Daily Risks: A Biocultural Approach to Acute Trauma in Pre-colonial Coastal Populations from Brazil

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ABSTRACT Brazilian coastal pre-colonial skeletal series were examined for accidental fractures, which were grouped according to biomechanical interpretation of the causative events, and results were interpreted based on cultural and environmental aspects. More than 18% of the shell mound builders and 27% of the fisher-hunter-gatherers presented healed fractures. Both series presented balanced values between male and female (18.7 and 20%, respectively, for shell mound builders; 28.1 and 25.6%, respectively, for fisher-hunter-gatherers), and more than the double that proportion of the individuals (69.6% for shell mound builder and 88.5% for fisher-hunter-gatherers) had localised lesions, associated with only one traumatic event. The most common type of fractures were those caused by falls blocked by lower limbs (47.8% for shell mound builders and 46.1% for fisher-hunter-gatherers), interpreted as a result of moving along the rocky coastal cliffs. Despite these similarities, both series presented particular aspects which were related mainly to differences in subsistence strategies. Copyright © 2009 John Wiley & Sons, Ltd.

Key words: paleoepidemiology; trauma; accidents; coastal groups; Brazil

Introduction

The most common pathological processes observed in ancient human skeletons include acute traumas, specifically fractures caused by accidents. The regularity with which fractures have been observed in pre-colonial populations that are associated with widely diverse cultural, geographic and chronological contexts and the relative diagnostic reliability as compared to other disease processes provide fractures with special potential for yielding useful information in paleopathological studies (Ortner, 2003; Lovell, 2008).

The interpretation of fracture patterns based on the environmental and cultural specificities of the respective groups provides information on many aspects of their way of life, principally related to daily activities, practised regularly, and interaction between humans and the environment (Lovell, 2008). Aspects related to the healing process and its morphological consequences allow inferences on possible treatments and care, as well as social support (such as Anderson, 2002, Neri & Lancelotti, 2004).

When analysed from a paleoepidemiological perspective, fractures help expand knowledge on the degree of physical and mechanical stress experienced by a given population, besides revealing differential exposures to risks in different age groups and between the sexes. Fractures thus point to tendencies in the division of labour within a society, in addition to providing indirect information on individuals’ quality of life, based on inferences concerning the types and amount of activities performed.

Although studies on fractures have been widely published in the international literature since the early days of paleopathology, recognition of all their informative potential has occurred mainly in the last decade. The development of increasingly complex methodologies, based on the knowledge provided by clinical medicine and biomechanics (such as Lovell, 1997, Djuric et al., 2006, Mays, 2006), and the attempts to effectively conduct biocultural interpretations (such as Judd & Roberts, 1999, Lessa & Mendonça de Souza, 2004, Lessa, 2005a, Brickley, 2006) demonstrate that
the more recent studies have adopted different analytical and interpretative perspectives and increasingly specific objectives.

In Brazil, the vast majority of studies on bone paleopathology, including the analysis of acute injuries, have been performed in sambaqui groups (shell mound builders), for example Neves (1984), Ferigolo (1987), Machado (1984), Kneip et al. (1995), Mendonça de Souza (1995), Silva & Mendonça de Souza (1999), Storto et al. (1999), Lessa & Medeiros (2001), Lusiardo (2000), Rodrigues-Carvalho (2004), Petronilho (2005) and Okumura & Eggers (2005), among others. However, none of these studies specifically approached accidental traumas from a biocultural perspective, combining paleopathological, archaeological and environmental data. Moreover, the lack of standardisation in diagnosis and segregation and quantification of samples often impedes a more refined comparison of the results obtained in the different studies.

In relation to the other, non-sambaqui pre-colonial coastal sites, very few paleopathological studies have been performed, probably due to the limited number of series and problems with conservation. Unlike the sambaquis, which have called the archaeologist's attention since the 19th century, the coastal villages (also called shallow sites or paleoethnographic deposits) have been the focus of only a few systematic excavations such as the work of Rohr (1959, 1966, 1977, 1984a) in Santa Catarina State. This situation was mainly due to the limited visibility of these sites, whose layers rarely exceed half a metre in depth, thus greatly hindering their localisation.

The few bone paleopathological studies performed in series from shallow sites include those of Lessa (2005b), Scherer et al. (2006) and Okumura et al. (2007), although only Lessa and Scherer (2007) provide a specific study on accidental traumas in coastal populations.

The latter study provided the basis for expanding the examined series of sambaqui groups and fisher-hunter-gatherers seeking a preliminary approximation to the fracture patterns in these two populations, from sites located in Rio de Janeiro and Santa Catarina states (Figure 1). Far from establishing an interpretative model based on the findings, the aim of this study was to launch reflections on both the lifestyle of pre-colonial coastal populations and its adaptive cost, based on post-accident sequelae in these populations. A biocultural approach was chosen, based on the general data for sambaqui populations and fisher-hunter-gatherers, without inferences based on each site’s specific contexts. More refined analyses should be performed in the future, capable of establishing particular patterns and inferences more specifically on the lifestyle of each of the studied series, whenever the quantitative and qualitative factors permit.

Based on comparison with future studies performed from the same perspective and with a similar methodology, it will be possible to construct an overall picture of accidental fractures, seeking overall patterns and particularities that will foster a better understanding of daily life for these populations.

