Anthropological Review • Vol. 89(4), 1–25 (2026)

ANTHROPOLOGICAL REVIEW

Available online at: https://doi.org/10.18778/1898-6773.89.4.01

Dental caries and antemortem tooth loss in two osteological assemblages from Yucatán, Mexico: A biosocial comparison within a structural vulnerability framework

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Abstract

Introduction
Dental caries and antemortem tooth loss (AMTL) are common clinical and bioarchaeological findings but are seldom examined through historically contextualized frameworks of structural vulnerability.

Study aim(s)
This study compares individual-level frequencies of dentin-involving caries and AMTL and descriptively examines caries severity and lesion location in two Yucatecan osteological assemblages: Pixoy, an 18th to 19th century assemblage associated with a rural Maya community and interpreted primarily within its 19th century context, particularly in relation to the period preceding and surrounding the Caste War, and Xoclán, a late 20th to early 21st century documented urban sample.

Material(s) and Methods
The study comprised 146 mandibles: 69 from Pixoy and 77 from Xoclán. Antemortem tooth loss was identified through alveolar remodeling, while carious lesions were classified according to dentin involvement, severity, and anatomical location. Individual-level comparisons used Pearson's chi-square tests or Fisher's exact tests; tooth- and lesion-level distributions were analyzed descriptively.

Original article
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Received: 25.05.2026; Revised: 9.09.2026; Accepted: 11.09.2026

Results
Recorded individual-level frequencies of dentin-involving caries and AMTL were significantly higher in Xoclán (80.5% and 83.1%, respectively) than in Pixoy (63.8% and 46.4%; $p = 0.023$ and $p < 0.001$, respectively). Descriptively, interproximal and root-surface lesions represented greater proportions in Xoclán, whereas occlusal lesions predominated in Pixoy.

Conclusion(s)
These contrasts must be interpreted in relation to age composition, preservation, and historically distinct food environments and opportunities for dental care. Joint consideration of caries and AMTL provides a contextualized biosocial perspective on oral-disease accumulation within a structural vulnerability framework.

Keywords: Bioarchaeology, oral health, Maya populations, nutrition transition, market integration, health inequalities

Introduction

Dental caries is a chronic, multifactorial disease characterized by the demineralization of dental hard tissues resulting from acids produced through bacterial metabolism of dietary carbohydrates, particularly sugars (Moynihan & Petersen, 2004; Pitts & Zero, 2016). Its expression reflects interactions among biological processes, dietary exposures, the oral environment, and social and behavioral factors (Pitts et al., 2017). Accordingly, caries has long been used in anthropological research to investigate dietary practices, subsistence strategies, and social differentiation in past populations (Larsen, 1997).

Within Maya bioarchaeology, studies of Classic-period assemblages have documented substantial variation in caries frequency and distribution. These patterns have been interpreted in relation to the consumption of maize and other carbohydrate-rich foods, differential access to dietary resources, and variation in social roles and associated lifestyles (Cucina & Tiesler, 2003, 2011; Cucina et al., 2011, 2019). Cucina et al. (2019) further underscored the influence of age and sex on observed caries patterns.

By contrast, bioarchaeological evidence for postconquest Maya communities, including the late colonial and 19th century periods, has received comparatively limited attention (Del Castillo Chávez et al., 2026). Pixoy, a rural Maya community in eastern Yucatán, provides a context for examining oral health during this underdocumented period. Recent research has reconstructed its demographic trajectory in relation to the Caste War (1847–1901), a prolonged conflict between the Yucatecan government and Maya rebel groups that unfolded amid depopulation, migration, food shortages, and increasing pressure on communal lands (Granados Vázquez et al., 2025).

Although antemortem tooth loss (AMTL) has been documented in Classic Maya assemblages (Cucina & Tiesler, 2003), it has received less interpretive attention than caries as a distinct outcome. Because its multiple etiological pathways cannot always be distinguished reliably in skeletal remains, AMTL is treated here as a multifactorial outcome rather than as a proxy for a single disease process (Klaus & Tam, 2010; Smith & Warinner, 2022).

