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Environmental Effects on Skeletal Versus Dental Development: Using a Documented Subadult Skeletal Sample to Test a Basic Assumption in Human Osteological Research

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ABSTRACT This study examines the relationship between measures of skeletal and dental development and socioeconomic factors in a 20th century documented skeletal sample of children from Portugal. The skeletons are of known sex and chronological age, and include other biographic data, such as cause of death. Growth in the length of the long bone is used as a measure of skeletal growth, and schedules of tooth formation are used as a measure of dental development. These two measures of physiological age were compared to chronological age, to assess growth and developmental status. Socioeconomic indicators were obtained from the supporting documentation, and include the occupation of the father and the place of residence, which were used to build a socioeconomic classification based on two groups, one of low and the other of high socioeconomic status. Growth and development status was then compared in these two groups. Results show that socioeconomic differences are much more pronounced in skeletal growth than in dental development. This largely supports the assertion that dental development is buffered against environmental factors relative to skeletal development. However, in this study, skeletal maturation could not be assessed, and findings indicate that dental development can show significant delays at the lower end of the socioeconomic gradient. Am J Phys Anthropol 132:223–233, 2007.

A basic assumption in human osteological research is that dental development is less influenced by environmental insults than skeletal development, and thus considered the best indicator of chronological age (CA) in human skeletal remains from archaeological populations and forensic contexts, while skeletal development is more affected, and thus provides a measure of growth faltering and health differentials between archaeological populations. In estimating CA of immature skeletal remains, researchers note that their skeletal (SA) and dental age (DA) assessments are actually physiological age assessments. If more than one indicator is available, researchers assume implicitly or explicitly that teeth provide more accurate CA estimations than does bone (Ubelaker, 1987, 1989). The question of age accuracy is put aside in growth studies of past populations, by assuming that the most useful comparisons of any group are between the two physiological indicators of maturation: DA, which is more stable, and SA, which is more sensitive to environmental influences (Saunders et al., 1993). DA is typically used as a standard by which one can judge whether skeletal growth corresponds to the "normal" rate of development (Johnston and Zimmer, 1989; Hoppa, 2000; Humphrey, 2000; Saunders, 2000). The demonstration of differential growth between samples is used as an evidence for differential health status between entire populations, either temporally or geographically (Johnston, 1962; Hoppa, 1992; Saunders et al., 1993; Lewis, 2002; Pinhasi et al., 2005). However, Merchant and Ubelaker (1977) also showed that, when different age determination methods were applied to a single sample, they produced distinctive growth curves, indicating that inaccuracy of age estimates also contributes to substantial error in growth studies of past populations.

The assumption that dental development is not as affected by environmental influences as skeletal development is supported by a number of sources. Some of the most widely cited papers are the study by Lewis and Garn (1960) and the literature reviews by Demirjian (1986) and Smith (1991). Lewis and Garn (1960) used roentgenographic data collected from the Fels Longitudinal Growth Study (Antioch College, Yellow Springs, Ohio) and found less variability, as assessed by the coefficient of variation, in dental development than in skeletal development. Tooth formation was less variable than tooth eruption, which in turn was less variable than skeletal maturation at the hand-wrist and at the appearance of ossification centers. In a similar study, Demirjian et al. (1985) evaluated the interrelationships between somatic, dental, skeletal, and sexual maturity in a longitu-

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dinal study of North American children and adolescents, and found that peak height velocity was the most variable measure of maturity, followed closely by the appearance of the ulnar sesamoid, whereas tooth formation and menarche were the least variable measures. Greater delays in skeletal maturation than tooth formation, in children with major abnormalities affecting growth and congenital diseases, have also been used as evidence for the lower sensitivity of dental development. For example, Garn et al. (1965) reviewed a series of North American children with growth disorders of varying etiologies, including hypothyroidism, celiac disease, and anemia, and found that, in general, the degree of delay in tooth formation of this mixed group was approximately one-third the magnitude of skeletal delay. Similar delays in skeletal development over dental development have been observed in cases of hypopituitarism (Edler, 1977), short familial stature (Vallejo-Bolaños and España-López, 1997), cerebral palsy (Ozerovic, 1980), and β-thalassemia major (Laor et al., 1982). Finally, the differential effect of socioeconomic status (SES) on dental and skeletal development has also been used to support the assumption of greater environmental sensitivity of skeletal growth and maturation. However, studies that report socioeconomic differences in dental and skeletal development are rare, and only examine tooth emergence and not tooth formation. In one example, Garn et al. (1973a,b) examined the relative impact of socioeconomic differences on permanent tooth emergence and postnatal ossification in nearly 10,000 North American children between 4.5 and 16.5 years. Overall, the income-related delay in dental development was less than was observed for ossification timing. While the mean overall delay in tooth emergence between the low- and high-income group was 0.098 years, the mean delay in skeletal maturation was 0.28 years. An analogous study was carried out by Low, Chan, and Lee (Low et al., 1964; Lee et al., 1965), who examined a sample of Chinese children in Hong-Kong from three different socioeconomic backgrounds (high, middle, and low). These researchers arrived at similar results: while the mean difference in eruption age between the high and low socioeconomic groups was 0.23 years in males and 0.27 in females (Lee et al., 1965), low SES boys and girls were skeletally delayed by an average of 2.56 and 3.06 years relative to the high SES group (Low et al., 1964).