Considerations on pre-colonial coastal populations and accidents

The available archaeological evidence for sambaqui groups and fisher-hunter-gatherers that occupied the Brazilian coast tells us that these populations displayed some common characteristics. They lived in similar environments, generally near large marine and lacustrine bodies of water, mangroves and rocky seaboards, typical of the geology of a major portion of the south and southeast coast of Brazil. These environments were rich in natural resources, and the human diet was based mainly on water resources. The groups’ bone, stone and shell artefacts were quite similar, probably as the result of successful adaptation to a very particular environment and their apparent isolation from the inlands, from which they were separated by an almost continuous mountain barrier formed by the Serra do Mar. Given this similarity of factors associated mainly with their daily economy and work activities, one would expect a similar overall pattern in accidental lesions when comparing the two populations.

However, the archaeological record also shows important divergent characteristics between the sambaqui groups and the fisher-hunter-gatherers. One
such difference is the absence, among the latter, of the skillfully built shell mounds where all types of activities were performed, from preparing food to burying the dead. According to Gaspar et al. (1994) and Gaspar (1998), shell mound building systems resulted in the creation of a three-dimensional space in which the volume reached by these sites was a marked and intentional space. Andrade-Lima (1999/2000) concurs, therefore, that the shell mounds do not represent casual garbage heaps, but obey an ideologically determined project. The authors contend that these mounds constituted veritable spatial and/or territorial landmarks, certainly imbued with a significant symbolic load, with grand, outstanding visibility in the landscape. Prous (1972) calls attention to another strong indication of an ideological and social unity, symbolised by the peculiar presence of exquisitely elaborate zoomorphic stone sculptures found in sambaquis located from the State of São Paulo to Rio Grande do Sul.

The shallow fisher–hunter–gatherer sites, unlike the sambaquis, do not consist of homogeneous shell deposits, since the lenses are dispersed in a sedimentary matrix composed of mineral elements. Thus, while the sambaquis reached up to 30 m in height, the shallow sites display strata with depths from only 30 cm to a maximum of 1 m (Prous, 1992).

Another difference between these two populations relates to dietary composition. Although both relished mostly seafood, the sambaquis groups consumed large amounts of shellfish in general (Andrade-Lima, 1991, Bandeira, 1992, Figuti, 1993; Figuti & Klöcker, 1996), with relatively less eaten by the fisher–hunter–gatherers, whose diet was diversified, based on fish and game (Beck, 1972; Tiburtius et al., 1950/51; Silva et al., 1990, Bandeira, 1992, Schmitz et al., 1993, Schmitz, 1996).

The available absolute dates indicate that the sambaquis were built from approximately 6000 years ago to the first millennium AD, while the shallow sites of fisher–hunter–gatherers correspond to occupations beginning in the late first millennium (Andrade-Lima, 1999/2000, Gaspar, 1998) demonstrating that at least the final and initial moments of the two respective forms of coastal occupation were contemporaneous. However, the distinct morphology of their settlements, considered a unifying characteristic among the sambaqui builders, as well as the dietary change observed in these settlements, strongly suggest that they were two distinct cultural units. Thus, despite a common overall pattern in traumatic lesions, we would expect to observe particularities that would in some way reflect their everyday activities and risks.

Material and methods

Due to the scarcity of specific data, accidental injuries in sambaqui groups were analysed based on unpublished data collected by the author and by systematising the small amount of available data in the literature segregated by sex (Table 1). A total of 64 males and 55 females were examined, totalling 119 adults. Although there are other studies on fractures in sambaqui groups, data quantification based on aggregated samples does not allow a more refined analysis that seeks to determine and understand possible differences in the patterns of lesions between the sexes, and is thus not pertinent to the current study's objective.

The data analysed here on fractures in fisher–hunter–gatherers were collected by the author in two series from shallow sites located in Florianópolis—SC (Praia da Tapera site and Base Aérea site) and one located in Balneário Camboriú—SC (Laranjeiras II site). A total of 57 males and 39 females were examined, totalling 96 adults.

Regarding the material analysed by the author, the state of preservation varies between regular and very good. Only individuals with at least 75% of the preserved bones had been included in the study.

Table 1. Sambaquis, location (state and region) and bibliographic reference from which the data on fractures were compiled

<table>
<thead>
<tr>
<th>Site</th>
<th>Region</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beirada</td>
<td>RJ (North)</td>
<td>Unpublished</td>
</tr>
<tr>
<td>Saquarema</td>
<td>RJ (North)</td>
<td>Kneip et al., 1995</td>
</tr>
<tr>
<td>Zé Espinho</td>
<td>RJ (Centre)</td>
<td>Unpublished</td>
</tr>
<tr>
<td>Ilhote do Leste</td>
<td>RJ (Centre)</td>
<td>Unpublished</td>
</tr>
<tr>
<td>Marechal Luz</td>
<td>SC (North)</td>
<td>Silva &amp; Mendonça de Souza, 1999</td>
</tr>
<tr>
<td>Laranjeiras I</td>
<td>SC (North)</td>
<td>Unpublished</td>
</tr>
<tr>
<td>Rio Vermelho I</td>
<td>SC (Centre)</td>
<td>Hubbe, 2005</td>
</tr>
<tr>
<td>Jabuticabeira II</td>
<td>SC (South)</td>
<td>Okumura &amp; Eggers, 2005; Okumura personal communication</td>
</tr>
</tbody>
</table>
Sex and age at death were determined according to the methodologies proposed byBuikstra and Ubelaker (1994). Age was accessed only for the fisher-hunter-gatherers series since this data and/or methodology were not available for the sambaqui series analysed by others (45.3% of the individuals examined here). Age categories were defined as young adult (18–29 years), middle adults (30–49 years) and older adults (50+ years). Quantification of affected individuals according to age considered the typical osteoporosis-related fractures: hip (neck of the femur), wrist (Colles’ fractures of the distal radius) and spine (compression fracture of the thoracic and lumbar vertebral bodies) (Brickley, 2002, Mays et al., 2006).

