Dental Corrosion in Preindustrial Societies: A Case Study of a Child from "Pedra do Cachorro" Dating to 1,470 BP, Northeastern Brazil

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ABSTRACT Reflux, frequent vomiting, and the high intake of acidic beverages in industrial societies result in a relatively elevated frequency of dental corrosion. In the past, however, chemical dental wear was rather rare. Here we present and analyze a child from the Fifth Century CE that evidenced a growth pattern which was below that expected for an infant of its age. Furthermore, the child also had a peculiar pattern of dental erosion. This 3-year-old child dated to 1470±30BP from the archaeological site of Pedra do Cachorro (northeastern Brazil) had its bones and teeth analyzed macroscopically, radiographically (X-ray and tomography), and microscopically (SEM). Harris lines, linear enamel hypoplasia, and the poor linear growth presented by this sub-adult suggest malnutrition or some other physiological stress. The unique pattern of chemical wear on the lingual surfaces of upper incisors was compatible with dental corrosion, reinforcing the diagnosis of frequent vomiting possibly caused by an undefined gastric disorder, which could have been a factor in the early death of this child.

Built from the hardest tissues found in the human body (enamel and dentin) teeth are commonly preserved in the archaeological record. Dental wear has long been studied as an important source of data regarding a broad spectrum of past and present human activities (d'Incau et al., 2012; Deter, 2009; Smith, 1984; Turner and Machado, 1983). Dental wear is the result of the non-carious loss of dental tissues due to the additive effects of mechanical and chemical processes (Brace and Molnar, 1967; Molnar, 2008; Oliveira and Neves, 2015; Van't Spijker et al., 2009).

It is used to classify tooth surface loss due to attrition, abrasion, abfraction, and corrosion, depending on the nature of the wasting process. In this sense, "attrition" is a type of dental wear caused by tooth-to-tooth friction that occurs during chewing, clenching, and deglutition. This type of tooth surface lesion affects the occlusal/incisal areas, as well as the proximal surfaces (Smith, 1984).

"Abrasion" is the result of friction between teeth and exogenous agents such as food (e.g. fruits, leaves, vegetables, shells, and bones) and exogenous particles in the food bolus (e.g. sand, stone, and charcoal). During mastication, lingual and buccal/facial surfaces can be worn down by the food bolus being forced against these surfaces by the tongue, cheeks, and lips (Grippo et al., 2012).

These two processes are strongly associated with the masticatory cycles responsible for the formation of occlusal wear. The severity of occlusal wear increases during the lifetime of an individual and can therefore be used as a proxy for estimating age-at-death (Prince et al., 2008). As abrasion is a direct result of the size and roughness of the ingested particles; the severity of occlusal wear can also be used in reconstructing dietary habits (Grippo et al., 2012; Scheid and Weiss, 2012).

Deviations from the typical erosion patterns resulting from attrition/abrasion masticatory occlusal wear are indicative of pathological conditions or paramasticatory habits. Some non-physiological activities can also change dental structure. Among others, parafunctional habits

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such as clenching and grinding of teeth (bruxism) are very common in modern societies, and might be directly associated to psychosocial problems (Carlsson et al., 2003; Manfredini and Lobbezoo, 2009; Pavone, 1985). However, the most common parafunctional activity observed in preindustrial and traditional societies is the use of teeth as tearing and grabbing tools, also called Lingual Surface Attrition of the Maxillary Anterior Teeth (LSAMAT) when these lesions are present on upper incisors (Irish and Turner, 1987; Larsen et al., 1998; Waters-Rist et al., 2010).

"Abfraction" is a less frequent type of mechanical dental wear observed on archaeological skeletons. Although the precise etiology is still a matter for debate, abfraction is broadly considered to reflect stress concentration on the cervical region of teeth, as a result of excessive cyclic loading (Lanigan and Bartlett, 2013; Lucas and Omar, 2012; Oliveira, 2014). Most likely this excessive loading is a consequence of parafunctional use of the masticatory apparatus.

While mechanical wear is commonly reported in archaeological contexts, chemical wearing is rare in preindustrial societies. "Corrosion" or "biocorrosion" are the terms used to define the chemical dissolution of teeth surfaces. Corrosion/biocorrosion can be divided into four (4) separate categories: exogenous, endogenous, proteolysis (degradation of the small amount of enamel protein in the caries process), and electrochemical (as the result of piezoelectric effects only on dentin, not on enamel) (Grippo et al., 2012). Nevertheless, in an archaeological context we usually find, and therefore discuss, exogenous and endogenous corrosion.

Corrosion happens when the dental surface is exposed to an acidic agent capable of creating a microenvironment with a constant pH of below 4.0 (Dong et al., 1999; Hillson, 2008; Järvinen et al., 1991; Scheid and Weiss, 2012). The solubilization of hydroxyapatite, the mineral structure of enamel, dentin, cementum, and bone, occurs when the local pH is 5.5 or below, whereas the critical pH for solubilization of fluorapatite is 4.5 or below (Ekstrand and Oliveby, 1999). Microbial biocorrosion or simply dental caries is the most common human pathological condition observed on archaeological skeletons. Dental caries is caused by the dissolution of the tooth surface due to the lactic acid produced by cariogenic bacteria (Larsen, 2008; Morimoto et al., 2014).

In contrast to the archaeological record, exogenous or endogenous corrosion (formerly known as "dental erosion") is more common in industrial societies (Robb et al., 1991a, 1991b). The elevated consumption of liquids with a pH below 3.0, such as carbonated beverages and citrus juice is most likely a major cause of the exogenous corrosion (Eccles and Jenkins, 1974; Honório et al., 2008; Järvinen et al., 1991; Lussi et al., 2011).

Among the "endogenous corrosions", gastroesophageal reflux disease (GERD) is a potential cause, given that it brings up extremely acidic gastric fluids to the mouth, and therefore in direct contact with dentition (Bartlett et al., 2013; Gudmundsson et al., 1995). Similarly, dental corrosion can be associated with bulimia and other eating disorders that involve systemic and recurrent vomiting (Gudmundsson et al., 1995; Lazarchik and Filler, 2000; Moazzez et al., 2004).

There are many case reports on dental corrosion in the archaeological literature, with most of them presenting dietary erosive wear with or without associated attrition as shown by Coupal and Soltysiak (2017). However, it is very rare to see cases in which the dental corrosion was caused by frequent regurgitation (Robb et al, 1991a; Coupal and Soltysiak, 2017).

