Archaeological and Anthropological Sciences (2023) 15:197
https://doi.org/10.1007/s12520-023-01893-3

RESEARCH

Interpreting oral conditions of the past: biocultural factors affecting Gran Canaria's population between the fifteenth and eighteenth centuries (Canary Islands, Spain)

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Received: 3 May 2023 / Accepted: 7 November 2023 / Published online: 30 November 2023

Abstract
The European colonization of the Canary Islands was accompanied by new farming and food processing techniques as well as new dietary patterns. The current study sheds light on the impact of these new techniques and foodstuffs by delving into the oral conditions of members of this society in this timeframe. The analyses of the oral conditions of 85 adults of the Modern Era of Gran Canaria combined with spatial, temporal, and sex criteria led to identifying a paleodietary profile characteristic of this population. This pattern served to evaluate differences among other populations of the archipelago such as the earlier Indigenous Period of Gran Canaria and the Modern Era populations of the neighboring islands of Tenerife and Lanzarote. This study reveals a high prevalence of caries, dental calculus, and antemortem tooth loss, notably along the lines of sex. Comparisons between the different Indigenous and the Modern populations also point to statistical differences between dental caries and heavy macrowear. The Gran Canaria's Modern Era population had a carbohydrate-rich diet compatible with the intake of cereal and sugar cane products. Oral conditions among males were likely influenced by the newly introduced consumption of tobacco. The results also confirm that the European colonization strongly altered the dietary patterns and food processing techniques inherited from the Indigenous Period. Finally, the comparisons of the Modern Era populations of the three islands of the archipelago reveal an asymmetry between dietary patterns and food processing techniques from one island to another.

Keywords Oral conditions · Dental anthropology · Diet · Modern era · Canary Islands

Introduction

Osteoarchaeological evidence combined with archaeological and historical data serve to delve into the impact of the European expansion during the Modern Era (fifteenth to eighteenth centuries) on dietary patterns, food processing techniques, human health, and cultural habits (Crubézy et al. 2021; Gámez Mendoza 2010; Klaus and Tam 2010; Larsen and Milner 1994). This set of information sheds light on the living conditions of the populations of the new settlements and the colonial impact on the Indigenous populations such as in the Canary Islands (Aznar Vallejo 2008). This period represented the globalization of the economy and an unprecedented exchange of autochthonous plants and animals throughout the world through colonization and trade. Certain crops were thus cultivated in areas far from where they were domesticated (Boivin et al. 2017). Sugar cane was key in this period as the sugar industry became very lucrative. This early globalization also had an impact on worldwide dietary patterns yielding an increase of dental caries and other oral conditions (Chazel et al. 2005; Giuffra et al. 2020; Malčić et al. 2011; Mant and Roberts 2015; Schats et al. 2021; Tomczyk et al. 2020; Vilkama et al. 2016). Klaus and Tam (2010), for instance, identified significant increases in dental caries, antemortem tooth loss, and frequency of dental calculus between the Late Pre-Hispanic and colonial Mochica populations of Mórrope (Lambayeque) in

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Peru. The incidence among females of the Mórrope colonial population also rose due to greater cariogenic diet. Similar results were observed among the Georgia Bight populations of southeastern North America with an increase in caries throughout the last centuries prior to the arrival of Europeans as consequence of the intensification of the cultivation of maize (Larsen et al. 1991). In any case, the evidence suggests a meaningful increase in dental caries after European contact with relatively greater impact on females. Oral condition analyses can therefore offer evidence serving to explore the characteristics and pace of historical colonization processes as their prevalence and severity fluctuated according to changes in diet and new cultural behaviors and food processing techniques (Hillson 2008).

The Canary Islands in the Modern Era (fifteenth to eighteenth centuries)

The Canary Islands is an archipelago comprising seven islands about 100 km off the northwestern coast of Africa. The islands were first populated in about the third century AD by Berber farmers from North Africa (Fregel et al. 2019; Hagenblad et al. 2017; Mora Aguiar 2021; Serrano et al. 2023; Springer Bunk 2019) who introduced domestic plants such as barley (*Hordeum vulgare subsp. vulgare*), durum wheat (*Triticum durum*), lentils (*Lens culinaris*), broad bean (*Vicia faba*), and fig (*Ficus carica*) (Morales et al. 2023). They were also accompanied by domestic animals, notably goat (*Capra hircus*), sheep (*Ovis aries*), pig (*Sus scrofa*), and dog (*Canis familiaris*) (Alberto-Barroso et al. 2015; Hernández et al. 2016; Olalde et al. 2015). Subsistence strategies also consisted of gathering wild plants (Morales and Gil 2014) and exploiting marine resources (Parker et al. 2020; Rodríguez-Rodríguez et al. 2021). Archaeological evidence suggests that barley was the staple of Gran Canaria's Indigenous populations (Morales et al. 2017) which was ground in rotary hand querns hewn from basalt or volcanic tuff (Arnay-de-la-Rosa et al. 2019; Naranjo-Mayor et al. 2016; Rodríguez-Rodríguez et al. 2007).

The European expansion throughout the Atlantic Ocean began between the Late Medieval and Early Modern Era (fourteenth to fifteenth centuries). This process, which led to the rediscovery of certain islands hardly known since Classical Antiquity, required navigating across vast expanses of water and knowledge of both the Macaronesia archipelagos and the western African coastline (Aznar Vallejo 2008). Both the Kingdoms of Castile and Portugal played prominent roles in this expansion and competed to obtain access to the commodities and trade routes through Africa (Onrubia Pintado and González Marrero 2018). The Canary Islands were eventually conquered and colonized by the Kingdom of Castile towards the end of the fifteenth century. The Castilians founded new capitals on the islands of Gran Canaria, Tenerife, and La Palma serving as ports and thus participated in the three-way triangular trade established between Europe, Africa, and America after its discovery by Columbus (Lobo Cabrera 2015). The European settlers introduced new domestic plants such as sugar cane (*Saccharum officinarum L.*), maize (*Zea mays* L.), potato (*Solanum tuberosum* L.), banana (*Musa acuminata* Colla), taro (*Colocasia esculenta* L.), and bottle gourd (*Leranaria siceraeria*) (Alzola 1984; Cullén del Castillo 1947). They also were accompanied by new draft animals such as cow (*Bos taurus*), horse (*Equus equus*), donkey (*Asinus asinus*), as well as small animals such as chicken (*Gallus gallus*) and rabbit (*Oryctolagus cuniculus*) (Brito-Mayor et al. 2023; Cullén del Castillo 1947; Morales Padrón 1974). The European colonization also ushered in new agricultural techniques such as animal driven plows and new means to process foods such milling mechanisms (watermills, windmills, and animal mills) (Cullén del Castillo 1947; Morales Padrón 1974).

The diet of the Modern Era also included products deriving from raising livestock and fishing (Brito-Mayor et al. 2023; Quintana Andrés 1997, 2003a, 2003b). The most common animal products were milk and cheese. The consumption of fresh or salted meat was restricted due to higher costs (Quintana Andrés 2003b). The Modern Era also saw an increase in the variety of meat sources through the introduction of animals such as cows, chickens, or rabbits (Cullén del Castillo 1947; Morales Padrón 1974). The consumption of salted, fresh, or smoked fish (Quintana Andrés 2003a) was the main source of animal protein and fat for the lower classes. This less costly product suffered from a sort of prejudice due to its being associated with the lower ranks of society (Quintana Andrés 2003a). However, both local (Quintana Andrés 2003b) and imported (Lobo Cabrera 2008) fish were consumed as required by the Catholic Church during certain religious festivities (Quintana Andrés 2003b). They likewise introduced new habits such as tobacco (*Nicotiana tabacum*) consumption that became extremely popular after the introduction of this plant in the Old World (Arnay-de-la-Rosa et al. 2015).