Although there is considerable evidence that dental development is less susceptible to environmental influences, these studies use many approaches to measure skeletal and dental development, and most focus on aspects of physiological development that are not accessible in skeletal samples. For example, studies frequently rely on tooth emergence, which focus on gingival emergence, to determine DA, and rely on changes in ossification centers of the hand and wrist to determine SA. Gingival emergence and skeletal maturation of the wrist and hand cannot be determined in skeletal material. Another problem is that there is a paucity of studies that examine dental and skeletal development against socioeconomic and nutritional status or even disease, other than congenital or of genetic origin. In addition, several of the studies rely on correlations of dental with skeletal maturation carried out in controlled clinical settings with living children, where examination of the potential effects of powerful environmental influences, such as malnutrition and chronic illness, cannot be carried out. Few studies have looked at environmental effects on skeletal and dental development in documented skeletal samples. Although this is related to the scarcity of subadult documented samples, these studies have only provided broad intersample comparisons (Bowman et al., 1992; Molleson et al., 1993; Liversidge, 1999; McVeigh, 1999). The issue of how dental and skeletal development are measured and compared is particularly important, since several researchers seem to imply that dental development is free from environmental influences.

In this study, a simple and straightforward hypothesis is tested, where skeletal and dental development are seen as deviations from an expected norm, and SES is seen as the main environmental factor contributing to such variation. If skeletal development is more sensitive to environmental factors than does dental development, then skeletal development will show greater deviations from the norm in depressed or poor environmental conditions. Deviations from normal development as a result of negative effects of SES may be expressed as a delay in the age at which maturation events are attained (timing of development) or as a reduction in the potential for growth at each stage (intensity of growth). To test the hypothesis, skeletal, dental, and documentary evidence was collected from a subadult sample of the "Lisbon Identified Skeletal Collection." Documentary data provided information about SES and then dental and skeletal development were compared across socioeconomic groups.

MATERIALS

The Lisbon collection

The Lisbon identified skeletal collection is housed at the *Bocage* Museum (National Museum of Natural History), Lisbon, Portugal. A more detailed description of its composition and history can be found in Cardoso (2006). Briefly, the collection is composed of over 1,700 skeletons at various stages of the curation process but, at present, only around 700 are available for study. It was collected between the late 1980s and 1991, and represents the remains of Portuguese individuals who died in Lisbon between 1880 and 1975. Sex, age at death, cause of death, and nativity are among the kinds of information available for most individuals in the collection. Ages at death range from birth to 98 years and both sexes are equally represented, females showing only a slight overrepresentation. The total subadult segment of the collection amounts to 126 skeletons (<21 years old), representing an increase from the 92 initially available, which results from the new acquisitions process initiated in 2000 (Cardoso, 2006). Most of the individuals represent the middle to low social class of the city of Lisbon, as inferred from the origin of the remains (temporary graves) and from the reported male occupations (Cardoso, 2006).

The study sample

The baseline sample is composed of 126 individuals younger than 21 years of age: 58 females and 68 males. The skeletons were selected on the basis of their preservation, completeness of their documentary information, and ancestry. This means that all individuals were born in Portugal and had at least one Portuguese-born parent. However, owing to differential preservation, the type of data collected, and analyses performed, sample sizes in the comparisons vary. Biographic information on the

Fig. 1. Age structure of the sample (n = 126).

subadult skeletons include name, age at death, cause of death, date of death, address at the time of death, nativity, name of parents, and several sorts of administrative data obtained from the cemetery records. Unlike the adult segment of the collection, death and birth records were obtained from civil registration offices for most of the children, which allowed for cross-checking of the information from the cemetery records, which is the source for the collection records. Access to death and birth records also provided access to additional biographic information. This includes date of birth, occupations of the parents at birth and death of the child, address at the time of birth, name and nativity of grandparents. Birth and death records allowed the calculation of exact calendar age, which was then converted into decimal age. Given that some concerns may be raised regarding the accuracy of age at death, it was necessary to validate such information. A measure of the accuracy of ages at death was obtained by cross-verification of the reported age in the death record with the difference between dates of birth and death. No gross discrepancies were detected between reported age at death and age obtained from subtracting the date of birth to the date of death, except for two cases which showed a 1 to a 3-year difference and, therefore, were not included in the analysis. Three other individuals showed only minor inconsistencies when comparing dates of birth and death to reported age at death, because of rounding off the calendar age in the death record. Individuals whose date of birth was unknown were also eliminated from the analysis.

The age structure of the baseline sample is depicted in Figure 1. The study sample spans almost a century, from 1887 (the earliest year of birth) to 1975 (the latest year of death), but most individuals were born between 1920 and 1940, while the distribution of years of death has a strong peak during the 1940s. All individuals in the study sample died in Lisbon or had their death registered in Lisbon (in cases of out-of-town children who were autopsied). Most of the children were also born in Lisbon (66%) and only two were born abroad. The epidemiological profile of the study sample indicates a significant influence from infectious diseases. Thirty nine percent of all individuals died of some form of tuberculosis, and the majority, prominently adolescents, died of pulmonary tuberculosis. The next most important causes of death are diseases of the respiratory system, mostly respiratory infections.

Putting the sample in context

The temporal time frame for the study sample is roughly 1900–1960, and during most of this period, Portugal remained a very isolated and underdeveloped society, where prevailing economic and social conditions were still those of the late 19th century. The geographical isolation of the country and its regions preserved a very traditional society. Portugal emerged from the 19th century as a declining world political power, with a fragile agricultural system, incomplete industrialization, a weak capitalist system, and a centralized and strong catholic church. Despite some initial promises of modernization from the early liberal movements, the establishment of a republic state in Portugal in the early 20th century and the rise of a dictatorship in 1933 established a strong state which, together with a weak aristocracy, an incipient bourgeoisie, and the absence of egalitarian and democratic traditions, reinforced the closed nature of the country. It was not until the 1960s, with economic liberalization, and then in the 1970s, with the shift from a dictatorial government to a democratic pluralist political system by a military coup, that outstanding improvements in economic and social welfare were accomplished (Tortella, 1994).

