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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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Keywords: dental wear, paleopathology, gastroesophageal reflux, dental corrosion, dental erosion

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

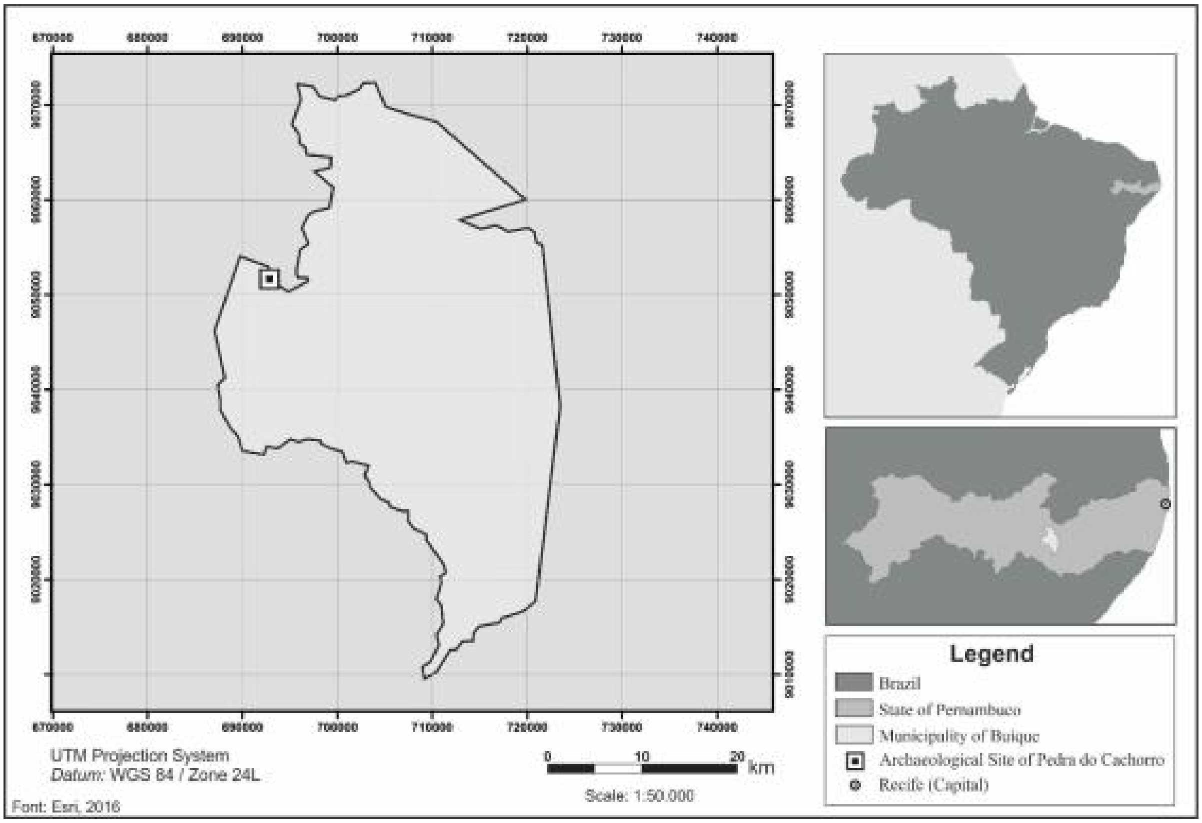

Figure 1. Location of the archaeological site of Pedra do Cachorro, Buíque – Pernambuco, Brazil.

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.

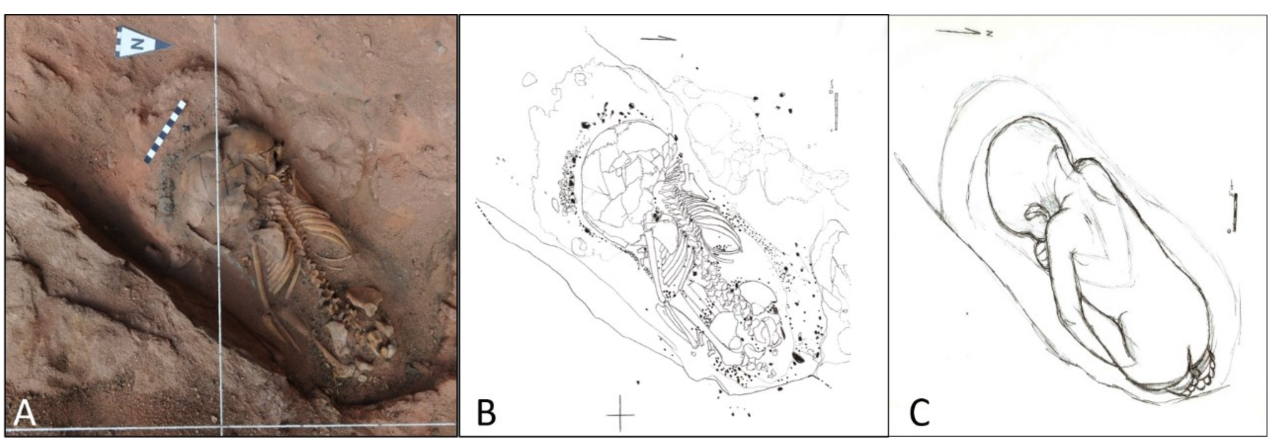

Figure 2. Burial 2 of Pedra do Cachorro: photograph of the exhumation (**A**), burial sketch (**B**), graphic reconstruction of the original burial position (**C**).

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).

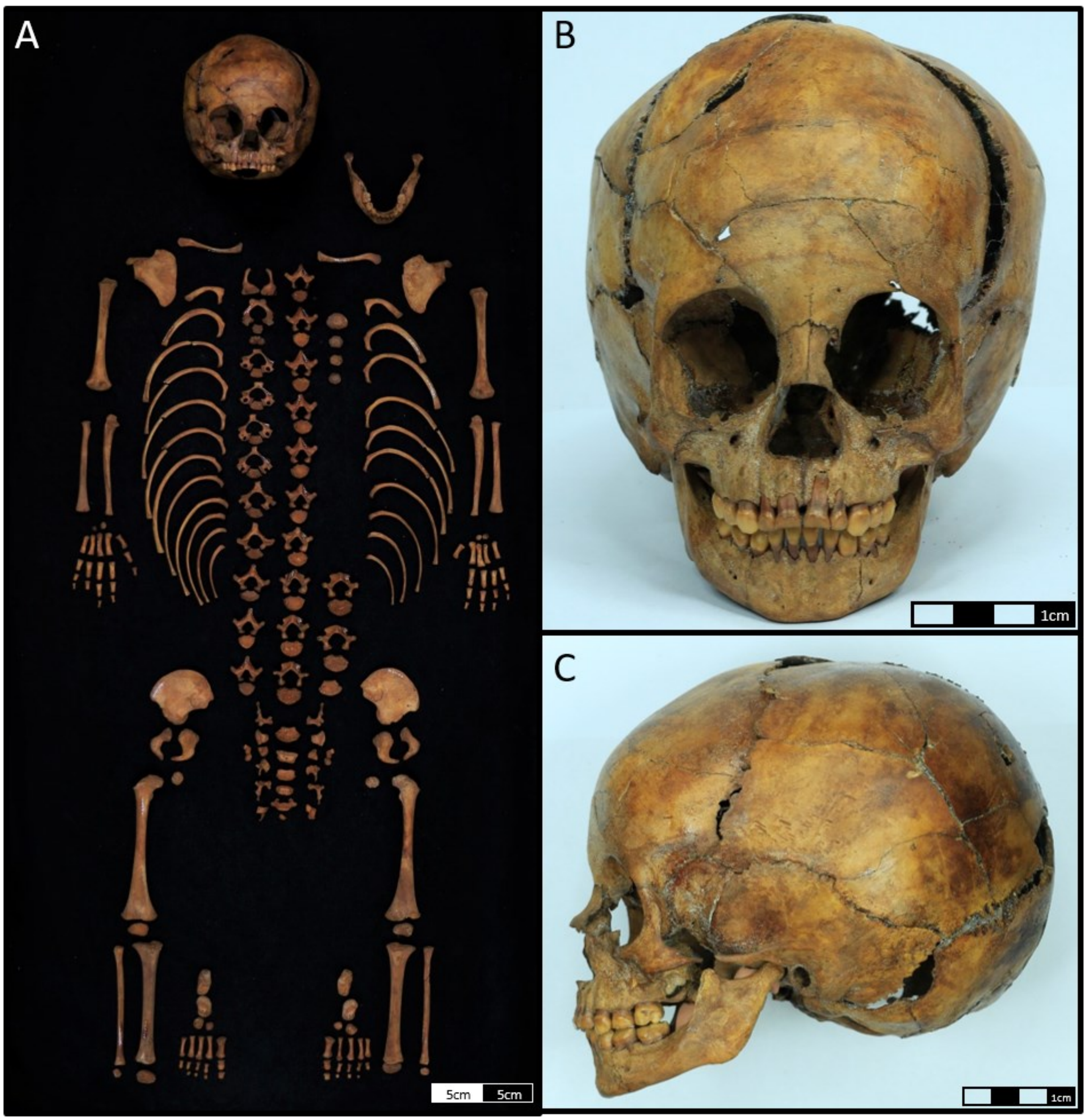

Figure 3. The complete child skeleton, showcasing its excellent preservation (**A**), anterior (**B**), and lateral (**C**) view of the cranium from Burial 2.

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

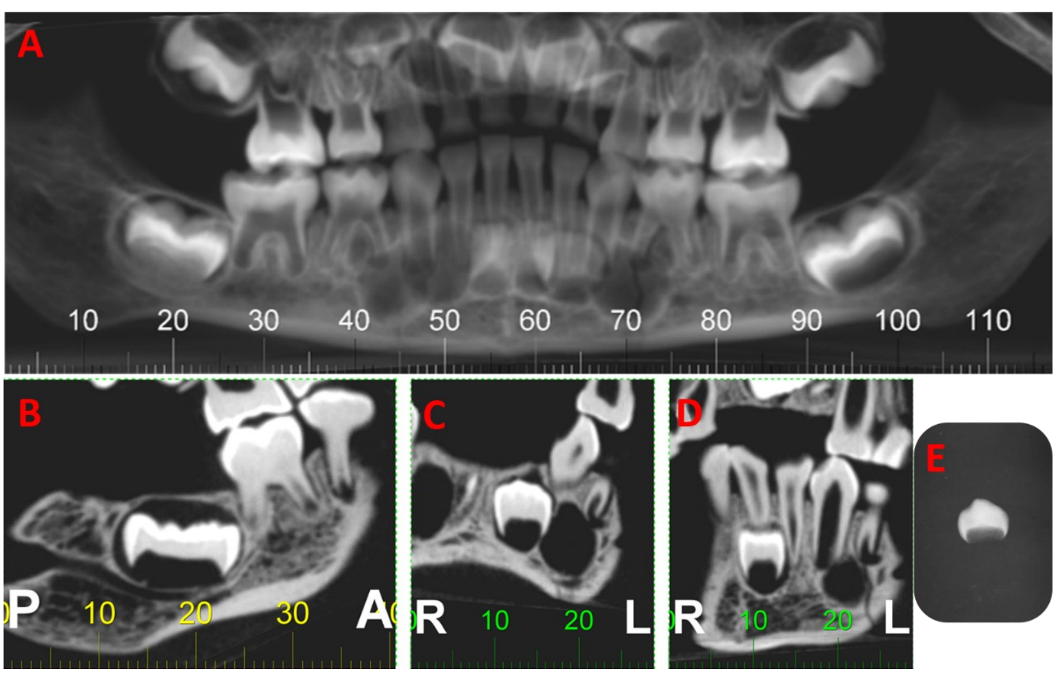

Figure 4. Panoramic reconstruction of the maxillae and the mandible (**A**). The coronal views (CBCT) of the developing mandibular teeth: left first molar - LM_1 (**B**); left lateral incisor - LI_2 (**C**); left central incisor - LI_1 (**D**); X-ray image from left canine - LC_1 (**E**).