According to the classification by Lovell (1997), only fractures and luxations were considered acute accidental traumas (although luxations were not observed in any of the series). A fracture may be defined as a discontinuity of, or a crack in, skeletal tissue, with or without injury to overlying soft tissue (Bennike, 2008).

Clinical and paleopatological studies demonstrate that cranial depressed fractures, facial fractures and transverse fractures of the distal ulnar epiphysis are more commonly caused by assault, although accidents also can cause these lesions (Walker, 1989, 1997, Rogers, 1992, Larsen, 1997, Lovell, 1997, Galloway, 1999, Ortner, 2003, Lovell, 2008). It may not always be possible to determine which of those two options caused the fracture. Thus, individuals with these types of fractures, but without any accidental fracture, were considered victim of violence and were excluded. All the other fractures were considered accidental. Cases of ulnar fractures from other studies were not included when the systematised data did not provide sufficient elements to identify them as associated with accidents or violence. Peri-mortem fractures, presenting imprecise diagnosis, were not considered.

Diagnosis of fractures was based on observation of the established diagnostic elements according to anatomopathological criteria (Steinbock, 1976, Adams, 1976, Merbs, 1989, Larsen, 1997, Ortner, 2003, Waldron, 2009). These elements were systematised as follows:

(a) morphological alterations: shortening and/or angulation can occur when the broken limb is not properly reduced;
(b) new bone formation: primary periosteal callus with fibrillar texture (woven bone);
(c) bone formation: secondary periosteal callus with dense texture (lamellar bone);
(d) fracture lines with healing reaction;
(e) avascular necrosis: bone resorption cause by interruption of blood supply;
(f) break of continuity of bone, with healed ends (pseudoarthrosis).

Fractures were identified and recorded from an osteobiographical perspective, mapping all the fractures observed in each individual, as well as secondary lesions resulting from acute traumas, like traumatic osteoarthritis, fragments of ossified tendons and localised periostitis. This allows us to establish more complete and comprehensive diagnoses on the process causing the lesions, as well as to infer functional problems arising from them.

Quantification of individuals considered the number of traumatic events and also the coherency of traumas. Individuals with one or more than one fracture caused by the same force (individuals with localised fractures, suggesting one accident) were counted separately from those ones who have injuries representing different forces (individuals with multiple random fractures, suggesting more than one accident). Methods used to distinguish both situations were: (a) observation of the healing stages: different healing stages—woven bone callus, lamellar callus, remodelled callus—indicate more than one event (Brickley, 2006) and (b) the anatomical coherency between fractured bones in relation to the causative event, expressed by the mechanism of trauma (direct or indirect), type of fracture (penetrating, comminuted, transverse, crush, compression, spiral, oblique, comminuted, avulsion, burst) and location (for a summarised discussion see Lovell, 1997).

Fractures were grouped according to the biomechanical interpretation of the causative events, considering such characteristics as location of the lesion in the bone, type of incident force, inferred through the fracture lines and the direction of poorly aligned or overlapping consolidated fragments. Thus, fractures were not presented and quantified according to the affected bone, but according to probable types of accidents. This methodology provides more coherent and clearer elements for inferences on daily behaviour and activities. The following types of traumatic mechanisms were observed:

(a) vertical impact on the vertebral axis (VI)—vertebral body compression fractures;
(b) direct chest impact (CI)—fractures of the ribs and sternum;
(c) falls blocked by upper limbs (UF)—fractures of the wrists, fingers, elbows and diaphyses of the humeri and clavicles (both by indirect force irradiation);

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(d) falls blocked by lower limbs (LF)—fractures of the femurs, talus and pelvis and of the proximal portion of the tibias and fibulas;
(e) crush fractures (CF)—comminuted fractures caused by heavy objects falling on limbs.
(f) direct impact on the vertebral segment (VD)—transverse fracture of the thoracolumbar spine, more specifically in the transverse processes.

$\chi^2$ and Fisher exact tests (95% confidence limits) were performed to assess the significance of the differences between prevalence. However, due to the insufficient sensitivity of the statistical tests for low values and small variations, some differences with no statistical significance were interpreted based on biocultural significance and considered as tendencies (Mendonça de Souza et al., 2003).