Portugal experienced a late and incomplete industrialization and, by the early 20th century, the majority of farmers were still practicing subsistence agriculture with little motivation for the establishment of industrial and capitalist economies (Giner, 1982). The majority of industries were small and familial or of traditional sectors, and the labor force was predominantly illiterate, with few or no technical skills, supported by women and child work and with no free association rights. Later in the 20th century, the decrease in the population working in the primary sector was not so much a consequence of increased productivity in the secondary and primary sectors, but of increased migration to urban centers and employment in the tertiary sector (Maia, 2001). Because industrialization arrived late, some of the class changes associated with rapid economic development did not appear until the late 19th century. Nevertheless, the emerging middle class joined the elite as the upper class, and the working class was kept down as a sort of urban "peasantry." In this way, the essentially conservative and two-class system of Portugal was perpetuated even into the era of industrialization, where structures of power and social relations were also ruled by catholic principles, such as manorial economic and social relationships. In addition, during the dictatorship, educational innovation lagged, illiteracy remained high, and vocational training was almost nonexistent. In 1900, only 22% of the Portuguese population were able to read or write and, by 1960, 38% of the population were still illiterate (Tortella, 1994). The strong Catholicism of the Portuguese was also reflected in social and cultural life. Traditionally, Portuguese notions of authority, hierarchy, and morality stemmed from Roman Catholic teachings, particularly during the dictatorship years. For example, the educational, health care and welfare systems were long the main sphere of the church's influence and private charity associations. Although they provided care for the most underprivileged members of society, such as the sick, poor, widows, and orphans, the family was still the basis for their support and well being (Reher, 1998). The constitution of 1933 included the promotion and support of private social assistance institutions but not the creation of a state-financed national social security system (Cardoso and Rocha, 2002). This implied an absent welfare state, whose only responsibilities were to frame and supervise the private system. Only the urban working class had limited welfare coverage from private insurance companies and professional associations. The countryside effectively did not receive benefits. Living conditions were particularly difficult for the poor and working classes, particularly in Lisbon, where overcrowding and unsanitary environments were the norm.

From the conditions described earlier, it is no surprise that health conditions in Portugal were long among the poorest in western Europe. In 1920, life expectancy at birth was 35.8 and 40.0 years for men and women, respectively (Instituto Nacional de Estatística, 2001). The situation had improved substantially by 1960, when life expectancy reached 60.7 for men and 66.4 for women (Instituto Nacional de Estatística, 2001). Such relatively low ages for life expectancy are related to high rates of infant mortality. By 1900, approximately half of the children died before reaching the age of 15, and infant mortality rates hit 200 deaths per 1,000, remaining very high up to the 1940s (Bandeira, 1996). By 1965, the infant mortality rate had dropped to 64.9 per 1,000 (Instituto Nacional de Estatística, 2001), but in Lisbon, infant mortality rates were among the highest in the whole country. The period after the 1960s experienced another more important decrease in infant mortality rate (Bandeira, 1996). The main causes of death during the fist half of the 20th century were infectious or communicable diseases (Morais, 2002), reflecting a third world pattern. Only between 1940 and 1960 did this pattern start to change. It was more marked in the cities where living conditions were poor. However, death and morbidity due to tuberculosis was still a major public health problem in the 1970s (Ferreira, 1990), and mass vaccination against some of the most common childhood infectious diseases only started in the 1960s (Gomes et al., 1999).

METHODS

Measuring growth and development

Measuring environmental effects on growth and development of the skeleton and dentition involves the identification of cases of growth deficit or delayed development. The designation of a child as having impaired growth or delayed development implies a comparison of the child's CA with a measure of physiological age. This comparison represents the level of physiological development or physical maturity, showing how much a given individual has progressed along his or her developmental path, regardless of his or her CA. Physiological age is estimated by using standards that describe age levels of maturation or physical development in a group of "normal" healthy representative children, which represent the "reference" age at which these children attain specific levels of maturation or physical development. Because, in the reference children, CA is the same as the physiological age, CA is the norm against which deviations in physiological (skeletal and dental) age are detected in the study sample. A child is said to be advanced if physiological age overestimates CA, and otherwise a child is said to be delayed. To determine growth status of the children in the study sample, simple discrepancies of skeletal (SA-CA) and dental age (DA-CA) with CA are used. Since these discrepancies are simple subtractions, a positive score indicates that SA or DA is in advance of CA, whereas a negative score indicates that SA or DA lags behind CA. Because the appropriate sex- and age-specific standards are applied, discrepancies between physiological and CA allow all individuals to be analysed jointly, reducing the problem of sample size, by controlling for sex and age of the children.

In this study, physiological age is measured as levels of attainment of bone size (skeletal age) and of levels of attainment of dental maturity (dental age). SA was estimated as the age at which femur length was attained relative to the average femur length provided by Maresh (1970) for each sex and age group. Femur length was measured on the left side using an osteometric board and recorded to the nearest whole millimeter. Femur length data in the study sample were then compared to the reference data of Maresh (1970). Because only diaphyseal lengths were measured, only children under 12 years of age were selected, since this is the age beyond which long bone measurements in Maresh's (1970) tables include the epiphysis. Children under 6 months of age were also eliminated from the analysis, because Maresh's data are not appropriate for this age group, and it is the age at which linear growth faltering is usually identified (Martorell et al., 1994; Shrimpton et al., 2001). One problem with Maresh's (1970) data is that it was obtained from radiographs of living subjects and, therefore, there is a certain amount of radiographic enlargement (Maresh, 1970). The appropriate correcting factors were estimated from Feldesman (1992) and were used to estimate true femur length from Maresh's (1970) data.

DA was calculated as the arithmetic mean of ages obtained for every available tooth, according to the sex-specific values for age prediction of the Moorrees et al. (1963a,b) data adjusted for the Demirjian et al. (1973) and Demirjian and Goldstein 1976) eight-stage maturity scale. The purpose of this transformation was to overcome problems in the Moorrees et al. scheme that refer to the inability to differentiate between two successive stages if they are only marginally different, and unfeasible assessments of stages based on proportions of completed root, when final root length is unknown. The additional advantage of the transformation is that variation in age estimation using the eight-stage modification of the Moorrees et al. (1963a,b) standards was not significantly different from variation in age estimation using the original 14-stage scheme. First, the Moorrees et al. method was adjusted for Demirjian's stage scheme according to McVeigh (1999), using mean ages of attainment interpolated from the graphic charts of Moorrees et al. (1963a,b) for the mandibular teeth. Moorrees' stages (M) were combined into Demirjian's stages (D) using the criteria on Table 1.