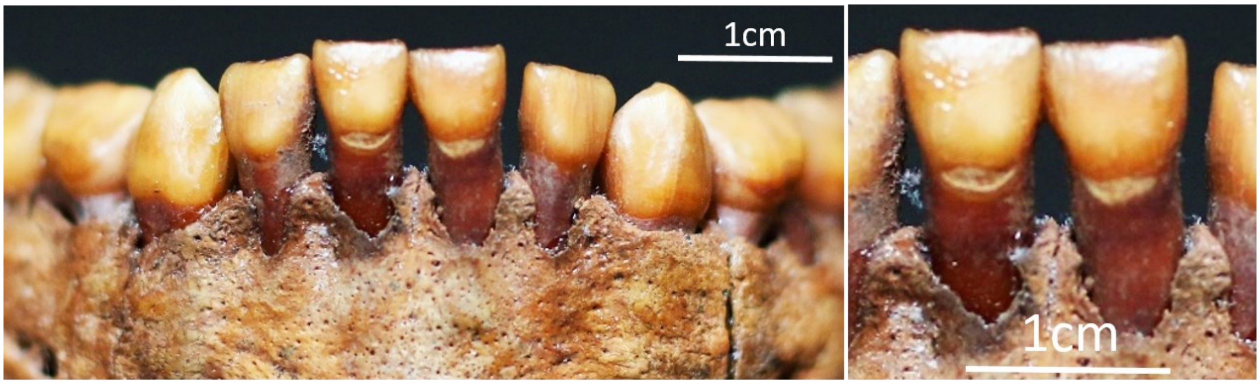

Figure 5. Buccal view from mandibular teeth from Burial 2 with two dental caries in CEJ of right and left central incisors.

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-

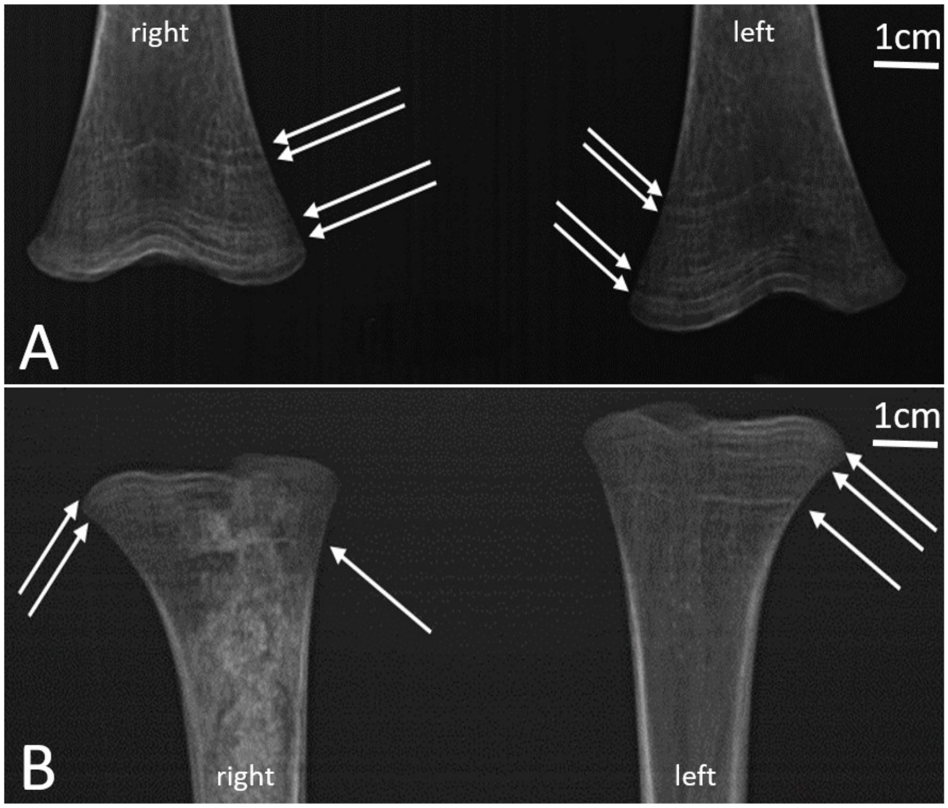

Figure 7. X-ray images of the proximal extremity of femora (**A**) and distal extremity of tibiae (**B**) showing the location of Harris lines (white arrows).

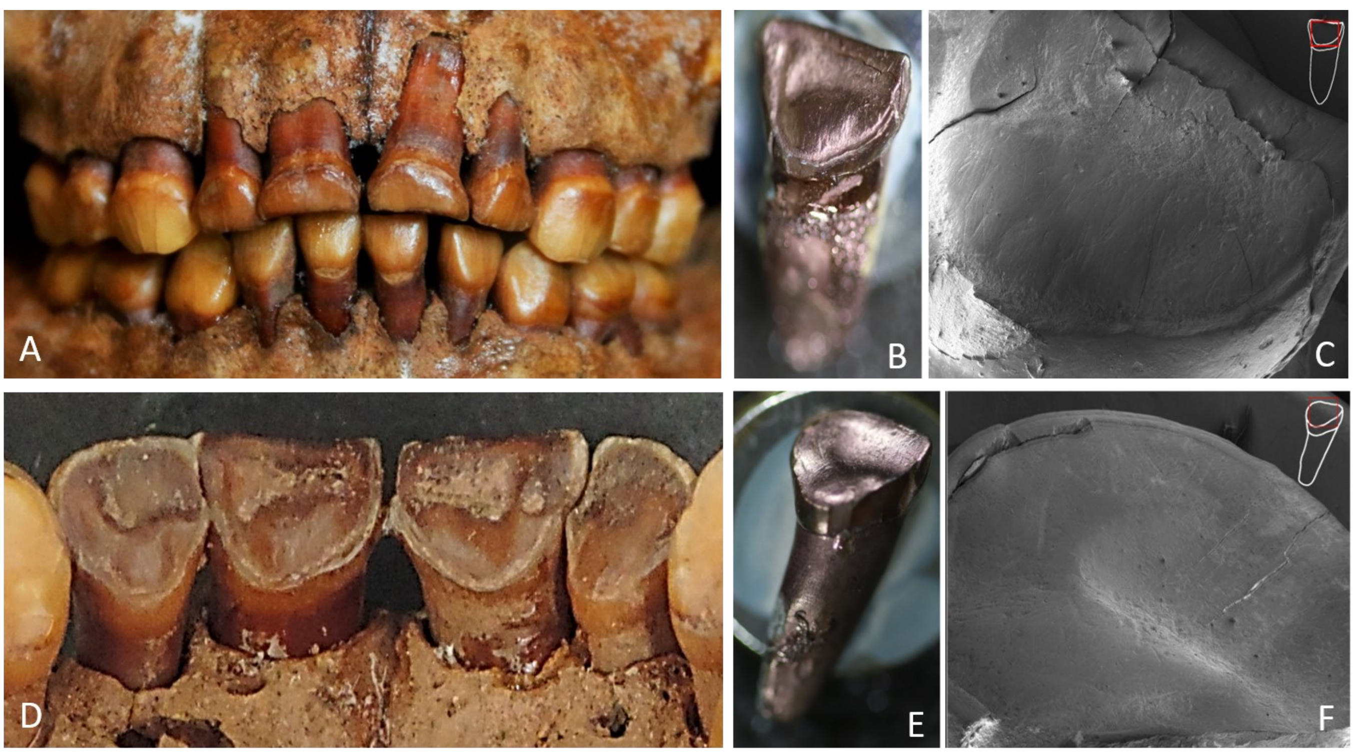

Figure 8. Detail of maxillary teeth: buccal/labial view (**A**) and lingual view (**D**) showing acid erosion on all incisors. It is possible to observe the convexities on the cervical third and the concavities on the incisal third of the lingual surface of upper incisor crowns. The rdi[1]: metalized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

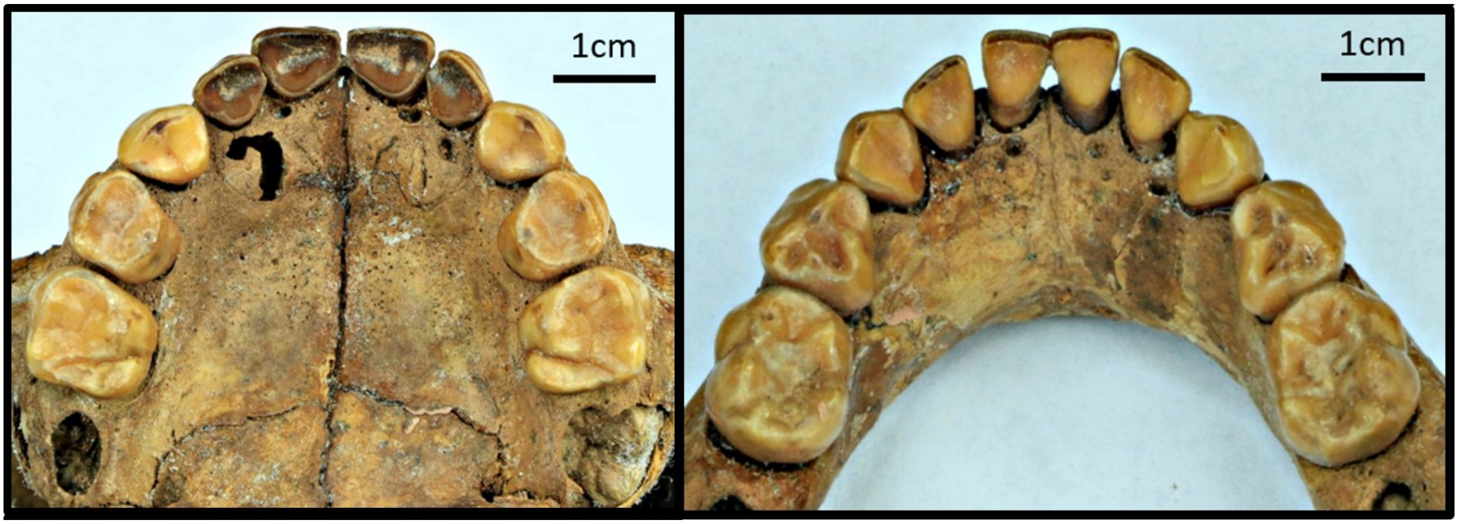

Figure 9. Maxillae and mandible from Burial 2. It is possible to observe physiological dental wear on the occlusal surfaces.

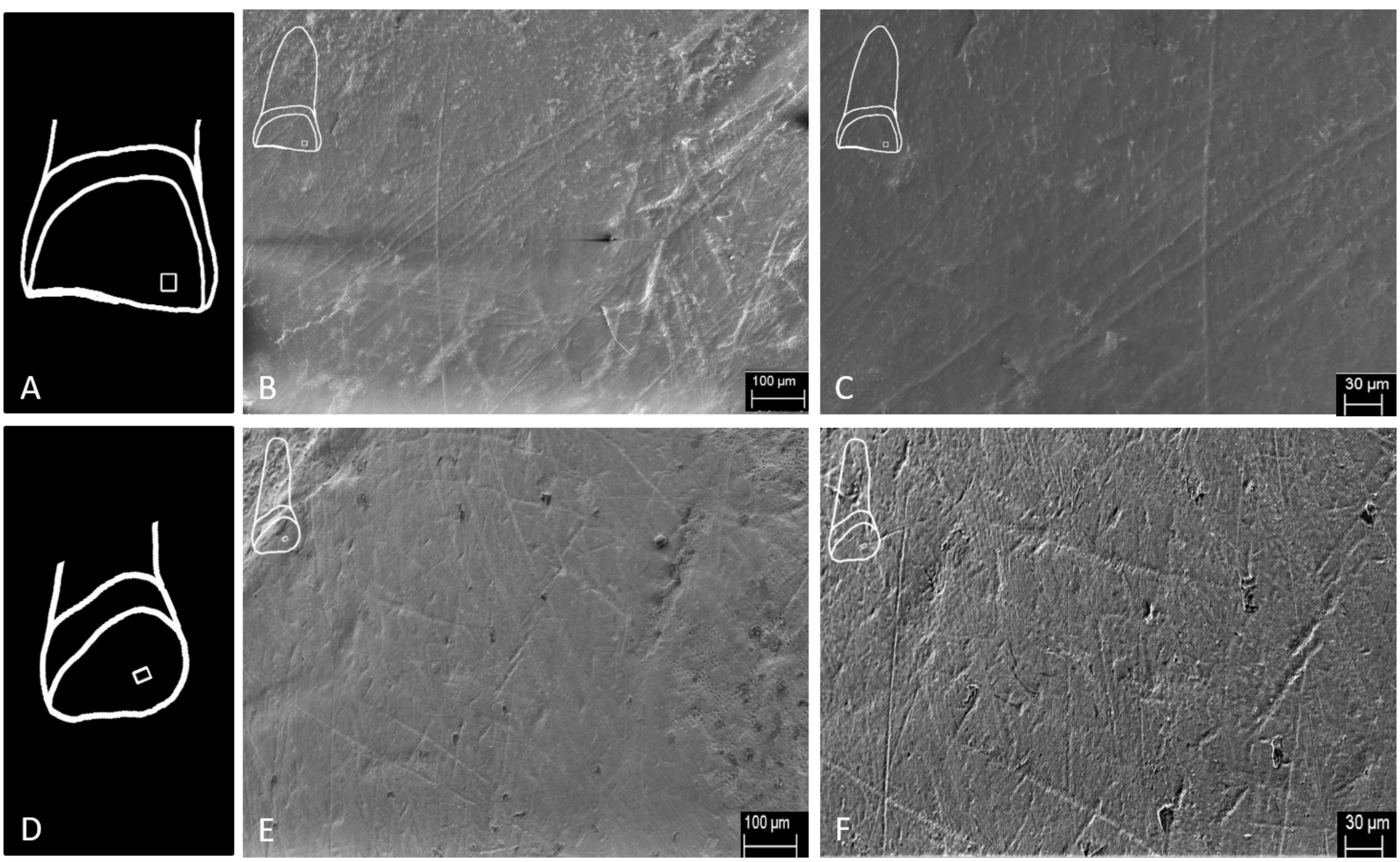

Figure 10. SEM of the lingual surface exposing a cross-hatched wear pattern of dental abrasion. Top row: drawing of rdi[1] shows the location of SEM analysis (**A**); rdi[1] SEM view: 200x magnification (**B**); rdi[1] SEM view: 400x magnification (**C**). Bottom row: drawing of rdi[2] shows the location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