Results

The overall prevalence of lesions in the sambaqui series was 19.3%. Fisher–hunter–gatherers series have somewhat higher prevalence, with 27.1%, although it is not statistically different ($\chi^2 = 1.81, p$-value = 0.1787681)

Prevalence by sex showed balanced values between men and women for both series, with 18.7 and 20%, respectively, for sambaqui series ($\chi^2 = 0.03, p$-value = 0.863874$)$ and 28.1 and 25.6%, respectively, for fisher–hunter–gatherer series ($\chi^2 = 0.07, p$-value = 0.793577$)$ (Table 2).

Regarding the number of traumatic events per individual in the sambaqui series, a statistical significant difference was observed for individuals with localised fractures (69.6%) as compared to those with multiple random fractures (30.4%) ($\chi^2 = 3.88, p$-value = 0.048803$)$.

Data segmented by sex showed that men and women had a similar rate of localised fractures, with 72.2 and 66.6%, respectively (Fisher exact 2-tailed $p$-value = 1). Among the individuals with multiple random fractures, the similar values are 27.2 and 33.3%, respectively (Table 3).

<table>
<thead>
<tr>
<th>Table 3. Frequency of affected individuals from the sambaqui series, according to number of traumatic events and sex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Localised fractures</td>
</tr>
<tr>
<td>A</td>
</tr>
<tr>
<td>Male</td>
</tr>
<tr>
<td>Female</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

A, affected individuals percentages based on the total affected individuals (male = 12; female = 11).

Among fisher–hunter–gatherers, many more individuals suffered localised fractures (88.5%) as compared to multiple random fractures (11.5%), with statistically valid difference ($\chi^2 = 17.70, p$-value = 0.0000258$)$.

The data segmented by sex showed that no women suffered more than one traumatic event, and just 18.8% of men suffered multiple random fractures, difference not statistically significant (Fisher exact 2-tailed $p$-value = 0.2615385$)$ (Table 4).

According to age at death among fisher–hunter–gatherers, 75% of affected males and 50% of affected females were young adults; 18.8% of males and 30% of females were middle adults and 6.2% of males and 20% of females were older adults. Regarding the presence of possible osteoporosis-related fractures, vertebral compression occurred in all age categories; all Colles' fractures occurred in young adults, and any fracture was not observed in the neck of the femur (Table 5).

Considering the total rates of type of accidents/fractures among sambaqui series, falls blocked by upper limbs were the most common (47.8%), followed by falls blocked by lower limbs (26.1%). Crush fracture of the lower limb was the less common, present in only one individual at the medial phalange of the foot (4.3%) (Table 6).

Data according to sex shows no statistically valid differences, despite the distance between some values. For both men and women the most common accidents/}

<table>
<thead>
<tr>
<th>Table 4. Frequency of affected individuals in fisher–hunter–gatherer series according to number of traumatic events and sex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Localised fractures</td>
</tr>
<tr>
<td>A</td>
</tr>
<tr>
<td>Male</td>
</tr>
<tr>
<td>Female</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

A, affected individuals percentages based on the total affected individuals (male = 16; female = 10).

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Table 5. Frequency of affected individuals in fisher-hunter-gatherer series according to age at death and number of possible osteoporosis-related fractures

<table>
<thead>
<tr>
<th></th>
<th>Male</th>
<th></th>
<th>Female</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Young</td>
<td>Middle</td>
<td>Older</td>
<td>Young</td>
</tr>
<tr>
<td>Vertebbral compression (%)</td>
<td>66.6</td>
<td>33.3</td>
<td>—</td>
<td>25</td>
</tr>
<tr>
<td>Colles' fracture (%)</td>
<td>100</td>
<td>—</td>
<td>—</td>
<td>100</td>
</tr>
<tr>
<td>Femur (neck) fracture</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Percentuals based on the total of affected individuals in each type of fracture.

Fractures were falls blocked by upper limbs, with 41.7 and 54.5%, respectively, not statistically different ($x^2 = 0.36, \ p-value = 0.5457980$). Men (33.3%) suffered more falls blocked by lower limbs than women (18.15) (Fish exact test: 2-tailed $p$-value = 0.6404054). Direct impact in the vertebral axis is present in 16.6% of the affected men and 27.2% of women (Fish exact test: 2-tailed $p$-value = 0.6404054). Direct chest impact was relatively uncommon among women (9%), but is present in 25% of affected men (Fish exact test: 2-tailed $p$-value = 0.5900621). Crush fractures were absent among men and present in 9% of women (Fish exact test: 2-tailed $p$-value = 0.4782609) (Table 6).

Among fisher-hunter-gatherers, falls blocked by upper limbs were the most common accidents (46.1%), followed by impact to the vertebral axis (38.4). Vertebral torsion was the less common, affecting only one male (3.8%) (Table 7).

As observed at the sambaqui series, data according to sex shows no statistical valid differences. The most common accidents in both sexes were falls blocked by upper limbs with 43.7% among men and 50% among women ($x^2 = 0.09, \ p-value = 0.7603899$). Direct impact in the vertebral axis is present in 37.5% of the affected men and 40% of women (Fisher exact test: 2-tailed $p$-value = 1). No falls blocked by the lower limbs occurred in women, but they were present in 25% of the men with fractures (Fisher exact test: 2-tailed $p$-value = 0.1357860). Accidents involving direct impact to the chest were relatively rare in both sexes, with 3.8% among men and 10% women (Fisher exact test: 2-tailed $p$-value = 1). Vertebral direct impacts were rare, affecting only one man, with 6.2% (Fisher exact test: 2-tailed $p$-value = 1) (Table 7).

