HOMO - Journal of Comparative Human Biology 66 (2015) 432–447

Contents lists available at ScienceDirect

HOMO - Journal of Comparative Human Biology

journal homepage: www.elsevier.com/locate/jchb

Interpretative potential of dental metrics for biodistance analysis in hunter-gatherers from central Argentina. A theoretical-methodological approach

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ARTICLE INFO

Article history:
Received 18 July 2014
Accepted 25 March 2015

ABSTRACT

The use of dental metrics as a reliable tool for the assessment of biological distances has diversified dramatically in the last decades. In this paper some of the basic assumptions on this issue and the potential of cervical measurements in biodistance protocols are discussed. A sample of 1173 permanent teeth from 57 male and female individuals, recovered in Chenque I site (western Pampas, central Argentina), a Late Holocene hunter-gatherer cemetery, is examined in order to test the impact of exogenous factors that may have influenced the phenotypic manifestation and affected dental crown sizes. The statistical association between dental metric data, obtained by measuring the mesiodistal and buccolingual diameters of the crown and cervix, and the quantification of hypoplastic defects as a measure to evaluate the influence of the environment in the dental phenotypic expression is evaluated. The results show that socioenvironmental stress did not affect dental metrics and that only the more stable teeth (first incisors, canines, first premolars and first molars) and three variables (buccolingual diameter of the crown and both mesiodistal and buccolingual measurements of the cervix) should be included in multivariate analyses. These suggestions must be strengthened with additional studies of other regional samples to identify factors of variation among populations,

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http://dx.doi.org/10.1016/j.jchb.2015.03.001

so as to develop general guidelines for dental survey and biodistance analysis, but they are a first step for discussing assumptions usually used and maximizing the available information for low-density hunter-gatherer societies.

RESUMEN

El uso de la métrica dental como una herramienta confiable para los estudios de distancias biológicas se ha diversificado significativamente en las últimas décadas. En este trabajo se discuten algunos de los supuestos básicos relacionados con esta temática y el potencial de las medidas del cuello dental en los protocolos del análisis de biodistancias. Se examina una muestra de 1173 dientes permanentes de 57 individuos, tanto masculinos como femeninos, procedentes del Sitio Chenque I (Pampa Occidental, centro de Argentina), un cementerio de cazadores-recolectores utilizado durante el Holoceno tardío, para poner a prueba el impacto de factores externos que pueden haber influido en las manifestaciones fenotípicas y afectado los tamaños de las coronas dentales. Se consideran las asociaciones estadísticas entre la métrica dental, obtenida a través del relevamiento de los diámetros bucolinguales y mesiodistales de la corona y el cuello, y la cuantificación de las hipoplasias de esmalte como una medida de evaluar la influencia del ambiente en la expresión fenotípica. Los resultados muestran que los estresores medioambientales no afectaron las medidas dentales y que solamente los dientes más estables (primeros incisivos, caninos, primeros premolares y primeros molares) y tres variables (diámetro bucolingual de la corona y diámetros bucolingual y mesiodistal del cuello) deben ser incluidos en los análisis multivariados. Si bien estas sugerencias deben ser fortalecidas con estudios adicionales en otras muestras regionales para identificar factores de variación entre poblaciones, de manera de desarrollar directrices generales para el relevamiento dental y el análisis de biodistancias, constituyen un primer paso para discutir los supuestos generalmente utilizados y maximizar la información disponible para las sociedades cazadoras-recolectoras de baja densidad poblacional.

Introduction

In the field of dental anthropology, biodistance studies have been increasingly important since the 1980s (e.g., Buikstra et al., 1990; Hillson, 1986, 1996; Scott and Turner, 1988, 2000). This analytical approach has an important potential for identifying migratory processes and biological interaction, highlighting investigations that consider the study of both discrete and continuous variables (Hillson, 1996; Kieser, 2008; Matsumura and Oxenham, 2014; Scott and Turner, 1988). Dental metrics investigations are usually supported by a series of assumptions about dental development and the environmental influences on it. First, it is stated that dental shape and size are largely determined by genotype and that no environmental constraints significantly influence them (e.g., Mayhall, 1992, 2000; Perzigian, 1975). Accordingly, it is supposed that teeth are always appropriate for analysing biological distances (e.g., Hanihara and Ishida, 2005; Harris and Lease, 2005; Matsumura and Hudson, 2005; Scott and Turner, 1988, 2000). Second, all available teeth are incorporated into the analyses (Hillson, 1996; Kieser, 2008), without considering that some of them would provide better information than others for biodistance research. Finally, mesiodistal and buccolingual diameters of dental crowns have been traditionally considered, with a recent inclusion of cervical measures (e.g., Bernal, 2008; Fitzgerald and Hillson, 2008; Hillson et al., 2005; Luna, 2008). While this allows analysing larger samples due to the slighter effect of tooth wear in cervix, the existence of high correlations between the two sets of variables need additional assessments for different historical and ecological settings.

After a first proposal by Potter et al. (1983), a thorough evaluation of the validity of these statements is still needed. An initial approach to this problem is developed in this paper with the aim of identifying the heuristic potential of dentition for biodistance analyses in a sample of permanent teeth from Chenque I site (Lihué Calel National Park, La Pampa province, central Argentina). The goal is to establish whether the patterns observed fit the trends mentioned, in order to further develop reliable biodistance analyses with this sample.

The theoretical debate about the influence of the genotype and the environment on dental development

Given that the phenotype is the result of the interaction between the genetic potential and the environmental constraints (Goodman, 1991; Goodman et al., 1988; Hillson, 1996; Larsen, 2000), it is important to assess if the action of environmental stressors impacted tooth size, prior to the interpretation of the data. If so, metric biodistance information would be biased since it would account both for the action of the genetic basis and the specific socio-environmental context. Conversely, a minimal influence would enable a genotypic explanation. This paper explores the statistical association between dental metric data and enamel hypoplasia frequencies in Chenque I site as a measure to evaluate the influence of the environment in dental phenotypic expression. Hypoplastic defects are nonspecific indicators of stress that occur during tooth formation and indicate the impact of internal and external factors that may have influenced the body homeostasis (Goodman and Rose, 1990; Hillson, 1996, 2000; Hillson and Bond, 1997; Skinner and Goodman, 1992). Were it is possible to identify significant positive associations between both sets of data in this sample, it would not be appropriate to use dental metrics for biodistance studies since the dentition would be affected by environmental constraints, inhibiting the optimal genetic expression.