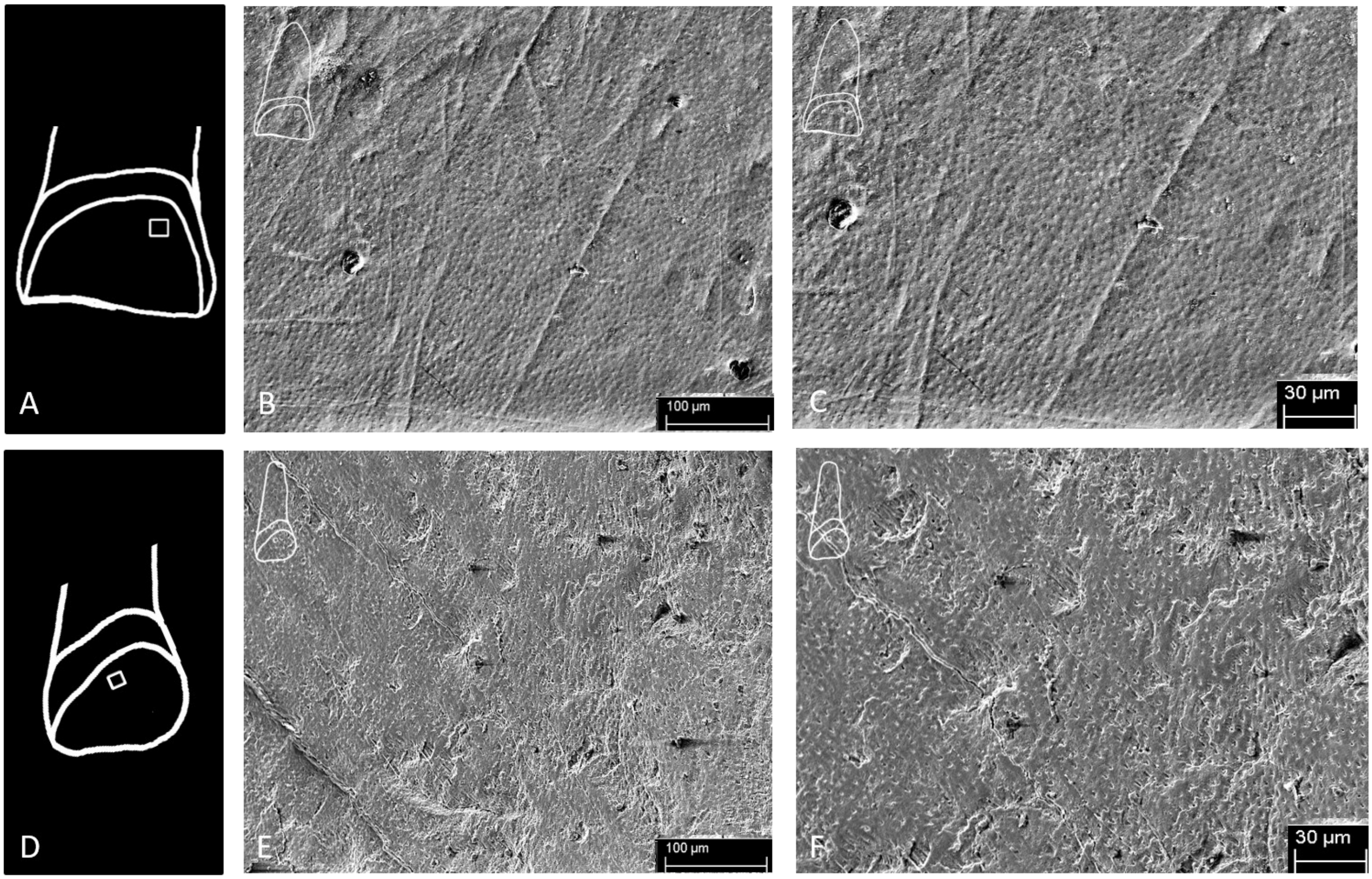

Figure 11. SEM of the lingual surface showing dentine with exposed dentinal tubules, indicative of dental corrosion. Top row: drawing of rdi[1] shows the location of SEM analysis (**A**); rdi[1] SEM view: 400x magnification (**B**); rdi[1] SEM view: 600x magnification (**C**). Bottom row: drawing of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

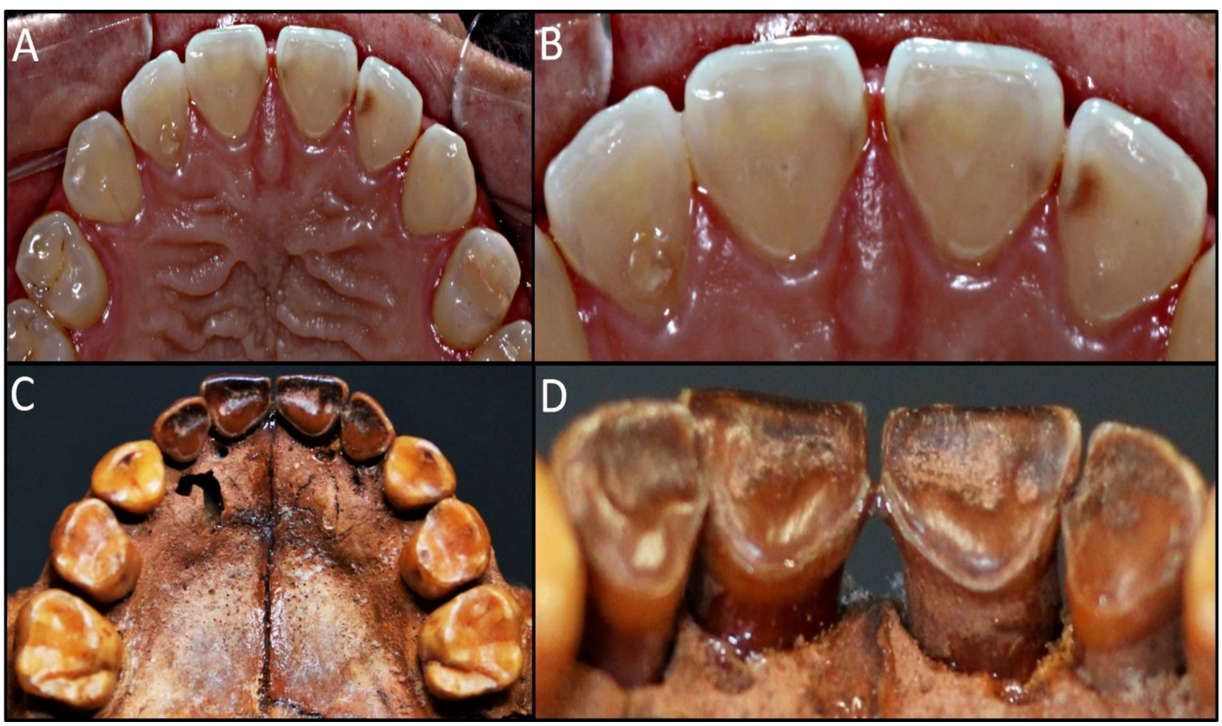

Figure 12. Comparison of the clinical case photos (above) and the archaeological case study photos (below). The upper anterior teeth of a 27-year-old female patient with lingual wear due to dental corrosion by GERD (**A** and **B**). Upper anterior teeth of the Burial 2 show very similar lesions along 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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A Dental Metric Study of Medieval, Post Medieval, and Modern Basque Populations from Northern Spain

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ABSTRACT Basque population history has been examined through classic genetic markers, mtDNA, Y chromosome haplogroups, craniometrics, and recently dental morphology. Dental morphological data show Basques have a classic European dental pattern but fall as an outlier among European populations. Expanding on that work, Basque tooth size was examined to further evaluate the affinities of the Basque population. Mesiodistal and buccolingual maximum crown measurements were taken from medieval and post medieval skeletons from the Catedral de Santa María in Vitoria, Spain, along with living samples of modern Basques, Spanish, and Spanish Basques from dental students at the Universidad del País Vasco. A dental metric examination affirms the outlier status of Basques, as they exhibit smaller crown areas than neighboring populations. In biodistance analyses Basque populations group with linguistically and geographically distant populations. Even with gene flow from Spain, France, and North Africa, Basque individuals still demonstrate a unique pattern coincident with their ancient origins.

The Basque Country, Euskalherria, is located in the southwestern corner of France and north central Spain. The population of the region is well known for its unique language, as "the sole surviving pre-Indo European language of Western Europe" (Trask, 1997:35). Many anthropological approaches have been taken to better understand the place of Basques in European history, from linguistic to archaeological research, and more recently investigating genetic haplotypes. Early research explored Basque blood groups, finding that Basques had high frequencies of the blood type O allele (ca. 75%), low rates of blood type B allele (ca. 3%), and the world's highest frequencies of the negative allele ("r" or "cde") in the Rhesus blood group system (ca. 50%) (Roychoudhury and Nei, 1988). These frequencies set them apart from other Western Europeans (Alberdi et al., 1957; Chalmers et al., 1948; van der Heide et al., 1952). These unusual blood types were interpreted by Cavalli-Sforza (2000) as a possible link to the first wave of people coming into Europe during the Paleolithic and served as the stimulus for many genetic studies to examine the origins and affinities of the Basque population. Analyses of mitochondrial DNA (mtDNA) show unique haplogroups suggesting *in situ* evolution with minimal gene flow (Alzualde et al., 2005; Alzualde et al., 2006; Martinez-Cruz et al., 2012). Y chromosome polymorphisms show low levels of diversity, suggesting that this population has been evolving in the region for millennia (Alonso et al., 2005; Hurles et al., 1999).

More recently, data on Basque dental morphology was investigated to explore the population history of this group. Typically, European populations are classified by morphologically simple teeth where trait *absence* is more common than trait *presence* (Scott and Turner, 1997). Scott and colleagues (2013) found that Basque samples, both historic and living, have high rates of hypocone and hypoconulid reduction on UM2 and LM2, respectively. There is also an extremely high frequency of double rooted lower canines, a classic European trait (Scott et al., 2013; Scott and Turner, 1997). These findings place Basque groups into the overall category of Western Europe, within the 'Eurodont' dental pattern (as coined by that study). There is no single trait that separates the Basques

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from other European groups. It is rather the accumulation of slight but consistent differences that create their outlier status (Scott et al., 2013).

To further explore dental variation among Basque populations we evaluate here dental metrics. The goal of the present study is to determine if the unique population history of the Basques is evident in tooth crown size throughout time. If preceding studies are any indicator, it is expected that Basques will show tooth size patterns like those of the other Western Eurasian groups, with slight differences reflecting their long-term occupancy in Western Europe along with relative geographic isolation. It is further expected that these patterns will be evident from Medieval to modern times.

Materials and Methods

The skeletal remains examined in this study were collected from the Catedral de Santa María in Vitoria-Gazteiz, Alava, País Vasco, Spain. These remains date from the 11th to the 19th century, and were also the subject of studies on dental morphology (Scott et al., 2013), oral health (Hopkinson, 2009), craniometry (Janzen, 2011), dental chipping (Scott and Winn, 2010), and taphonomy (Hopkinson et al., 2009). Sex was estimated by one of the authors (GRS) based on skull and pelvic morphology (Buikstra and Ubelaker, 1994).