This study focuses on six oral health conditions identified among a sample of 85 adult individuals from seven funerary sites of the island of Gran Canaria and dated between the fifteenth and eighteenth centuries (Table 1; Supporting information file). Dental remains are valuable resources applicable to osteoarchaeological research as their mineralized structure facilitates conservation over time. The prevalence and severity of caries, dental calculus, antemortem tooth loss (AMTL), periodontal disease, and dental macrowear shed light on dietary patterns, reproductive ecology, and food processing techniques of past societies (Cheung et al. 2019; Cohen and Crane-Kramer 2007; Nava et al. 2021). Dental calculus, AMTL, and periodontal disease also offer insights to examine cultural

Table 1 List of the sites yielding the osteoarcheological samples of this study, their location, chronology, and type of cemetery. A summary of the studied sample and demographic profile is included

Archaeological sites	Location	Chronology	Type of cemetery	Adults				Non-adults	Total
				Female	Male	Unknown	Total		
Iglesia de San Martín	Las Palmas de Gran Canaria	15th–18th cal AD	Churchyard	9	7	3	19	13	32
Convento de San Francisco	Las Palmas de Gran Canaria	16th–18th cal AD	Churchyard	6	18	9	33	21	54
Juan Rejón	Las Palmas de Gran Canaria	16th–17th cal AD	Single burial	0	1	0	1	0	1
Iglesia de San Juan Bautista	Telde	16th–18th cal AD	Graveyard	1	4	1	6	1	7
Iglesia de San Pedro Mártir	Telde	16th–18th cal AD	Churchyard	0	6	3	9	1	10
Hotel Agaldar	Gáldar	16th–18th cal AD	Graveyard	2	1	2	5	1	6
Finca Clavijo	Santa María de Guía	16th cal AD	Non-normative cemetery	4	5	3	12	2	14
			Total	22	42	21	85	39	124

habits such as tobacco consumption (Inskip et al. 2023; Walker and Henderson 2010). Lineal enamel hypoplasia (LEH) and dental calculus are also used to investigate the health status and physiological stress during development (Huynh et al. 2016; Towle and Irish 2020).

Firstly, this contribution reviews previous paleodemographic information based on skeletal remains by means of dental anthropology to investigate the burial dynamics of these funerary spaces. Then, the prevalence of oral conditions was analyzed to understand the general behavior of this population, and their relation to diet, food preparation, and cultural habits. Thirdly, this study assesses the hypothesis that females display a greater prevalence of caries and periodontal disease as result of sexual hormonal and/or diet-gendered differences. By investigating the oral conditions, this contribution also evaluates whether there was a relation between social status and food access as several social groups are included in this study (Table 1). The sample is relatively heterogenous as it includes, for instance, individuals from the Convent of San Francisco and the non-normalized and multi-ethnic cemetery of Finca Clavijo. Further, the role of tobacco consumption and its impact on oral health are evaluated to assess the hypothesis that this habit was widespread in the Canarian society of this period. This analysis also examines the hypothesis that the European colonization led to significant changes on the diet and food processing techniques in comparisons to the Indigenous population of Gran Canaria. Lastly, the findings were expanded to other Modern Era groups from the islands of Tenerife and Lanzarote to explore the possibility of inter-island differences resulting from dissimilar island environments, subsistence strategies, and cultural traditions.

Materials and methods

Materials

This current study focused on the remains of 85 human adults from seven different archaeological sites on Gran Canaria (Table 1; Table S1; Supplementary Text 1). The samples dating to the Modern Era (fifteenth to eighteenth centuries) are from four main settlements: Las Palmas, Telde, Gáldar, and Santa María de Guía (Fig. 1). Las Palmas, founded in 1478 by the Castilians at the outset of the conquest by the Catholic Monarchs, was the island's first city. Currently, it is the island's capital and the most populated city in archipelago. Telde and Gáldar were key Indigenous settlements at the time of the European conquest and rapidly took on important roles during the Modern Era. Santa María de Guía was also founded by Castilians at the outset of the sixteenth century linked to sugar cane plantations (Quintana Andrés 2006). Telde, Gáldar, and Santa María de Guía also still exist. The human remains from these different sites were recovered during archaeological interventions in churchyards (Iglesia de San Martín, Convento de San Francisco, San Pedro Mártir), graveyards (San Juan Bautista, Hotel Agáldar), and non-normative burial grounds (Finca Clavijo and Juan Rejón) (Table 1).

The study comprises both the dental remains of individuals from primary burials and isolated finds of earlier inhumations. The analysis also incorporated the dental remains among three ossuaries unearthed at the archaeological site of Convento de San Francisco (North Ossuary, Northwest Ossuary, and Southwest Ossuary). The total sample comprises 953 adult teeth (527 in situ and 426 isolated) and 1172 sockets. The analyses of the oral conditions were only

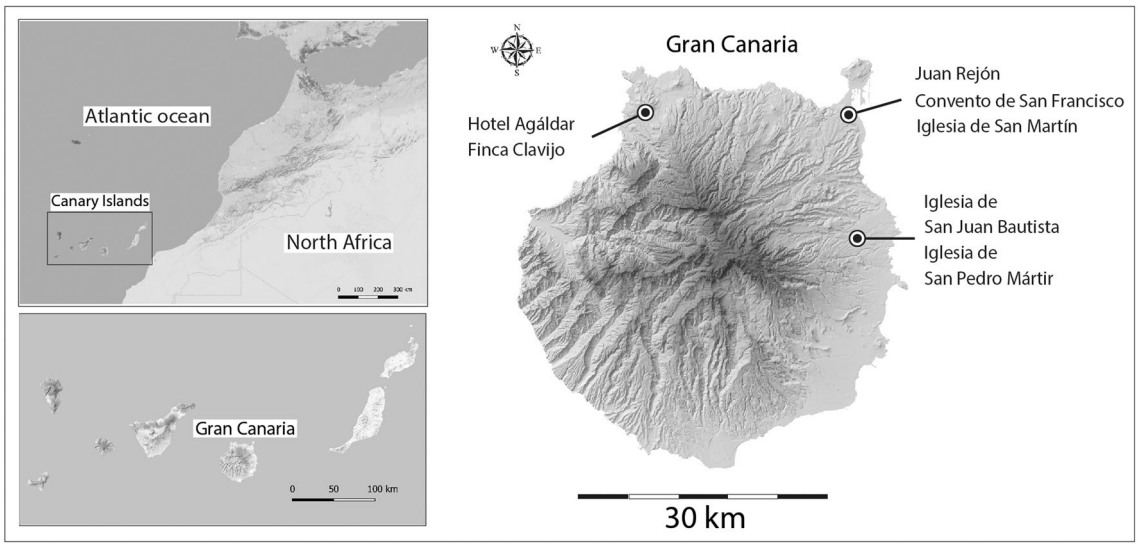

Fig. 1 Map of Gran Canaria and archaeological sites of the present study

conducted in 926 teeth (97.2%) due to the problems of preservation (Table S2).

Methods

Paleodemographic profiles

The minimum number of individuals (MNI) in this study was broken down into bone and dental representation, age, and sex (Buikstra and Ubelaker 1994; Lyman 1994). Age estimation was based on standard protocols (Buckberry and Chamberlain 2002; Buikstra and Ubelaker 1994; Schmitt 2005). Age at death in adult individuals was also estimated based on the rate and patterns of dental wear, which depend on several factors besides age, yielding a gross approximation of the real age. Observations of dental development and occlusal macrowear served to identify the adults when teeth were isolated. Estimation of sex was first based on standard protocols stemming from analyzing the crania and hip bones (Brooks and Suchey 1990; Bruzek 2002; Buikstra and Ubelaker 1994; Viciano et al. 2015). However, this study established the estimated MNI based on the dental remains and, thus, we developed a sample-specific sex estimation classification method consisting of observing 12 odontometric features. The method is based on the sectioning point method proposed by Albanese et al. (2005) where the pooled mean serves as a sectioning point. The sex of each individual was then estimated according to whether the measurement fell above or below this point (Albanese et al. 2005; Cardoso 2008). This study also applied the sectioning point method for sex estimation by resorting to five mandibular measurements. The procedure with these variables was the same as that with the dental measurements. Conflicting sex estimates were assigned following the criteria advanced by Viciano et al. (2015). This study also compared the estimated sex stemming from this method to the estimated sex of complete individuals based on the morphological attributes of their pelvis and cranium. Ultimately, the study applied a test of consistency based on the rate of success (i.e., the percentage of correctly classified males and females stemming from dental measurements relative to the results of the morphological traits) (Tables S3, S4, and S5).

Oral conditions

This study analyzes six oral conditions affecting on both in situ and isolated permanent teeth of adult individuals: caries (Hillson 2008), dental macrowear (Scott 1979), calculus (Mackie et al. 2017), periodontal disease (Dewitte and Bekvalac 2011), AMTL (Hillson 2005), and LEH (Guatelli-Steinberg 2015; Towle and Irish 2020). These features were examined macroscopically with a hand lens (×10) and artificial light. Teeth were classified as anterior (incisors and canines) and posterior (premolars and molars). Sockets were also counted according to mandible and maxillae bones to estimate the prevalence of periodontal disease and AMTL.