In this article, we describe the case of a 3-year-old child radiometrically dated to 1,470 ± 30 BP, that was exhumed from an archaeological site located in northeastern Brazil. This child presents a unique pattern of chemical wear that was compatible with dental corrosion. We then compared this observation, against a broader characterization of oral health, including caries, periapical lesions, dental calculus, and periodontal bone resorption (Guatelli-Steinberg et al., 2004; Hillson, 2008; Oliveira and Neves, 2015). Osteological markers of physiological imperilments, such as linear enamel hypoplasia (LEH) and transverse radiopaque lines (Harris lines) were also considered.

Burial 2 from Pedra do Cachorro

The skeleton analyzed in this study – Burial 2 – was uncovered in 2015 at the Pedra do Cachorro archaeological site, located in the Parque Nacional do Catimbau, Pernambuco, Brazil (Figure 1). This site is located in the sheltered area formed along the side of a large sandstone outcrop. The region presents an important archaeological record for the presence of prehistoric foraging groups, dating from 6,000 years before the present, onwards. Between 2015 and 2016, four field campaigns were undertaken at the site, resulting in the excavation of a 68 m² area. Two other burials, directly dated to 760 ± 30 and 3,560 ± 30 years BP respectively, were

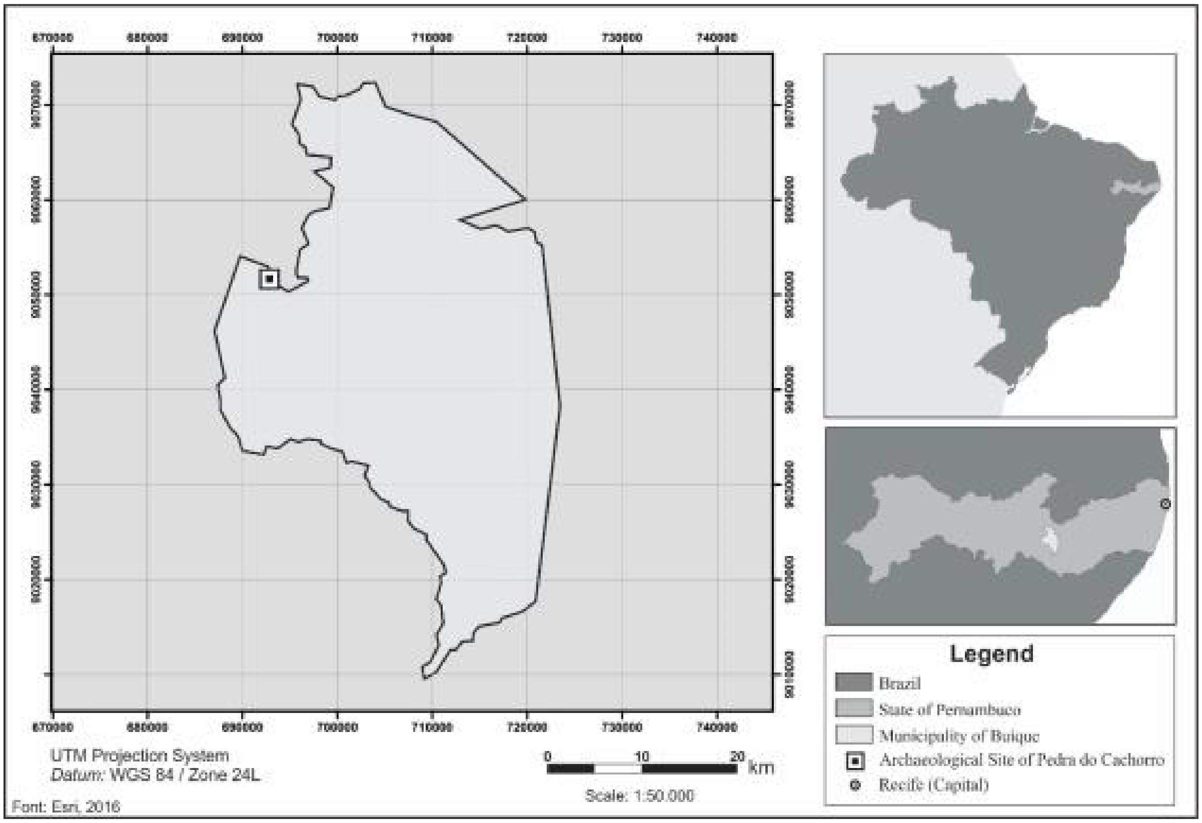

Figure 1. Location of the archaeological site of Pedra do Cachorro, Buíque – Pernambuco, Brazil.

also found in Pedra do Cachorro but they are not part of the present article (Solari et al., 2015,;2016).

Burial 2 contains the skeleton of a young child found within an oval pit (35 cm width; 92 cm long; 20 cm deep) surrounded by sandstone blocks. The burial did not contain grave goods. A rib fragment from Burial 2 was directly dated to 1,470 ± 30 BP (Beta 447238). The bone distribution indicates that the body was deposited in a prone position with flexed legs (Figure 2) (Solari et al., 2016). The burial pit was filled with loose red-brown sediment whose current pH was determined to be 6.64 - 7.15 (Silva et al., 2019). The reddish color of the external surface of the human bones most likely resulted from long exposure to the burial sediment as no evidence for ochre was identified (Figure 3). Charcoal fragments were found amidst the human bones and surrounding sediments. One charcoal piece was dated to 2,100 ± 30 years BP, indicating that it was not contemporaneous with Burial 2.

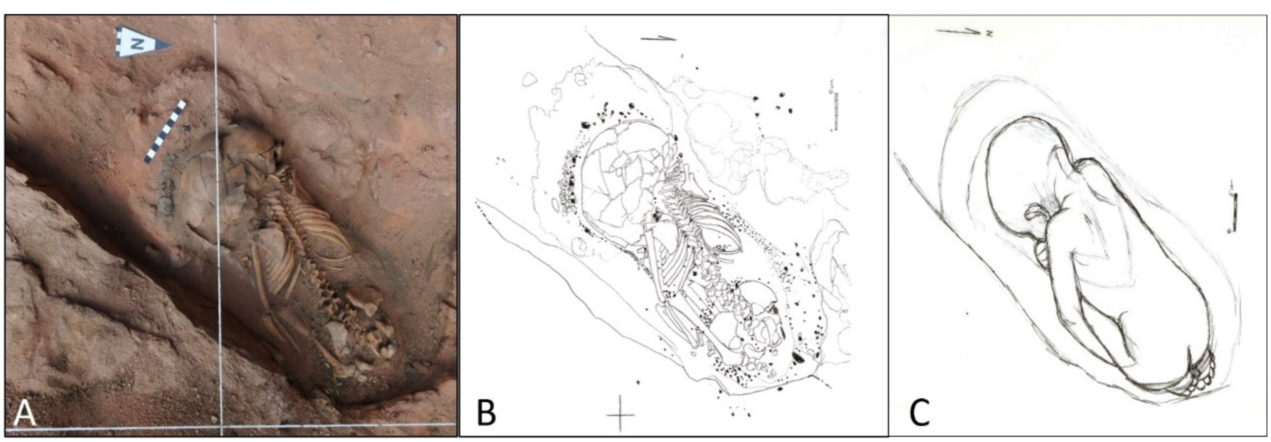

Figure 2. Burial 2 of Pedra do Cachorro: photograph of the exhumation (**A**), burial sketch (**B**), graphic reconstruction of the original burial position (**C**).