Additionally, dental casts were collected from living people by Alberto Anta at the University of the Basque Country from students who were enrolled in the dental school at that time. For these individuals, sex and cultural identification (Basque, Spanish-Basque, or Spanish) were recorded at time of casting.

Maximum crown measurements were taken by one of the authors (GRS) following Moorrees (1957). Measurements were taken on the left side of the dental arcade. The right antimere was substituted in cases of antemortem or postmortem tooth loss, gross carious lesions, excessive wear, or any other condition that would make the left side unobservable. Teeth with large carious lesions, excessive dental calculus, or marked occlusal wear were omitted from analysis. Table 1 is a summary of material available for study in this analysis.

Along with maximum mesiodistal (MD) and buccolingual (BL) crown measurements, two additional measurements were calculated. Tooth size as the product of the maximum crown dimensions was also analyzed (TS=MDxBL) as was total crown area for each tooth type. Crown area was defined as the sum of TS (ΣTS) for all teeth in a single tooth class, with the exception of the third molar.

To analyze sexual dimorphism, the male mean was divided by the female mean of each measurement for each tooth, and then multiplied by 100 (Garn et al., 1967b; Harris, 1997). Sexual dimorphism was also examined through a multivariate analysis of variance (MANOVA) and a Student's t-test. Statistical significance was measured using the Bonferroni correction. Principal components analysis (PCA) and discriminant function analysis (DFA) were used to explore differences between populations.

Three major benefits of using a PCA in the study of human tooth size variation include: (1) reducing data on inter-correlated variables into compound variables; (2) extracting the major developmental fields controlling tooth size; and (3) providing statistically independent measures for between group comparisons (Harris, 1997). The extracted components were then used in Euclidean

Table 1. Male and female samples by time period.

Time Period	Population	Location of Collection	Male (n)	Female (n)
Medieval (1100-1350)	Basque	Catedral de Santa Maria	65	28
Post Medieval (1400-1850)	Basque	Catedral de Santa Maria	90	126
Modern (2005)	Spanish	Dental Casts; Universidad del País Vasco, Dental School	8	48
	Spanish-Basque		13	39
	Basque		8	28
Total			**184**	**269**

distance analysis in which Ward's dendrograms were created.

Tooth apportionment was used to create residual scores, where the expected variation (PCA on the sum of the dental arcades) was subtracted from the observed variation (PCA for all individual tooth measurements). These are used to view a group's variation in the entire dentition or by morphogenetic fields, depending on research questions and available data sets (Harris, 1997).

The use of residual scores shows each group's variation from their predicted overall tooth size. These residual scores can be visualized through bar graphs or the scores can be subjected to further statistical analysis to show population grouping. The axis on which the scores are plotted represents the expected size of the dentition for each sample; negative scores, as indicated by bars plotting below the expected line, show teeth that are smaller than expected, while positive scores show teeth that are larger than expected. Analysis using residual scores allows published mean scores to be used, expanding sample sizes in comparative analyses (Harris and Rathbun, 1991).

While PCA emphasizes variation within populations, discriminant function analysis examines variation by maximizing differences between groups and minimizing variation in a group (Kachigan, 1986). Raw data are required to run a discriminant function; therefore, this method was only used to examine variation for samples collected as part of this study. Using these samples, a stepwise DFA was used to compare Basque temporal periods. All analyses were conducted in SPSS version 22 (IBM Corp., 2013).

To explore population variation, eighty-two comparative samples of summary statistics of dental metrics were assembled from published sources (Table 2). These samples cover multiple temporal periods and geographic areas and were divided into five regions (Western Eurasia, Sino America, Sahul Pacific, Sunda Pacific, and Sub Saharan Africa) for comparisons described by Scott and Turner (1997). To examine Basque variation, analyses focused on: (1) temporal variation within the Basque samples; (2) Basque variation viewed on a continental level comparing Basque samples to Western Eurasian groups; and (3) Basque variation in a global context.

Results

Dental metrics were evaluated for sexual dimorphism within the five samples: medieval, post medieval, modern Basque, Spanish, and Spanish Basque. The degree of sexual dimorphism ((male mean/ female mean)*100) is in line with other odontometric studies (Moorrees 1957; Keiser 1990) that show males with teeth on average 2-4% larger than females, with canines slightly more dimorphic at 4-6% (Table 3). The modern Basque sample was the only sample to vary, with males not exhibiting larger teeth than the females, although this is most likely due to the over representation of females in the sample (see Table 1).

First, temporal variation was examined. A cross-validated stepwise DFA classified individuals into one of three groups (medieval, post medieval, or modern) with an accuracy of 46.4%, which is slightly better than random chance (Table 4). Medieval and modern samples have the highest percentages of correct classification, both around 70%, while the post medieval was the hardest to classify with a rate of 27%. Poor classification of the post medieval group was expected, as this transitional group most likely represents the median between the medieval and modern groups, thus allowing for incorrect classifications to occur more frequently.

Crown areas were used to examine differences between temporal periods and population. Plotting anterior and posterior crown areas for all populations collected, there is a clear shift in tooth size as time increases. Although among males, there is a shift from the expected, as the modern Basque populations have slightly smaller teeth than medieval Basques (Figure 1). This is mostly likely due to the poor representation of males in the modern sample, where males were underrepresented in the dental school population when the casts were collected. When looking at females, post medieval Basques show larger tooth size for both premolars and molars when compared to medieval Basque samples (Figure 2). Premolars show an increase in size of 5.7% while molars increased by 6.6%. Modern Basques exhibit larger teeth than the post medieval samples at 8.3% in premolars and 1% in molars.

Examining Basque tooth crown apportionment along with other Western Eurasian populations from the published literature, residual factors for all dental arcades were used to make bar graphs following the methods of Harris and Rathbun (1991). As tooth crown measurements are sexually dimorphic, males and females were analyzed separately. Examining all measurements for male European samples, medieval Basques show scores of disproportionally small teeth, with post medieval Basques and medieval Norwegians falling interme-

Table 2. Published comparative samples used in analyses by region.

Region	Population	Citation
Western Eurasia	Anglo-Saxon	Lavelle 1968
	Bedouin	Rosenzweig and Zilberman 1969
	British	Lavelle 1968
	Caucasus	Kieser et al. 1985
	Circassian (Israel)	Koyoumdjisky-Kaye et al. 1977
	Coimbra	Galera and Cunha 1993
	Druse	Koyoumdjisky-Kaye et al. 1977
	English	Lavelle 1968
	Finland	Alvesalo 1985
	Iceland	Axelsson and Kirveskari 1983
	Jewish Cochini	Rosenzweig and Zilberman 1967
	Medieval Norwegians	Beyer-Olsen and Alexandersen 1995
	Modern Greek	Zorba et al. 2011
	Modern White	Axelsson and Kirveskari 1983
	North Finland	Kirveskari et al. 1977
	NP Lapp	Kirveskari 1977
	Pashtun	Sakai et al. 1971
	Rural Ancient Greek	Henneberg 1998
	Skolt Lapps	Kirveskari 1977
	South African Whites	Kieser et al. 1985e
	Tristan da Cunha	Thomsen 1955
	Urban Ancient Greek	Henneberg 1998
Sino America	Adena	Sciulli 1979
	Ainu	Brace and Nagai 1982
	Aleut	Moorrees 1957
	Cahokia Mound 72	Thompson 2013
	Canadian Eskimo (Iglooik)	Mayhall 1979
	Canadian Eskimo (HB)	Mayhall 1979
	Chinese Bronze	Brace 1976
	East Greenland Eskimo	Pedersen 1949
	Glacial Kane	Sciulli 1979
	Fukuoka	Brace and Nagai 1982
	Highland Beach	Iscan 1989
	Hopewell	Sciulli 1979
	Indian Knoll	Perzigian 1976
	Jomon	Brace and Nagai 1982
	Kansas Schultz Mound	Phenice 1969
	Korean	Brace and Nagai 1976
	Kyoto	Brace and Nagai 1982
	Lengua	Kieser et al. 1985e
	Pecos	Nelson 1938
	Shanghai	Brace and Nagai 1982
	St. Lawrence Island Eskimo	Scott and Gillispie 2002
	Tennessee (A)	Hinton et al. 1980
	Tennessee (M)	Hinton et al. 1980
	Tennessee (W)	Hinton et al. 1980
	Tibet	Sharma 1983
	Ticuna	Harris and Nweeia 1980b
	Xi Shang Neolithic	Brace, Shao, Zhang 1984
	Yayoi	Brace and Nagai 1982
	Yunnan	Brace and Nagai 1982

Table 2. Published comparative samples used in analyses by region (cont'd).

Region	Population	Citation
Sahul Pacific	Australian Aborigine	Campbell 1925
	Broadbeach	Smith et al. 1981
	Bougainville (Solomon Islands)	Bailit et al. 1968
	Walbiri, Australia	Barrett et al. 1963,64; Brace 1980
	Western Australia	Freedman and Lofgren 1981
Sunda Pacific	Cook Island, Mangaia	Yamada et al. 1988
	Cook Island, NS Group	Yamada et al. 1988
	Cook Island, Pukapuka	Yamada et al. 1988
	Cook Island, Rarotonga	Yamada et al. 1988
	Cook Island, S Group	Yamada et al. 1988
	Javanese Bronze	Brace 1976
	Java	Brace 1980
	India (Chalcolithic)	Lukacs 1985
	India	Acharya and Prabhu 2011
	India	Walimbe 1985
	Philippines	Potter et al. 1981
	South-east Java	Taverne 1980
	Tajik	Sakai et al. 1971
	Thai	Brace 1976
	Thai Bronze	Brace 1976
	Yang Shao Neolithic	Brace, Shao, Zhang 1984
Sub Saharan Africa	Bantu	Shaw 1931
	Griqua	Kieser 1985
	San	van Reenan 1982
	San	Drennan 1929
	South African Black, Contemp.	Kieser et al. 1987
	South African Black	Kieser et al. 1987
	South African	Jacobsen 1982
	Southern African	van Reenan 1982
	Teso	Barnes 1969

Table 3. Sexual dimorphism separated by temporal period

	UI1MD	**UI2MD**	**UCMD**	**UP1MD**	**UP2MD**	**UM1MD**	**UM2MD**
Medieval	105.23	105.39	104.00	103.66	103.64	103.86	106.09
Post Medieval	100.65	103.54	103.26	101.29	102.57	101.44	102.32
Spanish	102.79	104.51	102.39	101.71	103.35	102.29	101.26
Spanish-Basque	103.54	103.95	104.94	106.74	102.89	105.45	105.95
Basque	105.32	102.95	102.46	99.49	95.94	95.78	97.56
	UI1BL	**UI2BL**	**UCBL**	**UP1BL**	**UP2BL**	**UM1BL**	**UM2BL**
Medieval	103.21	104.73	102.54	102.61	103.97	103.30	105.78
Post Medieval	104.60	106.96	103.82	101.24	101.43	102.57	102.97
Spanish	105.88	103.77	103.04	100.68	102.82	101.73	104.15
Spanish-Basque	111.28	115.41	112.71	106.27	107.18	104.27	108.62
Basque	100.43	106.32	104.92	99.18	97.60	100.10	101.38
	LI1MD	**LI2MD**	**LCMD**	**LP1MD**	**LP2MD**	**LM1MD**	**LM2MD**
Medieval	97.15	101.33	102.02	103.46	104.94	105.25	104.84
Post Medieval	100.87	102.08	102.70	102.13	100.64	104.55	103.82
Spanish	102.99	104.47	102.55	100.60	100.55	100.16	102.38
Spanish-Basque	101.01	103.32	106.08	105.62	104.61	104.09	105.44
Basque	98.75	102.67	99.94	101.68	85.40	98.63	96.10
	LI1BL	**LI2BL**	**LCBL**	**LP1BL**	**LP2BL**	**LM1BL**	**LM2BL**
Medieval	101.56	101.57	103.89	102.50	102.69	101.87	102.42
Post Medieval	103.11	102.47	107.93	102.21	101.35	103.37	104.23
Spanish	104.25	98.66	102.38	100.49	99.43	102.80	103.35
Spanish-Basque	110.68	103.49	107.82	110.29	106.93	106.86	108.19
Basque	103.33	99.63	97.08	98.06	99.64	97.40	97.58

Table 4. Cross-Validated, Stepwise DFA Summary for all Basque temporal periods.

