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ORIGINAL ARTICLE

Prevalence of oral pathologic findings in an ancient pre-Columbian archeologic site in the Atacama Desert

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OBJECTIVE: To determine the prevalence of oral pathologic findings in an ancient culture that inhabited the Atacama Desert.

MATERIALS AND METHODS: A systematic examination was performed on the remains of 83 individuals unearthed from a prehistoric burial ground. A total of 57 skeletal remains achieved appropriate inclusion criteria, from which estimated age at death, gender, ante- and postmortem tooth loss, prevalence and location of caries, apical periodontitis sequela, alveolar bone resorption and attrition were recorded.

RESULTS: From the analyzed skeletal remains (13 male, 22 female and 22 not identifiable), the mean age estimated was 29.9 ± 13.8 years. A total of 89.4% of them presented permanent dentition with a mean ante-mortem tooth loss of 9.0 teeth and a postmortem mean tooth loss of 14.4 teeth per subject. In all, 46.4% of the postmortem remaining permanent teeth (*n* = 237) showed caries lesions. Interproximal caries was most frequently observed (31.5%), followed by occlusal (25.9%) and cervical caries (19.4%). Root remnants were found in 23.1% of the cases. In addition, 58.0% of the adults presented attrition, 26.0% signs of apical periodontitis and 44.0% loss of alveolar bone support >5 mm.

CONCLUSION: The remains of jaws and teeth of the individuals examined in this study presented sequelae of severe oral health damage due to caries and periodontal disease.

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Keywords: Pica-Tarapacá culture; maize; ante- and postmortem tooth loss; caries prevalence; apical periodontitis; alveolar bone resorption; attrition

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Introduction

Diseases are better understood when examined in the context of history. The evaluation of ancient human remains, an area of increasing medical interest, offers insights not only in regional reconstruction of ancient lifestyles and subsistence patterns, but also into the management of public health issues and disease epidemiology (Metcalfe, 2007). Anthropologists use paleopathology as one of their main tools for understanding the lives of ancient people. Oral paleopathologic studies based on the observation of oral findings allow general health conditions and diet habits among individuals and among communities to be explained. Additionally, these observations allow the effect of these diseases at that time to be seen without modern preventive, restorative or surgical interventions. Analysis of dental remains can provide relevant information about lifestyles and eating habits of individuals. Dental caries, alveolar bone resorption, dental abscess sequela, ante-mortem tooth loss and attrition can provide evidence of food preparation techniques and/or the type of food consumed. Attrition, for instance, is often related to a grit-contaminated diet, in which sand is involuntarily introduced into the food. On the other hand, the implications of a diet rich in fermentable carbohydrates, like a maize-rich diet common in ancient Amerindians, are reflected in epidemiologic studies by resulting high caries and prevalence of periodontal disease, both of which are the main justification for ante-mortem tooth loss in these communities. Several studies (Larsen, 1983, 1995; Larsen *et al*, 1991; Tayles *et al*, 2000; Metcalfe, 2007) show a positive correlation between the rates of dental caries and the adoption of agriculture by Amerindians. In case of maize-based economies, an increase in caries prevalence is observed. This assessment is based on the assumption that the moment a culture solely depends on one food source having cariogenic potential, like in this case maize, a significant increase in caries prevalence can be observed. Furthermore, absence of caries preventive measures and caries influencing factors also play a decisive role in this multifactorial process. This hypothesis has already been described in early works (Leigh, 1925; Steggerda and Hill, 1936; Gersohn, 1947; Clement, 1958; Turner, 1978) documenting dental anthropologic evidence from ancient cultures practicing intensive agriculture. In fact, these observations documented that caries presence, as a general rule, is much more frequent and severe in completely agricultural dependent prehistoric cultures than in mixed or non-agricultural cultures. Proportionally, the prevalence of caries in communities practicing hunting-, gathering and collecting is lower as in agricultural communities in which the amount of consumed carbohydrates is higher (Klatsky and Klatell, 1943; Mayhall, 1970).