Caries: This oral condition was identified by the presence/absence of demineralized regions of the enamel, stretching from small opaque spots visible as browning of the enamel to complete tooth destruction (Hillson 2001).

Dental macrowear: The degree of macrowear was assessed based upon enamel loss and dentine exposure following the Scott (1979) scoring system for molars and the methods proposed by Smith (1984) for incisors, canines, and premolars. Molar values obtained according to the Scott technique were divided by four to compare

them with the values deriving from the Smith method. For the statistical analyses, the dental macrowear values were divided into three categories: light dental macrowear (values of 1–2), medium dental macrowear (3–5), and heavy dental macrowear (values > 5) (Munoz 2017; Novak 2015; Šlaus et al. 2018).

Dental calculus: This oral condition was recorded as either supragingival or subgingival according to their position relative to the gingival margin (Hillson 2008).

Periodontal disease: This affection was identified by bone loss greater than 2 mm in both the sockets of teeth in maxillae or mandibles (distance between the CEJ-AC) and by the degree of porosity and/or exposition of the trabecular bone (Dewitte and Bekvalac 2011). It was only assessed when teeth were in place at maxillae or mandibles.

AMTL: Antemortem tooth loss was considered present when there was no tooth and obvious signs of socket resorption (Nelson 2015; Trombley et al. 2019). The record of AMTL was only conducted on observable sockets.

LEH: This study records linear enamel hypoplasia as indicator of stress according to presence/absence on individual teeth (Guatelli-Steinberg 2015; Towle and Irish 2020). Each of the oral condition was examined in all the dentitions and by tooth type.

Statistical procedures

The frequency of oral conditions (except for dental macrowear, as will be explained below) was calculated by two means: 1) per tooth or per sockets: the number of teeth or sockets with these ailments was divided by the total number of teeth or sockets; and 2) per individual: by dividing the number of individuals revealing these problems by total minimum number of individuals (MNI). Additionally, a *caries correction factor* (Lukacs 1995) was applied to account for potential underestimations associated with tooth loss throughout an individual's lifespan. The factor was calculated by the formula $(a+bx)/(n+b)$ (Lukacs 1995) with a corresponding to the number of teeth with at least one caries, b the number of antemortem tooth loss, and x the result of dividing the number of teeth with caries-related pulp exposure by the number of teeth with pulp exposure caused by heavy dental macrowear. This number was then divided by the total number of original teeth obtained from the sum of the total number of teeth (n) observed in the study and the total number of antemortem tooth loss (b).

Chi-squared tests were then conducted to delve into the differences of incidence of oral conditions between the different populations (male vs. female, inter-sites, Modern Era vs. Indigenous, and inter-islands). The null hypothesis was that of equal prevalence between the groups (McDonald 2009). This hypothesis was rejected when the level of significance was equal to or less than $\alpha = 0.05$. Furthermore, Fisher's exact test was used instead of the chi-squared test when the cases were expected to be inferior to five. Moreover, this study included three *G*-tests as the observed frequencies minus expected frequencies were inferior to the expected frequencies (Klaus and Tam 2010). Additionally, the dental macrowear data of Gran Canaria's Indigenous population presented in Delgado-Darias (2004) was processed into interval groups according to Munoz (2017), Novak (2015), and Šlaus et al. (2018), a procedure intended to convert the data into categorical statistical variables allowing comparison. This study did not consider age group differences in dental macrowear as age estimation was based on this oral condition (i.e., light wear corresponds to the age group 17–25 years old). Additionally, the statistical comparisons included data from the Indigenous groups of Gran Canaria from about the fifth to the fifteenth century (Delgado-Darias et al. 2021; Delgado-Darias et al. 2005), the Modern population of Iglesia de La Concepción of Tenerife from the eighteenth century (Gámez Mendoza 2010), and the sixteenth-century population of the churchyard of Iglesia de Los Remedios in Lanzarote (this study). The data from the archaeological site of Juan Rejón was excluded from this inter-site comparison due to its low sample size ($n = 1$). Finally, the descriptive and chi-squared statistical analyses were conducted with R studio software (R Core Team 2020).

Results

Sample composition and biological profiles

The sample, based on the analysis of dental and skeletal remains, comprised a minimum of 85 adult individuals (Tables 1 and S1). Previous osteoarchaeological research suggested at least 59 individuals for studies based on cranial and postcranial remains (Table S6). The sectioning point procedure revealed a consistent sex classification ranging from 50 to 89% when compared with the values of morphological sex in the case of tooth measurements, and from 45 to 76.5% in the case of mandibular variables for the 85 adult individuals (Tables 1, S3, S4, and S5). Only the mesiodistal diameters of upper canines, upper second molars, and mandibular body breadth attained a significant level of accuracy (Tables S3, S4, and S5). Resorting to estimating sex based on these variables of the overall number of adult individuals increased the numbers to 22 females, 42 males, and 21 undetermined (Tables 1 and S6).

Oral conditions among the Modern Era population of Gran Canaria

This population is characterized by high rates of caries, dental calculus, and AMTL at both teeth and individual levels

(Table 2; Fig. 2). This group, by contrast, does not exhibit high rates of periodontal disease (Table 2). The incidence of LEH is relatively low when counting per tooth (Table 2) yet relatively high when counting per individual (Table 2). The dental macrowear reveals no cases of pulp exposure deriving from wear and the more common traces fall into the medium and light categories (Table 3).

The oral conditions are not homogeneous neither by sex, class of tooth or site (Tables 2, 3, 4, and 5). The findings reveal that females at the individual level are characterized by a higher prevalence of caries (both corrected and uncorrected), periodontal disease, AMTL, and LEH (Table 2). These differences attain a statistically significant level only in the case of caries, although the *p*-value of periodontal disease is in the limit of statistical significance (Table 2).

When considering prevalence per tooth, differences are statistically significant among dental calculus, periodontal disease, and heavy macrowear (Tables 2 and 3). Females reveal more teeth with dental calculus and anterior teeth bearing heavy macrowear. Additionally, molars suffer the highest numbers of caries (both corrected and uncorrected) but the lowest incidence of LEH (Table 4). Dental macrowear is significantly higher in anterior teeth in males, as dental calculus in every tooth class (Table 4). There are differences along sex in the prevalence of periodontal disease in posterior teeth among females. Males also exhibit a higher incidence of AMTL for all tooth types except premolars (Table 4).

The results by site suggest that Convento de San Francisco had the highest frequency of corrected caries and AMTL, albeit the lowest prevalence of periodontal disease (Tables 5 and 6). Finca Clavijo, in turn, yielded the highest rates of heavy macrowear and LEH (Tables 5 and S7). No cases of periodontal disease were observed for the sites of Iglesia de San Juan Bautista, Iglesia de San Pedro Mártir, and Hotel Agáldar (Table 5).

Oral conditions differences between the Indigenous and the Modern Era populations of Gran Canaria

The Indigenous of Gran Canaria reveals significantly higher statistical rates per tooth of all the oral conditions than that of the Modern Era (Tables 7 and S8) except for caries. Uncorrected caries prevalence is similar between the Indigenous and the Modern Era populations although the corrected results point to a higher incidence for both the overall sample and for females compared to males (Table 7; Fig. 3). By sex, the Indigenous males reveal a higher prevalence of periodontal disease and AMTL, whereas Modern Era females appear to be more affected by periodontal disease (Table 7). Individual comparisons, in turn, could not be undertaken as there were no data available for the Indigenous Period (see Delgado-Darias 2004; Delgado-Darias et al. 2005).