The main assumption underlying biodistance dental studies is the family model originally proposed by Fisher (1918), which states that the size and the shape of the crowns are the phenotypic traits closest to the genotypic expression, the impact of social and environmental stressors on dental development being minimal (Buikstra et al., 1990). The vast amount of information generated by scholars such as Albert Dahlberg, Stanley Garn, Rosario Potter, Grant Townsend and their teams are examples of comprehensive research programs that included specific investigation designs to test this hypothesis. Populational, familiar, monozygotic and dizygotic twins observations and experiments on animals were developed, from which the values of heritability of dental sizes were calculated for different socioenvironmental contexts (Garn et al., 1965a,b,c; Potter and Nance, 1976; Potter et al., 1968, 1983; Townsend and Brown, 1979; Hillson, 1986, 1996). Numerous papers (e.g., Alvesalo and Tigerstedt, 1974; Goose, 1967; Hanihara and Ishida, 2005; Kolakowski and Bailit, 1981; Lundström, 1963; Osborne et al., 1958; Townsend, 1980; Townsend and Brown, 1978a; Townsend et al., 1994) identified medium/high heritabilities in dental size and shape, while a minimal environmental impact and a multifactorial inheritance hypothesis with multiple additive gene effect (Potter and Nance, 1976; Potter et al., 1968) were proposed.

Much of the bioarchaeological dental research is built on the statement that tooth size is not significantly affected by external factors (Christensen, 1998; Cucina et al., 1999; Harris et al., 2001; Perzigian, 1975; see Hanihara and Ishida, 2005; Harris and Lease, 2005; Matsumura and Hudson, 2005). However, another set of basic studies showed that the influence of socio-environmental context may be important (Garn et al., 1965b, 1979; Harris et al., 2001; Kolakowski and Bailit, 1981; Niswander and Chung, 1965; Potter et al., 1968, 1983; Smith et al., 1981; Townsend and Brown, 1978a,b). Some archeological investigations identified associations between tooth size and age-at-death as an adaptation measure, concluding that those individuals who reached adulthood may have developed teeth with sizes closer to the maximum genetic potential (Guagliardo, 1982; Manzi et al., 1997; Pérez-Pérez and Walker, 1988; Stojanowski et al., 2007). The analyses account for regional variations in environmental conditions, which support the hypothesis that different local adaptations may have influenced tooth size (Balciunienė and Jankauskas, 1993). These conclusions highlight the value of evaluating the impact of environmental factors prior to metric biodistance analyses.

Dental stability

Another aspect that should be considered is the relevance of including the whole dentition in metric dental studies. The option usually chosen points to the measurement of all the available elements (except third molars, given their high morphological variability) in order to maximize the information. No consideration has been given in modern bioanthropological investigations to the importance of each type of tooth for biodistance studies, taking into account the theoretical proposals about the dental morphogenetic process and the relative sensitivity of each element. Both aspects are directly related to the ages and the breadth of the calcification periods for each tooth (AlQahtani et al., 2010; Moorees et al., 1963; Reid and Dean, 2000). The identification of the most useful teeth for metric biodistance studies would allow discarding those more influenced by external stress.

The Butler's 'field theory' postulates the existence of qualitatively different fields of action to account for the paths of formation in tooth structure and states that teeth are metameric organs, which means that they develop as part of a system and not as individual units (Butler, 1937, 1939). Three different formation fields (incisors, canines and molars) are identified, each of them with a more stable polar tooth. Dahlberg (1945) applied this approach to human teeth and identified four critical morphogenetic fields (incisors, canines, premolars and molars) and a more stable tooth within each of them (first upper incisors, second lower incisors, canines, first premolars and first molars). Conversely, the 'clonal theory' proposes that human teeth are divided into three identical ectomesenchymal cell clones: incisors, canines and molars. Since each of them forms at different somatic growth periods, there is less stability for those late-formed, so that the variation would not be given by the existence of different control regions, but by differences in dental formation periods (Osborn, 1970, 1973; Osborn and Ten Cate, 1983). Many subsequent papers tend to support the Butler's proposal (Alvesalo and Tigerstedt, 1974; Garn et al., 1967; Harris and Nweeia, 1980; Hlusko and Mahaney, 2007; Lombardi, 1975; Potter et al., 1968), while others questioned its validity (Biggerstaff, 1970; Kieser et al., 1985), but the expected more stable teeth are the same for both theories. Comparative analyses indicate that the coefficients of variation (Hillson, 1996; Humphrey and Andrews, 2008; Kieser, 2008) for first upper incisors, second lower incisors, canines and first molars show the lowest scores (Bailit et al., 1968; Kieser, 2008). The present paper uses this statistical measure to establish whether the patterns of dental variability of Chenque I site sample fit these previously identified trends.

Comparison between variables

The association between the different metric variables and the influence of mechanical and post-depositional agents in the preservation of dental tissues received special attention in recent and past dental anthropological literature (Hillson, 1986; Kieser, 2008; Mayhall, 2000). In addition to the variables traditionally measured in odontometrics (buccolingual and mesiodistal diameters of the crown; (Hillson, 1986, 1996; Mayhall, 2000), others homologous for the cervical area have been systematically incorporated in past years in order to study larger samples. External and taphonomic factors, such as the intensity of tooth wear and the postdepositional deterioration of the enamel structure, usually reduce the quantity of crowns included, while the cervical region is much less affected (Fitzgerald and Hillson, 2008; Hillson et al., 2005; Kieser, 2008; Stojanowski, 2007). For these reasons, the measurements of the cervix have begun to be incorporated in dental anthropology studies (Falk and Corruccini, 1982; Fitzgerald and Hillson, 2008; Kieser, 2008; Stojanowski, 2007).

While it has been established that coronal diameters for the same tooth types show moderate positive correlations (Garn et al., 1968a,b), recent studies compare the statistical association between cervical and crown dimensions. Hillson et al. (2005) identified moderate/high correlations between crown and cervical diameters in a sample of permanent teeth from the East Smithfield site of London, a Black Death mass burial cemetery dating to 1348–1349. They concluded that cervical measurements can be obtained with the same precision, record similar information and allow the analysis of larger samples. Later, Stojanowski (2007) analyzed the preservation of the cervical area in a dental sample from the Windover Pond site, an early Archaic period (ca. 7500 years BP) mortuary pond in Florida. Results showed that cervicometrics may be also subject to multiple causes of missing data, including heavy attrition, taphonomic root loss, cervical abrasion, cervical caries, idiosyncratic use-related attrition and presence of calculus, so that its benefits would not be as important as initially proposed. The diversity of the results motivates the evaluation of the correlations between coronal and cervical variables using a dental sample from Chenque I site before they are used in biodistance studies.

Materials and methods

Before beginning a dental biodistance study using Chenque I site burials, an analysis regarding the validity of the assumptions previously described was developed in order to delineate the most appropriate procedure. This site is a hunter-gatherer pre-Hispanic cemetery located in southern La Pampa province, Western Pampean Region, centre of Argentina. Forty-two square meters (about 20% of the total area) have been excavated between 1997 and 2006. It was used by hunter-gatherer societies during the end of the Late Holocene, between 1050 and 290 years BP (Berón et al., 2015). It is one of the most important pre-Columbian burial places in the country, given the high mortuary diversity identified, the complexity of the social processes inferred and the fact that more than 200 individuals were buried in it, including both complete skeletons and a large amount of commingled and fragmented bones and teeth recovered (Berón, 2007; Berón et al., 2009, 2012; Luna, 2006, 2010, 2012).