**Discussion**

**The significance of results**

The first factor that determines the power of a study at the level of the statistical significance is its size, which affects mainly the strength of the association between exposure and outcome (Elwood, 1998). The results showed many frequencies without valid statistical differences. This occurred mainly when the types of accidents were compared between sexes, since the

Table 6. Frequency of the total affected individuals in sambaqui series, according to type of fractures and sex

<table>
<thead>
<tr>
<th>Type</th>
<th>Male (A = 12)</th>
<th>Female (A = 11)</th>
<th>Total (A = 23)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>%</td>
<td>A</td>
</tr>
<tr>
<td>VI</td>
<td>2</td>
<td>16.6</td>
<td>3</td>
</tr>
<tr>
<td>CI</td>
<td>3</td>
<td>25</td>
<td>1</td>
</tr>
<tr>
<td>UF</td>
<td>5</td>
<td>41.7</td>
<td>6</td>
</tr>
<tr>
<td>LF</td>
<td>4</td>
<td>33.3</td>
<td>2</td>
</tr>
<tr>
<td>CF</td>
<td>—</td>
<td>—</td>
<td>1</td>
</tr>
</tbody>
</table>

A, affected individuals.

VI, impact on vertebral axis; CI, direct chest impact; UF, fall blocked by upper limbs; LF, fall blocked by lower limbs; CF, crush fracture.

Percentages based on the total affected individuals, by sex.

*Jabuticabeira II series was not included due to the lack of data.

Table 7. Frequency of the total affected individuals in fisher-hunter-gatherer series according to type of accident and sex

<table>
<thead>
<tr>
<th>Type</th>
<th>Male (A = 16)</th>
<th>Female (A = 10)</th>
<th>Total (A = 26)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>%</td>
<td>A</td>
</tr>
<tr>
<td>VI</td>
<td>6</td>
<td>37.5</td>
<td>4</td>
</tr>
<tr>
<td>CI</td>
<td>1</td>
<td>3.8</td>
<td>1</td>
</tr>
<tr>
<td>UF</td>
<td>7</td>
<td>43.7</td>
<td>5</td>
</tr>
<tr>
<td>LF</td>
<td>4</td>
<td>25</td>
<td>—</td>
</tr>
<tr>
<td>VI</td>
<td>1</td>
<td>6.3</td>
<td>—</td>
</tr>
</tbody>
</table>

A, number of affected individuals.

VI, impact on vertebral axis; CI, direct chest impact; UF, fall blocked by upper limbs; LF, fall blocked by lower limbs; VD, vertebral direct impact.

Percentages based on the total affected individuals, by sex.
segmentation of the series according to these variables has generated very low and close values. In this case, the low sensitivity of statistical tests can be easily recognised, it being necessary to relativise its importance due to the specificities of funerary series. As discussed by Mendonça de Souza et al. (2003), modern epidemiology and paleoepidemiology deal with very distinct limits conditioned by the nature of the available data, and although sharing common principles, the research in archaeological material imposes the development of new methods or adaptation of existing ones. Facing small series, exploratory analysis and biocultural significance should be better tools to support discussion and interpretation. Thus, the values more distant from each other were considered tendencies or indicators to be verified in future studies. We do not consider that these differences in the values as indicators impoverishes the biocultural meaning of results, standardising the risks of accidents and masking any differences mainly related to sexual division of labour, something widely recognised for pre-colonial populations.

Percentage of individuals with fractures

The frequency of individuals with accidental fractures in the two groups can be considered high, when compared to the limited available data for pre-colonial coastal series from other regions: 12.7% in the Corondó series in Rio de Janeiro (Machado, 1984); 8.7% in the Chinchorro series from the North of Chile (Standen & Arriaza, 2000); 10.5% in the SCI-038 series from California (Jurmain, 2001) and 7.4 and 4.1% for the Khok Phanom Di and Nong Nor series, respectively, from Southeast Thailand (Domett & Tayles, 2006). Thus, the results (19.3% rate for sambaqui groups and 27.1% for fisher–hunter–gathers) suggest that these groups were more susceptible to accidents than other coastal groups. The extremely rugged coastline in South and Southeast Brazil was certainly a key factor in this susceptibility to accidents.

Although both groups occupied similar regions in terms of geomorphology, the results point to a tendency of increasing accidents among the fisher–hunter–gathers (19.3 and 27.1%, respectively) and thus an increase in risks in performing daily activities. The small number of individuals and series analysed certainly does not allow conclusive inferences on this result, and further research is needed to confirm it.

If future research actually shows a significant difference in fracture rates between the two groups, a possible interpretation is the change in subsistence pattern experienced by them. The sambaqui groups intensively gathered seafood in general, especially shellfish and fish (Andrade-Lima, 1991, Bandeira, 1992, Figuti, 1993, Figuti & Klicker, 1996), and land fauna was rare or absent in their diet (Proux, 1992). Fisher–hunter–gathers had a more diversified diet, including both fishing and hunting a large number of land and marine mammals, as reflected in the zooarchaeological remains and by the proliferation in bone points found in their sites (Beck, 1972, Tiburtius et al., 1950/51, Silva et al., 1990, Bandeira, 1992, Schmitz et al., 1993; Schmitz, 1996).