Table 2 Sex comparison of oral conditions per individual and per teeth of the Modern Era population of Gran Canaria included in Table 1

Oral condition	Per individual								Per teeth							
	Total		Female		Male		F vs. M		Total		Female		Male		F vs. M	
	N observed/total	%	*N* observed/total	%	*N* observed/total	%	χ^2/odds ratio	*p*-value	*N* observed/total	%	*N* observed/total	%	*N* observed/total	%	χ^2/odds ratio	*p*-value
Caries	34/63	54.0	18/19	94.7	19/34	55.9	8.73	0.00	161/925	17.4	48/247	19.4	34/258	13.2	3.62	0.56
Caries corrected	64/84	76.2	21/22	95.4	31/46	67.4	6.51	0.01	398/1162	34.2	122/321	38.0	158/382	41.3	0.81	0.36
Dental calculus	51/62	82.2	15/19	78.9	29/34	85.3	0.34	0.55	546/925	59.0	133/247	53.8	197/259	76.1	27.50	0.00
Periodontal disease	14/62	22.6	7/19	36.8	5/34	14.7	3.41	0.06	98/504	19.4	71/235	30.2	27/228	11.8	23.40	0.00
AMTL	44/84	52.4	14/22	63.6	23/44	52.3	0.76	0.38	237/1172	20.2	74/419	17.7	124/605	20.5	1.27	0.25
LEH	33/65	50.8	10/19	52.6	17/34	50.0	0.03	0.85	238/911	26.1	57/247	23.1	69/253	27.2	1.16	0.28

Abbreviations: *F* female, *M* male

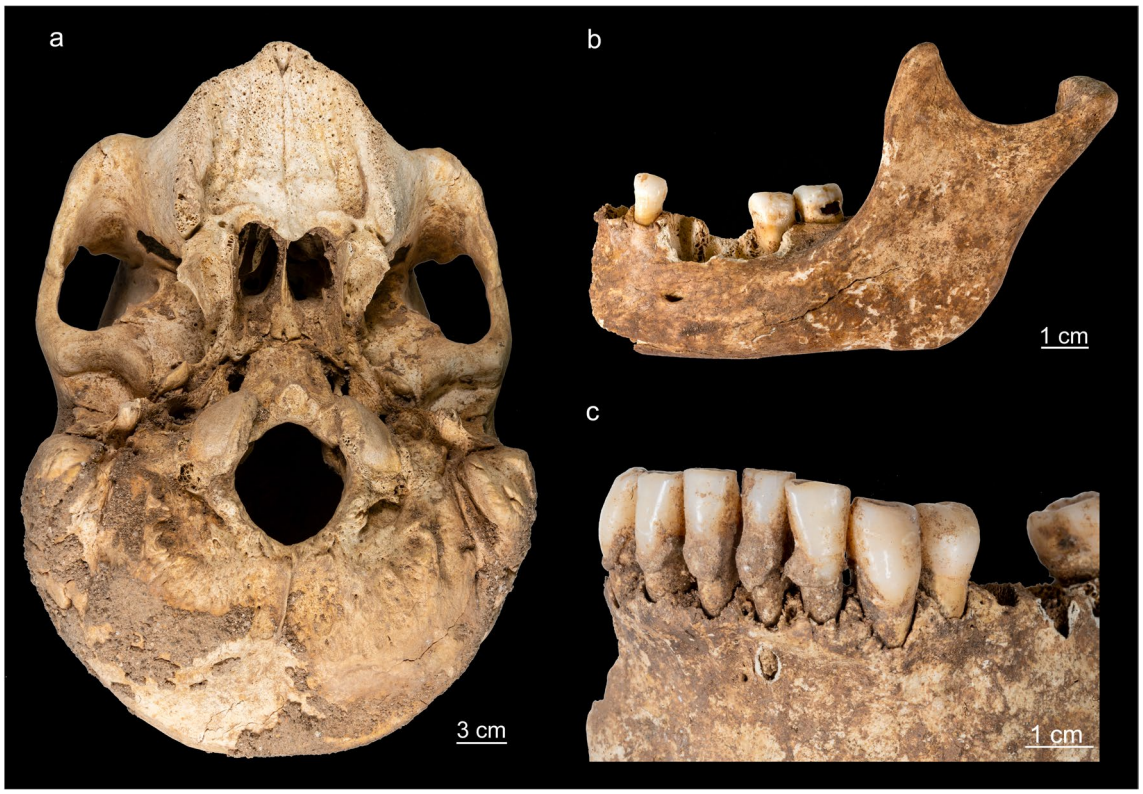

Fig. 2 Examples of oral conditions in the adult population of the Modern Era of Gran Canaria. **a** Antemortem tooth loss observed in the maxillary dentition of T11 (Convento de San Francisco); **b** Dental caries in the mandibular dentition of REG36 (Iglesia de San Martín); **c** Dental supragingival calculus and periodontal disease on the buccal surface of the mandibular dentition of REG61 (Iglesia de San Martín)

Table 3 Dental macrowear prevalence per teeth and sex comparison in the Modern Era population of Gran Canaria

Dental macrowear		Age	Modern Era		Female		Male		Female vs. male	
			N observed/total	%	*N* observed/total	%	*N* observed/total	%	χ^2/Odds ratio	*p*-value
Anterior	Light	17–25	207/361	57.3	67/92	72.8	35/92	38.0	22.52	0.00
	Medium	26–35	123/361	34.1	23/92	25.0	38/92	41.3	5.51	0.01
	Heavy	> 35	31/361	8.6	2/92	2.2	19/92	20.6	15.53	0.00
Posterior	Light	17–25	201/552	36.4	50/155	32.2	61/165	37.0	0.78	0.37
	Medium	26–35	312/552	56.5	97/155	62.6	90/165	54.5	2.12	0.14
	Heavy	> 35	39/552	7.1	8/155	5.2	14/165	8.5	1.37	0.24

Oral health differences among the Modern Era populations of the islands of Gran Canaria, Tenerife, and Lanzarote

The Gran Canaria group reveals the highest incidence of caries (uncorrected and corrected) at both individual and per tooth levels (Table 8). These differences are statistically significant only in the case of the frequency of caries calculated per tooth (Table 8). This population also yielded statistically higher macrowear rates per tooth when compared to that of Tenerife. However, no significant differences were found among the anterior dentition macrowear between the populations of Gran Canaria and Lanzarote. Yet a heavy macrowear rate was statistically higher among the posterior dentition of those from Lanzarote (Fig. 4). The prevalence of dental calculus was higher than Tenerife at both the individual and teeth level. No statistical differences were identified between Gran Canaria and Lanzarote (Table 8). AMTL incidence was significantly higher in Gran Canaria than in Lanzarote ($\chi^2 = 5.05$, $\rho = 0.02$; Table 8). No statistical differences were found among the rates of LEH per tooth between Gran Canaria, Tenerife, and Lanzarote. However, the prevalence of LEH per individual in Gran Canaria was statistically higher than that of Tenerife ($\chi^2 = 7.24$; $\rho = 0.00$) (Table 8).

Table 4 Comparison of the prevalence of oral conditions per class of tooth by sex among the population of the Modern Era of Gran Canaria

Oral condition	Incisors				Canines				Premolars				Molars			
	Total	Female	Male	F vs M	Total	Female	Male	F vs M	Total	Female	Male	F vs M	Total	Female	Male	F vs M
	N observed/ total (%)	*N* observed/ total (%)	*N* observed/ total (%)	χ^2/odds ratio (ρ-value)	*N* observed/ total (%)	*N* observed/ total (%)	*N* observed/ total (%)	χ^2/odds ratio (ρ-value)	*N* observed/ total (%)	*N* observed/ total (%)	*N* observed/ total (%)	χ^2/odds ratio (ρ-value)	*N* observed/ total (%)	*N* observed/ total (%)	*N* observed/ total (%)	χ^2/odds ratio (ρ-value)
Caries	14/214 (6.5%)	6/58 (10.3%)	0/56 (0%)	Inf.[a] (0.02)	12/146 (8.2%)	4/34 (11.8%)	2/35 (5.7%)	2.17[a] (0.42)	43/256 (16.8%)	9/66 (13.6%)	11/76 (14.5%)	0.02 (0.88)	90/304 (29.6%)	29/89 (32.6%)	20/90 (22.2%)	2.41 (0.12)
Caries corrected	59/259 (22.8%)	14/66 (21.2%)	27/83 (32.5%)	2.36 (0.12)	32/166 (19.3%)	9/39 (23.1%)	13/46 (28.3%)	0.29 (0.58)	101/314 (32.2%)	30/87 (34.5%)	41/106 (38.7%)	0.36 (0.54)	204/418 (48.8%)	69/129 (53.5%)	76/146 (52.1%)	0.05 (0.81)
Heavy dental macrowear	19/216 (8.8%)	2/58 (3.5%)	13/57 (22.8%)	9.49 (0.00)	12/145 (8.3%)	0/34 (0%)	6/35 (17.1%)	0 (0.02)[a]	12/252 (4.8%)	0/66 (0%)	5/76 (6.6%)	0 (0.06)[a]	27/300 (9.0%)	8/89 (9.0%)	9/92 (9.8%)	0.03 (0.85)
Dental calculus	141/215 (65.6%)	40/58 (69.0%)	50/57 (87.7%)	5.94 (0.01)	93/147 (63.3%)	18/34 (52.9%)	28/36 (77.8%)	4.78 (0.02)	151/256 (59.0%)	35/66 (53.0%)	55/76 (72.3%)	5.69 (0.01)	160/303 (52.8%)	40/89 (45.0%)	65/94 (69.1%)	10.95 (0.00)
Periodontal disease	18/106 (17.0%)	13/56 (23.2%)	5/47 (10.6%)	2.80 (0.09)	16/76 (21.0%)	11/34 (32.3%)	5/34 (14.7%)	2.94 (0.08)	29/142 (20.4%)	22/64 (34.3%)	7/67 (10.4%)	10.87 (0.00)	35/179 (19.5%)	25/81 (30.9%)	10/84 (11.9%)	8.86 (0.00)
AMTL	45/315 (14.2%)	8/103 (7.7%)	27/177 (15.2%)	3.33 (0.06)	20/164 (12.2%)	5/60 (8.3%)	11/89 (12.3%)	0.60 (0.43)[a]	58/318 (18.2%)	21/111 (18.9%)	30/160 (18.7%)	0.00 (0.97)	114/374 (30.5%)	40/145 (27.6%)	56/179 (31.3%)	0.52 (0.46)
LEH	80/210 (38.1%)	20/58 (34.5%)	21/53 (39.6%)	0.31 (0.57)	61/144 (42.4%)	13/34 (38.2%)	14/34 (41.2%)	0.06 (0.80)	48/254 (18.9%)	12/66 (18.2%)	15/76 (19.7%)	0.05 (0.81)	49/301 (16.3%)	12/89 (13.5%)	19/94 (20.2%)	1.47 (0.22)

