 1990, Tompkins 1996). There are also more localised indications of maturation differences which might be interpreted as environmentally based. A modern study of tooth maturation in Sardinian children found the Sardinian children to be delayed up to one year relative to the MFH data for the six post-incisor mandibular permanent teeth (Diaz *et al.* 1993).

An interesting approach to investigating patterns of dental development is that taken by Tompkins (1996) who assessed the differences in patterns of dental development by directly comparing formation stages of various teeth relative to the attained maturation status of a reference tooth in three samples, French-Canadians, black South Africans, and a mixed group of Aboriginal North Americans. This method allows the use of undocumented archaeological samples since the knowledge of actual chronological age is not required. Patterns of formation can be searched for differences but the determination of the causes of any differences must be detected from other independent evidence. Tompkins observed delayed molar development in the French-Canadian sample when compared to the other two groups, in support of earlier observations of Chertkow (1980), Owsley and Jantz (1983) and Harris and McKee (1990). In the current study, we compared the formation of several deciduous and permanent teeth for the Isola Sacra and St. Thomas' samples relative to the attained formation status of a reference tooth to look for any evidence of population-based differences in dental development.

MATERIALS

The necropolis of Isola Sacra, about 23 km west of Rome, Italy, was used by the inhabitants of Portus during the second and early third centuries A.D. In A.D. 41, Emperor Claudius ordered the construction of a sea harbour north of the mouth of the river Tiber. The plan was to improve on Ostia, a river port, which did not permit anchorage in all weather and seasons. The new harbour was only completed by Emperor Trajan in the second century A.D. Portus served as the port of Rome directing important goods such as grain into Rome until the decline of the imperial city. The necropolis belongs to the period when Portus was in its prime. It is composed of a wide variety of burial structures such as sand, brick of wooden coffins, amphorae, and terracotta sarcophagi interspersed among monumental multiple tombs. The occupants of the necropolis generally represent a kind of "middle class" of merchants and tradespeople as well as freed slaves.

The skeletal sample includes approximately 2,000 individuals of both sexes and from all age groups. The subadult sample totals 800. This represents one of the most significant skeletal collections from Mediterranean Europe for the Classical period. Ironically, the amount of palaeobiological information available for Classical antiquity is insignificant, particularly when compared to the richness of existing archaeological, historical and literary evidence. For this reason, extensive study of the remains from Isola Sacra could provide considerable evidence about the lives, habits and deaths of "ancient Roman people."

St. Thomas' Anglican Church in Belleville, Ontario was founded in 1818 and its associated cemetery was used from 1821 to 1874 (Herring *et al.* 1994). The total burials in the cemetery numbered 1,564 of which 558 or 36% were represented by completely intact, observable skeletons (Saunders *et al.* 1995a). Of these, 282 (50.5%) were aged less than 15 years and 148 of these were judged to be infants under one year by general dental development (Saunders *et al.* 1995b). The teeth of 229 of the subadult skeletons were sufficiently preserved for this analysis.

The town of Belleville was settled by United Empire Loyalists (mainly British or American born) after the American Revolution as well as further waves of settlers from the United States after the War of 1812, again of mainly British origin. Further extensive waves of immigrants arrived in the area beginning in the 1830s and these were mostly from Britain (Herring *et al.* 1994, Saunders *et al.* 1995b). During the 53 years period of cemetery use, the town of Belleville began as quite small and rural but developed into an important manufacturing and commercial town of several thousand after 1850.