Because caries and AMTL are shaped by interacting biological and social processes, their interpretation requires an analytical framework that links social conditions to exposure to oral health risks and the capacity to prevent or mitigate disease. Structural violence refers to avoidable, socially patterned harm produced or sustained by historically embedded social,

political, and economic arrangements (Galtung, 1969; Farmer, 2004). In bioarchaeology, this framework relates skeletal and dental patterns to historically documented political-economic conditions, while recognizing that lesions alone cannot demonstrate structural violence. Klaus (2012) integrated biological, archaeological, and ethnohistorical evidence to examine patterned health changes associated with colonial reorganization, labor relations, religious transformation, and unequal access to resources in northern coastal Peru. Whereas structural violence identifies socially organized harm, structural vulnerability emphasizes the unequal positional exposure through which such harm may be produced; the latter is the primary analytical concept used here.

In this study, structural inequalities refer to patterned asymmetries in material resources, living conditions, food environments, and access to healthcare (Bourgois et al., 2017; Peres et al., 2019). Structural vulnerability, the primary analytical concept, describes the socially produced positioning of individuals and groups within the intersecting social, political-economic, and institutional hierarchies that generate and reproduce these inequalities (Quesada et al., 2011; Bourgois et al., 2017). Through embodiment, exposures and constraints associated with this positionality may become biologically expressed across the life course (Krieger, 2001, 2005). In oral health, potential pathways include differential exposure to cariogenic food environments, prolonged untreated disease, unequal access to preventive and restorative dental care, and reliance on extraction after disease has advanced (Peres et al., 2019). Because these pathways were not measured at the individual level, they are considered here in relation to the historical context.

Building on these concepts, Walkup et al. (2023) examined AMTL through a structural-vulnerability framework in a documented contemporary U.S. skeletal sample, proposing it as a potential biomarker of embodied social inequity while emphasizing the complexity and context dependence of its interpretation.

Evidence from contemporary Maya communities in Yucatán highlights the roles of food environments and access to care. Research has associated differences in caries frequency with the degree of market integration and the availability of processed foods and sugar-sweetened beverages. Caries frequency was higher in the more market-integrated setting, although health services were more widely available there (Vega-Lizama & Cucina, 2014). Comparisons among contemporary Maya communities have also identified differences in oral-health outcomes according to subsistence economy, age, and sex (Vega-Lizama & Alonzo-Echeverría, 2017). More broadly, studies in Mexico indicate that the availability of dental services does not necessarily ensure their use, as social, geographical, and economic barriers may continue to restrict utilization (Lara Flores & López Cámara, 2002; Medina-Solís et al., 2006).

Caries and AMTL are therefore treated as context-dependent biosocial indicators whose interpretation requires demographic, preservation, and sociohistorical evidence.

The present study compares mandibular samples from two historically distinct Yucatecan skeletal assemblages. Pixoy is an 18th to 19th century assemblage associated with a rural Maya community in eastern Yucatán and interpreted primarily within its 19th century context. Xoclán is a documented urban

skeletal series dating from the late 20th to the early 21st century. Most documented individuals in Xoclán were born in the Yucatán Peninsula, primarily in Mérida or surrounding communities (Chi-Keb et al., 2013, 2015). Both assemblages are therefore situated within the broader regional history of Yucatán, although they are not assumed to be ethnically homogeneous or to represent direct biological continuity.

The comparison examines whether individual-level frequencies of dentin-involving caries and AMTL differ between the assemblages. It also provides a descriptive assessment of caries severity and lesion location. Its analytical value lies in applying the same mandibular indicators to two historically distinct Yucatecan contexts and interpreting the resulting patterns in relation to demographic composition, preservation, food environments, market integration, socioeconomic conditions, and opportunities for dental care. The assemblages are compared contextually rather than treated as epidemiologically equivalent populations or as stages in a simple temporal sequence. All comparisons refer exclusively to the mandibular dentition and should not be interpreted as whole-mouth estimates.

Drawing on the documented predominance of older adults in the Xoclán collection (Chi-Keb et al., 2015) and regional evidence associating market integration and access to processed, sugar-rich foods with higher caries frequency (Vega-Lizama & Cucina, 2014), we hypothesized that Xoclán would exhibit higher individual-level frequencies of dentin-involving caries and AMTL and that interproximal and root-surface lesions would represent greater proportions of recorded lesion locations than in Pixoy.

Materials and Methods

The Pixoy collection

In 2017, following a citizen report, human skeletal remains were documented in an ossuary located in a small room adjoining the southwestern corner of the nave of the Church of Santa Ana in the town of Pixoy, municipality of Valladolid, Yucatán. Because the deposit was at imminent risk of disturbance, it was recovered through a controlled archaeological rescue project registered with the National Institute of Anthropology and History (INAH) (Del Castillo Chávez et al., 2026).