Few studies have been carried out to analyze oral health in ancient South American cultures. One place that offers the opportunity to study prehistoric conditions is the Atacama Desert and its ancient inhabiting cultures in Chile. This desert is a virtually rainless land in South America, extending over 181.300 km^2 (Wright, 2007) in the north of Chile. The region has been a desert for about 20 million years (Dunai *et al*, 2005; Clarke, 2006), and the soil is composed mainly of salt basins, sand and lava flows. The Atacama Desert is the driest desert on earth and it is virtually a sterile place. The average rainfall in the Tarapacá is about just 1 mm per year, and some weather stations in the Atacama have never registered any rain (Wright, 2007). It is so arid that the presence of Mars-like soils has been recently reported by an international team of researchers in a work (Navarro-González *et al*, 2003) titled: 'Mars-like soils in the Atacama Desert, Chile, and the dry limit of microbial life'. In that paper, the results of tests to detect signs of life used by the Viking 1 and Viking 2 – spacecrafts sent to Mars as part of NASA's Viking program – were described. They found almost no microorganisms and only low levels of organic material (Navarro-González *et al*, 2003). This natural climate-controlled environment that prevents degradation has certainly played a decisive role in preserving valuable, only partially known, cultural and scientific patrimony. For instance, the environmental conditions of the Atacama have allowed the oldest known examples of both, artificially mummified human remains (about 5000 BC; dating to thousands of years before the Egyptian mummies) and naturally mummified human remains (about 7000 BC) to be discovered (Aufderheide *et al*, 1993).

In pre-Columbian times (before 1492), long before the Inca Empire (1438), the interior Andean area of the Atacama Desert was inhabited mainly by the Atacameño Native American tribe. These ancient inhabitants were nomadic hunters who presumably followed herds of wild South American camelids. Later on, the still existing vast herds of camelids and the development of primitive agricultural methods probably contributed to the evolution of a semi-sedentary lifestyle with seasonal movements. The Atacama aborigines fully adopted a sedentary lifestyle around 2000–1000 BC, with the development of an economy mainly based on camelids breeding and a maize-reliant agriculture in the oases (UNESCO, 1998). Approximately between 400 BC and 100 AD, knowledge of maize farming activities was at the peak of its development.

Research carried out by the University of Antofagasta in the 1950s resulted in the discovery of more than 22 archeologic sites corresponding to the denominated Pica-Tarapacá cultural complex that inhabited an oasis situated in the inland of the Atacama Desert approximately 1000 years (Núñez, 1966; Augustyniak, 2004; Briones *et al*, 2005) ago. This oasis, named *San Andrés de Pica,* is located in the Tamarugal Province of the Tarapacá Region in the north of Chile, at approx. 1000 m AMSL (Figure 1). Several formerly inhabited areas and also burial grounds were found. Later, excavations of the sites were continued by professionals of the Archaeological Museum of the University of Chile (Gordon, 1964; Zlatar, 1984). The Pica-Tarapacá culture performed intensive agriculture and achieved a previously unseen level of harvest efficiency, especially with maize (Uribe, 2006).

On the basis of these elements, the general aim of this study was to determine the prevalence of oral pathologic findings in skeletal remains of the Pica-Tarapacá cultural complex.

Materials and methods

A systematic examination was carried out on 83 human remains coming from a Late Intermediate (1000 AD) cemetery site (Pica 8, Figure 2), corresponding to the Pica-Tarapacá Culture. A total of 57 skeletal remains were eligible for inclusion by fulfilling the appropriate criteria. The latter were skeletons with complete head and gnathic remains, from which the estimated age at death, gender, ante- and postmortem tooth loss, prevalence and location of caries (WHO, 1997), alveolar bone loss, apical periodontitis sequela and attrition (level into dentine) were recorded. Additionally, dentine caries and dental calculus deposits on the teeth were

Figure 1 Partial view of the Pica-Tarapacá oasis in the Atacama Desert

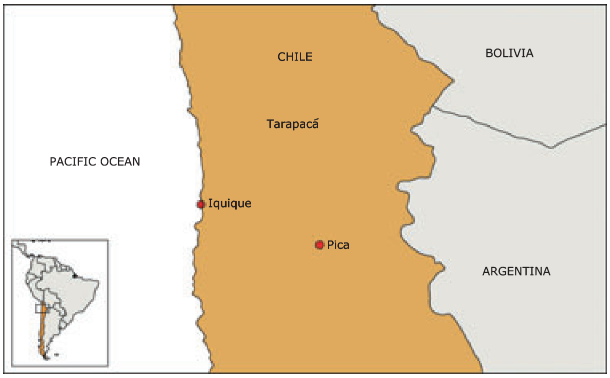

Figure 2 Pica-Tarapacá (approx. latitude: 20°28′S, 69°22′W), in the Atacama Desert

randomly collected and examined by scanning electron microscopy (Carl Zeiss DMS 940, Oberkochen, Germany) to identify morphologic types of bacteria.