Abbreviations: *F* female, *M* male

[a]Odds ratio values due to expected counts less than five (see methods)

Table 5 Oral conditions by archaeological sites of the Modern Era of Gran Canaria

Oral condition		Iglesia de San Martín	Convento de San Francisco	Iglesia de San Juan Bautista	Iglesia de San Pedro Mártir	Hotel Agáldar	Finca Clavijo
Caries	*N* observed/total	68/275	33/191	13/112	21/72	10/82	16/183
	%	24.7	17.3	11.6	29.1	12.2	8.7
Caries corrected	*N* observed/total	133/340	151/309	32/131	26/77	25/97	31/198
	%	39.1	48.9	24.4	33.8	25.8	15.6
Heavy dental macrowear	*N* observed/total	20/277	17/192	8/101	5/71	1/80	19/182
	%	7.2	8.8	7.9	7.0	1.2	10.4
Dental calculus	*N* observed/total	161/276	83/193	86/110	53/72	57/82	106/183
	%	58.3	43.0	78.2	73.6	69.5	57.9
Periodontal disease	*N* observed/total	46/177	10/75	No cases	No cases	No cases	42/165
	%	26.0	13.3	-	-	-	25.4
AMTL	*N* observed/total	65/336	118/324	19/109	5/72	15/54	15/261
	%	19.3	36.4	17.4	7.0	27.8	5.7
LEH	*N* observed/total	35/275	66/189	19/106	14/70	30/78	74/183
	%	12.7	35.0	18.0	20.0	38.5	40.4

Data from Juan Rejón were excluded from inter-site comparisons due to the low sample size ($n = 1$)

Discussion

This contribution is the first of its type to attempt to shed light on the oral conditions of Gran Canaria's population in the Modern Era. Dental remains from primary burials and isolated/disarticulated remains yielded a minimum number of 85 adult individuals. This number is significantly higher than that stemming from previous estimations based on the representation of cranial and infracranial remains (MNI = 59; Table S6). This new number is likely due to the burial dynamics of Christian churchyards and graveyards where multiple burials over time occupied the same pit due to removals or relocations that unwittingly left the teeth behind (Duday et al. 2009; Knüsel and Schotsmans 2022). Therefore, the results of this study bolster the notion that dental remains are crucial to establishing a precise demographic profile of a population as well as the "biography" of burials. The scrutiny of oral conditions is also rendered more comprehensive when not limited solely to the teeth from primary burials.

Oral conditions the Modern Era population of Gran Canaria

The global results of this study bear witness to a high prevalence of dental caries, calculus, periodontal disease and AMTL per individual and per tooth. (Table 2). Oral health research on contemporary groups throughout European case-studies listed in Table S9 also serves to contextualize and characterize the population of Gran Canaria. This pattern most likely relates to diets rich in carbohydrates with a large consumption of cereals such as barley, wheat, and maize (Akcalı and Lang 2018; Gasmi Benahmed et al. 2021; Hidaka and Oishi 2007). Sugar cane intake also explains the oral conditions of Gran Canaria's population as the island cultivated it during the Modern Era and locals consumed it raw or in the form of products such as jam and sweets (Rodríguez-Morales 2012; Viña Brito 2008).

Enhanced energy levels, stemming from substantial carbohydrate intake, could potentially influence the prevalence of linear enamel hypoplasia (LEH), given the vital importance of caloric intake for human growth and maintenance. However, this study reveals a nuanced, if not contradictory, picture when assessing LEH prevalence either on a per-tooth or per-individual basis. Tooth-specific analyses suggest intermittent developmental stress events, whereas individual-level data point to widespread stress exposure throughout the population. This contrast may arise from several factors. A methodological limitation precludes the definitive correlation of LEH between isolated teeth and their contemporaneously forming counterparts—a critical criterion for establishing the systemic nature of the observed stress. Such constraints may thereby inflate the perceived frequency of systemic stress events. Moreover, it is noteworthy that in this sample, molars—the most commonly represented type of teeth, constituting 33% of the dataset (see Table S2)—exhibit the lowest prevalence of LEH (16%, Table 4). Conversely, canines, the least frequently represented (accounting for 16% of the sample, Table S2), manifest the highest LEH prevalence (38%, Table 4). Prior research substantiates differential enamel hypoplasia predispositions between anterior and posterior teeth due to variances in their developmental trajectories (Goodman and Armelagos 1985; Hillson 1996; Hillson and Bond 1997). Thus, merging all tooth data may

Table 6 Comparisons of the chi-square and ρ-values of the different oral conditions among the Modern Era population from the different sites of Gran Canaria (excluding the site of Juan Rejón)

Site comparison	Oral condition													
	Caries		Caries corrected		Heavy dental macrowear		Dental calculus		Periodontal disease		AMTL		LEH	
	χ^2/odds ratio	ρ-value	χ^2/odds ratio	ρ-value	χ^2/odds ratio	ρ-value	χ^2/odds ratio	ρ-value	χ^2/odds ratio	ρ-value	χ^2/odds ratio	ρ-value	χ^2/odds ratio	ρ-value
ISM vs. CSF	3.68	0.05	6.25	0.01	0.53	0.46	10.69	0.00	4.88	0.02	23.99	0.00	32.39	0.00
ISM vs. SPM	0.57	0.44	0.76	0.38	0.00	0.98	5.62	0.01	8.08	0.00	0.19	0.65	2.42	0.11
ISM vs. SAJ	8.27	0.00	8.96	0.00	0.27	0.60	13.44	0.00	15.37	0.00	0.19	0.65	0.11	0.72
ISM vs. HAG	5.80	0.01	5.82	0.01	0.16[a]	0.05	3.31	0.06	2.08	0.14	2.02	0.15	27.77	0.00
ISM vs. FCA	18.74	0.00	32.50	0.00	1.46	0.22	0.01	0.93	0.01	0.91	23.40	0.00	46.52	0.00
CSF vs. SPM	4.52	0.03	5.66	0.01	0.24	0.61	19.66	0.00	3.55	0.05	23.90	0.00	5.32	0.02
CSF vs. SAJ	1.76	0.18	16.03	0.00	0.00	0.93	16.17	0.00	6.82	0.00	13.59	0.00	9.56	0.00
CSF vs. HAG	1.11	0.29	16.03	0.00	5.47	0.01	16.17	0.00	0.91	0.33	1.51	0.21	0.30	0.58
CSF vs. FCA	5.97	0.01	57.84	0.00	0.26	0.60	8.36	0.00	4.46	0.03	77.42	0.00	1.20	0.27
SPM vs. SAJ	8.97	0.00	2.10	0.14	0.15	0.69	0.50	0.47	0.00[c]	-	10.57	0.00	0.11	0.72
SPM vs. HAG	6.86	0.00	1.32	0.24	0.16[a]	0.09	0.31	0.57	0.00[c]	-	10.02	0.00	6.01	0.01
SPM vs. FCA	17.37	0.00	11.06	0.00	0.63	0.42	5.41	0.01	8.48	0.00	1.22[a]	0.77	9.32	0.00
SAJ vs. HAG	0.01	0.90	0.05	0.81	0.13[a]	0.07	1.85	0.17	0.00[c]	-	2.34	0.12	9.69	0.00
SAJ vs. FCA	0.64	0.42	3.91	0.04	0.47	0.48	12.48	0.00	14.91	0.00	12.57	0.00	15.58	0.00
HAG vs. FCA	0.76	0.38	4.33	0.03	6.65[a]	0.00	4.75	0.02	0.29	0.58	18.85[b]	0.00	0.08	0.76