The mesiodistal and buccolingual diameters of the crown and cervix of 1173 permanent teeth (first incisors to second molars) were measured following Hillson et al. (2005) proposal and using a Mitutoyo caliper, Model 573-721 Digital Pointed Jaw, specially designed for odontometric analyses. As cervical buccolingual dimensions are usually difficult to obtain when teeth are in situ, those measurements were taken when the removal from the jaws was possible. This fact did not influence the structure of the data because the majority of the teeth were out of the alveoli due to postdepositional processes, or could be easily removed from the sockets.

Priority was given to left teeth, measuring the antimere only when lefts were absent. All teeth with wear, tartar, damage or pathologies affecting the areas of measurement were excluded from analysis. The sample includes the permanent dentition of 57 individuals (25 females and 32 males, both subadults and adults). Conventional morphological and metric methods for skull, hip and long bones, were applied both to determine sex and to estimate age-at-death (Bass, 1987; Brickley and McKinley, 2004; Buikstra and Ubelaker, 1994; Latham and Finnegan, 2010). Dental metric intraobserver error has been previously studied using intraclass correlation coefficient (ICC), choosing 40 complete teeth and measuring each variable twice with a difference of two weeks. Data were processed using the program *R* 1.9.1. Statistics showed no significant differences between the two measurements taken for each variable. It could also be ascertained that age at death did not affect dental size (Luna, 2008).

In order to assess the relative influence on the environment, the number of enamel hypoplastic defects was analyzed (Luna, 2008; Luna and Aranda, 2010) for each element considered, and compared to the dimensions of each type of tooth. Teeth were segregated into two groups, with and without hypoplasiae. The recording of different manifestations of hypoplastic defects was done by quantifying each type of lesion (lines, pitting and planes; Goodman and Rose, 1990; Hillson, 1996, 2000; Ogden et al., 2007) and grouped together in this analysis. Mann–Whitney's nonparametric test (U) was applied to identify which of the observed differences were statistically significant, using a significance level of 0.05 and the SPSS 15.1 program. This method is suitable for analyzing the socio-environmental influence on dental phenotype because it evaluates the associations between the number of indicators of metabolic stress and tooth dimensions (Manzi et al., 1997; y'Edinack, 1989).

The analysis of the observed variance was conducted through the coefficient of variation ($CV = 100\,SD/$; Humphrey and Andrews, 2008), which evaluates the dispersion of the results, in order to know whether different teeth and variables have the same potential for biodistance studies or, on the contrary, if some of them must be chosen for their higher ontogenetic stability and lower influence of stochastic and environmental agents. The results were analyzed by type of tooth involved and also comparing the general trends identified with the data provided by previous publications for other human samples. Finally, crown and cervix data were evaluated to quantify percentages of missing data due to the dental wear and postmortem damage and to establish the magnitude of the correlations between them, using Pearson's correlation coefficient (*r*). Both aspects of this analysis help discern the importance of incorporating cervix dimensions in biodistance studies.

Results

Table 1 summarizes the descriptive statistics of each of the dimensions considered by sex and the values of the coefficient of variation. Tables 2 and 3 include the metric information for male and female teeth with and without hypoplastic defects. Average and range values are mostly lower for females, indicating varying degrees of sexual dimorphism in most types of teeth (Table 1). In addition, direct analysis of the data shows that there are no important differences when the two groups separated by the quantity of enamel hypoplasiae are compared, for each sex (Tables 2 and 3). Most of the ranges overlap, which is corroborated by the statistical results since all of them indicate non-significant differences. So it can be concluded that dental dimensions are not influenced by external factors.

The values of the coefficient of variation for each dental dimension (Table 1, Fig. 1) show that the overall trends are consistent with previous theoretical proposals about dental stability ('field theory' [Butler, 1937, 1939; Dahlberg, 1945] and 'clonal theory' [Osborn, 1970, 1973; Osborn and Ten Cate, 1983]). Teeth with lower (than other teeth) CV values are the first incisors, canines, first premolars and first molars for the sample studied, both upper and lower, and for both sexes. These are the elements with the greatest potential for biodistance studies. By contrast, the most variable teeth are second incisors and second premolars. No trend toward increasing coefficients of variation in the posterior dentition is observed, which would be expected considering the location and extent of dental formation periods, in contexts of strong impact of the environment. This fact adds support to the proposal of minimal influence of the socioenvironmental context in dental sizes.

Regarding the correlation between the dimensions of the crown and the cervix, *r* values in Table 4 and Fig. 2 show moderate to high associations for less variable teeth (1I, C, 1PM and 1M). When considering the overall results for the entire sample, correlations between the same measures of crown and cervix range between 0.654 and 0.921 for the buccolingual diameter and between 0.624 and 0.846 for the mesiodistal diameter. When the sample is discriminated by sex, the values are slightly higher: among females, between 0.645 and 0.956 for buccolingual diameters and between 0.600 and 0.971 for mesiodistal diameters, and among males, between 0.700 and 0.945 for the former and between 0.728 and 0.959 for the latter.

Finally, Table 5 and Fig. 3 show two different trends for the percentages of measurements actually made. Considering only the least variable teeth (first incisors, canines, first premolars and first molars), the coronal values range between 44.87% and 63.75%, while the cervical ones are much higher, between 82.05% and 100%. The mesiodistal diameter of the crown shows systematically lower percentages than the buccolingual, whereas cervical values are much more even.

Discussion and conclusions

Genetic and biological research developed in the last 30 years indicates that dental growth and development is based on multifactorial inheritance, highlighting the action of a large number of genes compared to other sources of variation. Polygenic traits may be affected in many ways by the environment, so the observed variation in tooth size may be due to genetic variation and environmental factors. For this reason, both sources of variation must be considered while evaluating dental metric diversity (Mizoguchi, 1980). Heritability values are not an intrinsic property of a body feature and are related to the environmental effects on individuals and populations. As stated earlier, it depends on the magnitude of all variance components, which often change in space and time, so it is not possible to establish a single value applicable to all populations (Vitzthum, 2003). For this reason, distinguishing between intrinsic (genetic) and extrinsic (environmental) effects to properly understand the observed variation in dental dimensions is of fundamental importance (Kieser, 2008).

The results obtained in this study support the idea that stress events experienced by individuals in the sample did not affect dental dimensions. It is possible to propose that in this case the history of life of the individuals studied does not preclude reliable biodistance interpretations. This trend is

Table 1

Descriptive statistics and coefficient of variation values for each dental variable considered. Measurements in mm.