METHODS

Jantz and Owsley (1994) have developed a method for deriving schedules of dental development that are specific to populations. The first step is to estimate the birth length of each long bone using the perinatal distribution of bone lengths. This is designed to establish a chronological start point for development to which a second estimate of birth length, derived from age estimates associated with particular tooth development stages, is compared. By this means, the difference between presumed actual newborn size and newborn size based on an external dental development standard, can be compared. If two different archaeological samples are then compared, the method allows chronological age to be estimated from corrected dental ages so that skeletal growth can be evaluated. This method relies on the assumption that infants around the time of birth have the highest probability of dying. This is not necessarily true (see Saunders 1992, in print). In the St. Thomas' and Isola Sacra samples, as with many skeletal samples, there are no high concentrations of individuals around a particular long bone length that might identify

M1 Stages

Dm1 Stages	Ci-Cco	Coc	Cr½-Cr¾	Crc-Ri	Cli-R¼	R¼-R¾	Rc-A½
Crc-Ri	* oooo o	**** oooo oooo	*				
Cli-R¼	ooo	*** ooo	*** oooo oooo	o			
R½-R¾		o	**** **** **** *** oooo oooo oooo oooo oooo ooo	**** oooo oooo oooo o	oo		
Rc-A½			** o	**** oooo oooo oooo oooo	* oooo		

* represents one individual from Isola Sacra sample
o represents one individual from St. Thomas' sample

FIGURE 2. Comparison of mandibular deciduous m1 and permanent M1 stages of formation.

M1 Stages

Dm2 Stages	Ci-Cco	Coc	Cr½-Cr¾	Crc-Ri	Cli-R¼	R¼-R¾	Rc-A½
Cr½-Cr¾	* ooo	** o	*				
Crc-Ri	oooo o	*** oooo oooo oo	**** ** oooo oooo oooo o	*			
Cli-R¼			**** **** * oooo oooo oooo oooo o	* oooo oooo oooo			
R½-R¾			**** ** oooo	***** * oooo oooo oooo oooo	o	o	
Rc-A½				* oooo oooo	oooo oo	ooo	

* represents one individual from Isola Sacra sample
o represents one individual from St. Thomas' sample

FIGURE 3. Comparison of mandibular deciduous m2 and permanent M1 stages of formation.

newborns. Comparisons of relative dental development do not require estimates of chronological age and therefore, age estimations have not been used in this analysis.

The mandibular jaws of all individuals in the two skeletal samples were radiographed and evaluated. The mandibular teeth were chosen because of the difficulties with evaluating tooth formation from maxillary radiographs (Tompkins 1997). Both right and left teeth were originally evaluated but for the purposes of this study, only left teeth were used unless unavailable and then the right side was used.

The teeth were scored initially using the formation stages proposed by Moorrees and colleagues for deciduous (1963a) and permanent (1963b) teeth. They proposed 13

M2 Stages

M1 Stages	Ci-Cco	Coc	Cr½-Cr¾	Crc-Ri	Cli-R¼	R¼-R¾	Rc-A½
Crc-Ri	* o	*					
Cli-R¼		***	*** oooo o				
R½-R¾			**** *** o	**** oooo oooo o			
Rc-A½			o	**** * oooo oooo oo	**** **** oooo	***	

* represents one individual from Isola Sacra sample
o represents one individual from St. Thomas' sample

FIGURE 4. Comparison of mandibular permanent M1 and M2 stages of formation.

stages for deciduous teeth and 14 stages for permanent teeth. The St. Thomas' and Isola Sacra samples were each scored by one observer but separately. The observed scores were checked twice. Any discrepancies in determinations were re-checked and a final decision made on a score. The differences between scores that were observed were never greater than one stage. These resultant scores were then revised to conform to one of eight stages, comparable to the system developed by Demirjian and co-workers (1973), in order to increase sample sizes at any one stage. The comparison between the Moorrees and colleagues' stages (1963a,b) and those proposed by Demirjian and co-workers, is shown in *Appendix A*. For easier recognition by the reader, the comparisons have been reported in the figures and tables using the descriptive formation stages of MFH.

The two site samples were tested for differences in the frequency distributions of formation stages of selected teeth while holding a reference tooth constant at different stages of its development. Tooth comparisons with the largest sample sizes included the following: deciduous first molar (dm1) × first permanent molar (M1), deciduous second molar (dm2) × first permanent molar, and first permanent molar × second permanent molar (M2). The earlier developing tooth was used as the reference tooth in each comparison, e.g. dm1 × M1.

