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Abstract

The aim of this work is to study the cortical cross-sectional geometry of tibias of individuals from a past Tenetehara population in order to explore the sex-related activity patterns in lower limbs in the initial moments of the contact. Total area, cortical area, second moments of area and polar moment of cross-section of tibias were estimated from computed tomography (CT) images. The results showed significant differences in mechanical demand be-tween sexes. Although several individuals revealed signs of cortical resorption in CT imag-es, the results indicate that this population was be exposed to a moderate nutritional-metabolic stress, supporting previous researches conducted in the same sample. © 2007-2011 Syllaba Press & Archaeodiversity Research Group. All rights reserved.

Keywords: Tenetehara Population, South American Natives, Cortical Bone, Cross-sectional Geometry.

Resumen

El objetivo de este trabajo es estudiar la geometría de la sección transversal cortical de tibias de individuos de una población antigua Tenetehara correspondiente a momentos iniciales del contacto, con el propósito de explorar patrones de actividad física relacionados con el sexo en los miembros inferiores. El área total, el área cortical, el segundo momento de área y el momento polar de las secciones de tibias fueron estimados a partir de imágenes obtenidas mediante tomografía computada. Los resultados muestran diferencias significativas en la demanda mecánica entre sexos. Aunque algunos individuos mostraron signos de resorción cortical en las imágenes tomográficas, los resultados indican que la población habría estado expuesta a condiciones moderadas de estrés sistémico-nutricional, apoyando investigaciones previas realizadas sobre la misma muestra. © 2007-2011 Syllaba Press & Archaeodiversity Research Group. All rights reserved.

Palabras clave: Población Tenetehara, Nativos Suramericanos, Hueso Cortical, Geometría de Sección Transversal.

Introduction

The Tenetehara is an agriculturalist ethnic group that inhabits the tropical forest region of Maranhão, in north-eastern Brazil (Figure 1). The contact between Tenetehara and Europeans, began in 1653. It initially had a small impact on Tenetahara´s health and culture because of two main reasons: 1) the settlement of Jesuitical Missions between 1653 and 1755, which attenuated slavery; and 2) the fact that they lived inland with their population scattered in several villages, a region that was not appropriate for the Portuguese agricultural system (Gomes 2002; Lima 1954). However, some changes were proposed as a result of native European contact, including division of works by gender and modifications in diet and

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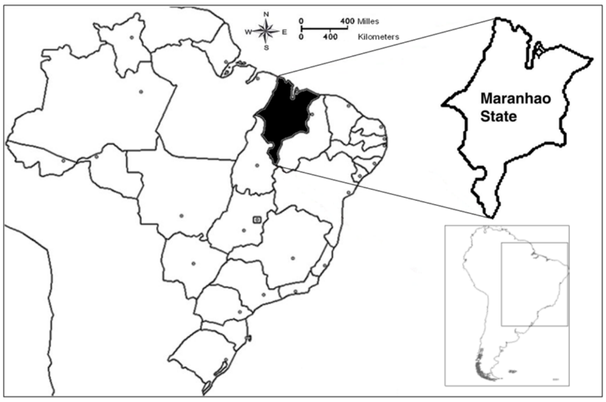

Figure 1. Map of Maranhão State, in Northeast Brazil.

nutritional health (Alvin & Gomez 1992; Braz, Rodríguez-Carvalho, Salles 2005).

Before the contact, women were responsible for heavy work such as water and food transportation, but the natives "learned" from the Europeans that these had to be done essentially by men, who were stronger. In relation to diet, the base of agriculture before the contact was corn, beans, pumpkin, cará, watermelon, peanuts, tobacco (to heal and for rituals), cotton and manioc. With the contact they included other products, like rice, sugar cane, banana, onion, cucumber, papaya, mammon and *Canabis indicus*. The last one, known as *diamba* or *dream grass*, was introduced by African slaves during the contact, although it had a moderate use among the Tenetehara (Gomes 2002; Lima 1954).