For age-at-death determination, the pubic symphysis of the pubic bone, the auricular surface of the ilium, the vertebral ring epiphyseal fusion, the degree of cranial suture synostosis, ossification patterns, the length of the long bones and the eruption state of the teeth were used. For sex determination, the shape of the pubic bone of the pelvis as well as morphologic characteristics of the sacrum, long bone and skull were analyzed.

Statistically, teeth that had been lost postmortem were assumed to be healthy to show an optimistic picture of caries prevalence. Ante-mortem tooth loss was identified by the absence of the tooth and signs of alveolar resorption. It was assumed that the bone alveolus would have healed if the tooth was lost before death. On the other hand, if the alveolus was not healed, it was assumed that the tooth was lost after the individual died.

A gold standard index to categorize degrees of alveolar bone resorption in skeletal remains has not been internationally established. Some decades ago, well-substantiated research findings established that the normal epithelial attachment occurs at the cemento-enamel junction and that in a healthy periodontium the distance between the cemento-enamel junction and the crest of the alveolar bone is constant at 1.0–1.5 mm (Ritchie and Orban, 1953; Garguilo *et al*, 1961; Lavigne and Molto, 1995). As a consequence, marginal bone level around the teeth was recorded by measuring the vertical distance between the cemento-enamel junction and the highest level of the alveolar bone crest with a periodontal probe (North Carolina; Hu-Friedy®, Chicago, IL, USA) at six sites per tooth. A mean value, expressed in millimeters, was then calculated for each tooth. A resultant value of 5 mm or more was interpreted as severe periodontitis following the new recommendations of the international classification system for periodontal diseases organized by the American Academy of Periodontology (Armitage, 1999, 2004; Wiebe and Putnins, 2000).

All analyses were carried out at the physical anthropology laboratory of the Anthropology Department of the University of Chile by three experienced specialized professionals, one dentist and two anthropologists.

Table 1 Subjects distribution according to gender and estimated mean age at death in the permanent dentition

Gender	n	*Mean age (years)* ± *s.d.*
Female	20	33.2 ± 6.2
Male	12	28.0 ± 8.3
Unidentifiable	19	31.1 ± 4.3
Total	51	30.7 ± 6.0

The material examined in this study was excavated during the 1950s by an archeologic mission under the direction of the Archaeological Museum of the University of Chile.

Results

From the skeletal remains of 83 individuals studied (mean estimated age: 29.9 ± 13.8 years), 57 complied with the inclusion criteria. Of these, 22 were identified as males, 13 as females and 22 were not identifiable (Table 1). Of the 57 individuals, 51 (89.4%, mean estimated age: 30.7 ± 6.0 years) presented permanent dentition, five (8.7%, mean estimated age: 3.8 ± 1.3 years) deciduous and only one (1.7%, estimated age 6.5 years) subject mixed dentition (Table 2). Clinical caries lesions, according to WHO criteria, were observed in 46.4% (n = 110) of the remaining permanent teeth (n = 237), with a mean ante-mortem tooth loss of nine teeth and a mean postmortem tooth loss of 14.4 teeth per subject (considering 28 teeth as a complete denture). Of the analyzed permanent teeth, 31.5% presented proximal, 25.9% occlusal and 19.4% cervical caries. Root remnants were found in 23.1% of the cases. The caries experienced by the remains studied presented an average DMT (F = 0) prevalence of 8.3 in the subjects with permanent dentition. Additionally, 58% of the subjects with permanent dentition presented attrition, 26% osseous signs of apical periodontitis and 44% alveolar bone loss > 5 mm (mean value of six measurements per tooth).

Of the remaining teeth analyzed (n = 7) on the subject (estimated age 6.5 years) with mixed dentition, only one deciduous tooth presented caries. No other oral pathologic findings were found.

A total of 36 remaining teeth was found in the five subjects (mean estimated age: 3.8 ± 1.3 years) presenting deciduous dentition. Three children showed one carious tooth each, 8.3% of the deciduous dental remains, and two individuals were caries-free. No signs of attrition, sequela of apical periodontitis and/or loss

Table 2 Distribution of the individuals according to dentition type

Dentition type	n *(%)*	*Mean age (years)* ± *s.d.*
Deciduous	5 (8.8)	3.8 ± 1.3
Mixed	1 (1.7)	6.5
Permanent	51 (89.5)	30.7 ± 6.0
Total	57 (100)	29.9 ± 13.8

of alveolar bone support were noted in the analyzed specimens with deciduous dentition.