This observation was compatible with the lack of any macroscopic signs of thermal modification on the bones.

Age-at-death was estimated using two different methods: linear measurements of long bones and dental development. The length of the limb bones and clavicle indicated an age-at-death of between 1.5 and 3 years, respectively (Table 1). Dental development was assessed using radiographic images generated with "Cone Beam Computed Tomography" (CBCT). Following Demirjian et al. (1973) each remaining permanent tooth in the mandible was scored according to the incremental formation of its root and crown (Figure 4). The resulting maturity index was 15.0 indicating an estimated age-at-death of 3.3 years for a sub-adult of indeterminate sex (Table 2).

Based on the greater sciatic notch morphology (Cunninghan et al., 2016; Schutkowski, 1993; Ubelaker, 1989), the skeleton was interpreted to be that of a female – although caution is required given that the application of this method to the skeletal remains of young children is associated with high levels of uncertainty (Mays and Cox, 2000).

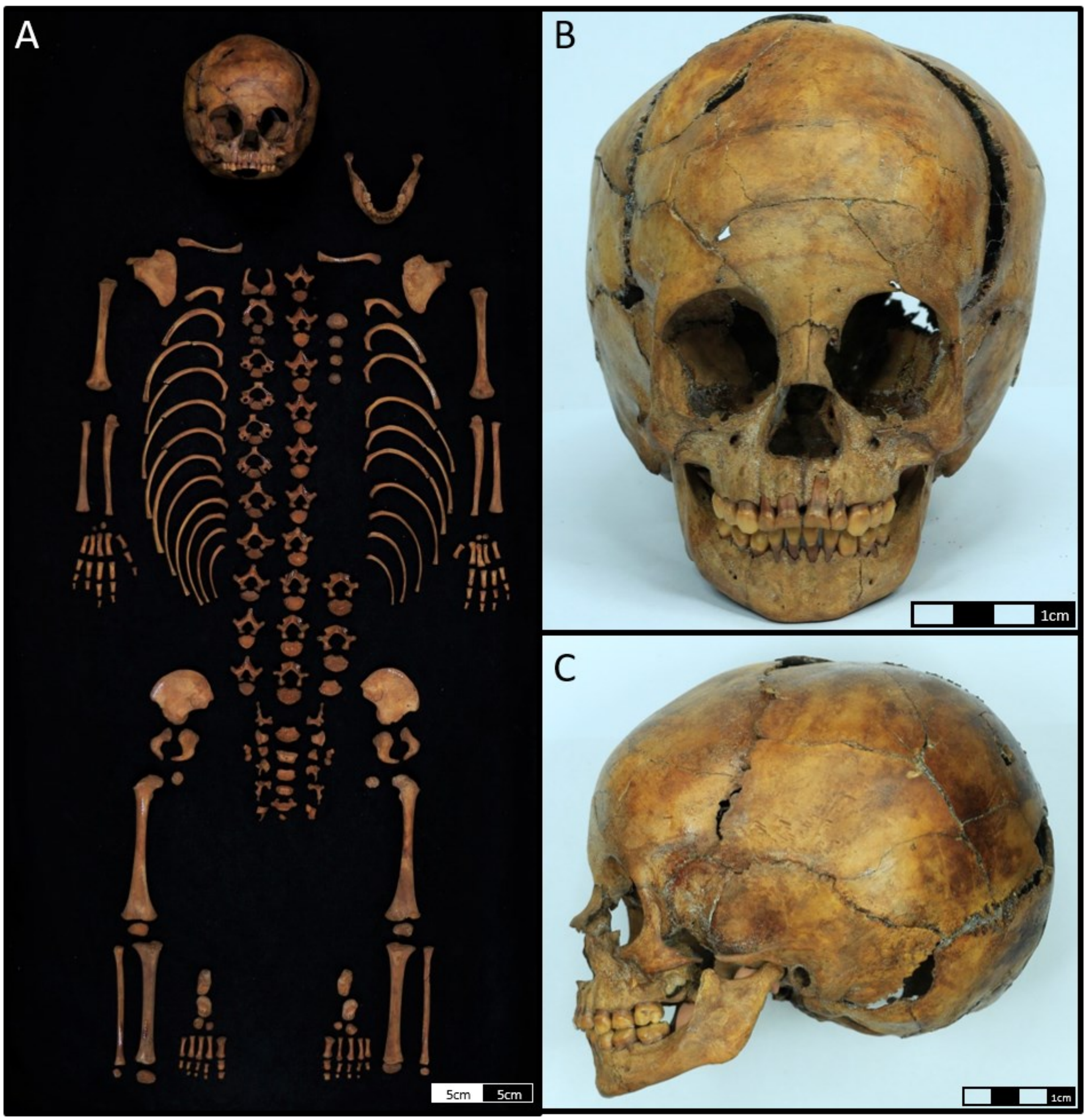

Figure 3. The complete child skeleton, showcasing its excellent preservation (**A**), anterior (**B**), and lateral (**C**) view of the cranium from Burial 2.

Table 1. Age estimation based on bone length of Burial 2.

Bone	Maximum Length (mm)	Estimated Age (years)	References
Femur L	147.2	1.5	Maresh, 1970
Femur R	146.7	1.5	Maresh, 1970
Tibia L	121.9	1.5	Gindhart, 1973; Maresh, 1970
Tibia R	120.7	1.5	Gindhart, 1973 Maresh, 1970
Fibula L	118.9	1.5	Maresh, 1970
Fibula R	120.4	1.5	Maresh, 1970
Humerus L	111.7	1.5	Maresh, 1970
Humerus R	110.9	1.5	Maresh, 1970
Ulna L	100.9	1.5	Maresh, 1970
Ulna R	99.5	1.5	Maresh, 1970
Radius L	92.2	1.5	Gindhart, 1973 Maresh, 1970
Radius R	91.3	1.5	Gindhart, 1973 Maresh, 1970
Clavicle L	66.0	2 to 3	Black and Scheuer, 1996
Clavicle R	64.9	2 to 3	Black and Scheuer, 1996

Table 2. Age estimation based on the maturity, based on the specimen being a female individual (Demirjian et al., 1973).