	MDcr					BLcr					MDce					BLce				
	n	Mean	Range	SD	CV	*n*	Mean	Range	SD	CV	*n*	Mean	Range	SD	CV	*n*	Mean	Range	DS	CV
Males																				
1LI	22	5.16	4.77–5.85	0.36	6.98	20	6.03	5.68–6.34	0.19	3.15	35	3.78	3.62–4.04	0.15	3.96	39	5.83	5.24–6.44	0.35	6.00
2LI	26	5.81	4.99–6.87	0.61	10.50	28	6.24	5.32–6.70	0.40	6.41	45	4.00	3.29–4.74	0.38	9.50	49	6.06	5.31–6.68	0.42	6.93
LC	24	7.99	7.31–8.80	0.44	5.51	28	8.12	7.22–8.85	0.43	5.30	51	5.99	5.54–6.47	0.33	5.51	54	7.91	7.28–8.68	0.47	5.94
1LPM	28	7.38	6.35–8.62	0.42	5.69	30	8.18	7.20–8.87	0.35	4.28	55	5.51	4.65–6.27	0.34	6.17	52	7.06	6.11–7.90	0.43	6.09
2LPM	24	7.51	6.63–8.02	0.51	6.79	23	8.59	8.04–9.32	0.46	5.36	47	5.53	4.92–6.12	0.45	8.14	49	7.40	6.56–8.03	0.64	8.65
1LM	30	12.07	11.42–12.46	0.37	3.09	32	11.40	10.46–12.41	0.59	5.14	55	9.63	9.00–10.09	0.39	4.07	54	9.69	9.09–10.01	0.68	7.06
2LM	31	11.90	10.90–13.09	0.89	7.45	28	11.27	10.54–12.40	0.92	8.21	45	9.97	9.34–11.13	0.72	7.24	48	9.63	8.80–10.67	1.00	10.34
1UI	24	8.75	8.17–9.50	0.50	5.66	29	7.61	7.01–8.04	0.29	3.78	49	6.67	5.68–7.40	0.52	7.76	51	6.90	6.38–7.72	0.31	4.48
2UI	20	7.35	6.08–8.68	0.88	12.01	27	6.71	5.16–7.36	0.55	8.13	39	5.24	4.11–6.21	0.76	14.44	39	6.37	5.60–7.44	0.44	6.91
UC	20	8.62	8.16–9.07	0.47	5.46	22	8.91	8.10–9.69	0.66	7.43	41	6.36	5.77–7.22	0.54	8.53	42	8.11	7.69–8.90	0.45	5.59
1UPM	23	7.76	6.98–8.21	0.27	3.73	28	9.59	8.78–10.79	0.41	4.39	41	5.45	4.89–6.83	0.25	4.61	43	8.81	7.67–9.76	0.30	3.40
2UPM	18	7.64	7.01–8.45	0.52	6.74	21	9.35	8.88–10.01	0.81	8.41	38	5.04	4.86–5.38	0.39	7.74	38	8.21	7.58–8.98	0.46	5.61
1UM	29	11.69	10.10–12.98	0.64	5.88	26	12.51	11.36–13.54	0.59	4.89	44	8.77	7.99–9.28	0.61	6.94	45	11.72	10.51–12.64	0.53	4.50
2UM	21	10.89	9.97–12.11	0.78	6.64	19	12.09	10.87–13.08	0.72	5.74	38	6.72	6.89–9.96	0.86	12.78	38	11.33	9.75–12.24	0.93	8.24
Females																				
1LI	13	5.145	4.27–5.19	0.03	0.60	18	5.86	4.98–6.14	0.17	2.90	29	3.60	3.05–4.71	0.07	1.95	31	5.69	4.89–5.91	0.29	4.73
2LI	18	5.67	6.23–6.68	0.57	10.05	22	6.16	6.08–6.57	0.21	3.41	32	4.50	4.24–4.97	0.29	6.44	34	6.13	5.80–6.40	0.34	5.98
LC	22	7.61	7.32–8.51	0.35	4.60	20	7.92	7.67–8.57	0.36	4.55	36	5.88	5.12–6.34	0.33	5.61	35	8.21	7.90–8.67	0.42	5.12
1LPM	15	7.21	6.98–7.40	0.16	2.22	19	8.28	8.02–8.39	0.08	0.91	29	5.55	5.20–6.08	0.27	4.80	30	6.97	6.74–7.19	0.19	2.68
2LPM	18	7.48	7.06–7.80	0.46	6.21	20	8.47	7.21–8.92	0.73	8.62	39	5.63	5.33–6.20	0.35	6.36	39	7.17	6.68–7.53	0.21	2.93
1LM	14	11.78	11.61–12.62	0.44	3.76	20	11.05	10.20–12.18	0.83	7.51	33	7.48	9.35–10.71	0.68	6.82	33	7.31	8.94–11.01	0.62	6.35
2LM	17	11.07	9.98–12.11	0.87	7.83	22	10.85	9.64–12.31	1.19	11.01	30	9.93	8.99–10.48	0.61	8.15	32	9.82	8.97–10.11	0.72	9.80
1UI	20	8.53	8.62–9.50	0.24	2.85	19	7.40	6.96–7.60	0.23	3.12	40	6.53	6.35–7.18	0.19	2.84	42	6.76	5.69–7.17	0.40	5.93
2UI	18	7.07	6.18–7.86	0.71	10.12	23	6.87	5.84–7.68	0.71	10.30	42	5.32	4.00–6.13	0.79	14.88	43	6.50	5.20–7.21	0.86	13.25
UC	21	8.49	7.61–9.16	0.46	5.44	33	8.34	7.67–8.84	0.44	5.32	44	6.32	5.82–6.77	0.45	7.13	42	7.71	6.89–8.35	0.60	7.84
1UPM	17	7.21	6.66–7.94	0.40	5.55	23	9.00	7.98–9.56	0.44	4.52	36	4.80	4.03–5.48	0.32	6.67	36	8.72	7.97–9.69	0.43	5.07
2UPM	19	7.66	7.00–8.28	0.29	3.79	25	9.73	8.97–10.09	0.63	7.00	34	5.02	4.26–5.18	0.41	8.17	35	8.48	8.10–9.01	0.47	5.39
1UM	21	11.22	10.34–11.84	0.52	4.65	25	11.79	10.97–13.21	0.28	2.52	36	8.35	9.45–11.97	0.60	7.21	33	11.21	10.29–11.98	0.07	0.61
2UM	24	10.76	10.44–12.76	0.64	5.92	26	11.28	10.41–11.60	0.67	5.67	32	6.29	7.69–8.66	0.46	7.38	32	11.01	10.65–11.49	0.50	4.45

References: SD: standard deviation; CV: coefficient of variation (CV = 100 SD/mean); MDcr: mesiodistal diameter of the crown; BLcr: buccolingual diameter of the crown; MDce: mesiodistal diameter at the cervix; BLce: buccolingual diameter at the cervix; 1LI: first lower incisor; 2LI: second lower incisor; LC: lower canine; 1LPM: first lower premolar; 2LPM: second lower premolar; 1LM: first lower molar; 2LM: second lower molar; 1UI: first upper incisor; 2UI: second upper incisor; UC: upper canine; 1UPM: first upper premolar; 2UPM: second upper premolar; 1UM: first upper molar; 2UM: second upper molar.

Table 2

Descriptive statistics for the crown and cervix measurements (in mm) by sex, for teeth without enamel hypoplasia. References: see legend of Table 1.