Mortuary and associated material evidence place the assemblage within a broad 18th to 19th century horizon (Del Castillo Chávez et al., 2026). One of the containers associated with the secondary deposit bore the date 1842, suggesting the possible presence of a pre-Caste War component. However, the dates and locations of the original primary burials remain unknown, and the date on the container cannot be extended to all individuals because the remains may have been reinterred before 1842 or subsequently deposited in a reused container (Granados Vázquez et al., 2025). The assemblage is therefore interpreted primarily in relation to 19th century rural Yucatán.

Oral accounts collected from current residents did not identify the individuals deposited in the ossuary as their ancestors; residents instead associated their ancestors with the later civil cemetery. The assemblage is therefore regarded as a historical collection associated with Pixoy rather than as a group directly linked to identifiable contemporary families (Del Castillo Chávez et al., 2026).

The demographic disruption and displacement associated with the Caste War may have contributed to discontinuities in settlement and collective memory at Pixoy (Granados Vázquez et al., 2025). The composition of the population during and after the conflict remains uncertain and may have included returning residents or their descendants, newcomers from other communities, or both. Such demographic reorganization could help explain why the ossuary was not recognized by contemporary residents as being associated with their ancestors.

Preliminary archaeothanatological observations suggest a two-stage funerary process. The bodies were initially placed in primary, probably individual burials and were subsequently exhumed, transferred into small containers—including wooden boxes, crates, and baskets—and deposited in the room adjoining the church nave. This sequence may reflect a parish clearance in which skeletal remains were transferred to an ossuary to permit the reuse of burial space. Secondary handling and postdepositional alteration contributed to commingling, fragmentation, and variable preservation (Del Castillo Chávez et al., 2026). These preservation conditions informed the criteria for analytical inclusion and comparison.

The Xoclán collection

The Xoclán reference collection comprises documented individuals recovered from the municipal cemetery of Xoclán in Mérida, Yucatán. Under local cemetery regulations, remains from temporary burial plots were exhumed and transferred to collective ossuaries or communal graves when the authorized occupancy period expired and the burial concession was not renewed. Through an interinstitutional agreement signed in 2005 between the municipal government of Mérida and the Autonomous University of Yucatán (UADY), identified remains were recovered, inventoried, and curated for research and teaching purposes (Chi-Keb et al., 2013).

The collection consists predominantly of adults, with older individuals and males overrepresented. Most documented individuals were born in the Yucatán Peninsula, primarily in Mérida or surrounding communities, and died around the turn of the 21st century. For individuals with an available last place of residence, socioeconomic context was approximated using neighborhood-level income profiles; most were associated with lower-income urban sectors. This regional provenance situates the collection within Yucatán but does not establish the ethnic affiliation of individual members (Chi-Keb et al., 2013, 2015).

Selection and preservation processes may have shaped the demographic composition of the collection. Differences in the renewal of burial plots may partly explain the predominance of males, while poor skeletal preservation may have reduced the recovery of some older and osteoporotic females. Municipal civil records provided biographical information, including sex, age at death, cause of death, place of origin, citizenship, and last residence. Documented sex and age-at-death data were compared with osteological estimates when preservation permitted (Chi-Keb et al., 2013, 2015).

Sociohistorical context of the assemblages

During the 19th century, Yucatán's agrarian organization exhibited marked regional differences. Haciendas—privately owned agricultural and livestock

estates—were particularly prominent in the northwest (Bracamonte y Sosa, 1988), whereas in the east the Maya population was concentrated primarily in towns where subsistence centered on communal lands and the milpa, a traditional agricultural system based mainly on maize (Hoil-Gutiérrez, 2019). In Pixoy, this agricultural orientation is reflected in the 1841 nominal population register: 98.3% of men with a recorded occupation were listed as *labradores*, a broad category encompassing both the cultivation of communal lands and agricultural work for large landowners (Granados Vázquez et al., 2025). Although this register does not permit the reconstruction of individual diets, it indicates the importance of agriculture and access to land for local subsistence.