Developing Teeth	Demirjian's dental score
First molar (M1)	D/8
Canine (C)	D/3.8
Lateral incisor (I2)	D/3.2
Central incisor (I1)	D/0
Maturity index: M1 + C + I2 + I1 = 15.0	

Health Indicators

The fully erupted deciduous dentition lacks any signs of periapical lesions, linear enamel hypoplasia (LEH), dental calculus, or periodontal bone resorption under macroscopic observation (for methods used to analyze all pathological conditions of the dentition, see Oliveira and Neves, 2015). The only pathological conditions in the deciduous dentition were superficial dental caries lesions in the buccal surface of the cementoenamel

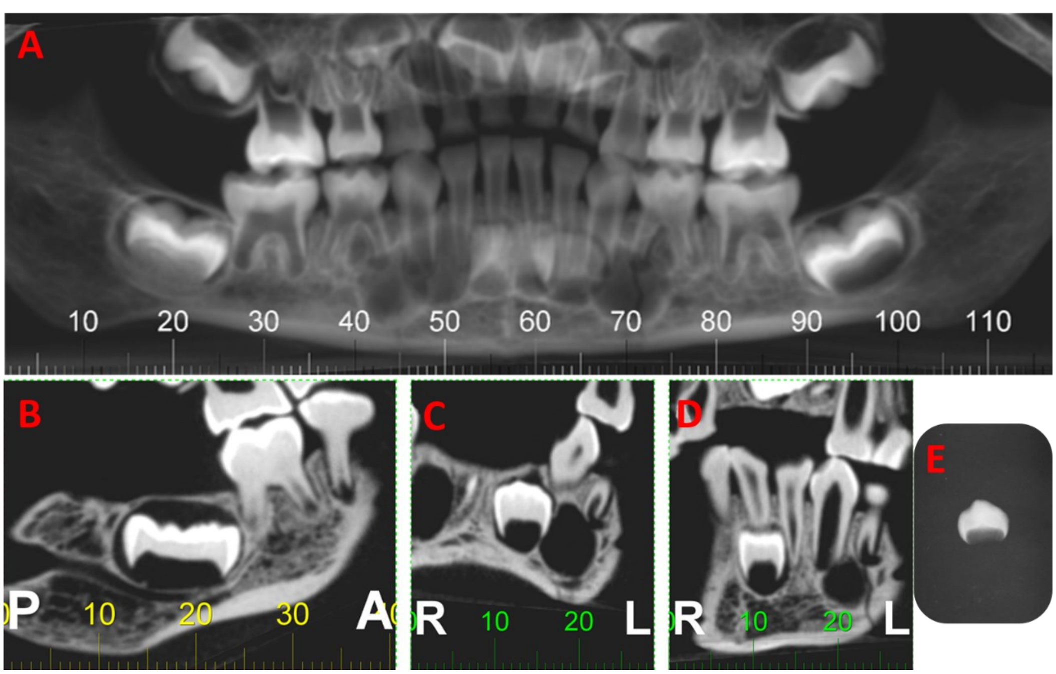

Figure 4. Panoramic reconstruction of the maxillae and the mandible (**A**). The coronal views (CBCT) of the developing mandibular teeth: left first molar - LM_1 (**B**); left lateral incisor - LI_2 (**C**); left central incisor - LI_1 (**D**); X-ray image from left canine - LC_1 (**E**).

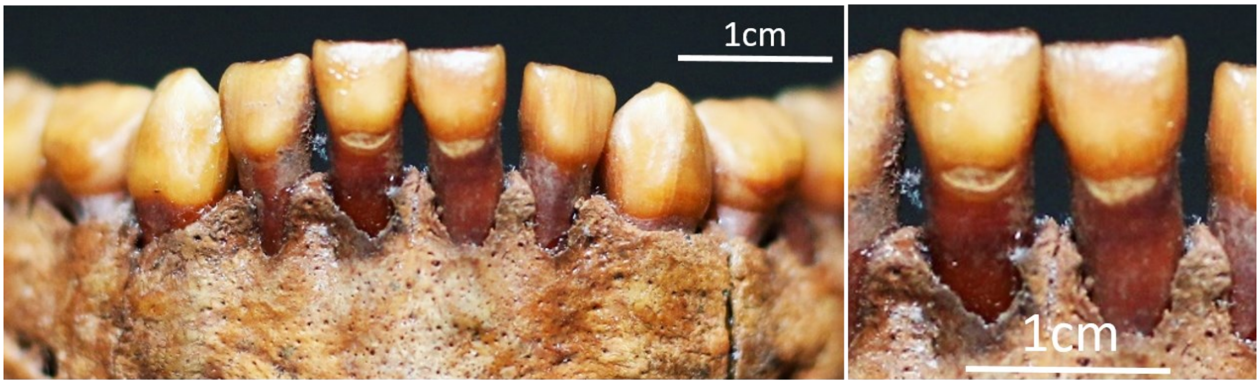

Figure 5. Buccal view from mandibular teeth from Burial 2 with two dental caries in CEJ of right and left central incisors.

junction of the lower central incisors (Figure 5). The irregular border and rough surface of these cavities, despite being located in the cementoenamel junction, distinguish them from abfraction lesions (Nascimento et al., 2016). The permanent canine (LC_1) presents linear enamel hypoplasia (Figure 6) and an analysis of the long bones using radiographic images revealed the existence of Harris lines along the femora and tibiae (Mays, 1995) (Figure 7).

Figure 6. Permanent canine of Burial 2 presenting linear enamel hypoplasia (red arrow).

Dental Wear

The upper incisors showed a unique pattern of non-incisal wear that is better described as dental corrosion. The severe loss of mineralized tissue resulted in the exposure of dentin on the lingual surface (classified as *IIIb* on the Eccles modified index for dental erosion; Eccles, 1979; Eccles and Jenkins, 1974) and the presence of a very thin enamel outline on the lingual surface (Figure 8). The enamel of the lingual surface of the deciduous canine and molars presented moderate to intense levels of thinning – with dentin observed under a thin layer of enamel on the lingual portion of both dm^1.

In addition to this pattern of differential corrosion, the lower and upper dentition – incisors included – also presented normal occlusal wear resulting from attrition and/or abrasion compatible with Degree 2 on Molnar's scale (Molnar, 1971; Smith, 1984) (Figure 9). The symmetrical occlusal dental wear pattern was observed between tooth rows indicating normal masticatory cycles.

A scanning electron microscopy (SEM) was used to observe microwear of the lingual surface of maxillary incisors. The rdi^1 and rdi^2 were fixed on aluminum stubs with silver-containing glue (Electron Microscopy Sciences/SDP - Colloidal Silver Liquid) and sputter-coated with gold (Balzers SCD050 – Bal-Tec/Leica Microsystems). Teeth were examined under Sigma VP microscope (Carl Zeiss NTS Ltd) with 50X to 600X magnification. It was possible to observe on both specimens some light cross-hatched scratches resulting from masticatory abrasion (Figure 10). However, the whole analyzed surface presented wide smooth areas with exposed dentinal tubules, indicating an erosion process (Figure 11).