	MDcr				BLcr				MDce				BLce			
	n	Mean	Range	SD	*n*	Mean	Range	SD	*n*	Mean	Range	SD	*N*	Mean	Range	SD
Males																
1LI	14	5.10	4.77–5.85	0.35	13	6.07	5.86–6.34	0.16	18	3.74	3.62–4.04	0.13	22	5.86	5.50–6.44	0.32
2LI	14	5.67	4.99–6.61	0.54	18	6.20	5.32–6.70	0.41	25	5.93	3.29–4.74	0.47	22	6.01	5.31–6.68	0.42
LC	13	8.13	8.00–8.25	0.17	16	8.31	8.15–8.85	0.43	30	6.13	5.54–6.47	0.43	26	8.20	7.83–8.68	0.37
1LPM	15	7.30	6.35–8.62	0.52	16	8.17	7.52–8.84	0.35	31	5.39	4.83–6.27	0.35	30	7.04	6.11–7.90	0.43
2LPM	16	7.51	6.63–8.02	0.51	11	8.60	8.04–9.32	0.46	25	5.53	4.92–6.12	0.45	25	7.40	6.56–8.03	0.64
1LM	16	11.99	11.42–12.46	0.52	20	11.48	10.46–12.12	0.76	30	9.68	9.16–10.09	0.34	31	9.72	9.09–10.01	0.29
2LM	18	11.87	10.90–13.09	0.68	14	11.28	10.76–12.40	0.47	20	9.96	9.34–11.13	0.73	21	9.60	8.80–10.27	0.63
1UI	16	8.82	8.38–9.50	0.39	18	7.62	7.10–8.01	0.44	25	6.56	5.68–7.40	0.69	32	6.92	6.54–7.72	0.48
2UI	8	7.18	6.08–8.68	1.00	17	6.73	6.20–7.36	0.38	21	5.17	4.11–6.21	0.87	24	6.30	5.60–7.01	0.40
UC	7	8.49	8.20–9.02	0.41	13	9.60	9.50–9.69	0.02	20	6.74	6.26–7.22	0.48	23	8.30	7.72–8.90	0.59
1UPM	13	7.89	7.29–8.31	0.52	13	9.97	8.96–10.78	0.59	18	5.70	4.97–6.83	0.39	20	8.89	7.95–9.75	0.39
2UPM	7	7.77	7.01–8.45	0.48	12	9.55	8.88–10.01	0.42	20	5.10	4.86–5.38	0.40	21	8.30	7.58–8.98	0.49
1UM	15	11.63	10.10–12.39	0.79	14	12.44	11.36–13.54	0.70	20	8.78	8.03–9.28	0.63	25	15.00	10.68–12.64	0.55
2UM	10	10.89	9.97–12.02	0.64	11	12.10	11.41–13.08	0.61	18	8.76	7.83–9.96	0.86	19	11.34	9.75–12.24	0.96
Females																
1LI	8	5.14	5.12–5.19	0.03	10	5.86	5.63–5.99	0.17	19	3.60	3.53–3.67	0.07	20	5.69	5.30–5.91	0.34
2LI	7	6.41	6.29–6.68	0.11	10	6.38	6.08–6.57	0.26	14	4.37	4.24–4.34	0.15	20	6.00	5.80–6.40	0.33
LC	13	8.25	8.04–8.40	0.27	9	8.26	8.10–8.38	0.65	19	5.48	5.37–5.60	0.23	22	8.15	8.13–8.27	0.29
1LPM	9	7.21	6.98–7.40	0.16	10	8.28	8.18–8.39	0.08	18	5.55	5.20–6.08	0.35	18	6.97	6.74–7.19	0.19
2LPM	8	7.50	7.06–7.80	0.29	12	8.40	7.21–8.92	0.77	22	5.66	5.33–6.00	0.30	21	7.16	6.88–7.53	0.24
1LM	8	12.13	11.61–12.62	0.50	11	11.20	10.20–11.68	0.91	17	9.98	9.35–10.44	0.62	18	9.83	8.94–10.62	0.82
2LM	10	10.88	9.98–12.11	0.93	10	10.20	9.64–10.65	0.87	18	9.71	8.99–9.93	0.74	15	9.43	8.97–10.11	0.97
1UI	10	9.29	8.87–9.50	0.52	10	7.32	6.96–7.60	0.39	23	6.89	6.48–7.18	0.52	24	6.32	5.69–6.60	0.45
2UI	7	6.76	6.18–7.61	0.75	12	6.22	5.84–6.84	0.54	20	4.60	4.00–5.59	0.87	25	5.75	5.20–6.40	0.61
UC	11	8.64	8.12–9.16	0.74	18	8.39	7.94–8.84	0.64	20	5.96	5.86–6.06	0.14	21	7.63	7.36–7.90	0.38
1UPM	8	7.21	6.78–7.94	0.53	12	9.00	7.98–9.53	0.48	16	4.80	4.03–5.48	0.38	17	8.72	8.01–9.69	0.35
2UPM	9	7.77	7.00–8.05	0.36	15	9.89	9.00–10.09	0.41	20	4.97	4.70–5.18	0.32	19	8.67	8.10–8.98	0.29
1UM	14	11.19	10.46–11.84	0.58	17	11.62	10.97–12.56	0.58	25	10.08	9.45–11.31	0.72	25	11.11	10.59–11.68	0.47
2UM	15	11.15	10.44–11.63	0.51	17	11.41	11.27–11.55	0.14	20	8.30	7.80–8.66	0.54	19	10.98	10.91–11.03	0.06

Table 3
Descriptive statistics for the crown and cervix measurements (in mm) by sex, for teeth with enamel hypoplasiae. References: see legend of Table 1.