Distinct forms of adaptation to the same environment have been identified as the main factors altering the risk of accidents during daily activities, although the studies have been based on comparison between hunter–gatherers and agriculturalists (such as Steinbock, 1976; Smith, 1996; Goodman et al., 1984). However, it is interesting that no pattern can be associated with the changes, since both increasing and decreasing fracture rates were observed.

In relation to the groups studied here, the main shift in the adaptive strategy appears to involve abandoning the systematic harvesting of shellfish banks and capturing more food resources on land, more dispersed and frequently located on the steep, rugged coastal cliffs of the Serra do Mar, covered by the Atlantic Forest.

When the data were segmented by sex, no major imbalance was observed in fracture rates between men and women, either in the sambaqui series (18.1 and 20%, respectively) or in the fisher–hunter–gatherer series (28 and 25.6%, respectively). Thus, both men and women practised risky activities, although in the sambaqui series a tendency is observed for more accidents to occur among women, while in the fisher–hunter–gatherer series this tendency is observed among men. This pattern would be compatible with the two groups’ respective survival strategies, assuming that women were primarily responsible for gathering shellfish, an activity that requires less physical effort and fewer forays away from the settlement, while men were in charge of fishing at sea and hunting in the forest.

Number of traumatic events per individual

One of the principal difficulties in studies on fractures in skeletal remains is to define the actual number of accidental episodes suffered by affected individuals. Unless the fractures display different degrees of consolidation, it is impossible to state unequivocally...
that an individual with multiple fractures sustained separate accidents or one single (and more serious) event (Judd, 2002a, 2002b).

However, the biomechanical coherency of lesions, observed by clinical analogy, may indicate that two or more bones were fractured by the same force during a single event, as in the case of crushing of contiguous vertebral bodies or wrist bones fractures, both of which configure interconnected joint systems. Biomechanical coherency may also indicate the possibility that two or more bones have been fractured by the same force during a single event, based on indirect propagation of the force, as in fractures of the mid-third of the clavicle, resulting from a fall on the extended upper limb, with transmission of the traumatic forces by the limb through the glenohumeral joint. In this case, the force directly impacts the distal epiphysis of the radius, and this bone is also commonly fractured (Christian, 2005). When the biomechanical coherency does not indicate the impact of a single force on the different bone segments, it is also possible that a single accident occurred in which different forces acted on bones without any anatomical connection. In this case it is impossible to distinguish this type of event from separate accidental episodes.

In the sambuqui series, more than twice individuals suffered localised fractures during a single accident as compared to those with multiple random fractures (69.6 and 30.4%, respectively). Since a tendency to increasing accidents among fisher–hunter–gatherers is observed, it seems correct to infer that sambuqui individuals with multiple fractures suffered accidents without a specific pattern of injury mechanism. In this case, the most likely scenario is that these individuals fell from great heights or fell without some immediate support to brace them, having slipped and/or suffered free falls, striking the ground several times.

A possible cause for the multiple fractures during a single accident would have been falls from the rocky coastal cliffs, which are extremely rugged and slippery due to the water and slime accumulated on their surface. The multiple fracture rates are similar for the two sexes, possibly indicating that both men and women circulated routinely along the cliffs.

Several activities by the coastal groups might be hypothesised which would be associated with climbing on the rocky cliffs. However, it would only be possible to verify a more specifically coherent association between such activities and each of the series by cross-analysing the fracture data and the archaeological data from the respective sites, an approach which is beyond the scope of the current study.

Possible risky activities associated with regular walks in rough areas include: gathering resources commonly found in sambuqui, like sea urchins (family Echinoidea), and certain genera of molluscs, such as mussels—Mytilus penicillatus (Linnaeus)—and oysters Ostrea ventula (Tayraudean) (Hurt, 1974; Schmitz, 1984), whose colonies attach themselves to these rocky cliffs from the tide line downward into the seawater, thus placing the gatherers in an extremely hazardous position, the use of fixed sharpening and polishing rocks, normally located on the cliffs themselves or between boulders where streams run into the ocean (places that are equally rugged and slippery) and climbing up to the tops of the cliffs to watch schools of fish and weather conditions, as well as to fish with lines and hooks, activities that are still practised by traditional fishers.

Among the fisher–hunter–gatherers, the frequencies of individuals with localised fractures suffered during a single accident and those with multiple random fractures are even more unbalanced (88.5 and 11.5%, respectively). It is possible that an association exists between this pattern and a decrease in accidents involving slips followed by free falls, compared to the previous period. Segmentation of the body by sex indicates that no women and 11.5% of the affected men sustained multiple fractures, which could be associated with an important decrease in molluscs gathering, particularly marine species.

Age at death

The interest in identifying the age categories which include the affected individuals is due to the possibility that fractures were osteoporosis-related. Unfortunately, comparisons between the sambuqui and fisher–hunter–gatherers series were not possible.