Discussion

Changes to bones and teeth can occur for many reasons and diagenesis is one of them. The enamel and dentine loss observed in the upper incisors of the subadult could be the result of dissolution in low-pH solutions from the burial sediment in contact with teeth. Nevertheless, Burial 2 did not have a low pH; rather, pH was neutral at 6.64 - 7.15 (Silva et al., 2019).

The unique pattern of dental wear found on Burial 2 of Pedra do Cachorro was clearly not related to the most common processes of occlusal attri-

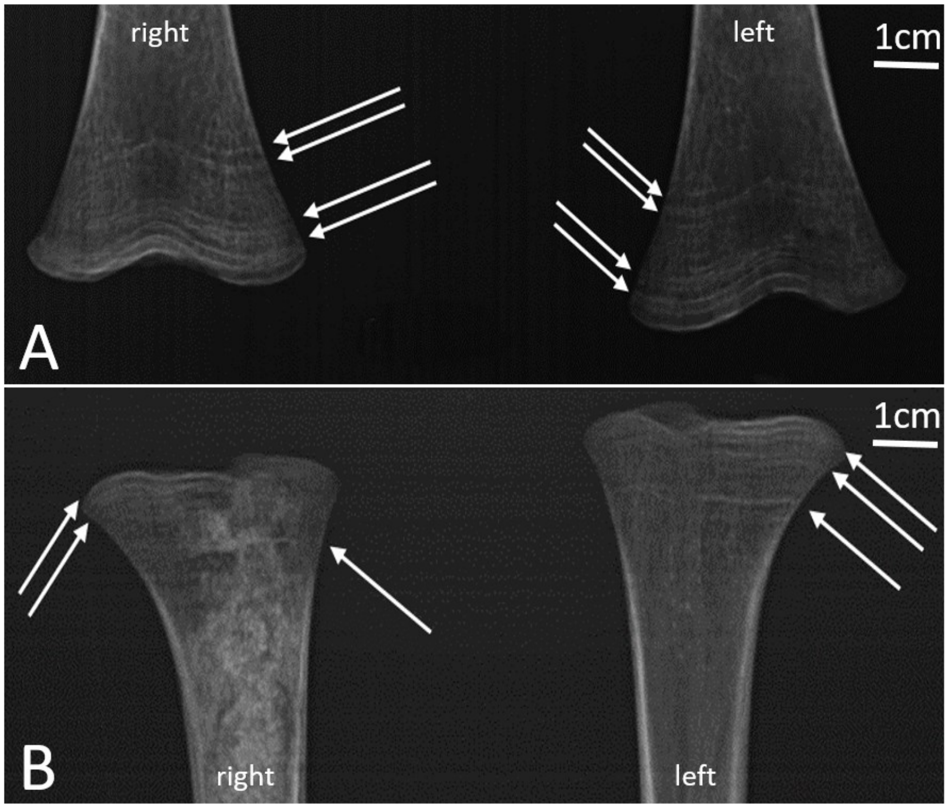

Figure 7. X-ray images of the proximal extremity of femora (**A**) and distal extremity of tibiae (**B**) showing the location of Harris lines (white arrows).

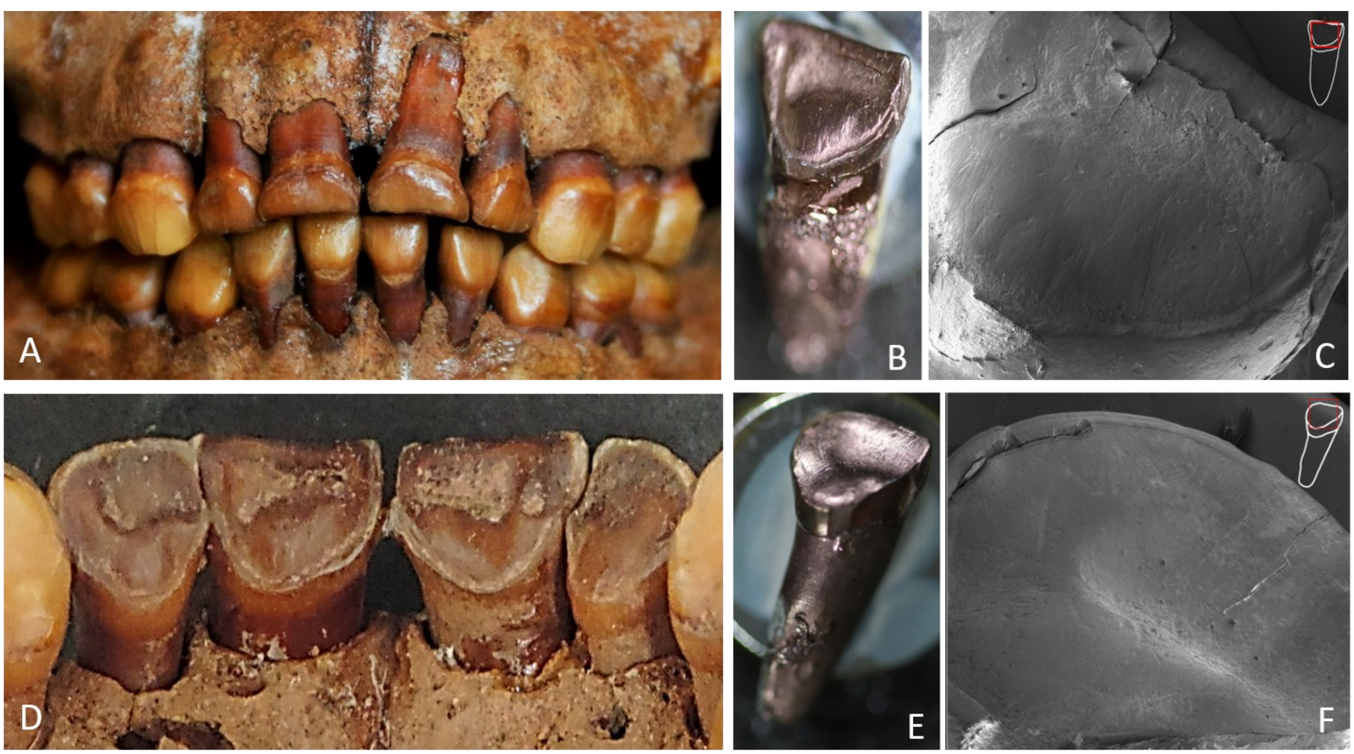

Figure 8. Detail of maxillary teeth: buccal/labial view (**A**) and lingual view (**D**) showing acid erosion on all incisors. It is possible to observe the convexities on the cervical third and the concavities on the incisal third of the lingual surface of upper incisor crowns. The rdi[1]: metalized sample (**B**); SEM view: 47x magnification (**C**); rdi[2]: metalized sample (**E**); SEM view: 49x magnification (**F**).