	MDcr				BLcr				MDce				BLce			
	n	Mean	Range	SD	*n*	Mean	Range	SD	*n*	Mean	Range	SD	*n*	Mean	Range	SD
Males																
1LI	8	5.57	5.50–5.62	0.21	7	5.89	5.68–6.10	0.29	17	3.96	3.88–4.04	0.11	17	5.67	5.24–6.10	0.61
2LI	12	6.37	5.87–6.87	0.71	10	6.56	6.42–6.69	0.10	20	4.44	4.21–4.67	0.32	27	6.34	6.12–6.57	0.32
LC	11	7.94	7.31–8.80	0.50	12	8.05	7.22–8.61	0.43	21	5.95	5.56–6.33	0.30	28	7.81	7.28–8.64	0.47
1LPM	13	7.28	7.07–7.65	0.20	14	8.20	7.20–8.87	0.43	24	5.29	4.65–6.09	0.31	22	7.12	6.48–7.74	0.30
2LPM	8	7.39	7.05–7.61	0.39	12	8.95	8.48–9.03	0.29	22	5.48	5.03–5.89	0.41	24	7.24	6.67–7.58	0.39
1LM	14	12.16	11.32–12.38	0.49	12	10.98	10.67–12.41	0.65	25	8.78	9.00–9.98	0.30	23	9.2	9.13–10.00	0.36
2LM	13	12.32	11.70–12.87	0.69	14	11.11	10.54–11.26	0.55	25	10.10	9.87–10.96	0.83	27	9.99	8.99–10.67	0.80
1UI	8	8.75	8.17–9.48	0.50	11	7.63	7.01–8.04	0.29	24	6.54	5.99–6.73	0.49	19	6.90	6.38–7.09	0.31
2UI	12	7.62	6.98–7.62	0.66	10	6.68	5.16–7.19	0.79	18	5.37	4.34–5.98	0.54	15	6.49	6.16–7.44	0.52
UC	13	8.62	8.16–9.07	0.47	9	8.79	8.10–9.38	0.65	21	6.27	5.77–6.65	0.53	19	8.06	7.59–8.76	0.43
1UPM	10	7.69	6.98–8.01	0.54	15	9.78	8.78–10.79	0.69	23	5.30	4.89–6.03	0.46	23	8.68	7.67–9.76	0.52
2UPM	11	7.67	7.58–7.76	0.23	9	9.50	8.90–9.78	0.37	18	5.08	4.97–5.30	0.38	17	8.15	7.78–8.40	0.38
1UM	14	12.30	11.10–12.98	0.60	12	12.73	11.65–13.02	0.51	24	8.62	7.99–9.19	0.51	20	11.71	10.51–12.37	0.48
2UM	11	10.77	10.00–12.11	0.59	8	11.92	10.87–12.74	0.48	20	7.89	6.89–8.98	0.43	19	11.15	10.01–11.98	0.56
Females																
1LI	5	5.01	4.27–5.98	0.41	8	5.49	4.98–6.14	0.51	10	3.85	3.05–4.71	0.50	11	5.28	4.89–5.61	0.48
2LI	11	6.36	6.23–6.54	0.03	12	6.32	6.29–6.35	0.03	18	4.90	4.82–4.97	0.07	14	5.98	5.87–6.03	0.07
LC	9	7.91	7.32–8.51	0.46	11	7.88	7.67–8.57	0.40	17	5.94	5.12–6.34	0.46	13	8.12	7.90–8.67	0.47
1LPM	6	7.28	7.08–7.38	0.12	9	8.21	8.02–8.31	0.18	11	5.47	5.40–5.52	0.19	12	7.00	6.88–7.09	0.12
2LPM	18	7.40	7.10–7.63	0.26	8	8.32	7.68–8.63	0.42	17	5.77	5.48–6.20	0.28	18	7.06	6.68–7.26	0.40
1LM	6	12.24	11.94–12.53	0.42	9	11.79	11.40–12.18	0.55	16	10.04	9.56–10.71	0.41	15	10.34	9.66–11.01	0.45
2LM	7	11.25	10.81–11.90	0.06	12	10.95	10.40–12.31	0.21	12	10.26	10.03–10.48	0.32	17	9.86	9.72–10.00	0.20
1UI	10	8.74	8.62–8.90	0.10	9	7.42	7.15–7.49	0.25	17	6.46	6.35–6.52	0.07	18	6.88	6.39–7.17	0.36
2UI	11	7.52	7.18–7.86	0.48	11	7.26	6.57–7.68	0.47	22	5.75	5.36–6.13	0.31	18	6.96	5.95–7.21	0.66
UC	10	8.66	7.71–9.12	0.44	15	8.33	7.67–8.83	0.44	24	6.41	5.82–6.77	0.77	21	7.72	6.89–8.35	0.67
1UPM	8	7.10	6.66–7.87	0.38	11	8.88	7.99–9.56	0.49	20	4.60	4.20–5.00	0.54	19	8.49	7.97–8.96	0.53
2UPM	10	7.70	7.20–8.28	0.46	10	9.69	8.97–9.98	0.36	14	4.86	4.26–5.15	0.40	16	8.47	8.12–9.01	0.38
1UM	7	11.40	10.34–11.78	0.39	8	12.66	11.03–13.21	0.47	11	11.24	10.02–11.97	0.52	8	11.45	10.29–11.98	0.29
2UM	9	12.18	11.38–12.76	0.43	9	10.89	10.41–11.60	0.39	12	8.26	7.69–8.60	0.48	13	11.08	10.65–11.49	0.38

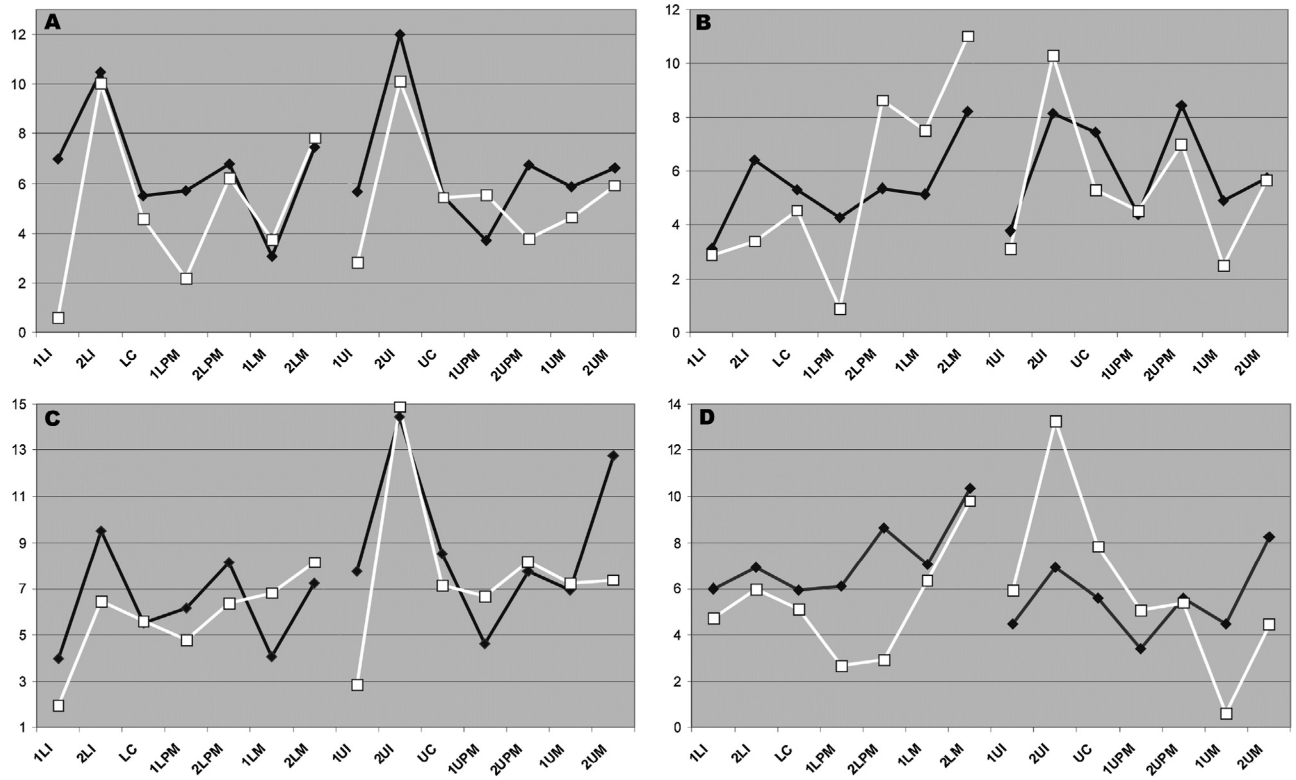

Fig. 1. Values of the coefficient of variation by sex. References: A: mesiodistal crown diameters; B: buccolingual crown diameters; C: mesiodistal cervical diameters; D: buccolingual cervical diameters; black line: males; white line: females; for abreviations, see legend of Table 1.