Despite the contact with white societies, the Tenetehara kept most of their traditions and lifestyles until the middle of the XX century. From the 1940´s on, the problems with the white societies increased due to the invasions of the Tenetehara territories, which exploitation were controlled by latifundiums in the centre of Maranhão State. As a result, many conflicts were registered between the 1960 and 1970 decades, when the native lands were largely invaded (Diniz 1994; Gomes 2002). Nowadays, even though many of the Tenetehara speak Portuguese, their language is still spoken in the villages. They wear industrialized clothes when they are visited, but they keep their traditional fishing, hunting and planting methods. Notwithstanding the constant white influence present in many daily aspects and the recently incorporated changes, the essence of their culture and traditions persists after 400 years since the first contact (Wagley & Galvão 1948, 1961).

Oriented to understand this acculturation process in past Tenetehara populations, some health and activity-related information was obtained from a bone sample of this ethnic group, re-covered in 1945 (*see Materials and Methods*). The high frequency of hyperostosis porotica observed in this sample was attributed to the impact of malaria instead of the nutritional factors (Alvin & Gomez, 1992). About activity patterns, low resorption processes in trabecular bone with no differences between sexes were described by Braz, Rodríguez-Carvalho, Salles (2005) in a biomechanical study of radius and calcaneus. However, the fact that the post-contact Tenetehara populations suffered changes in their activity patterns and nutritional deficiencies is accepted. In this context, the aim of this work is to study the cortical cross-sectional geometry of tibias of individuals from a past Tenetehara population in order to explore the sex-related activity patterns in lower limbs in the initial moments of the contact, providing new information about their physical demands in this particular moment.

Materials and Methods

Sample

In the 1940´s, The National Museum of Federal University of Rio de Janeiro sent a research team to Maranhão State to study the acculturation process that occurred, and still takes place, among Tenetehara natives. These studies integrate an anthropologic research programme in concert with the Anthropology Department of Columbia University, which included two expeditions. The first took place between November 1941 and March 1942 by a team composed by Charles Wagley, Eduardo Galvão, Nelson Teixeira and Rubens Meanda. The second expedition was carried out in February 1945, with the aim of confirming the information recovered in the first expedition (Wagley & Galvão 1948).

During the second expedition, Dr. Pedro Estevam de Lima excavated the funerary space of Camirang and Januária villages, recovering skeletal remains of 21 individuals (Alvin & Gomes 1992) near Pindaré River, at northwest of Maranhão State (Figure 1) and currently deposited in the National Museum (Rio de Janeiro, Brazil). This sample, although small in number of individuals, is the only available skeletal collection of Tenetehara past populations. The recovered skeletons were object of a research programme that produced the publication of a book by Eduardo Galvão (1996), and two books by Charles Wagley and Eduardo Galvão (1948, 1961) about the life of the Tenetehara. Moreover, several works about dental mutilation, craniometry and other biological anthropology analyzes of this human group were published (Lima 1945, 1947, 1954, 1955). More recently, this sample was studied by Alvin & Gomez (1992) and Braz, Rodríguez-Carvalho, Salles (2005), as was stated above.

The sample used in this research is the same sample recovered by Lima in Maranhão State. A radiocarbon date recently obtained from male individual number 718 resulted in 210 ± 40 years BP (^{13}C corrected-Sample Nº GX-31824-AMS), which corresponds with the early moments of the contact between Tenetehara and European populations. The criteria of acceptance of the individuals for this research were based on the macroscopically good conservation of complete bones, and the absence of external signs of erosion and sediment infiltration

(Mays, Turner-Walker, Syversen 2006). Only those individuals whose skeletal morphology corresponds to adults were included, avoiding some possible inconsistencies in cortical geometry due to developmental variations (Ruff 2008). After this selection, fifteen Tenetehara individuals were included, which corresponds to eight women and seven men (Alvin & Gomes 1992), according to the sex determination methods proposed by Buikstra and Ubelaker (1994), based on cranial and hip morphology.