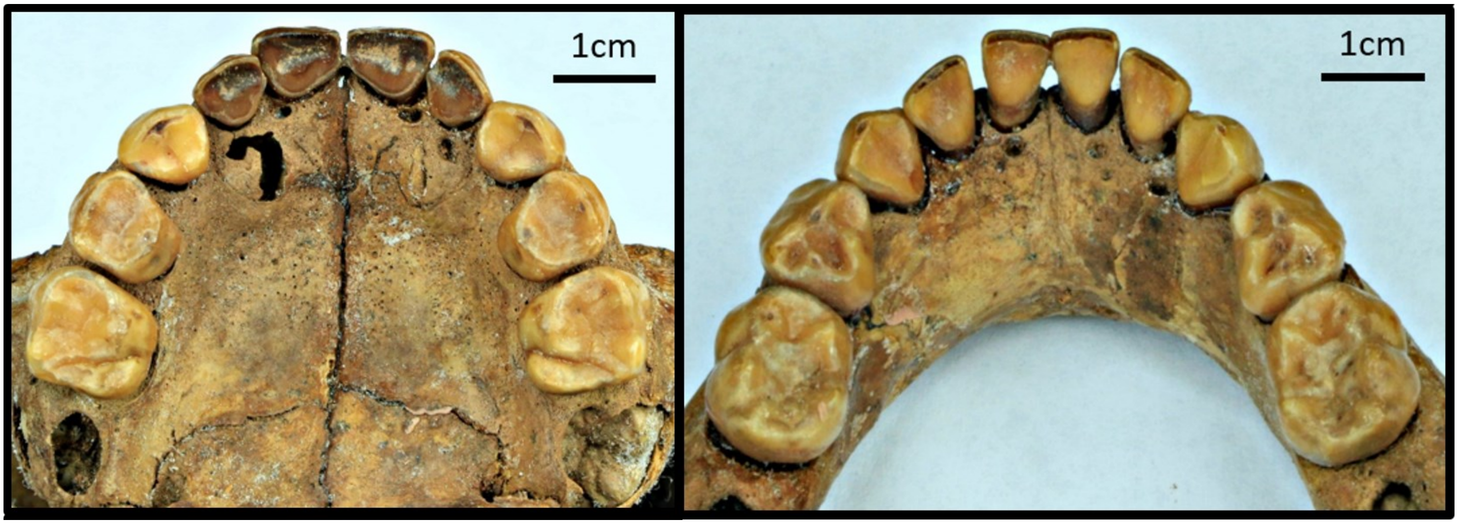

Figure 9. Maxillae and mandible from Burial 2. It is possible to observe physiological dental wear on the occlusal surfaces.

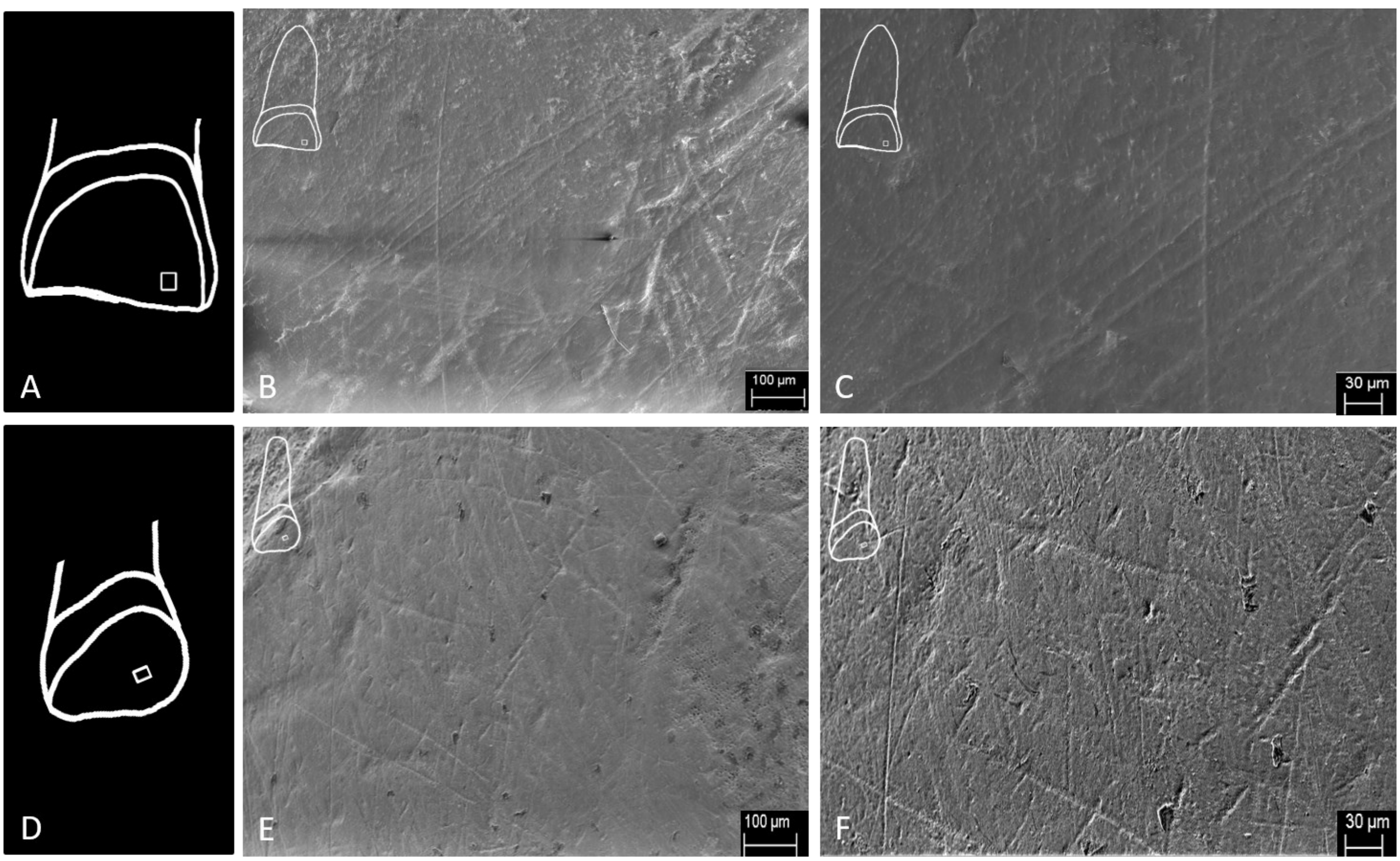

Figure 10. SEM of the lingual surface exposing a cross-hatched wear pattern of dental abrasion. Top row: drawing of rdi^1 shows the location of SEM analysis (**A**); rdi^1 SEM view: 200x magnification (**B**); rdi^1 SEM view: 400x magnification (**C**). Bottom row: drawing of rdi^2 shows the location of SEM analysis (**D**); rdi^2 SEM view: 200x magnification (**E**); rdi^2 SEM view: 400x magnification (**F**).