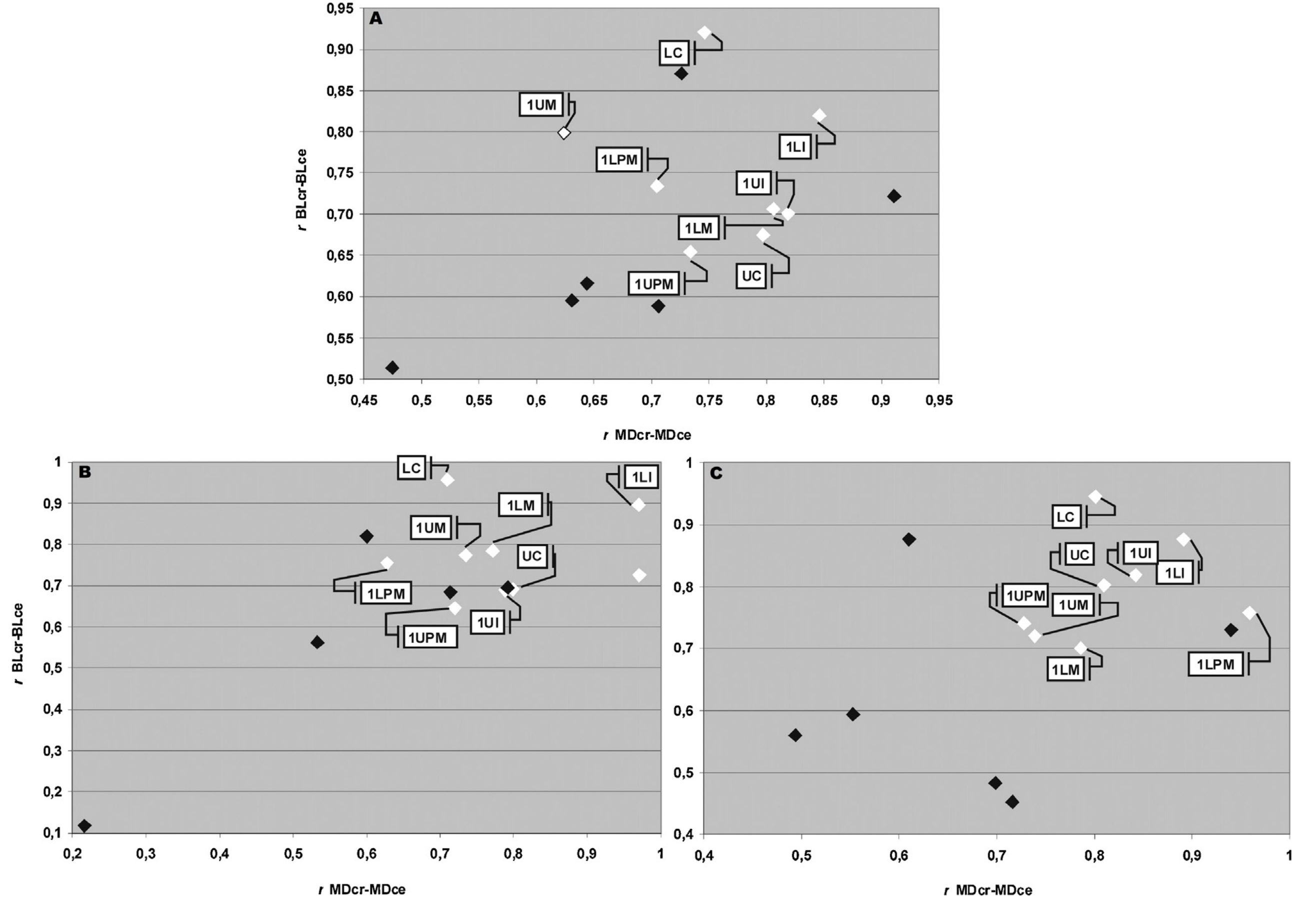

Fig. 2. Pearson's correlation coefficient (r) for pairs of crown and cervical homologous measurements. White diamonds indicate the least variable teeth. References: A: all individuals; B: females; C: males; for abreviations, see legend of Table 1.

Table 4
Pearson's correlation coefficients (*r*) for mesiodistal and buccolingual diameters (crown vs. cervix measurements). References: see legend of Table 1.

Sex	Tooth	MDcr-MDce			BLcr-BLce			Tooth	MDcr-MDce			BLcr-BLce		
		n	*r*	*p*	*n*	*r*	*p*		*n*	*r*	*p*	*n*	*r*	*p*
F	1UI	20	0.799	0.050	29	0.691	0.050	1LI	13	0.970	0.010	18	0.896	0.060
M		24	0.842	0.004	19	0.818	0.000		22	0.891	0.030	20	0.876	0.000
F + M		44	0.819	0.000	48	0.701	0.000		35	0.846	0.000	38	0.820	0.000
F	2UI	18	0.971	0.002	23	0.725	0.020	2LI	18	0.600	0.162	22	0.819	0.010
M		20	0.940	0.002	27	0.730	0.000		26	0.610	0.210	28	0.876	0.000
F + M		38	0.911	0.000	50	0.722	0.000		44	0.726	0.010	50	0.871	0.000
F	UC	21	0.789	0.100	33	0.688	0.080	LC	22	0.710	0.140	20	0.956	0.040
M		20	0.810	0.061	22	0.802	0.000		24	0.801	0.010	28	0.945	0.000
F + M		41	0.797	0.040	55	0.675	0.001		46	0.746	0.000	48	0.921	0.000
F	1UPM	17	0.720	0.130	23	0.645	0.030	1LPM	15	0.628	0.433	19	0.754	0.020
M		23	0.728	0.050	28	0.738	0.000		28	0.959	0.010	30	0.757	0.000
F + M		40	0.734	0.250	51	0.654	0.010		43	0.705	0.050	49	0.734	0.000
F	2UPM	19	0.533	0.060	25	0.562	0.020	2LPM	18	0.792	0.010	20	0.695	0.020
M		18	0.494	0.160	21	0.560	0.019		24	0.716	0.010	23	0.452	0.000
F + M		37	0.631	0.000	46	0.595	0.000		42	0.475	0.000	43	0.514	0.000
F	1UM	21	0.735	0.060	25	0.773	0.010	1LM	14	0.772	0.000	20	0.784	0.000
M		29	0.739	0.040	26	0.720	0.080		30	0.786	0.040	32	0.700	0.010
F + M		50	0.624	0.010	51	0.799	0.010		44	0.806	0.020	52	0.706	0.000
F	2UM	24	0.216	0.439	26	0.118	0.689	2LM	17	0.714	0.030	22	0.684	0.010
M		21	0.553	0.000	19	0.594	0.000		31	0.699	0.000	28	0.483	0.020
F + M		45	0.644	0.000	45	0.616	0.000		48	0.706	0.000	50	0.588	0.000

Table 5
Percentages of measurements recorded (*n*) against the number of teeth in the sample (*N*). References: see legend of Table 1.