	Assigned Group	Predicted Group Membership			
		Medieval	Post Medieval	Modern	Total
Count	Medieval	42	14	5	61
	Post Medieval	69	31	15	115
	Modern	3	7	25	35
Percentage	Medieval	68.9%	23.0%	8.2%	100.0%
	Post Medieval	60.0%	27.0%	13.0%	100.0%
	Modern	8.6%	20.0%	71.4%	100.0%

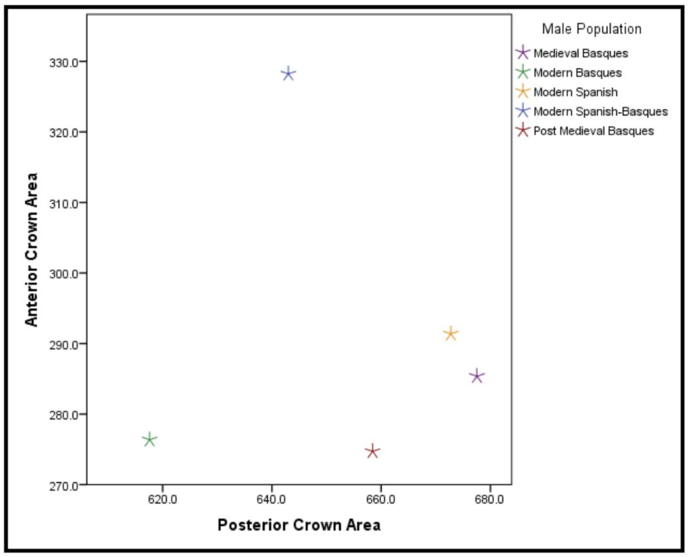

Figure 1. Anterior and posterior crown areas showing temporal change in tooth size for male samples.

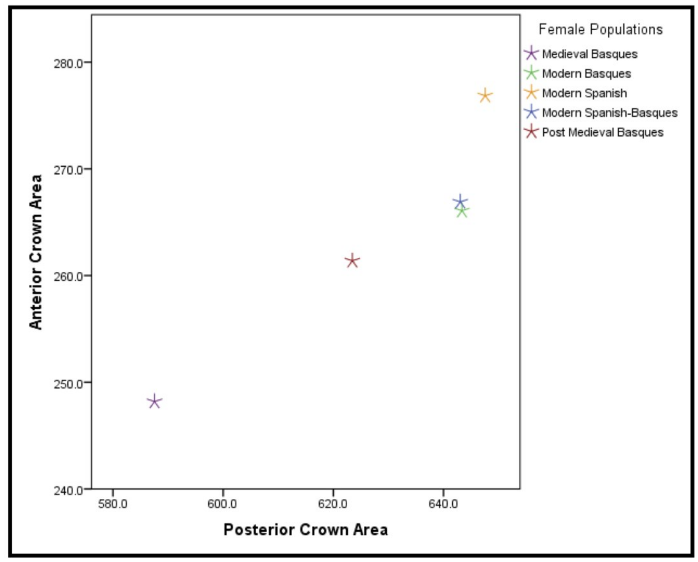

Figure 2. Anterior and posterior crown areas showing temporal change in tooth size for female samples.

diately. Modern Basques show the least divergences from the predicted dental size (Figure 3). Residual scores were then visualized through a Ward's dendrogram to view how Western European populations grouped based on tooth apportionment. In the male samples, modern Basques group with ancient Greeks and medieval Norwegians, while the medieval and post medieval Basques group clustered with NP Lapps and Coimbra samples (Figure 4).

Male world residual scores showed similar patterns to those observed within Western Eurasia when looking at all MD and BL measurements. The Basque samples show similar apportionment to each other, as well to the Coimbra and Ainu samples (Figure 5). In the male residual dendrogram for world populations (Figure 6), the medieval and post medieval Basques group near each other and the medieval Norwegian samples, as well as the Portuguese Coimbra sample; modern Basques group near ancient and modern Greeks, Jomon, South African Blacks, India, and Tibet.

As seen in the Western Eurasian male residual scores, the female Portuguese Coimbra sample, shows the greatest divergence from the predicted size of the dentition, followed by the medieval Basques, NP Lapps, and medieval Norwegians, respectively (Figure 7). Again, the post medieval Basques fall in between the medieval and modern Basque scores. When viewing residual scores through dendrograms, the modern samples and post medieval Basques group with Greek populations, and the medieval Basques group with Coimbra and NP Lapps (Figure 8). Many of the patterns observed in the Western Eurasian groupings are also reflected in residual scores for female world samples (Figure 9), as the medieval and post medieval Basque samples group with other Western Eurasian populations, Greeks, Coimbra, and NP Lapps, with two additional samples, the Ainu and the Griqua. The modern Basque sample aligns with populations that create a geographically isolated grouping that includes the San, India, Jomon, and the Philippines (Figure 10).

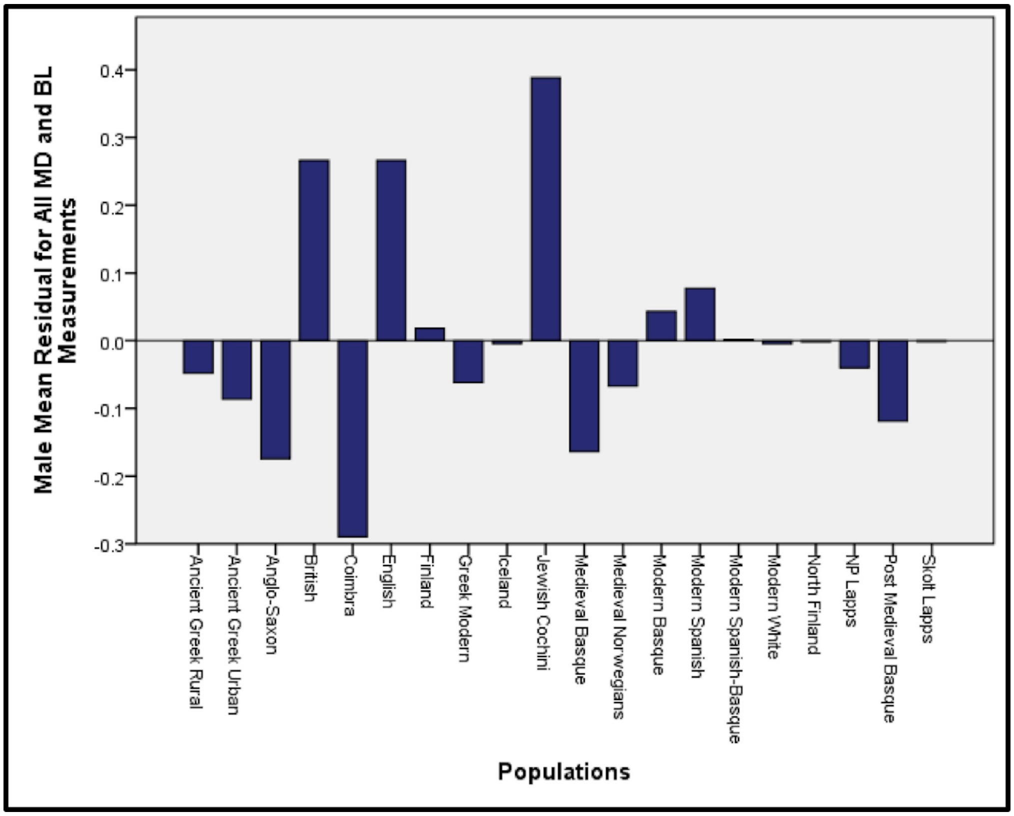

Figure 3. Residual factor graph plotting the residual of anterior MD and BL measurements for Western Eurasian male populations.

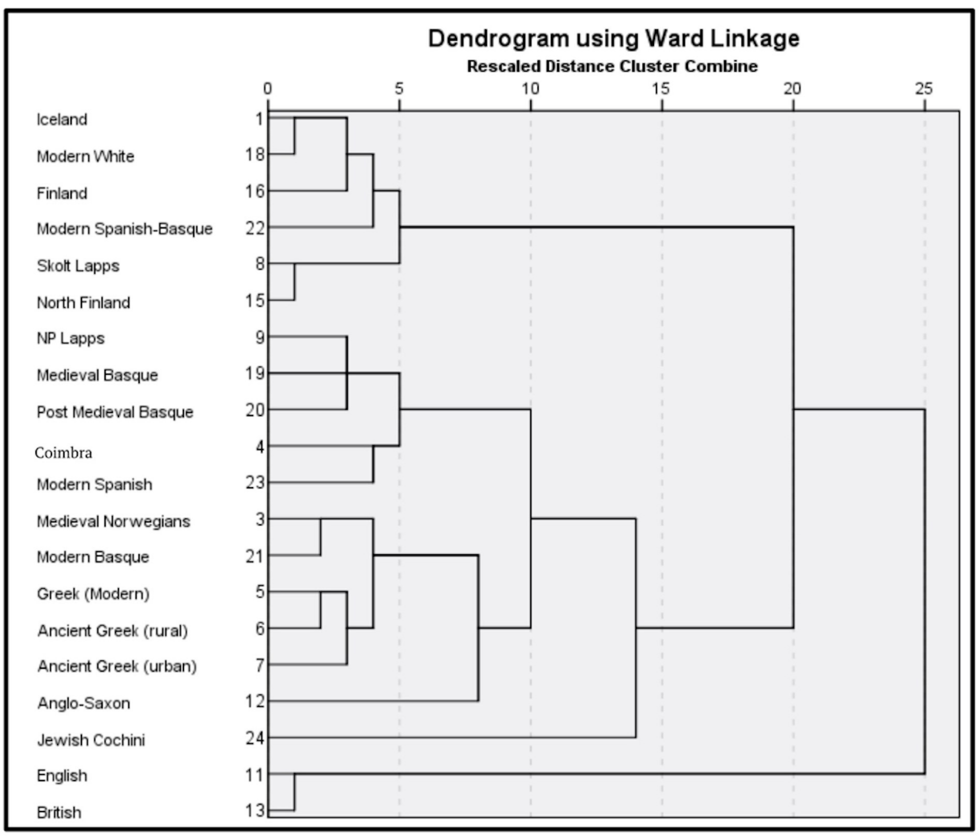

Figure 4. Ward's (1963) Dendrogram based on residual scores of all MD and BL measurements for Western Eurasian Male populations.

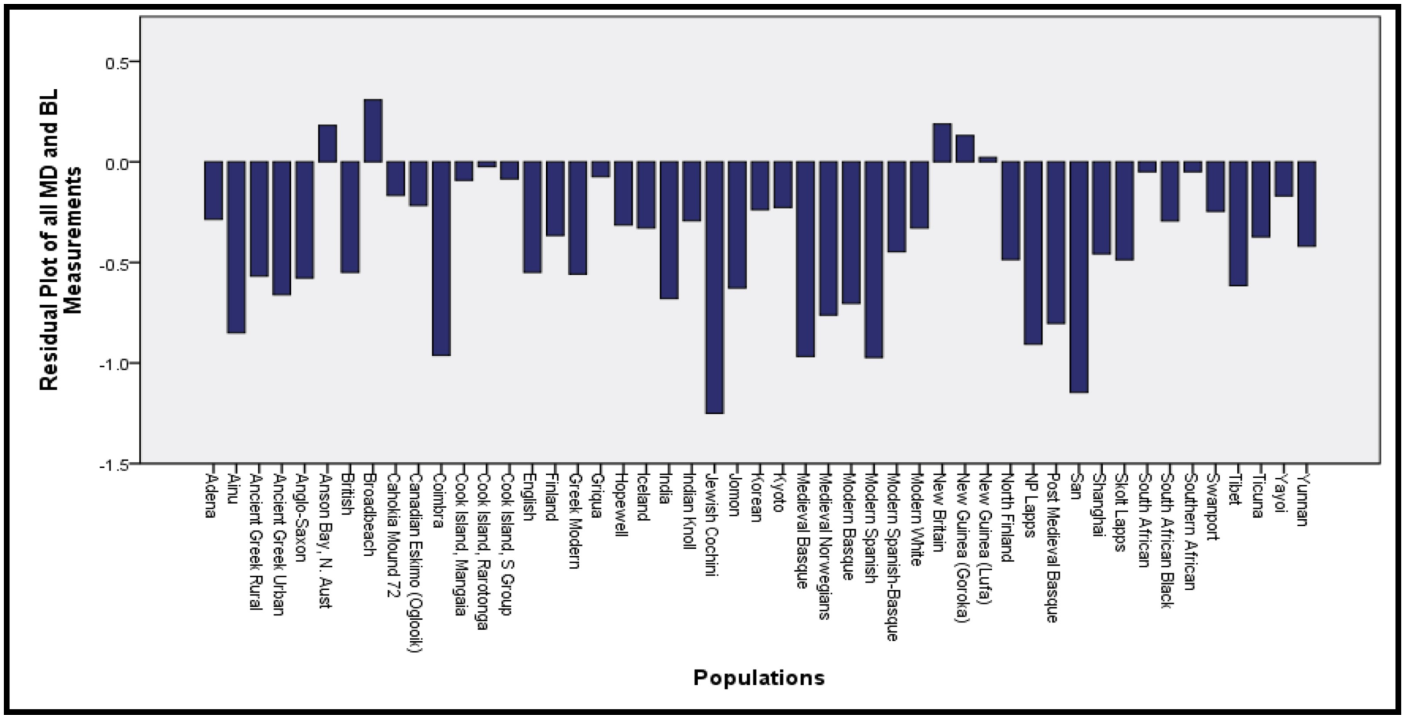

Figure 5. Residual Factor Graph plotting the residual of all MD and BL measurements for World Male populations.