Then, if one stage in Demirjan's method corresponded to one stage in Moorrees' method, the corresponding age of attainment was used, but if one stage in Demirjian's method corresponded to two stages in Moorrees' method, the average of the two corresponding ages of attainment was calculated. Mean ages of attainment for deciduous and permanent tooth development of Moorrees et al. (1963a,b) data adjusted for eight stages were recalculated as age prediction, according to the method suggested by Smith (1991). Observation of the stage of tooth formation was carried out by radiographic assessment or

TABLE 1. Criteria for the transformation of Moorrees et al. (1963a,b) stages of dental development into Demirjian et al. (1973) stages, according to McVeigh (1999)

Moorrees et al. (1963a,b)	Demirjian et al. (1973)
Initial cusp formation	Stage A
Coalescence of cusps	
Cusp outline complete	Stage B
Crown ½ complete	Stage C
Crown ¾ complete	
Crown complete	Stage D
Initial root formation	
Initial cleft formation (molars)	Stage E
Root length ¼	
Root length ½	Stage F
Root length ¾	
Root length complete	Stage G
Apex ½ complete	
Apical closure complete	Stage H

macroscopic assessment of loose mandibular teeth. Periapical radiographs were taken and mandibular teeth were chosen, because problems with radiographic image distortion and superimposition are far less than with maxillary teeth (Tompkins, 1997). All teeth were observed in the lingual–buccal plane, and only when the root was visible in this plane was the tooth recorded as having root initiation. Only left teeth were scored, except when they were missing, and in these cases the antimere was used instead. Age range was truncated at 12 years of age because of the upper age limit of Maresh's (1970) femur growth data.

The reference samples used in the construction of the standards for physiological age estimation are all roughly contemporaneous with the children in the study sample and are of high SES. Maresh's (1970) data derive from the Child Research Council of Denver longitudinal study and Moorrees et al. (1963a,b) data derive from a sample of children from the School of Public Health Harvard University Study, but mainly on the children from the Fels Longitudinal Growth Study. All samples are considered to be of middle to high SES (McCannon, 1970; Garn, 1980; Roche, 1992). The study sample can be considered to be drawn from a population under more adverse environmental conditions, whereas the other reference samples represent more privileged populations.

Measuring socioeconomic status

In human societies, SES is seen as the mediator of the risks and benefits people receive from their environments by stratifying human populations into groups that expose individual health to either positive or negative environments. In this context, SES mediates the relationship between human development and access to essential resources, such as nutrition and health care, which promote healthy growth and development. Comparing the growth of infants and children from subgroups within a population that differ in exposure to adverse environmental conditions is particularly useful for understanding variations in growth status due to environmental influences. Such comparisons assume that children in a higher socioeconomic group have preferential access to fundamental resources, such as better nutrition, sanitary living conditions, and health care, than do children in the lower socioeconomic group. They also assume that all individuals in the sample come from a similar genetic pool, and any differences in growth and development that may arise are the result of the interaction of different environmental circumstances with the unique genetic makeup of each individual.

The choice of measures of SES was limited to the accessibility of documentary data that could be attributed to the socioeconomic circumstances of each individual in the study sample. The occupation of the father and the place of residence were considered as the most relevant measures of SES. Owing to problems of sample size, sampling of socioeconomic groups, and overall socioeconomic classification, SES was treated as a rough dichotomy to differentiate between high and low SES individuals.

The occupation of the father has been used extensively to measure socioeconomic differentials in child growth and development, health, and morbidity or mortality studies. Information about occupation relies on the fact that it serves as the basis from which salaries and wages are derived, it grants its occupant authority and control over others and resources, and differential prestige is attributed to various occupations, thus representing a good measure of social inequalities in a society. Occupation of the father was collected from the child's birth record, but when there was missing information, the death record was used instead. Because social migration of the father during the child's life may occur, the father's occupation at birth of the child may be of a lower (or higher) socioeconomic condition than at death. However, comparing the classification of occupations in the birth and death records showed that there were no significant differences between the SES scale of occupations at the time of birth and death of the child. The only differences resulted in the same SES level change in occupations. For example, one of the fathers was a servant at the time of his child's birth, and at death he had become a roadmender. Father's occupations were classified, according to the British 1951 Registrar's General, as six major groups of occupations (I, professional; II, intermediate; III, skilled nonmanual; IV, skilled manual; V, partly skilled; VI, unskilled), which is considered a good measure of social stratification (Armstrong, 1972). This classification intended to capture the economic and social stratification of a society that was experiencing rapid urbanization, and some of the changes associated with industrialization, such as an emerging working class, but also that kept several features of a pre-industrial social structure, expressed in an important influence of the rural world and a minority of people employed in great industries. On the basis of these principles and to facilitate the analysis, the occupations were then allocated to one of the two broad occupational categories labeled nonmanual (groups I, II, and II) and manual (groups IV, V, and VI). Children whose father had a nonmanual occupation were classified as high SES, whereas children whose father had a manual occupation were classified as low SES. Owing to social and economic trends, the same occupation may not represent the same socioeconomic segment in the early and late 20th century. In order to adjust for this effect, occupations were classified as nonmanual (high SES) or manual (low SES) according to the earlier criteria for individuals born between 1920 and 1940. For individuals born before 1920, only upper nonmanual occupations (such as professional or administrative occupations) were classified as high SES, whereas for individuals born after 1940, only manual unskilled occupations were classified as low SES. The period between 1920 and 1940 represents the temporal mode of the sample and a time of relative stability in social and economic life in Portugal. The years before 1920 are largely characterized by periods of instability and depression associated with the decline of the monarchy and the civil unrest that followed the proclamation of Portugal as a republican state in 1910. The period after 1940 represents a time of some changes in socioeconomic conditions that followed World War II and the maturity of dictatorship.

