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Relationship between postcanine teeth, femur and mandible:

quantitative variables in a Portuguese modern human population

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Abstract. The relationship between the variability of the measured crown area (MCA) of the molars and the femur length and height of the mandibular body are analysed in a modern human Portuguese sample belonging to the Osteological Collections housed in the "Museu de Antropologia" of the "Universidade de Coimbra". In the male sample, the correlation coefficient between log MCA and log femur length was practically equal to 0 for the three molars, whereas in the female sample this coefficient was somewhat higher and significantly different from 0 for the third molars. In the combined sample of males and females, the correlation coefficient between these variables was also low, but significantly different from 0, for the three molars. Moreover, the allometric coefficient and its 95% confidence interval indicated that log MCA of the three molars in this combined sample scales negatively allometric to log femur length. Some sexual differences were also observed concerning the analysis of the relationships between log MCA and log height of the mandibular body, but the correlation coefficients between these variables were also low in all cases. The slope of the regression line and its 95% confidence interval indicated that log MCA of the three molars decreases with increasing log height of the mandibular body. The results are discussed considering the existence of different and specific growth factors and the uniqueness of the human growth pattern.

Key Words: modern humans; linear correlation; dental allometry.

Resumo. É analisada a relação entre a variabilidade da medida da área da coroa dos molares (MCA), o comprimento do fémur e a altura do corpo mandibular numa série portuguesa moderna pertencente às Colecções osteológicas do Museu de Antropologia de Coimbra. Na amostra masculina o coeficiente de correlação entre o log MCA e o log do comprimento do fémur era praticamente igual a zero para os três molares, enquanto que na amostra feminina este coeficiente era algo superior e significativamente diferente de zero para os terceiros molares. Na série combinada de homens e mulheres, o coeficiente de correlação entre estas variáveis era igualmente baixo, para os três molares, mas significativamente diferente de zero. Acrescente-se, também, que o coeficiente alométrico e o respectivo intervalo de confiança de 95% indicam que o log MCA dos três molares na amostra combinada, têm uma relação alométrica negativa relativamente ao log do comprimento do fémur. Foram observadas algumas diferenças sexuais na relação do log MCA com o log da altura do corpo mandibular sendo, no entanto, os coeficientes de correlação entre estas variáveis igualmente baixos em todos os casos. O declive da linha de regressão e o seu intervalo de confiança de 95%, indicam que o log MCA dos três molares diminui com o aumento do log da altura do corpo mandibular. Na discussão destes resultados tem-se em conta a existência de factores de crescimento diferentes e específicos e atende-se ao padrão único de crescimento humano.

Palavras chave: humanos modernos; correlação linear; alometria dentária.

Introduction

The study of the covariation between some qualitative and quantitative variables of the same or different anatomical elements of an organism has been one of the most important aspects of the evolutionary biology in the last two decades (Gould, 1977; McKinney & McNamara, 1991). We may be interested, for instance, in investigating the size of an unknown anatomical organ of certain extinct species from the size of another well known organ of that species. The habitual methodology in these cases lies in obtaining the algebraic relationship between the variables, which are under consideration in related living species of the same taxonomic group (Pilbeam & Gould, 1974).

A crucial point in researches on evolutionary ecology in continental environments is to quantify the height and weight of individuals belonging to a certain extinct vertebrate species by measuring the appropriate anatomical elements, e.g. the long bones of the anterior and posterior limbs. One alternative consists of to use the teeth, simply because of the characteristics of the dental tissues favour the preservation of these elements, which thus represent a very important quantitative part of the vertebrate fossil record. The use of the molar variables, such as the mesiodistal diameter or the crown area, to estimate the body size may give reliable results (Creighton, 1980). This alternative, however, seems to be less desirable in the case of the hominids, since some studies have shown a very low correlation between the corporal and dental variables in modern human populations (Garn *et al.*, 1968; Henderson & Corruccini, 1976; Anderson, *et al.*, 1977; Lavelle, 1977).