Viewing MD and BL measurements for world male samples using PCA in a dendrogram, clear geographic separations emerge (Figure 11). Distinctions between Sahul-Pacific and Sunda-Pacific are clearly seen. Sunda-Pacific and Sino-American are more mixed, yet still lie in the first branch of the dendrograms separating these groups from the Western Eurasian groups which diverged in the lower branch. The medieval Basque samples again group with their Coimbra neighbors, post medieval Basque samples grouped together with NP Lapps, medieval Norwegians, South Africa, and Ainu. Residual scores show modern Basques align with other small-toothed groups (Greeks, Anglo-Saxons, and English). Much like males, female world population samples show the same distinctions between the geographical regions (Figure 12). Ainu, medieval Norwegians, NP Lapps, Griqua, and Coimbra align with the medieval and post medieval Basque samples. The medieval Basque sample show the closest apportionment to Coimbra, representing the Iberian Peninsula. Modern Basques grouped with India, Jomon, South Africa, and British samples.

Discussion

Though genetic studies suggest increased movement into the Basque Country during post medieval times, the overall distinct phenotype of the modern Basque population is still evident when compared to geographically proximate populations. When viewing Basque variation in the context of other Western Eurasian groups, interesting patterns emerge. Medieval Basques consistently group within Western European populations, most often with Coimbra, their Portuguese neighbors. Post medieval and modern samples grouped with the NP Lapps, medieval Norwegians, and the Greeks, both ancient and modern. This grouping of Basque samples with these samples is consistent with their isolated status. NP Lapps differentiate at a high level because, like the Basques, they are geographically removed and linguistically distinct (Uralic language family vs. Indo-European) from other Western Europeans. This uniqueness has been suggested to be related to a Paleolithic origin of the Lapps (Cavalli-Sforza et al., 1994). The pattern of Basques grouping with other geographically and linguistically isolated Western European populations is also seen in genetic (Azualde et al. 2005; Azualde et al. 2006; Martinez-Cruz et al., 2012), and dental studies, both in terms of morphology (Scott et al., 2013) and metrics.

Given that Basques align with other geographically and linguistically isolated populations, rather than more neighboring European and North African populations, this could support the longheld position that they represent a continuous settlement in the Pyrenees since the Paleolithic followed by relative genetic isolation, while still al-

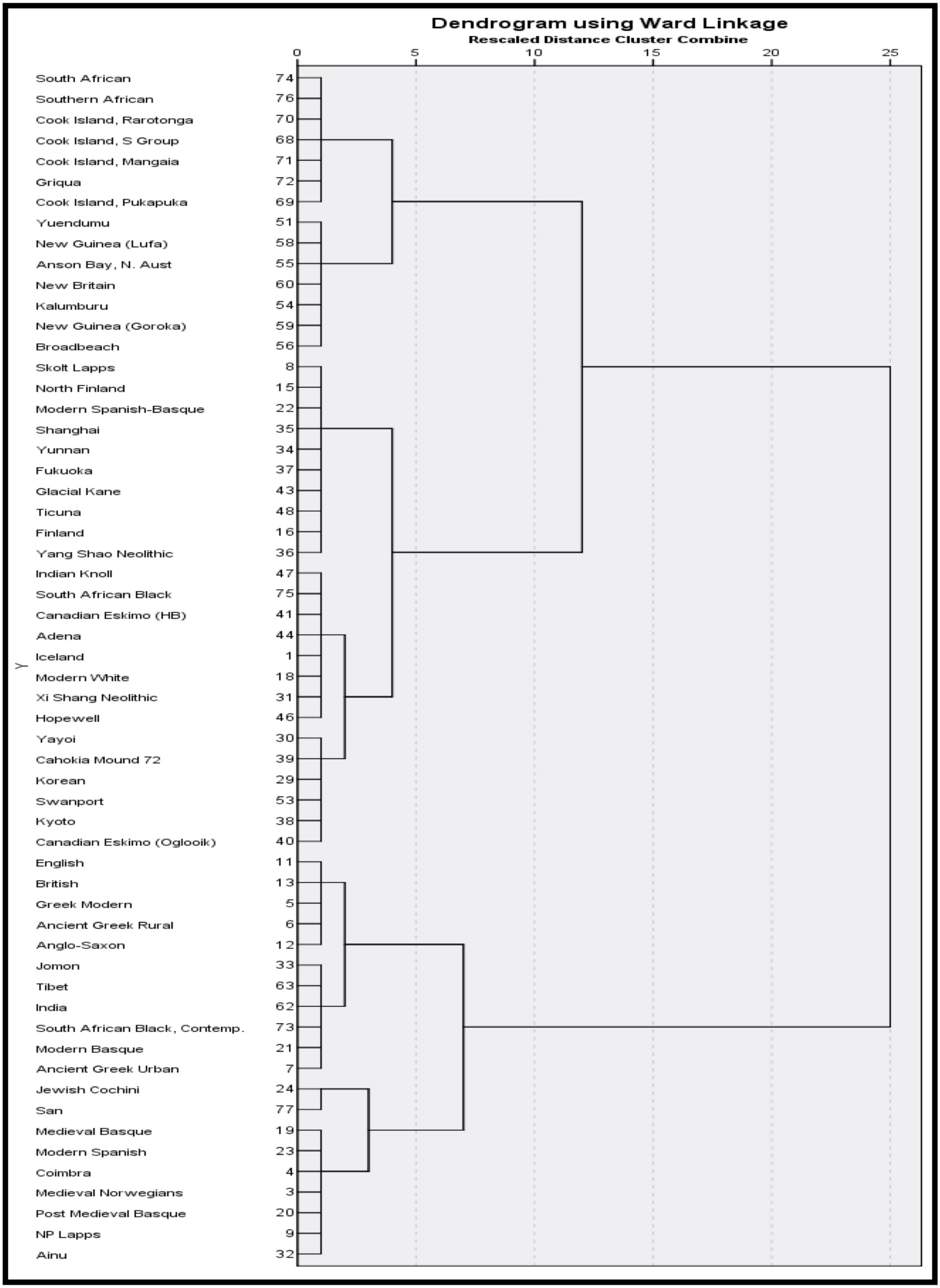

Figure 6. Dendrogram plotting the residual of all MD and BL measurements for World Male populations.

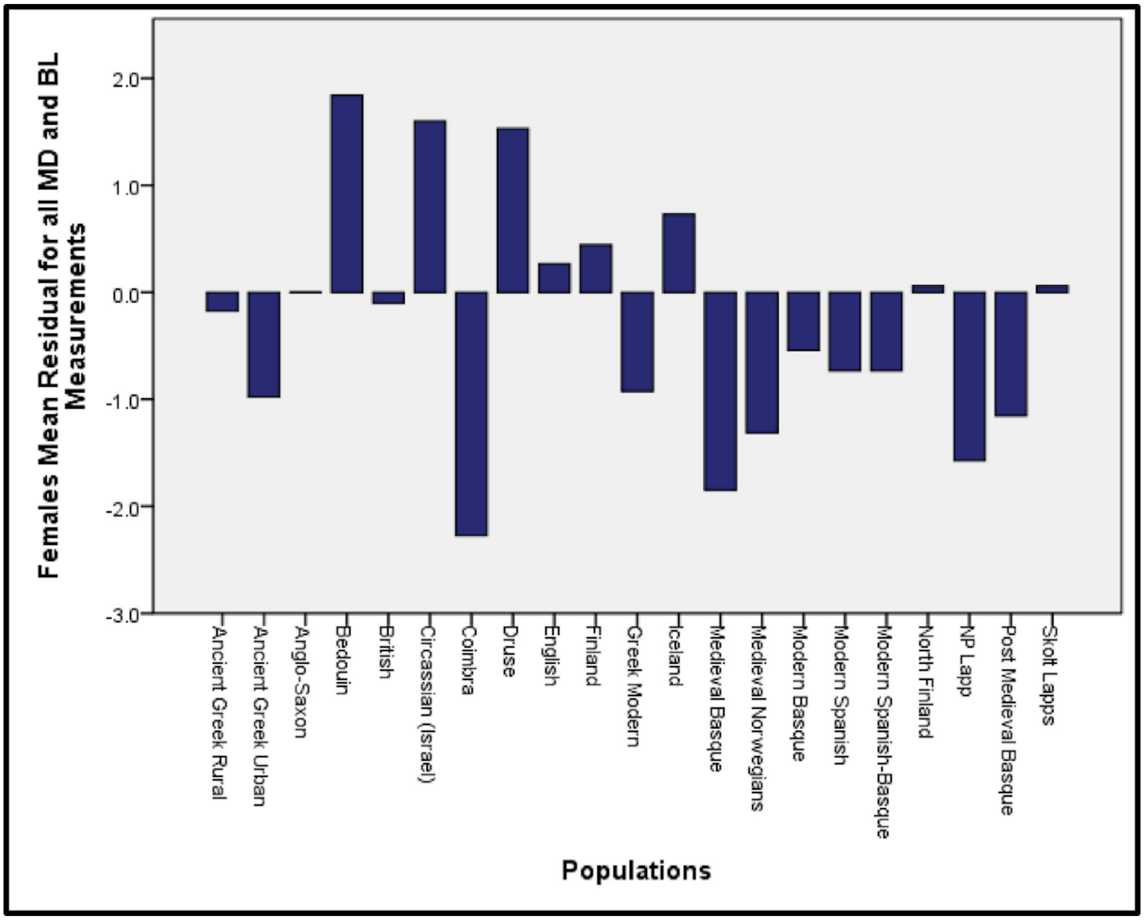

Figure 7. Residual Factor Graph plotting the residual of all MD and BL measurements for Western Eurasian Female populations.

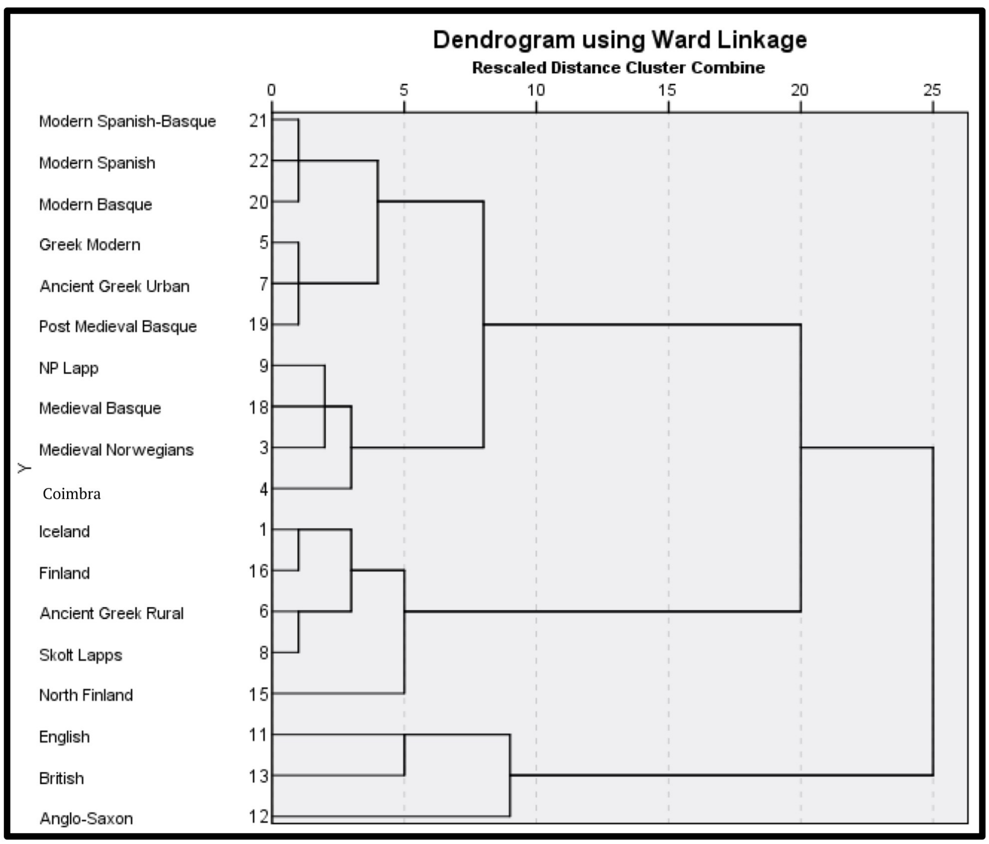

Figure 8. Ward's (1963) Dendrogram based on residual scores of all MD and BL measurements for Western Eurasian Female populations.