Measurements

Structural analyses of long bone diaphysis are frequently recognized as one of the best indicators of mechanical forces that operate over bone structures, and thus a reflection of occupational activities, assuming the relationship between bone structure and its function (Pearson & Buikstra 2006; Pearson & Lieberman 2004). Furthermore, because other factors like genetics, age, and hormonal and nutritional levels affect bone structures (Frost 1990; Martin 2000; Pearson & Lieberman 2004; Ruff 2008), cross-sectional geometry of long bones is informative about metabolic and nutritional health of individuals (Larsen 1997; Ruff 2008). In this sense, numerous studies about geometrical properties on long bones of past populations with evolutionary, biological and cultural aims have been carried out over the last three decades (Bridges 1995; Bridges, Blitz, Solano 2000; Brock & Ruff 1988; Holliday 1997; Holt 2003; Larsen 1995; Ledger *et al.* 2000; Pearson 2000; Robbins, Rosemberg, Ruff 1989; Ruff & Hayes 1982, 1983; Ruff, Larsen, Hayes 1984; Sládek, Berner, Sailer 2006; Stock 2006; Stock & Pfeiffer 2001; Trinkaus & Ruff 1999).

For this research, cross-sectional geometry of cortical bone of tibias was studied. Unlike femurs, where the cross-sectional properties are more related to body shape, tibias are more affected by activity related patterns and less by body shape and hip structure (Ruff 2008; Stock 2006). For that reason, cross sectional analyses of tibias are useful for studies of sexual dimorphism associated with cultural variation (Ruff 2008). Considering that, each shaft of tibias was scanned by computed tomography (CT), using a General Electric HiSpeed scanner at the Hospital Universitário Pedro Ernesto, Rio de Janeiro, Brazil. The technical protocol included images of 2 mm in width acquired at 80 Kv and 100 mA with a matrix resolution of 512x512 and FOV of 5 cm. The tibias were oriented and fixed in anteroposterior position, with their longitudinal axis coinciding with the axis of the equipment, following the procedures described by Ruff & Hayes (1983) and reproduced elsewhere (Ruff 2008). The CT images were obtained at 35% and 65% of biomechanical length of tibias, where the bone geometry is less influenced by dimensions of the ephyfisis (Trinkaus & Ruff 1999), consider-ing the proximal end as 100%.

From the digital CT images, indicators of mechanical rigidity according to different forces were calculated with ImageJ software <http://www.http://rsbweb.nih.gov/ij/>. Bone Cortical Area (CA) in bone shaft was calculated, as an indicator of rigidity and strength in pure compression and tension forces when the bones are loaded through their longitudinal axis. Moreover, Total subperiosteal Area (TA) was estimated, which includes the area encompassed by the outer perimeter of the section and reflects the relative distribution of bone in the section (Ruff 2008). However, due to the fact that long bones are normally loaded by forces out of their central axis, tension and compression forces are unusual. Therefore, CA and TA are of a more morphological rather than biomechanical interest and for that reason they frequently are result more appropriate to infer nutritional and metabolic health (Ruff *et al.* 1993; Ruff 2008). In contrast, bending and torsion are more common forces. In this sense, second moment of area (I) was calculated, in this about maximum (Imax) and minimum (Imin) axis, which estimates resistance to bending forces (Ruff 2008). In addition, polar moment or inertia (J), calculated by the arithmetic addition of Imax and Imin, is an indicator of torsional rigidity in two perpendicular planes, in this case maximum and minimum axis. Increments of I and J, with the same bone areas, suggest patterns of more physical activities, which in normal physiological conditions would result in transversal sections with more rigidity (Ruff 2008).

As the resistance of long bones is influenced by their length, comparative structural biomechanical properties between individuals must be size standardized. Some controversy exists about the most appropriate mean of standardization. As was pointed out by Ruff (2008), distal elements of both upper and lower limbs are less affected by body size. Considering that, this study, as others (Bridges, Blitz, Solano 2000; Ledger *et al.* 2000), follows Ruff et al. (1993), who suggested that CA and TA could be divided by bone lengths 3 x 108 and I and J by bone lengths 5.33x1012. For those standardizations, biomechanical length (Ruff & Hayes 1983; Trinkaus & Ruff 1999) of tibias was measured by an osteometric board. All indicators and bone length were calculated for both tibiae when available and the arithmetic average was considered as the final result.