Primary osteoporosis type I usually affects postmenopausal women from ages 45–75 years and is associated with fractures of the vertebrae and distal forearm caused by both osteoclast-mediated deficits and increase bone turnover. Type II osteoporosis is age related, commonly occurring in men and women after age 70 years, affecting trabecular and cortical bone. It is associated with fractures of the neck of the femur (Brickley, 2002; Mays et al., 2006, Agarwal, 2008).

Among fisher–hunter–gatherers series, older adult males were not affected by osteoporosis-related fractures. Among females, Colles' fractures affected just young adults, but 50% of individuals with vertebral body compression are included in older adult category. So, osteoporosis may be considered a possible aetiology for half of the vertebral body fractures.
presented. It is important to observe, however, that it is not possible to know the age of the affected individual when the traumatic event occurred, since all fractures were totally healed.

Interpretation of the fracture types

In both the sambaqui and fisher–hunter–gatherers series, the highest frequencies of lesions involved falls blocked by upper limbs (56.5 and 46.1%, respectively), although no single pattern was observed in these fractures. The anatomical sites included the elbow (olecranon), normally caused by falls with direct impact to this region (Leite, 2005a; Dias & Norris, 2004); clavicle, caused by falls with direct impact to the shoulder or falls with the forearm extended and the palm spread open (Lovell, 1997; Christian, 2005); humeral diaphysis, caused by either direct or indirect impact to the region (Lovell, 1997; Leite, 2005b); wrist, generally caused by falls from height with the hand spread open on the ground (Boles, 2006; Reis & Faloppa, 2005) (Figure 2); proximal third of the ulna (with an oblique fracture line), generally caused by indirect trauma after a fall with forced pronation (Lovell, 1997; Moscalcoff et al., 1997) and phalanges and metacarpals, caused by compressive longitudinal impact (Lovell, 1997).

This absence of pattern for fractures caused by falls blocked by the upper limbs allows one to suppose that they occurred in a context of falls with slips (not necessarily from great heights), and striking the ground or rocks several times, which can cause a direct impact to any bone of the arm, forearm or hand, or trips and slips, with fractures to the wrists, metacarpals, and phalanges and the mid-third of the clavicles, most common in the series studied here.

Considering the activities practised by the two groups, moving along the rocky coastal cliffs once more appears as a possible cause of trips and slips. The sambaqui and the fisher–hunter–gatherers series presented a similar percentage of these lesions (47.8 and 46.1%, respectively), and in both series women were more affected, although without a sharp imbalance between the sexes. This tendency appears to reinforce the plausibility of the previous inference, although more disparate values for these lesions would have been expected between women in the two groups (54.5% in the sambaqui series and 50% in fisher–hunter–gatherers), due to the important decrease in shellfish gathering (an activity with a high risk of slips/falls) among fisher–hunter–gatherers. However, the other previously discussed activities may have contributed to women’s presence in this setting.

Falls blocked by the lower limbs were the second most common cause of fractures in the sambaqui series (26.1%). Segmentation of the data by sex showed that men sustained this type of injury more frequently than women (33.3 and 18.1%, respectively). Interestingly, however, the only two women showing falls on the lower limbs were from the Rio Vermelho II series, which also showed a higher overall fracture rate among women (37.5%), indicating an exceptionally high risk for this sub-group and distinguishing this specific series from the overall quantitative pattern for sambaquis. There were no available data on the degree to which the excavated series represents the estimated total population buried in this site, thus raising the possibility that this high rate resulted from a sampling bias.

For the fisher–hunter–gatherers series, 25% of the affected men sustained fractures to the lower limbs, but no women suffered this kind of accident.

Fractures were observed in the distal epiphyses of the tibia and fibula and in the proximal epiphyses of the fibula. Among the data with details on fracture site or type, we identified lesions caused by vertical com-
pression force (compatible with vertical falls), but none due to torsion and fractures of the femoral diaphyses (Figure 3), resulting from injuries involving high kinetic energy, whose axial force produces an oblique fracture (Fernandes et al., 1998; Aukerman, 2006). Based on clinical studies, the only causes consistent with pre-colonial contexts would be falls from great heights, in addition to the impact of heavy bodies on limbs, whose perpendicular force would cause a transverse fracture.

Although the overall fracture rates for the both groups suggest that men and women experienced similar exposure to accident risks, the data on fractures due to falls blocked by the lower limbs point to a sexual division of labour. If the atypical series of women from Rio Vermelho II is removed from quantification, data indicate that only men, in both series, were involved in activities with increased risk of vertical falls from great heights or heavy objects falling on limbs.

Activities that are consistent with these risks included climbing tall trees (vertical falls) and felling trees (impact of heavy bodies on limbs), in addition to climbing steep slopes. This last activity would be probably more common among fisher–hunter–gatherers during hunting forays into the forest, although any groups (and both males and females) may have occasionally crossed the mountains to move their settlements or participate in rituals or exchange activities.

Trees falling on men are also a possible explanation for the fact that 25% of all affected males in the sambaqui series sustained direct impact to the chest. Direct chest impact was much less common among women from both groups and men from the fisher–hunter–gatherer series, ranging from 3.8 to 10%. Importantly, one of the functions ascribed to the large number of polished axe heads found in sambaqui sites is precisely to fell trees for making canoes (Prous, 1992).