Agrarian tensions increased during the mid-19th century as policies promoting the privatization of communal lands, fiscal and ecclesiastical burdens imposed on the Maya population, and political instability contributed to the outbreak of the Caste War (1847–1901) (González Navarro, 1979; Hoil-Gutiérrez, 2019). The conflict began as an armed uprising involving Maya groups from eastern and southern Yucatán against the region's economic and political elites (Hoil-Gutiérrez, 2019; Granados Vázquez et al., 2025). It brought economic disruption, death, displacement, and widespread devastation to settlements in eastern Yucatán (Hoil-Gutiérrez, 2019). Pixoy occupied a strategic location along the route connecting Valladolid and Mérida and was therefore directly exposed to hostilities. Historical sources document at least four occupations between 1847 and 1848; they also characterize the settlement as abandoned and destroyed (Granados Vázquez et al., 2025). Nominal population records also document a marked demographic decline, from 708 inhabitants in 1841 to 317 in 1890 and 119 in 1900 (Granados Vázquez et al., 2025). Maya insurgents also converted the Church of Santa Ana into a military stronghold and supply depot (Del Castillo Chávez et al., 2026).

The Caste War further accentuated regional differences in Yucatán's economic and agrarian trajectories. While eastern Yucatán continued to experience the consequences of the conflict, central and northwestern Yucatán became increasingly oriented toward large-scale, export-driven henequen production during the final decades of the 19th century (Hoil-Gutiérrez, 2019; Ramírez-Carrillo, 2020). Henequen is an agave cultivated as a source of fiber for rope and other cordage destined for international markets (Ramírez-Carrillo, 2020). By the turn of the 20th century, much of its production was concentrated among a relatively small number of landowning families (Ramírez-Carrillo, 2020). The industry relied heavily on Maya labor under coercive arrangements. Indebtedness and residence on haciendas constrained workers' freedom of movement (Bracamonte y Sosa, 2007; González Navarro, 1979).

Beginning in the 1970s, the structural crisis of the henequen agroindustry contributed to rural-to-urban migration and the rapid and often unplanned expansion of Mérida (Quezada, 2001). Hundreds of rural migrants settled in informal settlements in the southern, eastern, and western parts of the city, contributing to pronounced disparities between consolidated urban areas and peripheral neighborhoods in housing and access to basic services (Quezada, 2001). Most individuals in the Xoclán collec-

tion, for whom residential information was available, were associated with lower-income areas of Mérida or surrounding communities (Chi-Keb et al., 2015). Therefore, the collection can be situated within this broader context of unequal urbanization. These transformations coincided with shifts in food environments and the increasing availability of inexpensive, highly processed products, including sugar-sweetened beverages, commercially produced bread, cookies, and packaged snacks, particularly among economically disadvantaged urban populations (Tiesler et al., 2020). Although national oral-health programs and dental services existed, their utilization and coverage remained unequal across social sectors, while reliance on privately financed care created additional economic, social, and cultural barriers (Lara Flores & López Cámara, 2002; Medina-Solís et al., 2006).

Taken together, the available evidence situates Pixoy within a predominantly rural agrarian context centered on milpa cultivation and access to communal lands. In contrast, Xoclán represents an urban context shaped during the second half of the twentieth and the early twenty-first centuries by unequal urbanization, the nutrition transition, and socially differentiated access to dental care. These conditions provide population-level contexts rather than individual histories. They cannot be assigned uniformly to members of either assemblage because consistent information on occupation, diet, housing, socioeconomic circumstances, and utilization of dental services was unavailable. In addition, Pixoy's broad chronology prevents determining which individuals, if any, were contemporaneous with the Caste War.

Application of the structural vulnerability framework

Drawing on medical-anthropological approaches to structural vulnerability (Quesada et al., 2011; Bourgois et al., 2017), the framework was applied qualitatively at the assemblage-context level. Four interrelated domains relevant to oral health were considered: (1) material resources and means of subsistence; (2) food environments and potential exposure to cariogenic products; (3) political-economic disruption and its consequences for living conditions; and (4) opportunities for preventive, restorative, and extraction-based dental care. These domains were derived from the theoretical literature, the sociohistorical evidence described above, and established biosocial pathways relevant to oral health, independently of the direction or statistical significance of the dental findings.

These domains guided the contextual interpretation of caries, AMTL, lesion severity, and anatomical location. Because comparable individual information on diet, occupation, socioeconomic circumstances, and use of dental services was unavailable, the framework was applied at the assemblage-context level rather than as a measure of individual exposure or vulnerability.