Means and standard deviations were calculated for all variables. Pearson correlations were calculated between CA and TA, in order to explore the strength of the associations between these variables in the sample. The significance of differences between males and females was tested using the analysis of variance (ANOVA), were the independent factor was sex and the dependent variables were standardized TA, CA, moments of area (Imax and Imin) and polar moment of inertia (J). The alpha level was set at 0.05.

Results

Size standardized cross-sectional geometric data obtained from the tibia shafts for each 65% and 35% sites are summarized in tables 1 and 2 respectively. The mean values of TA and CA were slightly higher for men than for women in both 65% and 35% cross-sectional cortical bone. However, the amount of cortical bone in the cross sections had no significant differences between men and women in tibial shaft, which illustrates the similar axial loading between groups.

Moreover, in both cases the correlation between CA and TA was not significant (Figure 2) for both sexes. However, these low correlations could be associated with some individuals who showed lower CA in relation to TA values, particularly in men. Specifically, individual 715 among women and individuals 710 and 711 among men presented the lowest values of CA of the entire sample and lower than other individuals with similar values of TA. Consistent with this fact, the CT images of individuals T710, T711 and T715 showed alterations of endostium continuity in 65% and 35% cross-sectional cortical bone (Figure 3).

Despite the fact that no significant differences between sexes in CA and TA were observed, men showed significantly higher values than women for Imax, Imin and J both in 65% and 35% cross-sections (Tables 1 and 2). This suggests that cortical bone in men, although similar in amount, is situated further from the centroid than in women, resulting in a diaphysis more resistant to bending and torsional stresses. Indeed, resistance to flexional and torsional loads, in maximum and minimum axis, seems to be higher in men than in women.

Discussion and Conclusions

The analysis of cross-sectional geometry of tibias generates new information about the physical activities in men and women of a Tenetehara population. The results showed no significant differences of the CA and TA between sexes, which could be a response to similar axial loads. Moreover, the correlation between CA and TA both in Tenetehara men and women was similar to the models observed in normal metabolic and nutritional conditions for both sexes, which suggests a low impact of nutritional-metabolic stress in this population (Ferretti, Capozza, Cointry 2003). Nevertheless, the obtained CT images showed cortical resorption in some of the analyzed individuals manifested as endosteal discontinuities. Even though the effects of taphonomical processes cannot be completely excluded as the cause of cortical alteration, the outstanding conservation and the absence of postdepositional modifications on the external surface of the bones is a strong argument against that possibility. One of these individuals (T711) has an age estimation of ca. 50 years old, which could be a reason for its reduced CA in relation to TA. However, the other individuals (T710 and T715) are young adults and also showed similar resorption pattern, particularly individual T711, which could be due to other health issues. In this sense, both of them presented hyperostosis porotica, criba orbitalia and alveolar retraction as stress markers (Alvin & Gomes 1992). Although the observed cortical resorption allowed inferring nutritional deficits in these individuals, it would be moderate and not enough to represent a significant alteration of bone mechanical resistance, since they showed similar Imax, Imin and J values to the other individuals.

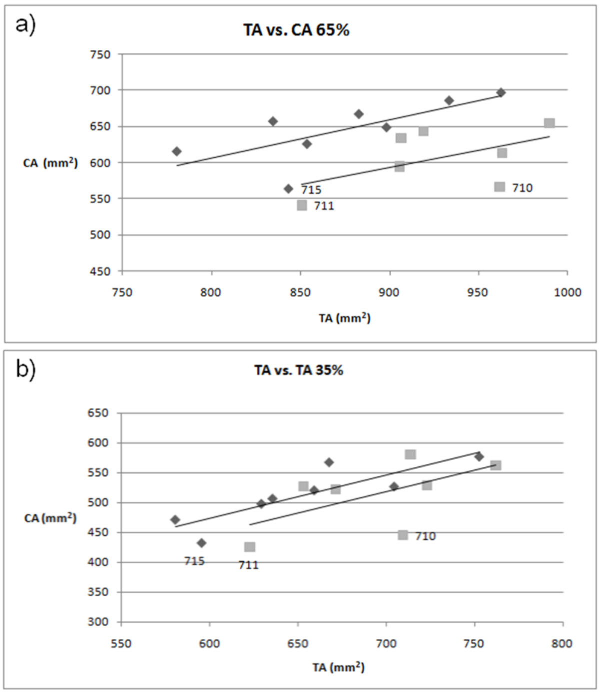

Figure 2. Cross-sectional TA and CA values for both sexes from a) 65% and b) 35% of tibias. a) Females: r=0,72; Males: r=0,53. b) Females: r=0,86; Males r=0,59. Individual with lowest CA values are indicated.