The estimation of body size in these populations employing the variability of the postcanine teeth has been barely used (Garn, *et al.*, 1977; Lavelle, 1977), and the aim of this paper is to expand our knowledge on this topic by means of the analysis of the relationship between some corporal variables (femur length, vertical diameter of the femur head, and height of the mandibular body) and dental variables (crown base area of the molars) in a modern human population. The results are discussed in the light of the most recent knowledge about the factors which control the growth of the diverse anatomical parts of the human body.

Materials and methods

The data used in this study were taken from the human remains of individuals belonging to the collections housed in the Museu de Antropologia of the Universidade de Coimbra (Portugal) (identified skeletons, identified skulls from Escolas Médicas, and identified skulls from the Conchada Cemetery). These individuals belonged to Caucasian Portuguese who died between 1896 and 1936. Records of sex, age at death, job, etc., were available for each of these individuals. We observed that individuals who died after reaching the age of 50 frequently had lost many of their posterior teeth and, when present, molars generally had a severe occlusal wear (including the third molars). Therefore, the sample examined here comprises only individuals who died among 7 and 50 years old. This sample includes a total of 106 males and 76 females.

The method used in this study lies in the determination, by means of the correlation coefficient, of the possible dependence or independence between a variable directly related to the body size, such as the femur length, and a variable that expresses the postcanine tooth size, such as the crown area of the molars. As a reference, the correlation coefficient between the femur length and the vertical diameter of the femur head and the height of the mandibular body, as well as the correlation coefficient between the last variable and the crown area of the molars, were also calculated. Furthermore, the algebraic relationship between all these variables was investigated by means of the regression analysis (model II). The size sexual dimorphism of each variable was estimated by obtaining the degree of overlapping of the male and female distributions, measured as the percentage of the cases belonging to both distributions (Bermúdez de Castro, *et al.*, 1993).

Separate occlusal photographs were taken of the three lower molars of these individuals. Each specimen was oriented so that the occlusal plane was perpendicular to the optical axis of a camera fitted up with a Tamron 90 mm F 2.5 lens and a Tamron extension tube 18F. In order to get a maximum depth of field, an aperture of f/32 was set. Before focusing on the occlusal plane of the specimens, the magnification ratio was adjusted to 1:1. A scale was included in each photograph and placed parallel to the occlusal plane of the specimens. This plane and that of the surface of the scale were set at approximately the same focal length. This yields a magnification of x5, which proved to be the most suitable magnification for using a planimeter Ushikata X-Plan 360d. The boundary of the crown, and that of each cusp (following the criteria of Wood *et al.*, 1983) was marked with ink on the photographs. Following Wood and Abbott (1983), the original mesial and/or distal crown borders of the teeth with interproximal wear were estimated by reference to the overall crown shape and the buccolingual extent of the wear facets. Before obtaining any measurement, the exact enlargement of each print was checked using the planimeter. Tests showed intra--observer measurement error to be less than 1%. The surface area of each cusp was used as an estimate of cusp size. The overall crown size (measured crown area: MCA) was taken to be the sum of the areas of the four or five cusps. The relative cusp areas are obtained by dividing each cusp area by the MCA for that tooth. Only those molars whose cusp boundaries were well-defined in the photographs were included in the sample. Furthermore, the femur length and vertical diameter of the femur head were taken following Martin & Saller (1957). The height of the mandibular body was taken at the M1 level.

Results

The descriptive statistics for the variables investigated in this study for both males and females, as well as the degree of overlapping between male and female populations for these variables, are presented in Table 1.

Tables 2 and 3 include all the information concerning the relationship between the skeletal and dental variables. As was to be expected, there is an appreciable correlation, significantly different from 0, between the femur length and the vertical diameter of the femur head for both males and females and the total sample. Furthermore, the F-tests indicate that a great and significant part of the variance of the vertical diameter of femur head is explained by the regression on log femur length. Similar results were obtained for the femur length vs. height of the mandibular body, but only for the female and total samples. Unexpectedly, the regression analysis indicated an independence between these variables for the male sample, and the correlation coefficient is equal to 0.

Table 1. Descriptive statistics for the femur, mandible and molar variables of the modern human Portuguese sample. DSO: degree of sexual overlapping between both the male and female distribution. MCA: measured crown area.