The scanning electron microscope (SEM) analysis revealed extensively mineralized cocci and bacilli-like bacterial cells in both, dentine caries and calculus samples. Fungal spores, yeasts and mycelium-like structures were also found.

Discussion

The good state of the specimens studied was essential for observing oral diseases. This was certainly possible due to their preservation in the dry, salty environment of the Tarapacá region in the Atacama Desert in Chile. This unique region on earth with its special environment has surely contributed to the well preserved state of the skeletal remains analyzed in this study.

The described findings in individuals with deciduous and mixed dentition were not included for discussion, as the sample size of the analyzed individuals was too small to be statistically significant. The maxillary and mandibular remains of the individuals with permanent dentition examined presented sequelae of having suffered from severe impairment of oral health. The damage observed due to caries (Figures 3 and 4) and periodontal disease (Figure 4) was high.

The relationship between dietary habits and caries has been well established (Stephan, 1966; Lingström *et al*, 2000). A diet rich in sticky carbohydrates and sucrose, such as a maize-based diet, is responsible for high caries rates (Green and Hartles, 1970). A similarly high prevalence of dental caries, as the one observed in this study, was noticed in ancient Mayas in Mexico. In a study of Cucina and Tiesler (2003), the observed high caries rate was interpreted as the result of a soft and refined diet based on maize. The Pica-Tarapacá culture is known to have been very dependent on maize. Maize was notoriously present in the excavated sites (Figure 5), being most probably the main food source harvested and consumed at that time (Uribe, 2006). Evidently, this fact could explain the high prevalence of caries and periodontal disease observed in this study. Previous studies have shown caries rate increase associated with diet changes, e.g., from a hunter-gatherer diet with meat and low carbohydrates to a diet rich in sticky carbohydrates and sucrose, like in a maize-based agricultural economy (Carr, 1954; Green and Hartles, 1970; Cucina and Tiesler, 2003). Thereby, the physical and chemical properties of maize, probably combined with its preparation methods, seem to provide a cariogenic potential in the oral environment.

Figure 3 Caries lesions in an approximately 35-year-old male specimen (Nr. 528)

Figure 4 Severe generalized alveolar bone loss and advanced proximal caries lesions in an approximately 35-year-old female (Nr. 517)

Figure 5 Maize rests deposit of an archeologic site of the Pica-Tarapacá cultural complex (Briones *et al*, 2005). Conventional radiocarbon maize age: 970 ± 50 BP (Beta-150710), Cal 990–1.180 AD (1 sigma). Photo courtesy of *L. Briones*, University of Tarapacá, Africa/Chile

As already mentioned, teeth that had been lost postmortem were statistically assumed to be healthy to show an optimistic picture (minimum DMFT), and thus avoiding overestimation of caries frequencies in the sample. Therefore, the observed presence of caries has to be considered as a caries prevalence in the best case, as in reality the occurrence of caries was probably much higher. Additionally, the high prevalence of apical periodontitis (Figure 6) found in the samples could be directly related to the caries prevalence rate, as findings of high caries rates represent a specific risk factor for apical periodontitis (Kirkevang *et al*, 2004, 2007).

The presented caries prevalence differs from the caries rate found nowadays in most industrialized countries, in which a caries decline has been observed in the past 25 years (Petersen *et al*, 2005). The improvements in self-care oral hygiene together with the use of fluorides have drastically contributed to this trend (Bratthall *et al*,1996), in spite of the fact that no changes have been performed on cariogenic food consumption. However,