With the exception of these three individuals, the results support the hypothesis that high frequencies of porotic hyperostosis observed in this sample could be produced due to malaria, endemic in that Brazilian region (Alvin & Gomes 1992) and not because of nutritional-metabolic stress. Consequently, the Tenetehara seem not to have been exposed to an important nutritional metabolic stress in early moments after the native european contact. As it was pointed above, the practice of a varied horticulture an exploitation of native forest, the gathering of several products and a regular hunting during all the year also support this hypothesis (Gomes 2002; Wagley & Galvão 1948, 1961).

Moreover, the second moment of area and polar moment of inertia showed significant differences between sexes, with higher flexion and torsion values (Imax, Imin and J) in men compared with women. These results could indicate that the mechanical

Table 1. Standardized cross sectional geometry indicators from 65% of the shafts of tibias.
* Significant difference based upon ANOVA with α = 0,05

Individual	*Age*	*Sex*	*TA (mm^2)*	*CA (mm^2)*	*Imax (mm^4)*	*Imin (mm^4)*	*J (mm^4)*	*Tibial lenght*
T700	18	F	898,1	648,7	410,1	202,0	612,1	335
T701	20-25	F	962,5	696,6	510,9	199,1	710,0	333
T702	20-34	F	834,4	657,0	330,1	130,0	460,2	322
T703	50	F	853,4	625,8	577,2	262,3	839,4	331
T706	20-34	F	933,3	685,6	388,3	179,3	567,5	319
T707	18	F	780,2	615,5	243,9	124,2	368,1	320
T709	50	F	882,6	667,1	379,3	165,3	544,5	318
T715	20-34	F	843,0	564,0	440,8	192,4	633,2	348
Mean			873,5	645,0	410,1	181,8	591,9	328,3
SD			58,3	42,7	103,1	44,0	145,2	10,4
T699	20-25	M	918,9	643,3	521,9	233,1	755,1	349
T704	30-35	M	906,4	634,2	797,1	361,1	1158,2	377
T708	20-34	M	989,7	654,8	641,5	228,4	869,8	357
T710	20-25	M	961,8	566,4	480,3	333,5	813,8	358
T711	+50	M	850,7	540,7	432,7	289,6	722,3	368
T717	20-50	M	905,5	594,6	530,8	284,2	815,0	370
T718	20-34	M	963,2	613,4	441,0	266,3	707,3	373
Mean			928,0	606,8	549,3*	285,2*	834,5*	364,6*
SD			46,9	42,0	129,8	49,0	153,8	10,1

demand in lower limbs was higher in men and it is coincidental with the distribution of heavy works commented above during the beginning of the contact. Thus, physical activities between sexes would have been higher in men during this moment of contact, at least for ambulatory activities that imply mechanical loads for tibial shaft. This idea contrasts with a study published by Braz, Rodriguez-Carvalho, Salles (2005) about the trabecular bone of radio and calcaneus in the same sample studied in this work, which reported similar physical activity in women and in men in lower limbs. However, the differences could be attributed to some particular activity patterns involving localized bending and torsional loads on tibiae, different than those produced in trabecular bone of calcaneus.

Usually, it is a complex issue to isolate biological from cultural stress factors that affect the skeletal development. According to Jurmain (1999), biomechanical properties as a tool for the study of lifestyle patterns of past populations require more extensive analyses, which should include results from clinical trials that document the effects of specific human activities and nutritional patterns on cross-sectional geometry of cortical bone. Nevertheless, the biomechanical studies of human bones, current and archaeological, are important sources of information that collaborate in the comprehension of these processes. In past populations they support complementary results with other bioarchaeological and historical evidences. In this paper, biomechanical data of cortical bone collaborate the interpretation of previous results of stress indicators and analyses of trabecular bones. However, the exploratory nature of the results, principally because of the reduced number of studied bones- the only ones available from these