	N	MDcr		BLcr		MDce		BLce	
		n	%	*n*	%	*n*	%	*n*	%
1LI	78	35	44.87	38	48.72	64	82.05	70	89.74
2LI	86	44	51.16	50	58.14	77	89.53	83	96.51
LC	93	46	49.46	48	51.61	87	93.55	89	95.70
1LPM	90	43	47.78	49	54.44	84	93.33	82	91.11
2LPM	89	42	47.19	43	48.31	86	96.63	88	98.88
1LM	90	44	48.89	52	57.78	88	97.78	87	96.67
2LM	80	48	60.00	50	62.50	75	93.75	80	100.00
1UI	95	44	46.32	48	50.53	89	93.68	93	97.89
2UI	78	38	48.72	50	64.10	78	100.00	78	100.00
UC	87	41	47.13	55	63.22	85	97.70	84	96.55
1UPM	80	40	50.00	51	63.75	77	96.25	79	98.75
2UPM	74	37	50.00	46	62.16	72	97.30	73	98.65
1UM	83	50	60.24	51	61.45	80	96.39	78	93.98
2UM	70	45	64.29	45	64.29	70	100.00	70	100.00

consistent with previously obtained results with a smaller dental sample (also included in the present investigation) from the same archeological site: although there were no significant differences in tooth sizes by age-at-death, adults dying at younger ages tended to have higher prevalence of dental stress indicators (Luna, 2008; Luna and Aranda, 2010). This concatenation of factors allows affirming that in this case the stressful events suffered during subadulthood did not influence dental phenotype, which would be mainly patterned by genetic constraints.

The coefficients of variation show a set of dental types with smaller variations in size that is congruent with systematic trends found in previous research (Kieser, 2008). Thus, the first incisors, canines, first premolars and first molars, both upper and lower, would be the most effective for biodistance

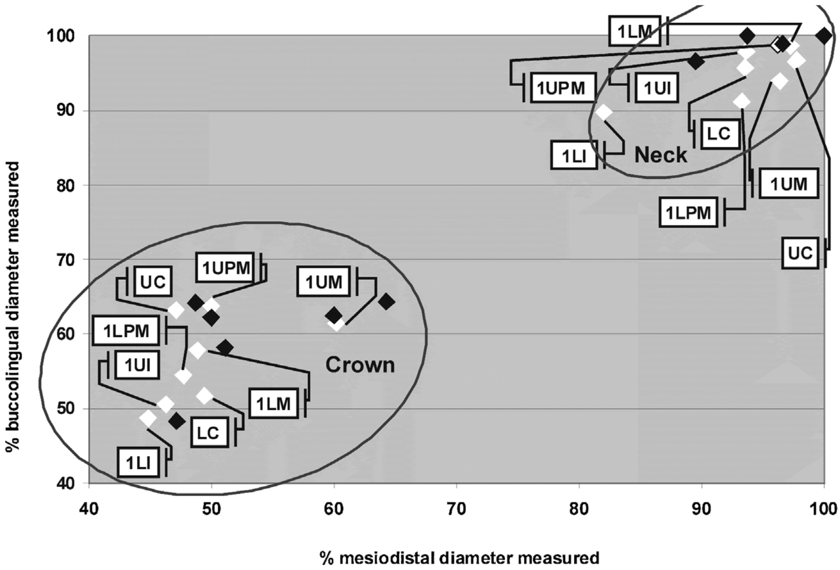

Fig. 3. Percentages of crown and cervical measurements on the total sample teeth. References: see legend of Table 1.

analysis. The only discordant data compared to previous results are about lower incisors, as this investigation identifies the first incisor as the most stable, while previous research points to the second incisor. In this sample, the variation observed for the second incisor is the largest (Table 1).

R values (Table 4) show relatively high correlations between coronal and cervical measurements, which suggest that both would enable tight interpretations. Moreover, the comparison of percentages of measurements effectively recorded for both sets of variables indicates that sample sizes increase when cervical dimensions are incorporated. By contrast, the incidence of deterioration factors such as tooth wear, mainly for mesiodistal diameters of the crown, had a very important effect that decreases the amount of teeth recorded, affecting more than 50% of the measures for some teeth (Table 5). The incorporation of cervical measurements is, considering the information obtained in this research, suitable from a morphometric point of view, which is also consistent with previous proposals (Fitzgerald and Hillson, 2008; Hillson et al., 2005). Moreover, despite the action of some agents that may affect the recording, the increase of the sample ensures an improvement in the strength of the interpretations about biological distances from dental metrics (Bernal, 2008; Fitzgerald and Hillson, 2008; Luna, 2008).

In conclusion, it is proposed that, considering the diversity of previous information and interpretations available in the literature, it is relevant, whenever possible and as a precautionary procedure, to assess the impact of environmental factors on dental size, as it may affect the results obtained in different environmental settings and therefore introduce external error factors. In this case, stressors did not significantly affect dental dimensions, which ensure that metric information obtained can be effectively used for biodistance studies. Secondly, another proposal is the exclusive analysis of more stable teeth (first incisors, canines, first premolars and first molars, both upper and lower), which improves the accuracy of the results obtained by eliminating the variability due to other extrinsic factors which could obscure the real biological trends. Finally, since the mesiodistal diameter of the crown is usually not preserved, it is suggested that only the coronal buccolingual diameter in association with both cervical dimensions might be included, or in samples with very marked attrition rates, only the cervical variables.

The incidence of multiple biological (phenotypic), extrinsic (environmental), behavioral (patterns and intensities of tooth wear) and taphonomic (postdepositional deterioration) factors produces variations in the formation of dental samples. The previous analysis of the characteristics of these variables in both living populations and bioarchaeological contexts is important to establish general patterns and identify the expected diversity for human biology. For this reason, the trends and proposals developed in this paper, although supported by previous research developed in multiple samples around the world, are initial and should be tested with larger collections and from different social and environmental contexts, so as to establish global patterns of variation.

Acknowledgements

I specially thank Claudia Aranda and Mónica Berón for their comments about this research. I am also very grateful for the suggestions made by three anonymous referees. This research was supported by the following grants: PICT 0437 and PIP 0122.

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