Information on place of residence was linked to aggregate statistical data to provide an area measure of SES. Using the administrative subdivisions (*freguesias*) of Portuguese urban municipalities, where each individual lived and published aggregate-level statistical data available for each area, a socioeconomic typology was built to reflect the social and economic stratification of these areas. This typology was then used to allocate children in the sample to two broad (high and low) socioeconomic groups, according to their place of residence. Place of residence provides socioeconomic information at a different level from the occupation of the father, since using area-level data to measure individual SES means that individuals are ranked according to their residential area variables and not according to their own characteristics. To build the socioeconomic typology, first, only the administrative areas (*freguesias*) represented as place of residence at the time of birth were selected. Because the study sample spans more than 5 decades, the classification needs to incorporate information about decade of birth. This meant that all areas had to be disaggregated by decade and analysed separately. A survey of the available historical statistical data showed that the only sources of usable area-level data were the Portuguese decennial census and the demographic annals, which, when corrected for inconsistencies of dates, only provided information for the city of Lisbon and the city of Porto *freguesias* in 1911, 1920, 1930, 1940, and 1950. Therefore, only the *freguesias* of the children, whose place of residence at the time of birth was Lisbon or Porto, could be used in the analysis. If the child was born outside of Lisbon but the place of residence at the time of death was in Lisbon, the appropriate *freguesia* was used instead. This meant that 27 Lisbon *freguesias* and one Porto *freguesia* were considered and disaggregated in 5 decades, in a total of 143 areas (each *freguesia* is represented five times, except one which is represented only three times). According to the available aggregate-level statistical data, four variables were chosen as the indicators of socioeconomic conditions of the *freguesia* of residence, an illiteracy rate and three crude mortality rates: mortality due to diarrhoea and enteritis in children under 2 years of age, mortality due to pulmonary tuberculosis, and mortality due to violent events. The basis for the choice of variables is that individuals of lower SES are at greater risk of poorer education, higher mortality, and fatal injury (Michelozzi et al., 1999; Cubbin et al., 2000; Lienhardt, 2001, Krieger et al., 2003). The methodology that was followed to combine *freguesias* into two groups of distinct socioeconomic position was similar to that suggested by Chow (1998). The four socioeconomic indicators for the 143 *freguesias* were first examined using exploratory factor analysis. The factor analysis method used was the principal components and classification analysis, to extract a minimum number of factors that would retain a large percentage of the variance and eliminate the problem of co-linearity of variables. Two factors were retained, and explained 78% of the variance. The factor scores of each *freguesia* were then used to group similar *freguesias* by cluster analysis. The *k*-means method was preferred, because it is a nonhierarchical partitioning method, and it allows the user to predefine the number of cluster, which in this study are two (high and low SES). Two groups were obtained from the clustering of the two factor scores, and the cluster that reflects the lower extreme of all variables (highest mortality rates and highest illiteracy rate) was considered the low socioeconomic group, whereas the other reflected the opposite extreme of variable values and therefore was considered the high socioeconomic group. According to the socioeconomic groups obtained, each individual was classified as high or low SES according to the socioeconomic condition of the *freguesia* of place of residence at birth and the decade closest to the date of birth, irrespective of the age at death. Individuals that were born outside of Lisbon, but that died in the city were classified according to their death *freguesia* and to the decade closest to the date of birth. Owing to improvement in living conditions and truncated data, individuals born before 1911 could only be allocated to a statuses, if the *freguesia* of place of residence was classified as low in 1911, and individuals born after 1950 could only be allocated if the *freguesia* of place of residence was classified as high SES in 1950. Due to geographic heterogeneity of *freguesias*, some were classified as high SES, but individuals living in those areas were living in neighborhoods identified as for the lower classes. This was the case for seven individuals, who were initially classified as living in areas of high SES, but subsequently reclassified as living in areas of low SES according to the address or place of residence.

Analytical approach

While many exogenous factors can affect growth and development, in discussions of environmental influences, the main premise is the selection of groups within a population that differ in socioeconomic conditions. In this study, socioeconomic comparisons were performed within groups of the study sample, and the existence of differential effects of environmental factors on growth and development was inferred from group differences. Intra-sample assessment was carried out by comparing discrepancies between SA or DA and CA (SA-DA or DA-CA) in high and low SES groups. The significance of the differences between these two groups was tested with two-tailed *t*-tests. Although there may be concerns about assumptions of normality and heterocedasticity of the data, the *t*-test is robust enough to allow for departures from its theoretical assumptions (Zar, 1999). Because there may be some concerns that the variance in the DA assessment when using multiple teeth may add considerable noise to the inference that differences between DA and CA are environmental, the mean within individual standard error of DA estimates and the standard error of the difference in DA-CA between SES groups was calculated. The use of multiple teeth should only be adding considerable noise to a significance test for differences in DA-CA between SES groups, if the mean within individual standard error of DA estimates is considerably greater than the standard error of the difference in DA-CA between SES. Another concern was to ensure that there are no significant differences in the mean age between the low and high SES groups. Because the groups may not have comparable demographic profiles due to greater magni-

TABLE 2. Age distributions (in percentage) for the two socioeconomic status (SES) groups defined by the occupation of the father and by the place of residence