The samples contain both males and females since sex cannot be determined for these individuals. This raises the possibility that any observed differences between groups might be due to unequal sex ratios within groups rather than true between-group differences. Consequently, the comparisons of canine stages of formation to those of other teeth were not calculated since canines are the teeth that have been shown to have significant within-group sex differences in patterns of formation (Tompkins 1996).

The comparison of formation stages for the deciduous first molar against the first permanent molar covers an approximate period from birth to two years. The comparison of formation stages for the deciduous second molar against the first permanent covers an approximate

period from 6 months to three years. The comparison of formation stages for the first permanent molar against the second permanent molar covers an approximate period from 3 years to 9 years. Only a few researchers have so far presented patterned comparisons of tooth formation based on radiographs (Tompkins 1996, Liversidge 1998, Watt, Lunt 1998). In his study, Tompkins did not examine deciduous molars because of small sample sizes in the modern (and non-archaeological) groups, in contrast to what is found in archaeological mortality samples.

The Kolmogorov-Smirnov non-parametric two group test was used to test for differences in the observed frequency distributions of between-tooth formation stage comparisons between the Isola Sacra sample and the St. Thomas' sample. This test allows the investigator to examine all tooth stage comparisons at once rather than pairwise Mann-Whitney tests which only look at one stage of formation for the reference tooth at a time. Sample sizes for the groups in each test were always above thirty.

RESULTS

Figures 2 to *4* illustrate matrix comparisons of the number of individuals in the St. Thomas' and Isola Sacra samples with the stages of formation compared for two teeth. As can be seen, most cases from each site fall along the diagonal with only the occasional individual from either site falling far from the major clusters of tooth formation. These three visual comparisons suggest that there are no differences between the two sites in terms of patterns of tooth formation. However, it should be noted that for the comparisons of the deciduous first molar and the second deciduous molar to the first permanent molar it appears as if the Isola Sacra sample is behind at the last stage of formation of each deciduous tooth, Rc-A1/2. This is illustrated in *Figure 5* which shows the cumulative percentage frequencies of the paired tooth formation stages for dm1 × M1 and dm2 × M1 for each of the samples. It can be seen here that the greatest gaps in the comparisons of Isola Sacra to St. Thomas' are found between the last few tooth formation stage pairings.

The results of the Kolmorgov-Smirnov two group tests are presented in *Table 1*. It can be seen that there are no significant differences between the Isola Sacra and the St. Thomas' samples for any of the three teeth pairwise comparisons.

TABLE 1. Kolmogorov-Smirnov. Two group tests of tooth formation – comparisons for Isola Sacra and St. Thomas'.

Comparison	Probability	D.F.	Critical value at p = 0.05
dm1 × M1	0.3664	2	0.2665
dm2 × M1	0.2382	2	0.2617
M1 × M2	0.3811	2	0.3211

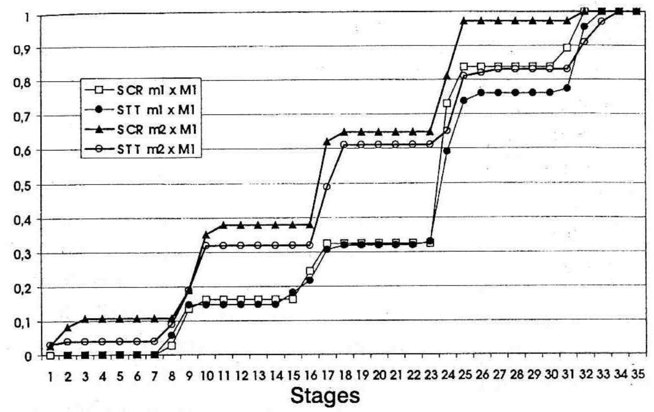

FIGURE 5. Comparison of cumulative percentage frequency distributions of tooth stage pairings.