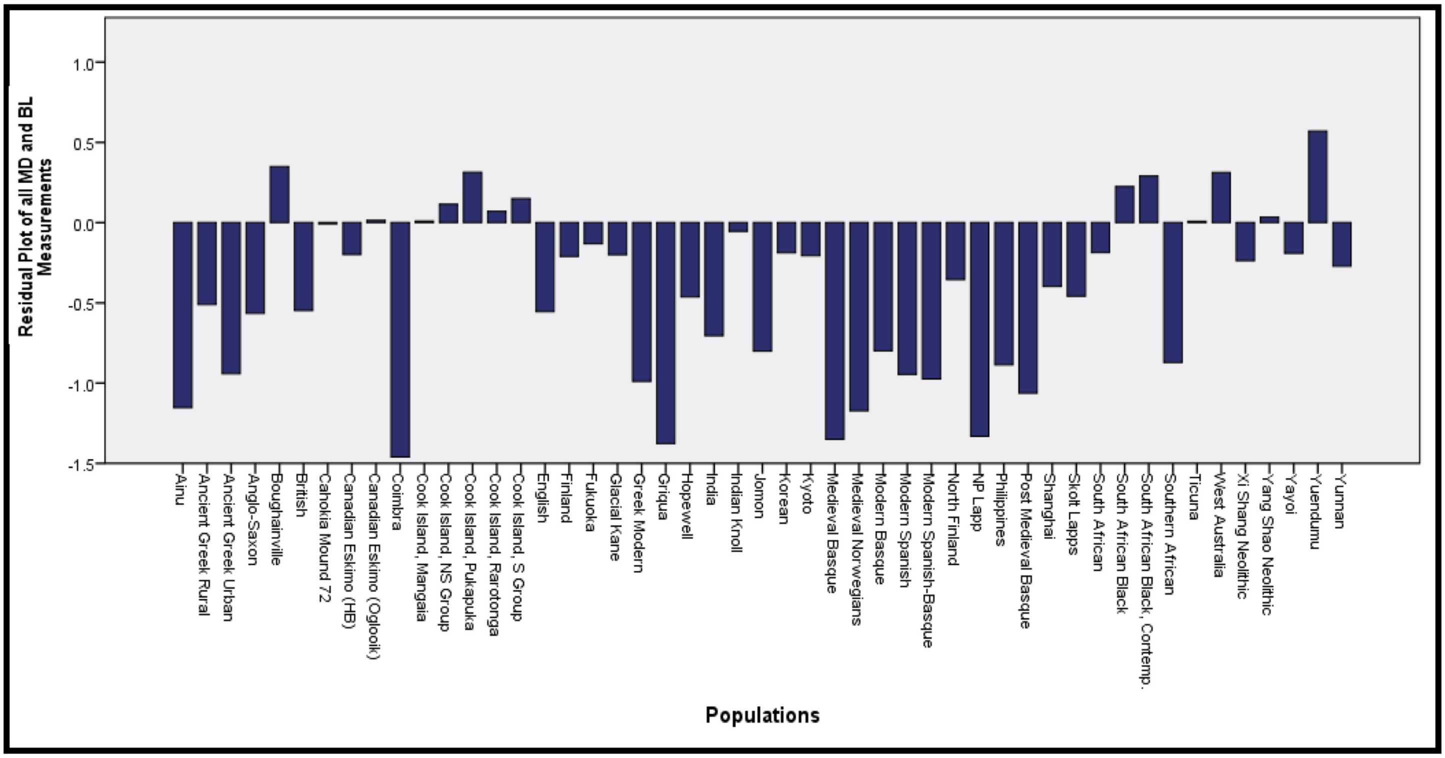

Figure 9. Residual Factor Graph plotting the residual of all MD and BL measurements for World Female populations.

lowing for recent gene flow from Iberian and/or North African groups.

Using dental metrics to view the Basques on a worldwide scale, they do remain distinct. There are clear separations between world regions, with Western Eurasia separating on its own branch. Medieval and post medieval Basque samples do, however, group with other distinct groups, including Coimbra, NP Lapps, medieval Norwegians, and somewhat surprisingly, the Ainu. The modern Basque samples showed similar patterns, as they grouped with small-toothed Western European populations (British and Greeks), but they also group more frequently with non-European populations, such as India, Griqua, and the Jomon.

The medieval and post medieval samples show a more consistent grouping within Western Europe, whereas modern Basques were more likely to group with outside populations within the Western Eurasia branch. The differences between the modern samples and those from the preceding periods (i.e. medieval and post medieval) might be explained by the overrepresentation of females in the modern sample, ethnic self-identification, or to disparities between measurements taken directly from the teeth of the two skeletal samples and those taken from dental casts of the modern sample. It is very likely that the modern Basque sample is representative of a more genetically diverse population in comparison to the earlier skeletal samples.

Focusing on medieval and post medieval Basques, there is a pattern of grouping with Western Eurasian samples in general, and with outliers in particular. These consistent groupings could further provide support that the Basque population has a deep history in Western Europe, one that precedes by millennia the influx of Indo-European farmers from the Middle East and Anatolia (Cavalli-Sforza, 1994; Izagirre et al., 2001).

Conclusions

Basques are an anthropologically significant population due to their antiquity and genetic isolation in the Pyrenees mountains of northern Spain and southern France. A better understanding of this population would help to provide greater insights into the movement and interaction of human populations in Europe.

As genetic (Azualde et al. 2005; Azualde et al. 2006; Martinez-Cruz et al. 2012) and dental studies show (Scott et al. 2013), the Basques are a Western Eurasian population, yet they fall outside this broader population grouping, often clustering with

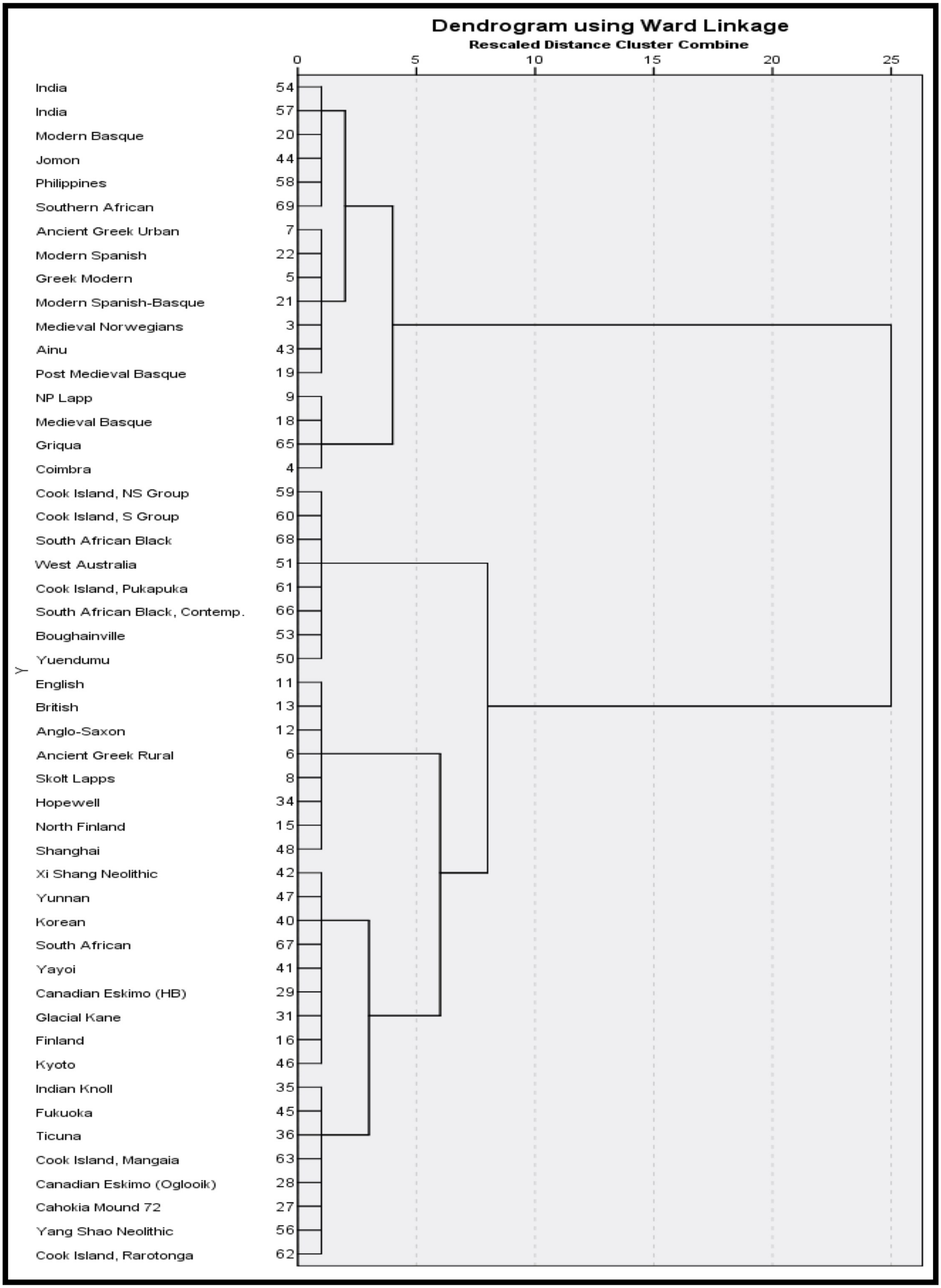

Figure 10. Dendrogram plotting the residual of all MD and BL measurements for World Female populations.

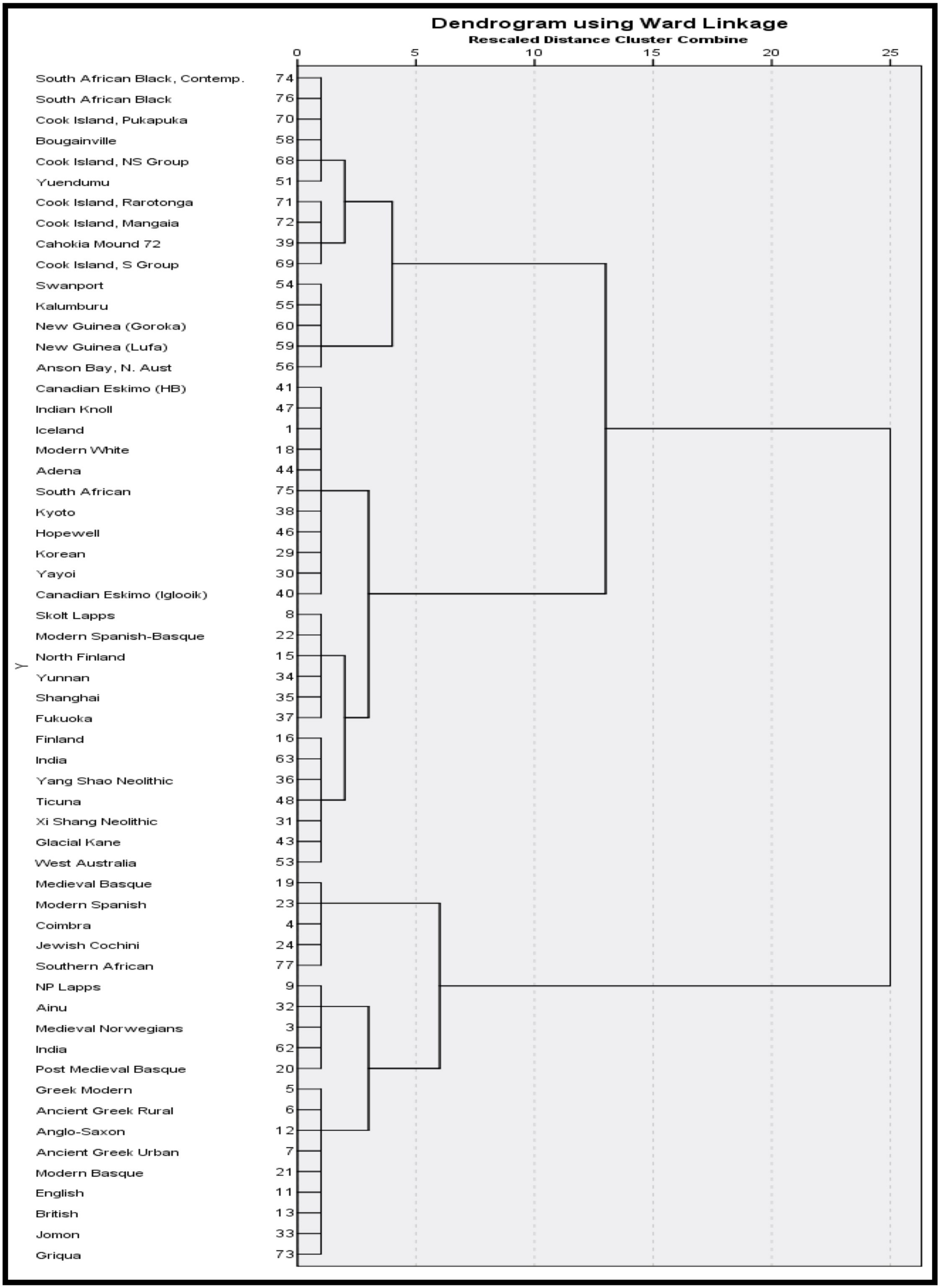

Figure 11. Dendrogram plotting the first PCA score of all MD and BL measurements for World Male populations.