Age group (years)	Occupation of the father		Place of residence	
	Low SES	High SES	Low SES	High SES
<0.99	0.0	4.2	8.3	2.8
1.00–1.99	13.8	29.2	8.3	30.6
2.00–2.99	6.9	16.7	8.3	13.9
3.00–3.99	3.4	4.2	8.3	5.6
4.00–4.99	17.2	4.2	8.3	11.1
5.00–5.99	10.3	4.2	16.7	5.6
6.00–6.99	3.4	0.0	0.0	0.0
7.00–7.99	6.9	4.2	0.0	2.8
8.00–8.99	0.0	4.2	25.0	0.0
9.00–9.99	13.8	0.0	0.0	2.8
10.00–10.99	10.3	8.3	8.3	5.6
11.00–11.99	6.9	16.7	0.0	13.9
12.00–12.99	6.9	4.2	8.3	5.6

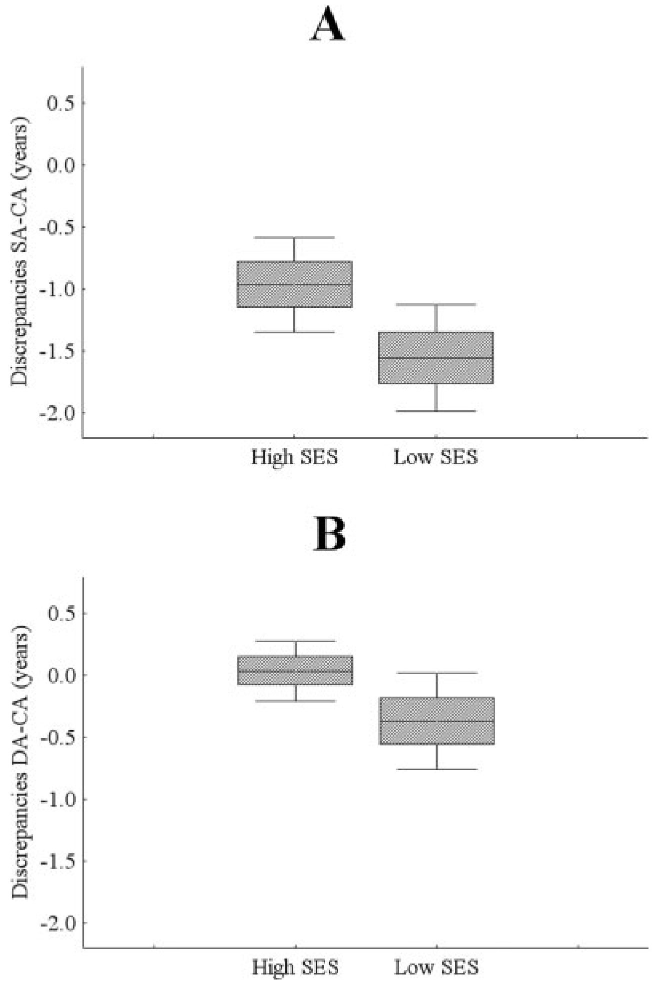

Fig. 2. Box plots for the distribution of discrepancies between SA and CA (graph A; $n_{\text{high SES}} = 20$, $n_{\text{low SES}} = 23$), and between DA and CA (graph B; $n_{\text{high SES}} = 21$, $n_{\text{low SES}} = 25$). SES groups are based on the classification of the father's occupation. The mean is represented by the line, the box includes the mean ± the standard error, and the whiskers the 95% confidence interval for the mean.

tude in growth deficit of older children (i.e. accumulated deficit over more years) and to the fact that one would expect fewer older children from high SES to have died (i.e. selective mortality), it was important to determine the age structure of each socioeconomic group.

RESULTS

The age structure of each socioeconomic group is depicted in Table 2. Although there is a slight tendency for the higher socioeconomic groups to show a higher proportion of younger children, the age structures are largely comparable, as mean age does not differ between low and high socioeconomic groups for the SES classification, based either on the occupation of the father ($t = 1.16$, $P = 0.2597$, d$f = 49$) or on the place of residence ($t = 1.11$, $P = 0.2741$, d$f = 46$).

The box plots in Figure 2 show the distribution of discrepancies of SA and DA relative to CA when SES was determined on the basis of the occupation of the child's father. Graph A, which shows the distribution of discrepancies between SA and CA, illustrates the socioeconomic differences in skeletal growth. A t-test shows that the socioeconomic differences are significant ($t = 2.07$, $P = 0.0451$, d$f = 41$), with the low SES group showing an average deficit in SA of 0.63 years relative to the high SES group. It should be noted that discrepancies between SA and CA are always negative, indicating an overall and consistent growth deficit relative to the reference population (Maresh, 1970). The high SES group shows an average deficit of 0.94 years relative to the reference, whereas the low SES group shows an average deficit of 1.57 years.

Comparatively, graph B illustrates socioeconomic differences in dental development. Statistically, there are no significant differences in dental development between the high and low SES groups ($t = 1.85$, $P = 0.0705$, d$f = 44$). This was the only comparison where nonequal variances were detected (Levene test = 14.80, $P = 0.0040$). Owing to different group variances, the t-test for unequal variances was calculated, but the differences between SES groups still failed to reach statistical significance. However, the results are only marginal at the 0.05 significance level, and on average, the low SES group shows a dental delay of 0.47 years relative to the high SES group. This may suggest in fact real differences between the SES groups. Overall, there is only a slight dental delay in the sample relative to the reference population (Moorrees et al., 1963a,b). Compared to the reference, the high SES group shows a slight advancement of mean 0.13 years, whereas the low SES group shows a mean delay of 0.34 years.

The box plots in Figure 3 show the same data as in Figure 2, when socioeconomic groups are defined according to the classification of place of residence. Graph A shows clear socioeconomic differences in skeletal growth, and a t-test confirms that they are highly significant ($t = 3.77$, $P = 0.0005$, d$f = 42$). On average, the low SES group shows a skeletal growth deficit of 1.17 years relative to the high SES group. When compared to the reference population, the low SES group shows an average deficit of 2.11 years, whereas the high SES group shows an average deficit of 0.94 years.