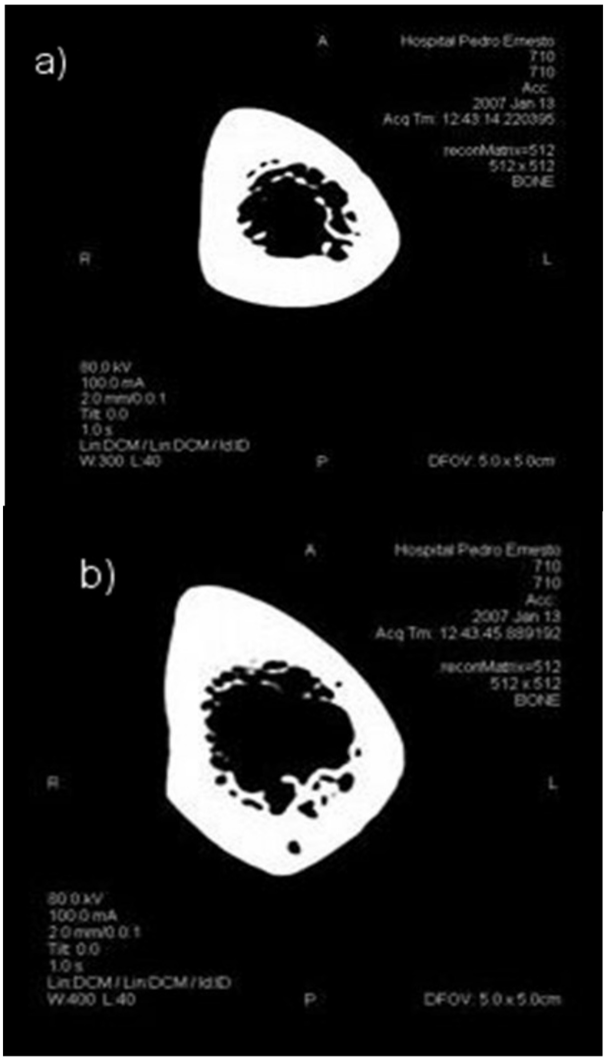

Figure 3. CT images of 35% (a) and 65% (b) cross-sectional tibia of individual 710.

Table 2. Cross sectional geometry indicators from 35% of the shaft of tibias.
* Significant difference based upon ANOVA with α = 0,05

Individual	*Age*	*Sex*	*TA (mm^2)*	*CA (mm^2)*	*Imax (mm^4)*	*Imin (mm^4)*	*J (mm^4)*	*Tibial lenght*
T700	18	F	659,12	520,65	194,99	135,50	330,49	335
T701	20-25	F	635,51	506,69	274,83	150,22	425,04	333
T702	20-34	F	667,58	567,90	179,10	103,69	282,79	322
T703	+50	F	704,46	527,04	297,12	184,27	481,39	331
T706	20-34	F	752,70	577,36	214,96	115,79	330,75	319
T707	18	F	580,35	471,10	122,19	81,75	203,94	320
T709	+50	F	629,19	497,96	180,72	115,36	296,08	318
T715	20-34	F	595,29	431,99	219,90	145,84	365,74	348
Mean			653,03	512,59	210,48	129,05	339,53	328,3
SD			56,47	47,80	55,63	31,77	86	10,4
T699	20-25	M	671,21	522,25	237,45	158,20	395,65	349
T704	30-35	M	652,86	526,35	354,68	234,87	589,55	377
T708	20-34	M	722,89	528,93	298,73	172,65	471,38	357
T710	20-25	M	622,61	425,13	295,30	178,73	474,03	358
T711	+50	M	709,16	445,70	291,49	176,17	467,66	368
T717	20-50	M	713,58	580,24	283,54	189,81	473,35	370
T718	20-34	M	761,88	561,94	293,88	208,36	502,24	373
Mean			693,45	512,93	293,58*	188,40*	481,98*	364,6*
SD			47,19	57,28	34,2	25,7	57,58	10,1

population must be taken with caution and contrasted with other lines of evidence, which would provide new information about the physical activity and health patterns of the Tenetehara in the past.

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