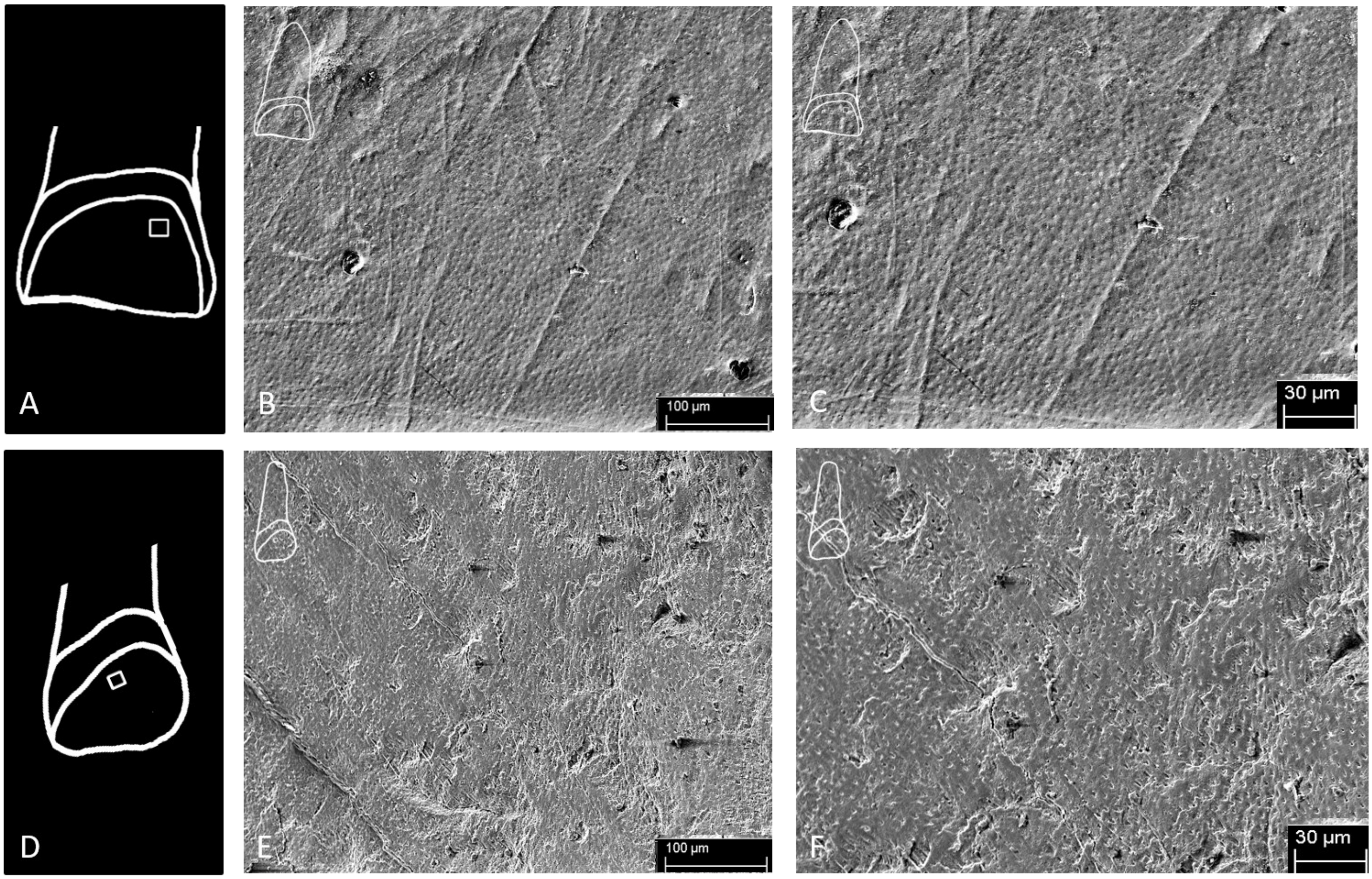

Figure 11. SEM of the lingual surface showing dentine with exposed dentinal tubules, indicative of dental corrosion. Top row: drawing of rdi[1] shows the location of SEM analysis (**A**); rdi[1] SEM view: 400x magnification (**B**); rdi[1] SEM view: 600x magnification (**C**). Bottom row: drawing of rdi[2] shows the location of SEM analysis (**D**); rdi[2] SEM view: 400x magnification (**E**); rdi[2] SEM view: 600x magnification (**F**).

tion resulting from masticatory cycles. Parafunctional habits provide alternative mechanisms capable of generating distinct patterns of dental wear. Bruxism, for example, results in considerable loss of mineral material. However, the abrasion angles observed in the dentition of Burial 2 were not compatible with the limited movements of the temporomandibular joint involved in bruxism (Brace and Molnar, 1967; Molnar, 1971). Alternatively, injuries or malformation of the temporomandibular joint could result in abnormal wearing of teeth. However, for Burial 2 of Pedra do Cachorro normal masticatory movement was indicated both by the perfect positioning of the upper and lower dentition, and by the presence of occlusal wear pattern compatible with children with a mixed fed/ weaned diet, or those who had started exclusively masticatory functions earlier in life (Martinez-Maza et al., 2016; Moynihan, 2005; Warren et al., 2002). Additionally, the presence of a few carious lesions and no periodontal bone resorption is to be expected in a normal 3-year-old child. The child's deciduous teeth could have been exposed for a short period of time to a cariogenic diet, with or without breastfeeding, that lasted until the third year of life. This was common in other precolonial societies (Da-Gloria et al., 2017; Iida et al., 2007; Kaplan, 1996; Spielmann, 1989).

It is important to note, as mentioned above, that sex determination is imprecise, and for some authors, it is impossible to be sure of sex when analyzing sub-adult skeletons. Nevertheless, if we estimate age-at-death of this skeleton then, our analysis suggests that if the skeleton was a girl then age-at-death would have been 3.2 years, while in the case of a boy, it would have been 3.5 years (Demirjian et al., 1973). Even if we considered that Burial 2 was a girl, her long bone length was that of a 1.5 years-old. Therefore the child had a low height for her age.