The data from the site of Juan Rejón were excluded from inter-site comparisons due to low sample size ($N=1$)

Abbreviations: *CSF* Convento de San Francisco, *FCA* Finca Clavijo, *HAG* Hotel Agáldar, *ISM* Iglesia de San Martín, *SAJ,* Iglesia de San Juan Bautista, *SPM* Iglesia de San Pedro Mártir

[a]Odds ratio values due to expected counts less than five (see methods)

[b]*G*-value as the observed frequencies minus expected frequencies are superior to expected frequencies

[c]No recorded cases of Periodontal disease at Iglesia de San Pedro Mártir, Iglesia de San Juan Bautista and Hotel Agaldar

Table 7 Oral conditions in the Modern Era and Indigenous populations of Gran Canaria per teeth

Oral condition		Modern Era	Indigenous[a]	Female Modern Era	Male Modern Era	Female Indigenous[a]	Male indigenous[a]	Modern Era female vs Indigenous female[a]		Modern Era male vs Indigenous male[a]		Modern Era vs Indigenous[a]	
								χ^2/odds ratio	*p*-value	χ^2/odds ratio	*p*-value	χ^2/odds ratio	*p*-value
Caries	*N* observed/total	161/925	1164/6730	48/247	34/258	364/1796	567/3843	0.09	0.75	0.21	0.63	0.00	0.93
	%	17.4	17.3	19.4	13.2	20.3	14.7						
Caries corrected	*N* observed/total	398/1162	1741/9328	122/321	158/382	677/2526	1064/5154	14.50	0.00	79.59	0.00	73.82	0.00
	%	34.2	18.6	38.0	41.3	26.80	20.6						
Heavy dental macrowear	*N* observed/total	70/911	1094/6191	10/247	33/266	No data[b]	No data[b]	No data[b]	No data[b]	No data[b]	No data[b]	57.80	0.00
	%	7.7	17.7	4.0	12.4	-	-						
Dental calculus	*N* observed/total	546/925	4227/6730	133/247	197/259	873/1523	2249/3324	1.04	0.22	1.48	0.22	5.12	0.02
	%	59.0	62.8	53.8	76.1	57.3	67.6						
Periodontal disease	*N* observed/total	98/504	1349/6507	71/235	27/228	263/1635	708/3208	28.09	0.00	18.00	0.00	0.47	0.49
	%	19.4	20.7	30.2	11.8	16.1	22.1						
AMTL	*N* observed/total	237/1172	2598/16495	74/419	124/605	730/4644	1311/8803	1.08	0.29	13.74	0.00	16.35	0.00
	%	20.2	15.7	17.7	20.5	15.7	14.9						
LEH	*N* observed/total	238/911	2398/4765	57/247	69/253	654/1286	1357/2683	64.29	0.00	50.26	0.00	180.07	0.00
	%	26.1	50.3	23.1	27.2	50.9	50.6						

[a]Delgado-Darias 2004; Delgado-Darias et al. 2021

[b]Published data for indigenous population did not include distribution of dental macrowear by sex

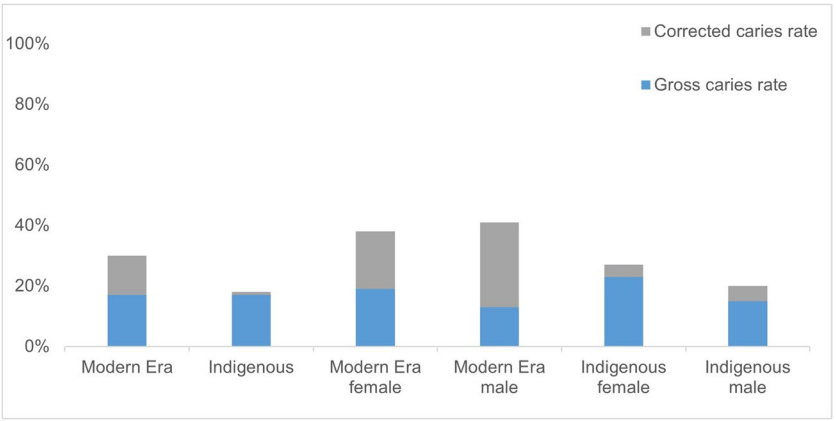

Fig. 3 Gross and corrected caries rate in Gran Canaria (Modern Era and Indigenous populations)

underrepresent systemic stress instances. However, it merits mention that even when the focus is narrowed to canines, which show the highest LEH rates in this sample, these rates remain significantly lower than those reported in populations characterized by extensive developmental stress (Guatelli-Steinberg and Lukacs 1999). In summary, the observed complexities, and apparent contradictions in the findings of this study underscore the need for a more nuanced and robust methodological framework to interpret LEH more accurately as a reliable marker of developmental stress.

Oral health differences according to sex

The findings gleaned from caries prevalence at the individual level suggest significant differences according to sex (Table 2). The ratios per tooth point to great disparities of dental calculus, periodontal disease and heavy macrowear according to sex (Tables 2 and 3). Males exhibit greater dental macrowear, calculus and AMTL, a pattern most likely resulting from age due to asymmetries in the demographic composition between sites. Elevated calculus levels in certain cases can also be linked to high protein diets (Lieverse 1999). However, its occurrence in combination with a high ratio of dental caries may point to a carbohydrate rich diet (Gasmi Benahmed et al. 2021; Hidaka and Oishi 2007).

Tobacco consumption aggravated the oral health of the populations in the past (Inskip et al. 2023; Walker and Henderson 2010). Clinical literature also indicates it provoked periodontal lesions (Chaffee et al. 2021; Ramseier et al. 2017; Yaragani et al. 2020) and tooth loss (Chaffee et al. 2021; Dietrich et al. 2007; Morse et al. 2014). The consumption of tobacco among Gran Canaria's population became an extremely popular habit in all the social spheres of the Canarian society after its introduction during the sixteenth century (Arnay-de-la-Rosa et al. 2015). This habit may explain the highest prevalence of calculus, periodontal disease and AMTL in males (Kinane et al. 2017; Murakami et al. 2018). Early written narratives (Morales Padrón 2011; Solbes Ferri 2003), as well as archaeological evidence (Arnay-de-la-Rosa 2009; Sainz Sagasti and González Marrero 2011), corroborate tobacco's key role at this time in the Canary Islands (Arnay-de-la-Rosa et al. 2015). However, historic records do not illustrate sexual differences in relation to the consumption of tobacco, so this interpretation should be met with caution.

The differences of dental wear and loss, given the chronic nature of each of these conditions, could potentially stem from the fact that the number of samples of males > 40 years old is greater than that of females (Hillson 2001; Keenleyside 2008). Dental wear is an oral condition of dual nature, that is, biological and cultural (Griffin 2014). This increases progressively during the aging process as the oral cavity is exposed to a longer interaction with food (Griffin 2014; Lee et al. 2012). It is noteworthy that the differences between males and females manifest themselves especially in the anterior teeth, those more ubiquitous on dentitions of mature adults as molars are more affected by AMTL. This suggests that dental macrowear differences may be influenced by the average age-at-death of males and females of this sample (Gámez Mendoza 2010). However, this condition also increases when the diet consists of harder or fibrous foods that require greater effort to chew (Belcastro et al. 2007; Šlaus et al. 2011). So, the higher prevalence among males may also be linked to a more abrasive diet stemming from differences in food processing, consistency, and consumption as result of gendered dietary patterns. Given the possible relationship between dental calculus and male tobacco consumption, it is likely that the greater severity of wear among the anterior teeth relates to smoking with kaolin pipes, artifacts unearthed at certain archaeological sites from this sample such as Iglesia de San Martín and Convento de San Francisco. These clay pipes may have intensified dental wear due to their abrasive material (Silvester 2021). Nevertheless, within the human remains analyzed, there were no discernible indications, such as wear facets or perforations, suggestive of smoking pipe usage.