Study sample and analytical scope

The study sample included 146 mandibles, comprising 69 from Pixoy and 77 from Xoclán. The analysis was restricted to permanent mandibular teeth and alveoli; maxillary elements were not assessed. This restriction standardized anatomical coverage and reduced potential bias arising from differences in the availability of maxillary elements between the

assemblages. Accordingly, all reported caries and AMTL frequencies, severity distributions, and anatomical patterns refer exclusively to the mandibular dentition and alveolar positions. Evaluable positions were defined as those containing a present tooth or showing antemortem tooth loss (AMTL) or postmortem tooth loss (PMTL). Positions whose status could not be determined because of taphonomic damage were excluded.

Sex and age-at-death estimates

Sex estimation

For the Xoclán sample, documented sex was obtained from the existing collection database, compiled from municipal civil registry records from Mérida, and corroborated through pelvic morphology when preservation permitted (Chi-Keb et al., 2015). In Pixoy, sex was estimated as part of the present study. This assessment was complicated by fragmentation, variable preservation, and the absence of anatomical associations among cranial, postcranial, and maxillofacial elements. Sex classifications were therefore interpreted cautiously, particularly because associated pelvic indicators were unavailable. Two discriminant functions validated in modern Mexican populations were applied to all measurable mandibles (Álvarez-Villanueva et al., 2017). Measurements were obtained by the first author using a Mitutoyo digital caliper, model NTD12-6″ (Mitutoyo Corporation, Japan), with a resolution of 0.01 mm. Intra-observer repeatability was evaluated in a random subsample (n = 20) using the Technical Error of Measurement (TEM) (Table 1). When metric assessment was precluded by taphonomic alteration or the two discriminant functions produced discordant results, mental eminence morphology was assessed independently by two observers (Del Castillo Chávez and Pimienta Merlín) following Buikstra and Ubelaker (1994). Disagreements were resolved by consensus, whereas cases that remained ambiguous were classified as indeterminate.

Table 1. Technical error of measurement for mandibular measurements

	Measurement				
	Bigonial width	Maximum ramus height	Mandibular body height	Bicondylar width	Mandibular body length
TEM (mm)	0.11	0.24	0.08	0.08	0.21
%TEM	0.11	0.42	0.31	0.06	0.26

Note: TEM, technical error of measurement. Absolute TEM values are expressed in millimeters and relative TEM values are expressed as percentages. Intra-observer repeatability was evaluated in a random subsample of 20 mandibles.

Age information and dental wear

For Xoclán, documented age at death was summarized using three categories: young adults (18–34 years), middle-aged adults (35–49 years), and older adults (≥50 years). Comparable estimates could not be obtained for Pixoy because of fragmentation, commingling, and the absence of consistently associated pelvic or cranial indicators. To assess whether dental wear could serve as a proxy for age at death in Pixoy, Spearman's correla-

tion was used to evaluate the association between Xoclán's chronological age and wear. No statistically significant association was observed between Lovejoy wear phase and documented chronological age in Xoclán (Spearman's $\rho = -0.12$, $p = 0.606$, $n = 21$). This finding did not support the use of occlusal wear as a proxy for estimating age at death in Pixoy. Because different adult age-estimation methods can produce substantially different age distributions (Clark et al., 2020), dental wear was not considered equivalent to documented age and was used only to characterize variation in molar wear. Consequently, no age-standardized comparisons were performed between the assemblages. Dental wear exhibits substantial interpopulation variability and is influenced by diet, food-processing practices, environmental abrasives, and parafunctional activity (Alayan et al., 2018; Cucina, 2024).

Because the validation subset was small ($n = 21$) and preservation-selected, the association between Lovejoy wear phase and documented age was treated as exploratory; it was used to assess whether wear could reasonably support age-standardized comparisons, not to establish age-equivalent wear categories.

Mandibular molar wear was characterized in both assemblages using Lovejoy's tooth-specific criteria for mandibular first and second molars, based on occlusal wear and dentin exposure (Lovejoy, 1985). Classification required at least one evaluable mandibular first molar (M1) and one second molar (M2), irrespective of side. All available M1s and M2s were evaluated. An individual wear-pattern category was assigned only when the combined pattern of the available molars was compatible with a single mandibular phase in Lovejoy's 1985 classification. When the available molars indicated incompatible phases or did not permit assignment to a unique category, the individual was classified as indeterminate. For descriptive summaries, the resulting categories were organized into three groups: lower-wear patterns (B1–F), higher-wear patterns (G–H), and phase I patterns. These analytical groupings were defined for the present study and were not assigned chronological age ranges. Wear-pattern summaries were restricted to individuals who met the molar-availability criteria.