	Sex	N	X	S.D.	Range	DSO (%)
Femur lenght	M	106	431.4	21.9	384 - 482	73.08
	F	76	397.7	18.6	342 - 443	
Vertical diameter of the femur head	M	106	45.3	2.3	40.0 - 51.5	50.55
	F	76	40.4	2.1	34.1- 44.6	
Height of the mandibular body at the M1 level	M	101	31.4	2.3	25.3 - 37.7	95.97
	F	73	28.5	2.6	23.0 - 37.8	
MCA of M1	M	78	94.2	6.9	76.7 - 110.4	90.91
	F	54	88.6	6.9	73.6 - 104.6	
MCA of M2	M	95	88.4	8.9	67.0 - 111.7	94.19
	F	60	82.7	8.4	66.8 - 102.6	
MCA of M3	M	71	85.5	10.4	59.9 - 106.6	91.66
	F	37	78.5	11.1	55.0 - 98.5	

The regression analysis of log crown area of the three molars on log femur length offers an interesting difference between the male and female sample. In the male sample, the correlation coefficient between these variables is practically equal to 0 for the three molars, and the null hypothesis, r=0, cannot be rejected. In the female sample, the correlation coefficient between the log femur length and the log MCA is low for the three molars, and it is significantly different from 0 in the case the third molars. The analysis of the combined sample of males and females also gave low correlation coefficients, but they are significantly different from 0 for the three molars. Furthermore, in the male sample the slope of the regression line of the log MCA on the log femur length is near 0 for the three molars though the 95% confidence interval indicates either a negative allometry of the log MCA, or a decrease of the log MCA with increasing log femur length. Obviously, the F-test does not reject the null hypothesis of independence between the variances of the two variables. In the female sample, the regression analysis indicates a negative allometry the log MCA for the first and second molars, and a positive allometry of this variable for the third molars. The analysis of the combined sample seems to be more clear, since both the allometric coefficient and its 95% confidence interval indicate that log MCA of the three molars scales negatively allometric to log femur length. In the three molars, a considerable and significant part of the variance of log MCA is explained by the regression on log femur length.

Table 2. Regression slopes (b) of log femur length on log vertical diameter of the femur head, height of the mandibular body at the M1 level, and measured crown area (MCA) of the three lower molars of the modern Portuguese sample. S.E (b): standard error of b; r: correlation between the log femur lenght and log of the other variables.

		N	b	S.E. (b)	95% conf. interval b	r	t	F
Vertical diameter of the femur head	M	106	0.51	± 0.17	0.68 - 0.34	0.50	5.89*	34.80*
	F	76	0.65	± 0.21	0.86 - 0.44	0.58	6.17*	38.12*
	M & F	182	0.90	± 0.23	1.02 - 0.79	0.74	15.14*	226.35*
Height of the mandibular body at the M1 level	M	101	- 0.01	± 0.28	0.27 - (-0.30)	0.00	0.08	0.00
	F	73	0.54	± 0.43	0.97 - 0.11	0.28	2.49*	6.21*
	M & F	174	0.60	± 0.21	0.81 - 0.39	0.40	5.79 *	33.54*
MCA of M1	M	78	0.10	± 0.34	0.49 - (-0.23)	0.07	0.62	0.38
	F	54	0.35	± 0.42	0.77 - (-0.07)	0.22	1.65	2.74
	M & F	132	0.42	± 0.21	0.63 - 0.21	0.32	3.96*	15.72*
MCA of M2	M	95	0.04	± 0.42	0.46 - (-0.37)	0.02	0.21	0.04
	F	60	0.42	± 0.56	0.98 - (-0.13)	0.19	1.51	2.29
	M & F	155	0.43	± 0.26	0.69 - 0.17	0.25	3.26*	10.68*
MCA of M3	M	71	- 0.15	± 0.62	0.47 - (-0.76)	0.06	0.48	0.23
	F	39	1.29	± 1.17	2.46 - 0.12	0.35	2.25*	5.07*
	M & F	108	0.57	± 0.47	1.04 - 0.09	0.22	2.40	5.76*

* $P < 0.05$.