In both the sambaqui and fisher–hunter–gatherer series, the second most common type of fracture among women was impact to the vertebral axis (27.2 and 40%, respectively). Men sustained fewer such accidents, although there was not a huge imbalance between the sexes (16.6 and 37.5%, respectively).

The data with details on fracture site and type showed lesions caused by longitudinal impact to the vertebral axis, which produces axial compression and is characterised by crushing or wedging of the vertebral bodies (Nadalo & Metter, 2004) (Figure 4). Most of the

Figure 3. Male right femur with poorly aligned fracture—lateral view. Sambaqui Zé Espinho. This figure is available in colour online at wileyonlinelibrary.com/journal/oa.

Figure 4. Male eleventh lumbar vertebra with body crush fracture—superior view. Base Aérea Site. This figure is available in colour online at wileyonlinelibrary.com/journal/oa.
individuals showed fractures between the eighth dorsal and fifth lumbar vertebrae, but mainly concentrated between the twelfth dorsal and second lumbar, indicating a similar traumatic aetiology in terms of the type of incident force. The exception was one male from the Ilhote do Leste series, with fractures located in the third and fourth cervical vertebrae.

The most probable cause of crushed lower vertebral bodies is falling in the sitting position. In addition to falls from great heights (discussed previously among men, due to the fracture pattern in the lower limbs), falling in the sitting position with heavy loads on the head could increase the risks of this type of fracture due to the increased incident axial energy.

Finally, from the qualitative point of view, a large amount of fractures must have caused severe sequelae with important functional limitation, especially fractures of the femur (10.2% of all the individuals with fractures). Such fractures frequently injure the arteries and nerves (mainly the sciatic), in addition to causing a shortening of the limb and joint involvement. In current clinical cases, with modern medication and therapeutic techniques, average recovery time is 3–4 months, and stabilisation surgery is required in most cases, with blood transfusions in 40% (Lovell, 1997; Aukerman, 2006).

Another type of fracture that would have permanent consequences for victims and society are those resulting in pseudo-arthrosis or non-union with the formation of a false joint (Figure 5), whose most frequent causes are deficient blood flow to the fractured ends, inadequate limb stabilisation, and stabilisation without adequate reduction of the bone fragments. In modern clinical cases, 5% of fractured long bones present this complication (Mercadante, 2005; Reis et al., 2005). For the total sample of the two groups studied here, 18.9% of fractured long bones and ribs presented pseudo-arthrosis.

Given the severity of the fracture types discussed above, it is logical to suppose that among coastal pre-colonial societies, whose available therapeutic resources were certainly insufficient in such cases, recovery time for fractures was much longer than the currently required. The time needed for special care, in addition to the serious functional limitations suffered after healing suggest the existence of strong social support to compensate the morbidity resulting from injury.

Final remarks

The current results differ on several points from findings published previously (Lessa and Scherer, 2007). Sambaqui and fisher–hunter–gatherer samples presented different frequencies of fractures compared with those presented here (14.7% and 30%, respectively and 41.7% of sambaqui individuals with multiple randomic fractures). This was due to the use of different methodologies, including only series with data grouped by sex, examination of new series and the use of imaging techniques in cases where diagnosis by macroscopic observation left doubts.

This divergence of results emphasises the limitations of paleoepidemiological analyses performed with a small number of series and based on few individuals, some in an unsatisfactory state of conservation, theoretically representative of extremely numerous populations. It is possible to have a notion of these numbers by the total of 958 sambaquis registered until the past decade at IPHAN, the Brazilian National Institute for Historical and Artistic Heritage (Gaspar, 1998), which give a good dimension of this limitation.

The shallow sites identified down to date, only 21 and all in the State of Santa Catarina (Rohr, 1984b; Tiburtius et al., 1950/51; Fossari, 1998), present even lower numbers, probably due to their limited visibility, although they are certainly under-represented. Those that have been excavated are located in urban areas, and by the time they were officially located they had already been at least partially (if not almost totally) destroyed. Even so, the size of the settlements and the number of inhabitants strongly suggest that the region was being densely populated during the period. A good indicator is the Praia da Tapera site (Rohr, 1966, Silva et al., 1990), in which less than half of the dwelling area was excavated due to recent occupations and destruct-

![Figure 5. Female left clavicle with pseudoarthrosis—inferior view. Sambaqui de Beirada. This figure is available in colour online at wileyonlinelibrary.com/journal/oa.](image-url)
tion. More than 2000 m² were excavated and 172 individuals removed.

Despite the short studied samples in relation to the original size of these groups, these are the available data at present. Failing to tap these data, however limited, would mean simply to ignore their informative potential. On the other hand, to consider them sufficient for sweeping generalisations without any relativisation would be a gross methodological error.

Thus, we propose that the current findings serve as the starting point for new reflections on the way of life of pre-colonial coastal populations, and that the interpretations resulting from these data provide the working hypotheses to be tested with a similar methodology in other series. The attempt here was to paint a broad overview of the fracture data and consequently of the accidents sustained by these populations in their daily lives. However, future research should attempt to expand on this knowledge, based on inferences at a more regional level, capable of identifying the particularities of each cultural expression, while tracing the common characteristics that fostered the successful process of adaptation by these amazing lords of the seacoast.

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