Antemortem Tooth Loss (AMTL)

Antemortem tooth loss (AMTL) refers to tooth loss occurring before death. Determining its etiology in skeletal remains is methodologically complex because tooth loss may result from advanced caries, periodontal disease, severe occlusal wear, trauma, intentional removal, or therapeutic extraction (Hillson, 2001; Klaus & Tam, 2010; Smith & Warinner, 2022). Because these causes cannot always be distinguished reliably, AMTL was treated as a cumulative, multifactorial outcome rather than as a proxy for a single disease process.

Antemortem tooth loss was identified macroscopically through direct examination of the alveolar bone. Alveolar positions corresponding to absent teeth and exhibiting partial or complete remodeling of the alveolar socket were classified as AMTL. Empty sockets without evidence of remodeling were classified as PMTL (Buikstra & Ubelaker, 1994). Positions affected by extensive taphonomic destruction that prevented reliable assessment were classified as non-evaluable. For each individual, the AMTL proportion was calculated as the number of positions exhibiting AMTL divided by

the total number of evaluable mandibular positions. Evaluable positions comprised present teeth, AMTL, and PMTL; positions whose status could not be determined because of taphonomic damage were excluded.

Mandibular third molars were documented during examination but were excluded from all reported caries and AMTL calculations, resulting in a maximum of 14 mandibular positions per individual. Molar identity was determined from crown morphology, position within the dental arcade, and relationships with adjacent teeth and alveoli. No positional or morphological evidence indicated that an M3 occupied an M1 or M2 position; therefore, no molar positions required reclassification.

Caries

All teeth were examined at 4× magnification using an illuminated magnifying desk lamp (Corner Office, model LA28671G, China) with integrated direct illumination. Enamel-only lesions were recorded when identifiable but were excluded from the primary dentin-involving caries analysis because superficial enamel defects in skeletal material may be difficult to distinguish from taphonomic surface alterations or other types of pitting not related to caries (Hillson, 2001). For analytical purposes, carious lesions were classified using a five-category severity scale developed for the present study and informed by clinical and bioarchaeological diagnostic criteria (Hillson, 2001; Ismail et al., 2007): A) no recorded dentin-involving carious lesion, including teeth without visible caries and teeth with changes confined to enamel; B) early dentinal lesion, defined as a small lesion with dentinal shadowing and/or cavitation clearly involving dentin; C) deep dentinal cavity without pulp chamber exposure; D) lesion with pulp chamber involvement; and E) extensive carious destruction of the crown or a retained root remnant showing evidence of carious destruction (Figure 1). For each individual, the dentin-involving caries proportion was calculated as the number of teeth with category B–E lesions divided by the total number of present teeth. As noted above, teeth with no visible lesion and teeth with enamel-only lesions were grouped as having no recorded dentin-involving carious lesion. When more than one lesion was present on the same tooth, the most advanced lesion determined the tooth-level severity category; consequently, each present tooth contributed to only one severity category.

The anatomical location of each recorded dentin-involving carious lesion was classified as occlusal, interproximal, cervical, or root-surface. Cervical lesions were located on buccal or lingual crown surfaces adjacent to the cementoenamel junction, whereas root-surface lesions occurred apical to the cementoenamel junction. Anatomically distinct lesions were recorded separately; therefore, a tooth could contribute more than one lesion-location observation. Teeth with extensive carious crown destruction or retained root remnants were excluded from the lesion-location analysis when the original lesion location could not be determined.

Evidence of dental treatment in Xoclán—including restorations, crowns, and prosthetic appliances—was recorded qualitatively when observed. Because treatment observations were not collected using a predefined quantitative protocol, they were not used to calculate frequencies or conduct inferential analyses.



Figure 1. Representative examples of the five-category classification used for caries assessment in this study. A, enamel-confined change, classified as category A (no recorded dentin-involving carious lesion), as indicated by the arrow; B, early dentinal lesion, characterized by dentinal shadowing and/or cavitation involving dentin, as indicated by the arrow; C, deep dentinal cavity without visible pulp chamber exposure; D, lesion with pulp chamber involvement; E, extensive carious crown destruction or retained root remnant showing evidence of carious destruction.