As with Figure 2, graph B of Figure 3 illustrates socioeconomic differences in dental development. Once again, when both SES groups are compared, a t-test shows no significant differences between the high and low SES groups ($t = 1.76$, $P = 0.0848$, d$f = 45$). Despite the absence of statistically significant socioeconomic differences

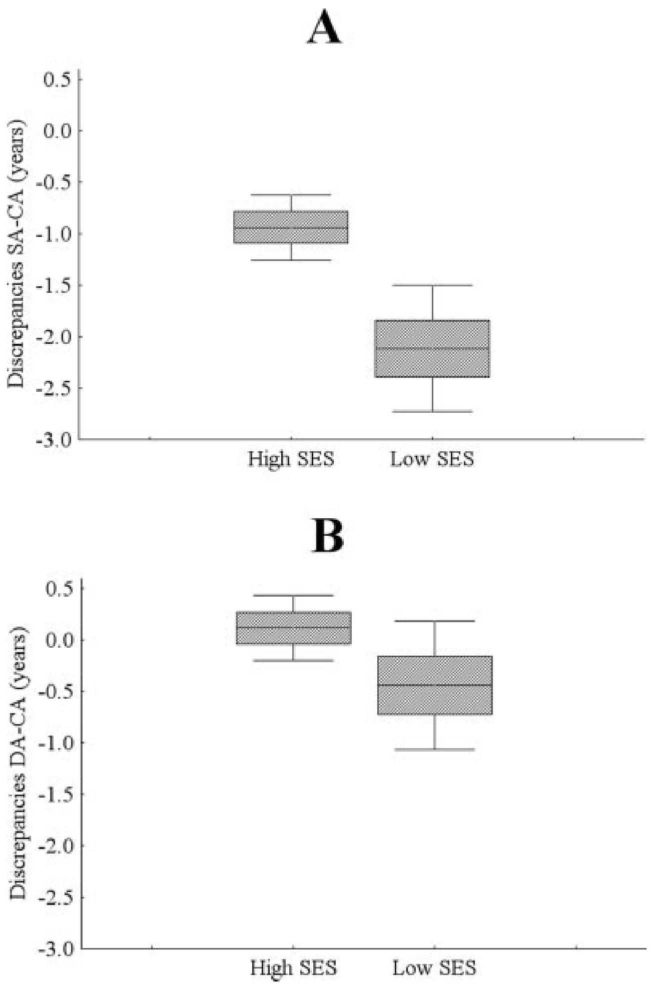

Fig. 3. Box plots for the distribution of discrepancies between SA and CA (graph A; $n_{\text{high SES}} = 33$, $n_{\text{low SES}} = 11$), and between DA and CA (graph B; $n_{\text{high SES}} = 35$, $n_{\text{low SES}} = 12$). SES groups are based on the classification of the place of residence. The mean is represented by the line, the box includes the mean ± the standard error, and the whiskers the 95% confidence interval for the mean.

in dental development, the low SES group still shows some delay relative to the high SES group and results are again only marginal at the 0.05 significance level. The average dental delay of high and low SES groups is 0.55 years. Compared to the reference, the high SES group shows a slight average advancement of 0.11 years, and the low SES group shows a mean delay of 0.44 years.

Finally, the influence of the variance in DA assessment, when using multiple teeth, in the inference that differences between DA and CA are environmental, was assessed by comparing the mean within individual standard error of DA estimates (due to the number of teeth contributing to individual mean age) with the standard error of the difference in DA-CA between SES groups. The mean within individual standard error of DA estimates is 0.3894 and does not increase with increasing number of teeth available to estimate age ($R = -0.05$, $P = 0.7207$). The standard error of the difference in DA-CA between SES groups is 0.3596 when socioeconomic groups are defined according to the occupation of the father, and 0.4397 when the groups are defined according to the place of residence.

DISCUSSION

Overall, results in this study support the assertion that dental development is more buffered against environmental insults, whereas skeletal development is not. Socioeconomic differences in skeletal growth vary between a delay of 0.63 years and 1.17 years, and socioeconomic differences in dental development vary between a delay of 0.47 years and 0.55 years, depending on how SES is measured. In addition, looking at the discrepancies between skeletal/dental and chronological in the entire sample, data in the plots show that SA always lags behind CA, whereas DA does not lag or lags only slightly. Because the use of standards for the estimation of physiological age involves an explicit comparison of the study sample with the samples from which the standards were derived, overall discrepancies between physiological and CA also illustrate differential sensitivity of bone and teeth to environmental influences. However, marginal significance of the *t*-tests at the 0.05 level, in socioeconomic comparisons of dental development, suggests some dental delay in the low SES group. In fact, a more detailed look at the lower end of the socioeconomic gradient shows considerable delays in DA relative to CA (Cardoso, 2005). At the low end of the socioeconomic scale, dental delays can be as high as 1 to 2 years. One problem that can be raised is whether the observed differences derive from the use of reference standards. Although a different choice of criteria to calculate physiological age would produce different results, because intragroup comparisons are based on the same criteria for age, results are internally consistent and, therefore, should reflect real differences. In other words, because intrasample comparisons are made using the same reference standards for physiological age estimation, any group differences in discrepancies between physiological and CA cannot be attributable to the use of those specific standards.