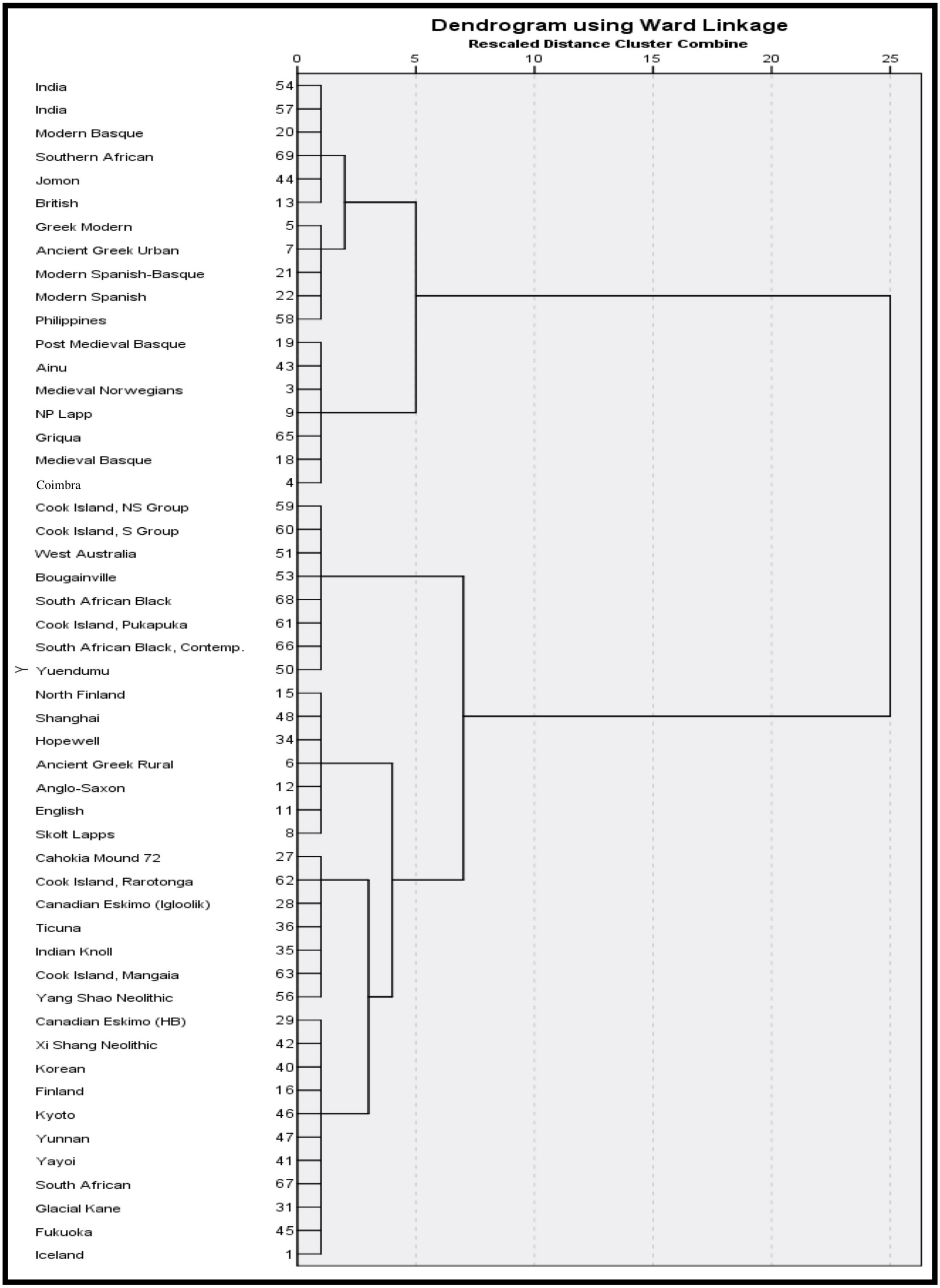

Figure 12. Dendrogram plotting the first PCA score of all MD and BL measurements for World Female populations.

non-European populations. While genetic isolation played a major role in the genetic make-up of the Basques, there is evidence of gene flow between Basques and linguistically and culturally different surrounding populations, specifically the Spanish and North Africans (Azualde et al. 2005; Azualde et al. 2006; Martinez-Cruz et al. 2012). Though gene flow is evident, it does not mask the uniqueness of Basque genetics, be it in blood groups, mtDNA, Y chromosomes, or dental morphometrics.

Geographic and linguistic barriers could be major factors in the isolation of the Basques in prehistoric times, though these would have been barriers more easily crossed in historic times, as evidenced by genetic studies. This research supports the idea that the Basques are one of the oldest populations in Europe. Their subsequent isolation throughout prehistoric times appears to have preserved their unique genetic heritage. Interestingly, increased gene flow in later periods does not correspond with stronger connections with other Western European populations in terms of dental metrics.

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BOOK REVIEW

The Anthropology of Modern Human Teeth. Dental Morphology and Its Variation in Recent and Fossil Homo sapiens. By G. Richard Scott, Christy G. Turner II, Grant C. Townsend, and Maria Martinon-Torres. Cambridge University Press. 2018. 396 pp., $44.99 (paperback). ISBN:978-1-316-62648-1

The Anthropology of Modern Human Teeth second edition has been published 20 years after the original Scott and Turner (1997). The first edition made the Arizona State University Dental Anthropology System (ASUDAS) dental morphology data collection methodology accessible to scholars around the world. Since that time multiple generations of dental anthropologists have graduated and continued the exploration of information gleaned from modern human and fossil hominid teeth. The second edition closely follows the same outline as the first edition. Each chapter has been updated with the inclusion of almost every single published study up to the publication date. The developmental and genetic sections have been expanded. The most obvious difference between the two editions is the addition of an entire chapter focused on dental variation among fossil hominids.

G. Richard Scott was Turner's first graduate student and their close research relationship is the core of this book. Scott brings his expertise in covering the breadth of dental anthropology populations studies on European and Arctic populations, familial studies on patterns of inheritance, and the possible effects of gene flow on trait expression. This book greatly benefits from Christy G. Turner II's global dental morphology data and his unique slide collection of dental variation and rare traits. Both of these researchers have seen almost every dental morphological variation recorded in modern human populations. The addition of two new co-authors helps to round out the scope of this book. Grant C. Townsend's extensive research into odontology, dental development, and genetics provides the background to understand the necessity for morphological studies. María Martinón-Torres specializes in the dental anthropology of fossil hominins. She brings a unique perspective on dental variation among fossil hominids with a focus on sites in Spain and China.

The organization is straightforward with a prologue, eight chapters, and an epilogue. The prologue summarizes the present state of dental morphological research. They address potential problems encountered in the process of data collection. Finally, dental anthropology class teaching objectives are mentioned. Chapter 1 covers the history of dental morphological studies, what has been the research focus of dental anthropologists, who are the key historical figures, and research trajectories through time. Chapter 2 is a thorough description of crown and root dental traits in permanent teeth. Dental anatomical terminology, direction and positional terminology, and cusp numbers are reviewed. Data collection, interobserver error, and intraobserver error are discussed. Thirty-six traits are shown with photographs of real teeth and dental casts. Each trait is listed with a brief description, observable variants, and which key teeth to be scored. Chapter 3 switches directions and introduces ontogeny, dental trait development, asymmetry, intertrait associations, and dental genetics. Chapter 4 focuses on the genetic background of dental traits. How are dental traits influenced by intertrait associations and levels of heritability? How is trait expression affected by the combination of genes and environment? Chapter 5 looks at the distribution of dental traits along five macro-regional divisions using over 30,000 individuals from Turner's data set. More intra-regional subdivisions have been added since the first edition to provide a more detailed picture. The two regions which benefit the most from the added data sets are Sub-Saharan Africa and North America. The tables and figures help greatly to organize this immense amount of information. The specific dental traits used to define macro-regional dental complexes are explained. Chapter 6 introduces the theoretical and methodological issues encountered in population history studies. Many studies use either a historical or processual basis for their hypotheses. Studies are grouped according to whether they are addressing natural selection, gene flow, gene drift, mutation, or sexual selection. An attempt is made to determine possible adaptive mechanisms for dental traits based on structure, function, strength, or durability. An interesting section mentions the potential of using rare dental traits to determine kinship or marital patterns. The authors mention the level of congruence (or not) dental trait studies have had with linguistic regions, historical records, archaeological evidence, blood group patterns, cranial nonmetric traits, odontometrics, and dermatoglyphics. Finally, extensive citations are mentioned for micro-regional studies, which have exploded since the publication of the first edition. Chapter 7 goes into detail about the macro-regional dental complexes and how they contribute to the understanding of population history in very deep time. These studies focus on the "Peopling of the World" hypothesis which was the driving factor in Christy G. Turner II's lifetime of research. Some exploration into the evolution of dental traits is mentioned. In the end all of the data supports an origin of modern humans from Africa. Chapter 8 is a new addition to this edition focusing on fossil hominids. This is an excellent and much needed overview on fossil hominid dental variation. While the emphasis is on finding a dental complex, which will identify modern *Homo sapiens*, almost every fossil hominid species are represented. Twelve potential distinguishing dental traits are examined in detail. While no single dental trait is unique to modern humans, a particular combination and expression of traits may provide some discrimination. A large number of individual hominids is represented. The numerous photographs allowing a side-by-side comparison of individual teeth, more or less to scale, is impressive. The epilogue covers areas that are outside the authors' research focus including deciduous teeth, dendrochronology, and forensics applications.

Many things about this edition are incredible achievements. The writing style and tone are comfortable and clear. Very complicated concepts are explained well and made accessible. The manipulation and visualization of the huge data set is an accomplishment. The tables, graphs, and figures are well designed and explained within the text. The sheer number of photographs is a huge asset to any researcher. The bibliography in itself is probably the most valuable part of this book. This is a refreshingly inclusive collection of national and international research.

The main weaknesses of this edition have to do with being too ambitious with lapses in structure and organization. The flow of the chapter topics can be abrupt. It may have flowed more smoothly with all of the background information first, then introduce the traits, ending with the populational studies. The prologue, epilogue, and Chapter 8 feel as if they are tacked on, and not well integrated into the rest of the chapters. This may be a result of the all-inclusive nature of the book, that there is just too much information to fold everything in smoothly. With the exception of Chapter 8, the photo quality of the rest of the book is not as good as the first edition. This may be the result of quantity overshadowing quality in the photographs. Some of the dental traits are difficult to visualize due to the small size or not enough contrast.

Overall, this book is a much needed addition to the fields of dental anthropology, dental genetics and development, population history, and fossil hominid research. The numerous photographs and all-inclusive bibliography make this a unique contribution to the field. While the information is too dense to use as a textbook, researchers and advanced graduate students will find this a valuable addition to their libraries. This is a poignant last publication and a fit tribute to the career of Christy G. Turner II

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