Statistical analysis

For individual-level analyses, AMTL presence was defined as at least one evaluable mandibular position exhibiting antemortem loss, and dentin-involving caries presence was defined as at least one tooth with a category B–E lesion. Teeth without visible caries and those exhibiting enamel-only lesions were classified as having no recorded dentin-involving caries. Descriptive statistics were used to summarize individual-level frequencies of dentin-involving caries and AMTL and the distributions of dental preservation, caries severity, and lesion location by assemblage, sex, and dental region. Primary inferential analyses evaluated differences between the assemblages at the individual level. Within-assemblage comparisons by sex and sex-specific interassemblage comparisons were treated as exploratory secondary analyses and interpreted cautiously. Individual-level frequencies were compared using Pearson's chi-square test when all expected cell frequencies were ≥5. Fisher's exact test was used for 2×2 tables when at least one expected cell frequency was <5. No adjustment for multiple comparisons was applied to the exploratory sex-stratified analyses; their p-values were therefore interpreted as exploratory rather than confirmatory.

Spearman's rank correlation was used to assess the association between ordinal Lovejoy wear phase and documented age-at-death in Xoclán. Consistently assigned phases were treated in their original ordinal sequence: B1, B2, C, D, E, F, G, H, and I. Within Xoclán, Spearman's rank correlations were also used to evaluate associations between documented age-at-death and (1) the individual proportion of present teeth affected by dentin-involving caries and (2) the individual proportion of evaluable mandibular positions affected by AMTL. Statistical significance was set at $p < 0.05$. Analyses were conducted using IBM SPSS Statistics, version 31.0.0.0 (IBM Corp., 2025, Armonk, NY, USA).

Tooth- and lesion-level findings were treated descriptively because individuals contributed different numbers of present teeth and recorded lesions. These included tooth-level frequencies of dentin-involving caries, tooth-level distributions of maximum lesion severity, and lesion-level distributions of anatomical location.

Because these distributions weighted teeth or lesions rather than individuals, they could be disproportionately influenced by individuals contributing numerous teeth or lesion locations. Inferential comparisons were therefore restricted to individual-level outcomes to avoid treating observations from the same individual as statistically independent. As a descriptive sensitivity analysis addressing differences in the anatomical composition of the retained dentition, caries frequencies were also examined after restricting observations to retained mandibular first and second molars. This analysis evaluated whether the direction of the interassemblage difference persisted when both samples were restricted to retained mandibular molars. Because multiple molars originated from the same individual, no tooth-level inferential test was performed.

Results

The analyzed sample consisted of 69 mandibles from Pixoy and 77 mandibles from Xoclán. In Pixoy, 41 individuals were classified as female and 28 as male. In Xoclán, the sample included 18 females and 59 males. Intra-observer measurement error in Pixoy was low, with relative TEM values ranging from 0.06% to 0.42%, indicating high measurement repeatability (Table 1).

In Xoclán, 24/77 individuals (31.2%) preserved at least one evaluable mandibular first molar (M1) and one evaluable mandibular second molar (M2). Of these, 3/24 (12.5%) could not be assigned a unique individual Lovejoy phase. Therefore, 21/24 eligible individuals (87.5%) were included for descriptive wear classification.

In Pixoy, 41/69 individuals (59.4%) met the M1–M2 inclusion criterion for descriptive wear classification. Of these, 32/41 (78.0%) exhibited phases B1–F and were assigned to the lower-wear group, whereas 7/41 (17.1%) exhibited phases G–H and were assigned to the higher-wear group. Two individuals (4.9%) were classified as indeterminate because their molars produced phases belonging to different broad wear groups. None of the eligible individuals (0/41, 0.0%) exhibited a consistent phase I pattern. These wear-derived groups were interpreted as approximate descriptive classifications rather than estimates of chronological age. For descriptive context, the documented age distribution in Xoclán included 4/77 young adults (5.2%), 24/77 middle-aged adults (31.2%), and 49/77 older adults (63.6%).

Dental and alveolar preservation patterns differed between the two assemblages (Table 2). Of the 966 expected mandibular tooth positions in Pixoy, 353/966 (36.5%) preserved the tooth in the socket, 124/966 (12.8%) showed evidence of AMTL, 481/966 (49.8%) represented postmortem tooth loss, and 8/966 (0.8%) were non-evaluable because of taphonomic damage. Of the 1,078 expected positions in Xoclán, 700/1,078 (64.9%) preserved the tooth in the socket, 264/1,078 (24.5%) showed evidence of AMTL, and 114/1,078 (10.6%) represented postmortem tooth loss; no positions were classified as non-evaluable (0/1,078, 0.0%).