Table 8 Oral conditions in the Modern Era populations of Gran Canaria, Tenerife, and Lanzarote

Oral condition		Per individual			GC vs. TF[a]	GC vs. LZ[b]	Per teeth			GC vs. TF[a]	GC vs. LZ[b]
		Gran Canaria	Tenerife[a]	Lanzarote[b]	χ^2/odds ratio (*p*-value)	χ^2/odds ratio (*p*-value)	Gran Canaria	Tenerife[a]	Lanzarote[b]	χ^2/odds ratio (*p*-value)	χ^2/odds ratio (*p*-value)
Caries	*N* observed/total	34/63	31/62	3/9	0.19 (0.65)	2.31[d] (0.44)	161/925	228/3322	3/97	96.64 (0.00)	13.35 (0.00)
	%	54.0	50.0	33.3			17.4	6.9	3.1		
Caries corrected	*N* observed/total	64/84	No data	6/9	n/a (n/a)	0.39 (0.52)	398/1162	No data	26/120	n/a (n/a)	7.78 (0.00)
	%	76.2	-	66.6			34.2	-	21.7		
Heavy dental macrowear[c]	*N* observed/total	No data[c]	No data[c]	No data[c] -	n/a (n/a)	n/a(n/a)	70/911	73/3189	19/98	61.26 (0.00)	14.17[e] (0.00)
	%	-	-	-			7.7	2.3	19.4		
Dental calculus	*N* observed/total	51/62	39/62	7/9	5.83 (0.01)	0.10 (0.74)	546/925	1630/3325	50/74	28.64 (0.00)	2.10 (0.14)
	%	82.2	62.9	77.8			59.0	49.0	67.6		
Periodontal disease	*N* observed/total	14/62	No data	3/9	n/a (n/a)	0.58[d] (0.43)	98/504	No data	7/74	n/a (n/a)	4.32 (0.03)
	%	22.6	-	33.3			19.4	-	9.4		
AMTL	*N* observed/total	44/84	No data	3/9	n/a (n/a)	2.18[d] (0.31)	237/1172	No data	23/176	n/a (n/a)	5.05 (0.02)
	%	52.4	-	33.3			20.2	-	13.1		
LEH	*N* observed/total	33/65	17/62	4/9	7.24 (0.00)	1.28[d] (1.00)	238/911	785/3323	23/73	2.44 (0.11)	1.00 (0.31)
	%	50.8	27.4	44.4			26.1	23.6	31.5		

Published data of Tenerife Island does not include correction factor for caries, dental macrowear by individual, periodontal disease, and AMTL results

Abbreviations: *GC* Gran Canaria, *LZ* Lanzarote, *TF* Tenerife

[a]Gámez Mendoza (2010)

[b]This study

[c]Heavy macrowear analysis was restricted to teeth

[d]Odds ratio values due to expected counts less than five (see methods)

[e]*G*-value as the observed frequencies minus expected frequencies are superior to expected frequencies (see methods)

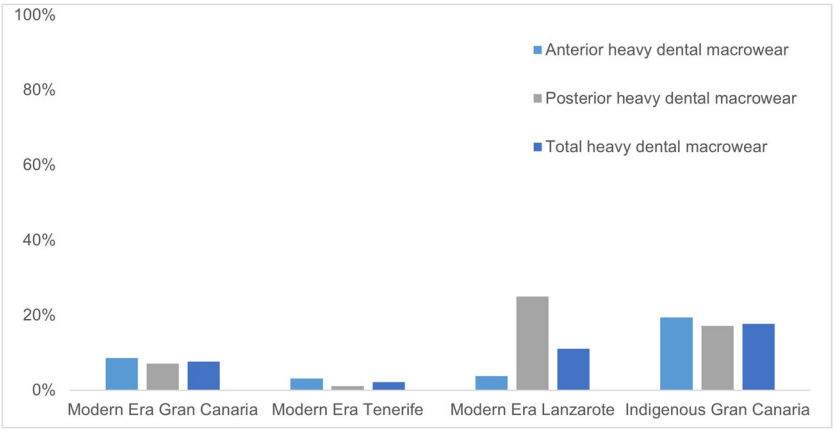

Fig. 4 Heavy dental macrowear prevalence in the populations of Gran Canaria (Modern Era and Indigenous), Tenerife, and Lanzarote

The findings for females reveal a relatively high prevalence of dental caries and periodontal diseases although only the caries shows statistical differences. This could be interpreted as a consequence of a more cariogenic diet among females, although males do also display higher ratios when applying the correction factor. This has led several authors to interpret the higher rates of caries among females to a greater access to cariogenic foodstuffs due to their role in food preparation (Larsen et al. 1991; Novak 2015). If this were the case, the female diet would have had a richer carbohydrate content than that of males. But other factors such as development and physiology can play important roles in the degree of frequency of caries according to sex. The first of these is affected by the eruption of the posterior teeth which occurs earlier in females than males (Demirjian and Levesque 1980). This suggests that females were subjected to a greater exposure to cariogenic elements and therefore were more prone to caries (Larsen 1998). This issue can be addressed by considering the differences of sex in the incidence of caries of later forming teeth (such as premolars and the second and third molar) than the incisors and canines. The results in fact suggest that there are no statistically significant differences between sexes for any type of tooth (Table 4). The sole exception is that of uncorrected caries affecting incisors as the eruption of these teeth takes place during childhood for both males and females (Table 4). Thus, differences according to sex cannot be directly attributed to these differences of timing.

Regarding the effect of physiology on the incidence of caries according to sex, certain authors propose that estrogen level fluctuations in saliva associated with female reproductive patterns can explain the higher ratios among females (Lukacs and Largaespada 2006). Estrogen levels in both males and females increase from birth to puberty. The levels among males after puberty remain stable. In turn, the estrogen levels among women fluctuate according to their menstrual cycle and due to pregnancy and menopause. Thus, the effect of estrogen on caries incidence according to sex, if any, will be cumulative and increment from puberty to menopause and depend on fertility. It is nevertheless possible to explore this possibility from the standpoint of other evidence. Apart from caries, peaks in estrogen levels during pregnancy also have adverse effects on periodontal health (Lukacs and Largaespada 2006; Watson and Tuggle 2019). Although high levels of estrogen during pregnancy do not directly provoke periodontal conditions, they can exacerbate existing cases (Watson and Tuggle 2019). Interestingly, the findings of this study show differences according to sex at the level of the individual are not statistically significant (although bearing low *p*-values), while those associated with individual teeth are. Thus, it would be likely that a higher number of cases among females could stem from high levels of estrogen during pregnancy. If these higher levels instigated periodontal disease, they could also influenced caries frequency. This hypothesis, however, could not be tested here as the data does not allow comparing caries prevalence between sexes for specific age groups and the assemblage offers no data on birth rates.

Inter-site comparison of the Modern Era populations of Gran Canaria

The results indicate higher caries rates among the populations of the city of Las Palmas (Table 5) that potentially reflect greater access to cariogenic foods such as sugar cane and its derivatives. In fact, the city and its port were the hub of the international sugar cane export. Las Palmas was also the residence of the higher social class who could afford these sugar products (Lobo Cabrera 2015; Quintana Andrés 2016). This interpretation is provisional and bespoke for this dataset, which is biased by sample size (Table 1), sex distribution and social status, so that any further application would need to be treated cautiously. The assemblage of Iglesia de San Martín is, indeed, dominated by females, while males are predominant at Iglesia de San Pedro Mártir and Iglesia de San Juan Bautista (Table 1). As already

mentioned, the results point to differences between the sexes that could explain why certain sites present internal differences. Dental calculus rates are higher, for example, among the groups dominated by males (Table 5). This group is also marked by a lower incidence of periodontal disease (Table 5).