A particularity of the results is that socioeconomic differences in skeletal and dental development are greatest when groups are defined by place of residence rather than by occupation of the father. Socioeconomic position measured by the occupation of the father does not always match the socioeconomic position measured by birth *freguesia*, and such disparity results from the multidimensionality of SES. Research in developing nations (Timaeus and Lush, 1995; Desai and Alva, 1998; Spencer et al., 1999) and studies involving historic investigations of the recent past (Haines, 1995; Ferrie, 2001) have found that area measures of SES perform better when describing the socioeconomic inequalities of child health. In the study sample, area measures of environmental quality are the reflection of a deeply stratified urban society, where place of residence was the mirror of social class (Ramos, 1994). Low socioeconomic areas aggregated the less skilled, the less educated, and the poorer adults, but also the more diseased individuals and the highest crime rates. In addition, these areas were characterized by poor and crowded living conditions, extremely bad sanitation, and increased risks of infection. In contrast, information about occupation may only capture wage disparities and social prestige. A more detailed analysis of the socioeconomic background of the children in the sample (Cardoso, 2005) showed that the socioeconomic extremes are not sampled, particularly the individuals at the lower end. This means that the socioeconomic gradient in the study sample is curtailed and not representative of the gradient in the population and that the results may be conservative estimates of socioeconomic differences in dental and skeletal development in this population. In addition, it is reasonable to admit a certain number of socioeconomic misclassified cases due to restrictions of access and incompleteness of biographic data. This misclassification of cases may result from inaccuracies of reported occupations, socioeconomic heterogeneity of *freguesias* or individual idiosyncrasies.

Because the study sample is a mortuary sample, there may be a concern whether diseases that contributed to the death of a child can have an effect on growth status. Not all diseases or conditions are likely to have an effect on growth and development and conditions of rapid onset, and brief duration (acute) are less likely to affect growth and development, compared to continuous conditions that persist through time (chronic). If chronic conditions are more prevalent in any one of the socioeconomic groups, such situation would influence the results. However, no association between SES and cause of death was found in the study sample. The frequency of chronic cases in each socioeconomic group is not statistically different, whether the SES classification is based on the occupation of the father or on the place of residence (Cardoso. 2005). Therefore, chronic conditions are independent of the socioeconomic group and do not seem to contribute to the observed results. Another related aspect that derives from the fact that the study sample is a mortuary sample is selective mortality. Because one would expect that high SES children received better care and nutrition, and would be less exposed to the cumulative effects of adverse living conditions, selective mortality would favor the less healthy children of high SES, and consequently, would tend to favor the children of high SES, with the greatest growth deficit with increasing age. This suggests that the differences in skeletal and dental development between the high and low SES groups could be, again, conservative estimates of the real differences.

A relatively small absolute mean difference between dental and CA may add concern to whether the variance in the DA assessment when using multiple teeth is introducing noise to the inference that those differences are environmental. This is particularly important if there is any association between number of teeth available and SES. However, because variance in DA estimation is also dependent on the age of the child, it would only add significant noise if one of the SES included more older children than the other. Not only there are no significant differences in age structure in both SES groups, but there is also no systematic SES bias in the number of teeth available for determining DA. Additionally, the mean within individual standard error of DA estimates (due to the number of teeth contributing to individual mean age) was also shown to be of the same magnitude or smaller than the standard error of the difference in DA-CA between SES groups.

One of the limitations of this study is that skeletal maturation could not be measured. Bone maturation in skeletal samples can be easily assessed in adolescent individuals, but in preadolescents, the methods that are routinely applied in clinical settings are difficult to apply in skeletal material. Problems of recovery and preservation hamper the use of methods that rely on maturation of hand and wrist bones. Methods that rely on the epiphysis of the knee (Pyle and Hoerr, 1955; Roche et al., 1975) may provide an alternative method to assess bone maturation in skeletal samples. Their advantage over the hand and wrist bones is that the epiphyses of the femur and tibia have fewer problems of recovery and preservation. The recent application of developmental indicators of bone maturation in the knee to a skeletal sample (Goode-Null, 2002) suggests that these methods may hold some promise in future research. On the other hand, there is evidence that suggests that timing of epiphyseal union in adolescents is less sensitive to environmental influences (Cardoso, 2005). Similarly, timing of tooth formation was found to be less affected by environmental stress, whereas intensity of skeletal growth was more affected. As a comparison, May et al. (1993) examined the effects of nutritional supplementation upon bone and enamel development in a sample of rural Guatemalan children and found that formation of enamel responded positively to increased supplementation, while no differences in ossification were found between supplementation groups. Higher prevalence of linear enamel hypoplasias in the nonsupplemented group suggests that enamel matrix formation is more sensitive to changes in nutritional status than skeletal maturation (May et al., 1993). Although analogous aspects of bone and tooth formation are not being compared, these results suggest that environmental effects on growth may be more severe on intensity than on timing.

In this study, results also indicate that estimating CA in preadolescents from mean long bone diaphyseal lengths produces gross divergences and particularly biased estimates, especially in low SES children. Although DA shows fewer socioeconomic differences, indicating that it is a good overall estimate of CA, there will still be some variation in age estimates, mostly influenced by individuals of lowest SES who tend to show the greatest dental delays. On the other hand, because skeletal development is a good measure of somatic growth due to its greater environmental sensitivity, it has the potential to capture socioeconomic effects in the growth of past populations. Although the overall pattern of skeletal growth is only affected by how accurately it represents the living population, the pattern of skeletal growth within the study sample is strongly affected by SES.

CONCLUSIONS

The study of the subadult sample of the identified skeletal collection housed at the *Bocage* Museum (Natural Museum of Natural History) in Lisbon offered the unique opportunity to test a fundamental assumption in osteological research. Although the greater environmental sensitivity of dental development compared to skeletal development was confirmed in this study, results also show that dental development is not free from environmental influences. The results also provide an analysis of the biological costs of poor living conditions and limited access to proper nutrition and health care in a sample of Portuguese 20th century urban children, where SES contributes greatly to the understanding of the variation in growth and development status among members of this mortuary sample. Low SES children are severely delayed in skeletal growth and also frequently delayed in dental development compared to high SES children. The major implication of the results for bioarchaeological and forensic studies is that dental development proved to be a better measure of true CA in subadult skeletal samples than skeletal growth. In addition, the detection of socioeconomic differentials in growth status suggests that similar data might also be a powerful indicator of socioeconomic inequalities in past societies.

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