The frequent use of teeth as tools for creating artifacts from vegetable fibers, leather, or bones is another parafunctional mechanism capable of generating wear patterns not related to the masticatory cycle. However, once again the angles of the wear facets, the macroscopic non-flat surface of superior incisors, and the absence of complementary or similar wear on the mandibular incisors described for Burial 2 of Pedra do Cachorro were not consistent with this usage (see Figure 10 and 11). It is also important to observe that Burial 2 was that of a young child, and therefore, less likely to participate in these kind of socio-cultural activities (e.g. Oliveira, 2014; Larsen et al., 1998; Molnar, 1971).

We consider that recurrent episodes of vomiting or chronic reflux were the best candidates in explaining the pattern of corrosion observed for Burial 2. The direction of the flow of gastric fluids into the mouth resulting from these conditions (posterior-anterior) are known to cause a strong and moderate/mild demineralization of the lingual surface of the anterior and posterior maxillary dentition, respectively (Bartlett et al., 2013; Lazarchik and Filler, 2000). The buccal surface of maxillary teeth is partially protected by the oral mucosa, whereas mandibular teeth are protected by the cheek and tongue during vomiting, protecting these dental surfaces from gastric fluids, as seen in Burial 2 (Linnett and Seow, 2001). In fact, abrasion and attrition may have contributed to the dental wear noted on the occlusal surface, but the evidence present on the lingual surface of the maxillary incisors shows an acidic corrosion context similar to that from clinical cases of regurgitation lesions as seen in Figure 12 (Grippo et al., 2012; Lanigan and Bartlett, 2013; Lussi et al., 2011). In both cases, the lingual surfaces presented tissue loss near the gingival margins where tooth-to-tooth contact does not occur (Robb et al., 1991b).

In addition, the SEM views strongly suggest a dental erosion scenario. Parallel scratches observed in attrition or LSAMAT cases are totally absent on rdi[1] and rdi[2] (see Figures 10 and 11) (Kieser et al. 2001). The microscopic images show a combination of light abrasive wear due to a normal chewing process (see Figure 10), and most of the dentine surface with exposed dentinal tubules caused by a corrosive process on the maxillary incisors of Burial 2 (see Figure 11) (Kieser et al. 2001).

Gastric disorder leading to systemic vomiting or chronic reflux can be caused by a broad range of specific conditions such as gastrointestinal inflammatory diseases, anatomical abnormalities, malignant tumors, intracranial hypertension, central nervous system infection, metabolic diseases, and toxic food intake (Katz et al., 2013; Nebel et al.,

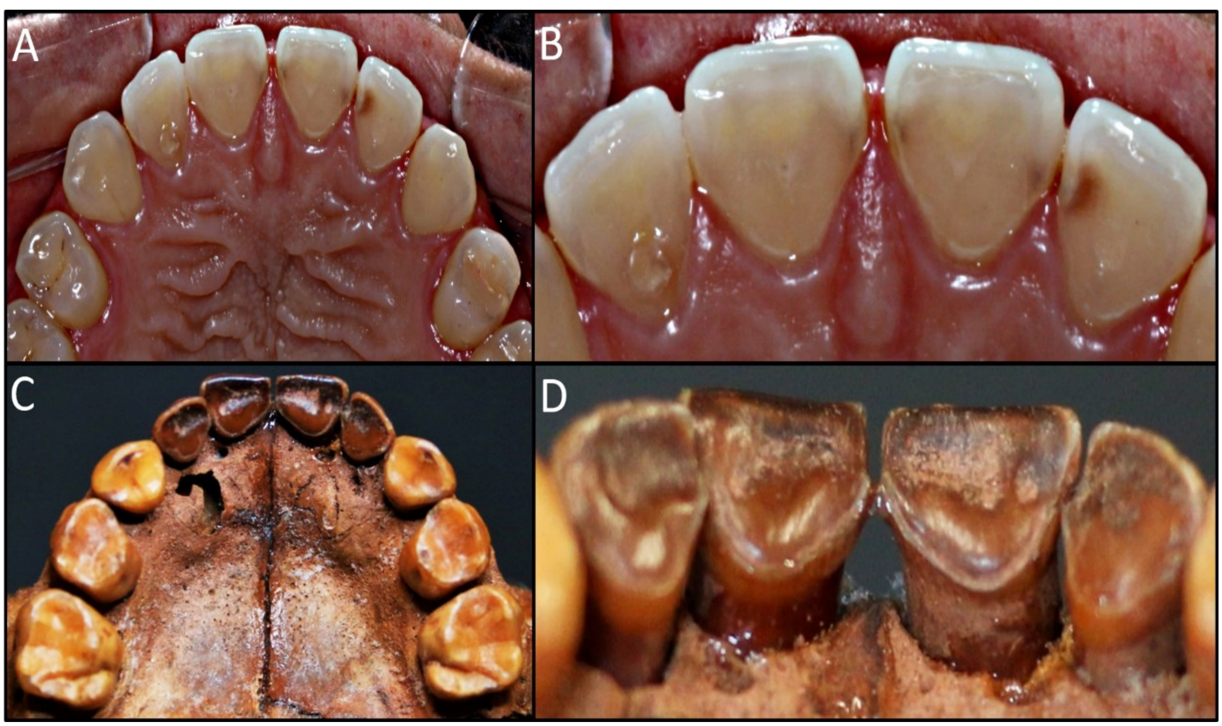

Figure 12. Comparison of the clinical case photos (above) and the archaeological case study photos (below). The upper anterior teeth of a 27-year-old female patient with lingual wear due to dental corrosion by GERD (**A** and **B**). Upper anterior teeth of the Burial 2 show very similar lesions along the lingual surface (**C** and **D**).

1976; Rudolph et al., 2001; Vakil et al., 2006; van Herwaarden et al., 2000; Vandenplas et al., 2009). For Burial 2 of Pedra do Cachorro the presence of LEH, Harris lines, and relatively short limbs seem to indicate that the pathological condition leading to vomiting/reflux was associated with an overall scenario of malnutrition and physiological stress (Guatelli-Steinberg et al., 2004; Oliveira and Neves, 2015; Umapathy et al., 2013; Mays, 1995). These chronic disorders could be associated with the premature death of this child (Deaton, 2008; Kielmann and McCord, 1978; Maitland et al., 2006; Onis, 2010; Rice et al., 2000; van den Broeck, 1995). It is interesting to note that standard osteological markers of metabolic distress during early childhood such as *cribra orbitalia* and porotic hyperostosis were not observed on this individual. Finally, our study supports the notion that physical illnesses such as gastric disorder could have been responsible for cases of dental corrosion in ancient human remains.

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