Figure 6 Apical periodontitis affecting a mandibular premolar

the increasing consumption of sugar together with the advent of new lifestyles, and a probably inadequate exposure to fluorides are now increasing the caries levels in several underdeveloped countries, particularly on the African continent (Petersen *et al*, 2005). Comparing this tendency with that of the findings from this study, it can be noticed that this phenomenon has already taken place in ancient cultures, in which dietary changes were responsible for affecting not only the quality of life, but also oral health (Larsen, 2006). A change in lifestyle patterns with the development of a maize-dependent diet was presumably the main etiologic reason for the described caries rate. Similar observations were found in the Maya culture in North America, where a refined softer diet based on maize was assumed to be the cause for high caries prevalence (Gagné, 1993; Cucina and Tiesler, 2003). Historically, dental caries has shown different prevalence reports depending on time and place. For instance, populations living in Europe at that time (i.e. ±1000 AD) show overall notoriously less caries prevalence than the one found in the Pica-Tarapacá culture. A study on caries prevalence in a medieval population in Finland concluded that caries was less prevalent than in modern times (Varrela, 1991). Another study of a medieval population (1240–1440 AD) in the southwest of Scotland showed a caries prevalence of just 6.4% (Watt *et al*, 1997). Likewise, an ancient population studied in medieval (1000–1200 AD) Croatia showed a carious tooth rate of 9.5% of all analyzed teeth. In this study, nearly half of all examined permanent teeth showed caries lesions, mainly on proximal, followed by occlusal surfaces. The interesting lower prevalence on occlusal areas (in comparison to proximal areas), commonly the most caries-susceptible surface on teeth, could be explained by the high occurrence of attrition. In general, groups presenting high attrition rates often exhibit reduced caries rates on the occlusal area (Caglar *et al*, 2007). It is thought that attrition might slow down, inactivate and/or eliminate occlusal caries at its initial stage by removing tooth substance through abrasive-masticatory forces. In other words, attrition progresses more rapidly than initial caries does. Likewise, attrition may also alter fissure morphology and thus disturb caries activity. Additionally, it is suggested that the ingestion of more refined foods causes more tooth-to-tooth contact wear by means of a softer diet (Watson, 2008). Recent studies assume that changes in food processing methods as well as the unintentional ingestion of sand by individuals living in sandy desert areas directly affect occlusal dental wear (Chattah and Smith, 2006; Watson, 2008). Thus, in a sandy environment, like in the Atacama Desert, it seems reasonable to think that the introduction of refined food processing methods and the unintentional addition of sand in the prepared food led to the observed attrition prevalence of the analyzed ancient remains of the Pica-Tarapacá culture.

The SEM analysis allowed morphologic identification of conserved cocci and bacilli-like bacteria in both dentine caries (Figure 7) and calculus samples (Figure 8). External morphology and size of the bacteria observed corresponded (Kneist S, personal communication) with that of bacteria normally found in caries (Figure 9) and dental calculus nowadays (Kneist *et al*, 2008). Further investigation of the cell wall structure to determine the presence of *Streptococcus mutans*, as described in the paleomicrobiologic work of Linossier *et al* (1996), was not possible. However, in their study of ancient samples

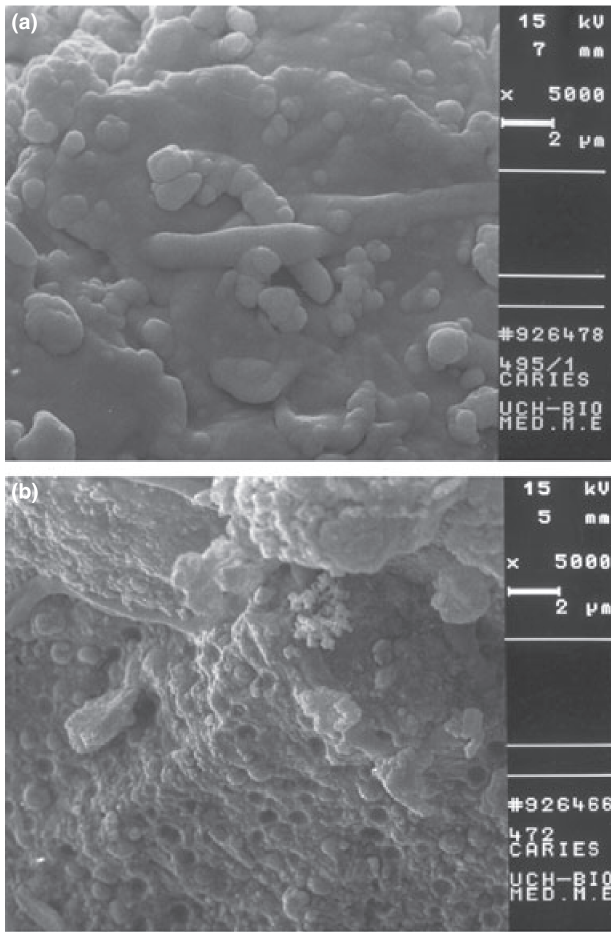

Figure 7 (**a,b**) Fossilized cocci and bacilli-like microorganisms in dentine caries (SEM magnification, 5000×)