Social status also appears to have played a role in frequency of oral conditions. The group from the site of the Convento de San Francisco consisted of mainly male members of a monastic community (Cuenca Sanabria et al. 1995). Finca Clavijo, in turn, was a multi-ethnic cemetery containing burials of marginal individuals of African origin, probably slaves during the sixteenth century (Santana et al. 2016). The high prevalence of AMTL among the monastic members of the Convento de San Francisco group could be due death at greater ages than other populations of this study. Moreover, historical records note a limited access by the slaves of Gran Canaria to certain costlier food products such as meat and sugar derivatives. This population did nonetheless consume great amounts of fish, at the time much more affordable (Quintana Andrés 2003a). The pattern of Finca Clavijo suggests they consumed more abrasive, yet less cariogenic and refined, foodstuffs (Table 5). This combination is likewise interpreted for other archaeological populations (Esclassan et al. 2009; Kaidonis 2008; Novak 2015). The Finca Clavijo social group also presented the highest prevalence of LEH (Table 5) suggesting greater physiological stress during growth certainly stemming from worse living conditions. High levels of LEH have also, in fact, been observed among other slave populations of this timeframe (Wasterlain et al. 2020).

Oral health differences between the populations of the Indigenous Period and the Modern Era in Gran Canaria

This study also reveals significant differences between Gran Canaria's Indigenous and Modern Era populations. The oral conditions of the Indigenous are interpreted as stemming from agriculture-based strategies of subsistence marked by local adaptations depending on environmental diversity (inland vs coast). These are likewise linked to social status, manifested either through burial under *tumuli* or in caves (Delgado-Darias 2004; Delgado-Darias et al. 2005). The findings of this study show a slightly higher prevalence of dental caries, calculus and AMTL among the Gran Canarians of the Modern Era. When a correction factor for caries was applied to account for potential underestimations, a higher prevalence was observed in the population of the Modern Era. This increase is likely related to the introduction of new crops such as sugar cane and tobacco (Anderson et al. 2009; Gasmi Benahmed et al. 2021) (Table 7). Although it is not possible to rule out other factors among different populations such as lack of oral hygiene, low consumption of marine foodstuffs rich in fluoride and differences in dental morphology (Paiva et al. 2018; Sánchez-Pérez et al. 2019; Shuler 2001; Wang et al. 2012).

Dental macrowear manifests a significant decrease from one period to the other as European food processing techniques generated more refined foodstuffs (Table 7 and Fig. 4). This change can be linked to the introduction of milling mechanisms powered by water, animal or wind (Cullén del Castillo 1947; Morales Padrón 1974; Quintana Andrés 1998) that substituted the traditional hand-driven rotary quern (Gámez Mendoza 2010; Naranjo-Mayor et al. 2016; Rodríguez-Rodríguez et al. 2007). Innovations in milling led to a decrease in the number and caliber of stone particles in the flour and meal, decreasing their abrasiveness. This change also potentially contributed to an increase in the risk of caries among the Modern Era population by prolonging the preservation of dental enamel. The results also suggest a relationship, as observed among other populations (Maat and Van der Velde 1987), between the incidence of caries and lower dental macrowear.

The findings also show a decrease of LEH among the population of the Modern Era. An explanation is an improved diet, a more secure food supply and an increase in the variability of food resources after the European colonization (Perrin et al. 2022). This colonization led to establishing commercial networks at both inter-island and transatlantic scales ensuring the supply of food (Santana Pérez 2004). This reality contrasts with that of the Indigenous period devoid of navigation systems and contacts with the outside leading to an autarkic form of subsistence devoid of the possibility of importing supplies from other islands or the mainland (Navarro Mederos 1997; Santana et al. 2019; Sánchez-Cañadillas et al. 2023).

Inter-island oral conditions during the Modern Era of three islands of the Canarian archipelago

This study also bears evidence as to differences between the Modern Era populations of Gran Canaria, Tenerife, and Lanzarote. The Gran Canaria group reveals a higher prevalence of dental caries indicative of a diet rich in cariogenic products such as sugar cane. These results corroborate prior hypotheses as sugar cane plantations are absent on Lanzarote and scarce on Tenerife (Viña Brito et al. 2008). Moreover, a higher incidence of heavy dental macrowear for Lanzarote also suggests that not all the island populations of the Modern Era benefitted from identical food processing techniques (Table 8). This idea is also not surprising as only Gran Canaria and Tenerife saw the development of significant urban settlements with access to more complex infrastructures. The situation of Lanzarote in the Modern Era could also be due to the continuity of indigenous milling

techniques due to their lesser infrastructure development. Furthermore, the absence of water courses on Lanzarote impeded the installation of watermills to grind grains. Another noteworthy aspect is that the population of Lanzarote has origins in an older sixteenth century framework. The teeth of Tenerife's population, in contrast, reveal less severe wear, characteristics restricted to a population stemming from a more recent timeframe (eighteenth century). Hence the differences between each of these populations could also reflect changes over time in the means of grinding, notably using more developed infrastructures in Tenerife evidenced by watermills as opposed to more domestic forms of processing cereals in Lanzarote by less sophisticated hand-driven querns.

Conclusions

This study presents a first approach to the oral conditions of the Modern Era population of Gran Canaria. The results indicate high prevalence of dental caries, dental calculus, periodontal disease and AMTL. This pattern is likely related to a diet rich in carbohydrates with a significant role of cereal consumption (barley, wheat, and maize). Sugar cane intake may also explain the dental health of this population as Gran Canaria produced this crop during the Modern Era and local population consumed it as raw or derived products such as jam or sweets. Males exhibit highest prevalence of dental macrowear, calculus and AMTL but, this pattern is result of a strong effect of age due to asymmetries in the demographic composition between sites. However, this pattern may also be influenced by the male consumption of tobacco as recorded in the historical records. Results in females reveal relatively high prevalence of dental caries and periodontal disease, but only the former display statistical differences. This result may be interpreted as consequence of a more cariogenic diet in females, although males display a highest prevalence when a correction factor is applied in caries prevalence. Therefore, the findings are supportive of the notion of a comparatively egalitarian access to plant and animal-based foods. On the contrary, the differences observed in the prevalence of caries between both sexes could be attributed to the pernicious effect that estrogen activity has on female oral health.

The results also show differences between the Indigenous and the Modern Era populations of Gran Canaria. These differences were expected as the European colonization of the island entailed new products and new food processing techniques. Dental caries, calculus and AMTL exhibit a higher prevalence in the Modern Era population. This finding likely reveals the impact of the new products on the dental health such as sugar cane and tobacco. Dental macrowear displays a significant decrease between both periods as European food processing techniques generated more refined foodstuff. The results also suggest a relation between dental caries prevalence and a lower dental macrowear. Moreover, the decrease of LEH in the Modern Era population suggests that the introduction of new plants and animals, as well as the development of new commercial networks, contributed to reducing episodes of non-specific stress.

This study also suggests differences between the three Modern Era populations of the Canary Islands. The population of Gran Canaria shows a higher prevalence of dental caries that likely indicates a diet richer in cariogenic products such as sugar cane. These results corroborate our expectations as sugar cane plantations were absent in Lanzarote and underdeveloped in Tenerife. Moreover, a higher prevalence of heavy dental wear in Lanzarote also suggests that not all the island populations benefited from the same food processing techniques during the Modern Era. This is also expected as only Gran Canaria and Tenerife developed significant urban settlements with access to more complex infrastructures. Future work should also consider oral conditions of rural populations as well as historic and isotopic information relating to diet and food preparation to investigate if differences between islands are influenced by the specific paleodietary patterns of urban settlements such as Las Palmas de Gran Canaria.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12520-023-01893-3.

Acknowledgements The authors wish to thank María del Carmen Cruz Mercadal for her collaboration throughout the project as well as Aitor Brito and Jared Jiménez for their assistance. The authors also acknowledge Arqueocanaria, Tibicena, and El Museo Canario for facilitating access to fieldwork reports.

Author contributions Conceptualization: all authors; material selection: A.M. and J.S.; analyses and data collection: all authors; writing: all authors; all authors read and reviewed the submitted manuscript.

Funding Open Access funding provided thanks to the CRUE-CSIC agreement with Springer Nature. This research was supported by the RTI2018-101923-J-I00, PID2020-117496 GB-I00, and RYC2019-028346 projects (Ministerio de Ciencia e Innovación, Spain) and the ERC Starting Grant project IsoCAN (grant 851733, European Commission).

Data availability The article includes all relevant new data.

Declarations

Consent for publication All the authors agree to the publication of this article.

Competing interests The authors declare no competing interests.

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