The correlation coefficients between log MCA of the three molars and log height of the mandibular body are low and significantly different from 0 in the male sample for the first and second molars, and in the combined sample for the three molars (Table 3). In contrast, the correlation coefficients are near 0 in the female sample for the three molars, and the null hypothesis, r=0, cannot be rejected. In the male and combined samples, the slope of the regression line indicated that log MCA of three molars decreases with increasing log height of the mandibular body. In the female sample, the slope of the regression line is near 0 for the three molars, and the F-test cannot reject the null hypothesis of independence between the variance of the variables.

Table 3. Regression slopes (b) of log height of the mandibular body at the M1 level on log measured crown area (MCA) of the three lower molars of the modern Portuguese sample. S.E. (b); r: correlation between the log height of the mandibular body and log of the dental variables.

		N	b	S.E. (b)	95% conf. interval b	r	t	F
	M	75	0.34	± 0.23	0.57 - 0.11	0.32	2.94*	8.66*
MCA of M1	F	54	0.10	± 0.23	0.33 - (-0.11)	0.13	0.95	0.89
	M & F	129	0.30	± 0.14	0.44 - 0.17	0.36	4.43*	19.61*
	M	92	0.43	± 0.28	0.71 - 0.15	0.31	3.08*	9.52*
MCA of M2	F	58	0.03	± 0.32	0.35 - (-0.29)	0.02	0.19	0.04
	M & F	150	0.36	± 0.18	0.54 - 0.18	0.30	3.93*	15.49*
	M	66	0.31	± 0.45	0.76 - (-0.15)	0.16	1.34	1.79
MCA of M3	F	35	0.14	± 0.65	0.79 - (-0.50)	0.08	0.45	0.21
	M & F	101	0.42	± 0.31	0.73 - 0.11	0.26	2.76*	7.62*

* $P < 0.05$.

Discussion

The correlation coefficients between femur length and crown area of the molars obtained in modern human Portuguese sample range from 0.02 to 0.35. These figures are very low, though in the combined sample of males and females the coefficients were significantly different from 0 for the three molars. These results are not surprising according to the observations made by other authors. Thus, Garn *et al.* (1968) reported low, but significant correlations between mesiodistal and buccolingual dimensions of all teeth and stature in a sample of Caucasoid participants in the Fels Longitudinal Study, whereas Henderson & Corruccini (1976) also found low correlations between canine size and body size in a sample of American Negroes. In this case, however, the values obtained were not signi-ficantly different from 0, and Henderson & Corruccini (o.c.) concluded that dental size to body size inferences in hominids are unwarranted. The present study confirms that the correlation and covariation between body size and posterior-tooth size are low in modern humans. Therefore, it is risky to obtain inferences about body size from the size of the posterior teeth in modern human populations, and the question is whether this conclusion can be extrapolated or not to Plio-Pleistocene hominids.

Martin (1971) and Mahler (1973) reported high correlation coefficients between femur length and postcanine tooth areas in gorillas and orangoutangs respectively, whereas this coefficient was much lower in chimpanzees (White, 1974). These results seem to indicate, according to Wolpoff (1976), that there is a high correlation between tooth size and body size only in hominoids having a high degree of sexual dimorphism in body size. Wolpoff (1976) investigations indicated that inferences about body size from posterior-tooth size are possible in *Australopithecus*, since the species of this genus, according to him, are characterised by a remarkable sexual dimorphism in body size. The problem is to demonstrate the existence of a certain degree of sexual dimorphism in body size in any extinct species from the evidence of the fossil record, generally limited to a few fossil remains belonging to one or a few individuals. One approach to this question is that of Gingerich (1977), who reported a very high interspecific correlation coefficient between the averages of the lower second molar length and body size in both males and females of some primate species, including *H. sapiens*. This author concluded that "...tooth size can be used in dentally unspecialized fossil hominoids as one method of predicting the average body weight of species".

On the other hand, the regression analysis made in this study indicated that a great and significant part of the variance of log MCA of the three molars is explained by the regression on log femur length (at least for the combined sample of males and females). Likewise, a significant part of the variance of log MCA of the three molars is explained by the regression on log height of the mandibular body (combined sample), and the correlation coefficient between these variables is also low, but significantly different from 0. Therefore, though the correlation between the MCA of the molars and other skeletal variables is low, there is a certain covariation between these variables that ought to be explained. Moreover, some differences have been observed between males and females, which demand an explanation as well.