DISCUSSION

This analysis did not discover any evidence of patterned differences in tooth formation between the Imperial Roman period Isola Sacra sample from Italy and the nineteenth century British-based sample from Canada. This suggests that any comparisons of skeletal growth between the two populations, using the same standards for dental formation, are valid.

It should be noted that observations of both the matrices of comparison of tooth formation stages which present the raw data (*Figures 2* to *4*) and a comparison of the cumulative percentage frequency distributions of the tooth stage pairings[2] (*Figure 5*) suggest there is a difference between Isola Sacra and St. Thomas' towards the end of M1 formation. The Isola Sacra sample lacks cases in the later stages of M1 formation, which suggests a delay in formation. But the statistical analysis indicates that this difference is not significant. A closer inspection of *Figure 1* shows that a deficiency of cases in the Isola Sacra sample at around three years of age accounts for the gap. This should serve as a reminder to researchers that biases in archaeological mortality samples may sometimes mimic apparent biological differences.

The absence of any differences in patterns of dental development between the two samples negates any expectations either of micro-level genetic differences in dental development between populations or differences due to environmental factors that might affect dental formation.

Tompkins (1997) found broad population differences in dental formation patterns between native Americans, French Canadians and black South Africans. Watt and Lunt (1998) also report differences between a Scottish sample and the French Canadian sample studied by Tompkins. The

[2] For example, for the comparison of Isola Sacra to St. Thomas' of dm2 × M1 when the dm2 stage is Crc-Ri and the M1 stage is Cr½-Cr¾ the cumulative percentages are 35% (SCR) and 32% (STT).

Isola Sacra and St. Thomas' samples, although both of European origins, are widely dispersed in both space and time. It would be worthwhile having further information on more geographically localised populations over time to search for environmentally based differences in dental development.

Returning to the skeletal data, we can say that there are no obvious differences between the two samples in patterns of skeletal size increase. The St. Thomas' sample has previously been shown to be similar to modern North American children in terms of skeletal size increase. The Roman sample does not fall short of the St. Thomas' sample until about 8 years of age. Since the correlation between final stature and stature during childhood increases dramatically into late childhood (Tanner 1978), and early childhood is the more risky period in terms of chronic growth stunting, this would suggest that the Roman sample becomes shorter at 8 years due to a reduced growth potential for genetic reasons. It does not rule out the possibility of the influence of environmental factors on skeletal growth in the Roman sample. Other investigations of the sample have identified the presence of chronic diseases affecting the skeleton (Rossi *et al.* 1999). But the absence of substantive differences in diaphyseal size between the Isola Sacra sample and St. Thomas' at early ages, in contrast to other studies (Hoppa 1992, Saunders *et al.* 1993) suggests that there was ample opportunity for catch up growth. This could be investigated further by examining other aspects of development in these two samples. Further research on the Isola Sacra sample will take this approach.

MFH Decid.	**MFH Perm.**	**Demirjian**
	Ci	A
Cco	Cco	A
Coc	Coc	B
Cr1/2	Cr1/2	C
Cr3/4	Cr3/4	C
Crc	Crc	D
Ri	Ri	D
Cli	Cli	E
R1/4	R1/4	E
R1/2	R1/2	F
R3/4	R3/4	F
Rc	Rc	G
A1/2	A1/2	G
Ac	Ac	H

APPENDIX A.

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Shelley R. Saunders
Department of Anthropology
McMaster University
1280 Main St. West
Hamilton, Ontario
Canada L8S 4L9
E-mail: saunders@mcmail.mcmaster.ca

Robert D. Hoppa
Department of Anthropology
University of Manitoba
Winnipeg, Manitoba
Canada, R3T 2N2

Roberto Macchiarelli
Luca Bondioli
Museo Nazionale Preistorico
Etnografico "L. Pigorini"
P. le Marconi 14
Rome, Italy