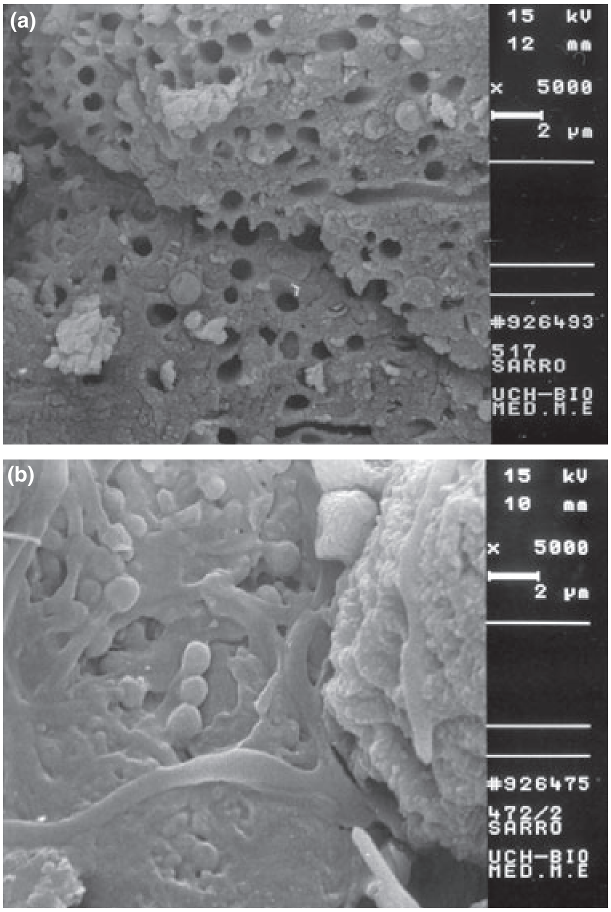

Figure 8 (**a,b**) Fossilized cocci and bacilli-like forms in dental calculus (SEM, 5000×)

Figure 9 SEM magnification (4500×) of cocci (mutans streptococci) and bacilli findings in dentine caries (Kneist *et al*, 2008). Photo courtesy of S. Kneist, Friedrich Schiller University, Jena / Germany

obtained in the Atacama Desert, similar microorganisms were found.

Similar ante-mortem tooth loss observations were shown in the Maya culture, on people having a diet mainly based on maize consumption (Cucina and Tiesler, 2003). Dento-alveolar bone loss is the result or sequela of periodontal disease. This finding is also directly related with both ante- and postmortem tooth loss. This may suggest that most probably the majority of the high number of teeth lost postmortem was induced by the observed periodontal disease and/or by incautious site excavation procedures. Results of a recent study that focused on the influence of different factors related to postmortem tooth loss suggest that the degree of alveolar bone loss significantly affects ante- and postmortem tooth loss (Durić *et al*, 2004). These findings indicate that additional care should be taken when exhuming remains from old archeologic sites.

Periodontal disease has affected man since the earliest times. Previous studies of prevalence and natural history of periodontal disease in prehistoric human remains found no evidence of a higher prevalence of periodontal disease than in modern societies. For example, the prevalence of periodontitis appears to have remained practically constant during the past 3000 years in Britain, despite the fact that considerable changes in the oral environment must have happened. Kerr (1998) concluded that the significance of these findings regarding untreated populations in underdeveloped countries is nowadays considerable. In spite of the fact that observation exposed an apparently insignificant variation of periodontitis prevalence when compared to present times, it is important to point out that the improvement of live expectancy and people's health has postponed the manifestation of advanced periodontal disease. In consequence, populations from the present time having similar mean ages than the remains analyzed in this study show a significant less amount of periodontal disease. The high values of alveolar bone loss together with the high prevalence of ante- and postmortem tooth loss suggest that the individuals examined must have suffered from severe periodontitis.

Conclusions

In summary, the maxillary and mandibular remains of jaws and teeth examined in this study revealed signs of having suffered from severe impairment of oral health due to caries and periodontal disease. Although a maize-dependant diet was interpreted to be the main explanation for the observed oral pathologic findings, a definitive assumption cannot be stated due to the complexity of caries influencing etiology. Further studies are required of this and other ancient Amerindian cultures to achieve more knowledge about the reasons and implications of each of these findings.

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SEM-images from this research. Any written, possibly remaining errors are certainly our own.

Author contributions

IU participated in the design, co-ordination and analyzed the skeletal remains with the assistance of GM. IU carried out the statistical analysis. IU and CM analyzed the results. CM wrote the manuscript. CvO and IU proofed the manuscript. CM submitted, revised and resubmitted the final version of the manuscript.

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