In order to understand the relationships between different quantitative variables of the human beings, it would be advisable to have a previous knowledge about the specific factors responsible for the growth of each one of the anatomical elements on the organism. For a long time, the function of the growth hormone (GH) is reasonably well-known. GH is synthesized by the anterior pituitary gland and secreted in discrete pulses, which arise from interactions of hypothalamic GH-releasing hormone and somatostatin (see a recent review in Hartman *et al.*, 1993). GH has a number of important metabolic actions, such as the retention of nitrogen, sodium, potassium, calcium and other elements necessary for a normal growth (Cheek, 1968). GH stimulates long bone growth directly (Isaksson *et al.*, 1982), and the protein synthesis in skeletal muscle (Fryburg, *et al.*, 1991). A wide variety of cells produce somatomedins, the socalled insulin-like growth factors (IGFs) (Clemmons & Van Wyk, 1984), as a response to the presence of GH in the bloodstream. Two of these substances, the

IGF-II and IGF-I, control in humans the prenatal and postnatal growth respectively, and its presence is necessary to normal growth (Merimee *et al.*, 1982). The small stature of African Pygmies, for instance, seems to be due to the genetic incapacity of these individuals to produce levels of IGF-I (Merimee *et al.*, 1968, and see also Shea & Gómez, 1988). The levels of IGF-I, however, seem to have too little influence on the brain growth (Atchey *et al.*, 1984).

The GH and IGF-I play a limited role during the puberty (Rosenfeld *et al.*, 1983). In fact, though normal levels of GH and IGF-I are necessary during the adolescence, the acceleration of growth in this life period (adolescent growth spurt) is related to a remarkable increase of the secretion of testosterone and estradiol (Prader, 1984; Preece *et al.*, 1984), which stimulates bone growth in early puberty, and facilitates epiphyseal closure in later puberty by suppressing cell division. Besides the IGFs, there are other growth factors, such as the Fibroblast Growth Factor, Bone-derived Growth Factor, and Nerve Growth Factor, which regulate growth in specific corporal tissues (D'Ercole & Underwood, 1986). In recent studies, three growth factors namely Epidermal Growth Factor, Transforming Growth Factor-ß1, and Transferrin have been reported to play an important role in odontogenesis (see a revision in Russo et al., 1992).

Therefore, because the existence of specific growth factors, it could be deduced that any quantitative variable of the postcanine teeth ought to be independent of any other somatic variable in both humans and nonhuman mammal species. However, the correlation coefficients between dental and corporal variables are high in mammals, included some primate species (Creighton, 1980; Martin, 1971; Mahler, 1973). Moreover, the present results suggest the existence of a common factor responsible for the covariation between body size and dental size in human populations.

In our species, the crown formation of permanent teeth, except for the third molars, ends about the age of eight years, whereas body growth continues up to the age of eighteen. However, human growth is characterized by the adolescent growth spurt, which determines about a 14 per cent of the total postnatal growth. Therefore, though a common factor may be considered to determine the strong covariation between the dental and corporal variability in all mammal species, the unique human growth circumstances from the age of eight years contribute in our species to diminish remarkably the covariation between dental and other somatic variables.

The qualitative and quantitative differences between the growth of boys and girls during the adolescence (see for instance Bogin, 1988 and Eveleth & Tanner, 1990) could determine the different behaviour of male and females samples in the present analysis. The adolescent growth spurt occurs, on average, two years later in boys than in girls, and the average peak height velocity is 1 to 2 cm/year faster in boys than in girls (Largo *et al.*, 1978). In other words, boys have an additional growth in relation to girls, which theoretically ought to decrease the covariation and correlation between dental and other somatic variables to a greater extent in the former than in girls. The results of the present analysis concerning femur length support this interpretation. Later growth also seems to contribute to decrease tooth-mandibular size covariation (Kieser, 1990), and the correlation between log MCA and log height of the mandibular body is very low. However, in this case the correlation and covariation are lower in females than in males. We have not a convincing explanation for these results, and it is evident that the relationship between dental and jaw variability needs further research.

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