In Pixoy, PMTL affected 307/414 anterior positions (74.2%), 139/276 premolar positions (50.4%), and 35/276 molar positions (12.7%). The corresponding proportions in Xoclán were 71/462 (15.4%), 30/308 (9.7%), and 13/308 (4.2%), respectively. The mean number of present teeth per individual was 5.12 ± 3.26 in Pixoy and 9.09 ± 3.07 in Xoclán. The mean number of mandibular positions for which tooth status could be determined was 13.88 ± 0.56 per individual in Pixoy

and 14.00 ± 0.00 in Xoclán. Among the present teeth, anterior teeth represented 24.4% in Pixoy (86/353) and 47.7% in Xoclán (334/700), premolars represented 30.3% (107/353) and 33.6% (235/700), and molars represented 45.3% (160/353) and 18.7% (131/700), respectively.

At the individual level, AMTL was significantly more frequent in Xoclán, affecting 64/77 individuals (83.1%), compared with 32/69 individuals (46.4%) in Pixoy ($\chi^2 = 21.81$, df = 1, $p < 0.001$) (Figure 2A). Within Pixoy, AMTL affected 20/41 females (48.8%) and 12/28 males (42.9%), with no statistically significant sex difference ($\chi^2 = 0.23$, df = 1, $p = 0.628$). In Xoclán, AMTL affected 17/18 females (94.4%) and 47/59 males (79.7%) (Fisher's exact test, $p = 0.279$). When stratified by sex, AMTL was more frequent among females from Xoclán (17/18, 94.4%) than among females from Pixoy (20/41, 48.8%; $\chi^2 = 11.15$, df = 1, $p < 0.001$). A similar interassemblage difference was observed among males: 47/59 (79.7%) in Xoclán and 12/28 (42.9%) in Pixoy exhibited AMTL ($\chi^2 = 11.78$, df = 1, $p < 0.001$). Descriptively, molars showed the highest AMTL frequency in both assemblages, affecting 164/308 evaluable molar positions (53.2%) in Xoclán and 81/276 evaluable molar positions (29.3%) in Pixoy (Table 3).

Table 2. Distribution of expected mandibular tooth positions by preservation, dental region, and assemblage

Assemblage	Region	Expected positions, n	Present teeth, n (%)	AMTL, n (%)	PMTL, n (%)	Non-evaluable, n (%)
Pixoy	Anterior	414	86 (20.8)	17 (4.1)	307 (74.2)	4 (1.0)
	Premolar	276	107 (38.8)	26 (9.4)	139 (50.4)	4 (1.4)
	Molar	276	160 (58.0)	81 (29.3)	35 (12.7)	0 (0.0)
	Total	966	353 (36.5)	124 (12.8)	481 (49.8)	8 (0.8)
Xoclán	Anterior	462	334 (72.3)	57 (12.3)	71 (15.4)	0 (0.0)
	Premolar	308	235 (76.3)	43 (14.0)	30 (9.7)	0 (0.0)
	Molar	308	131 (42.5)	164 (53.2)	13 (4.2)	0 (0.0)
	Total	1,078	700 (64.9)	264 (24.5)	114 (10.6)	0 (0.0)

Note: AMTL, antemortem tooth loss; PMTL, postmortem tooth loss. Third molars were excluded, yielding 14 expected mandibular tooth positions per individual: six anterior, four premolar, and four molar positions. Percentages were calculated using the expected number of positions within each dental region as the denominator. Non-evaluable positions were those whose status could not be determined because of taphonomic damage. Individual sample sizes were Pixoy: n = 69, including 41 females and 28 males; and Xoclán: n = 77, including 18 females and 59 males.

Table 3. Position-level frequency of antemortem tooth loss by dental region, sex, and assemblage

		Pixoy				Xoclán			
		AMTL*	PMTL positions (n)	Present teeth (n)	Total evaluable positions**	AMTL*	PMTL positions (n)	Present teeth (n)	Total evaluable positions**
Anterior teeth	Females	16 (6.6)	173	54	243	14 (13.0)	11	83	108
	Males	1 (0.6)	134	32	167	43 (12.1)	60	251	354
	All	17 (4.1)	307	86	410	57 (12.3)	71	334	462

		Pixoy				Xoclán			
		AMTL*	PMTL positions (n)	Present teeth (n)	Total evaluable positions**	AMTL*	PMTL positions (n)	Present teeth (n)	Total evaluable positions**
Premolars	Females	17 (10.5)	93	52	162	19 (26.4)	5	48	72
	Males	9 (8.2)	46	55	110	24 (10.2)	25	187	236
	All	26 (9.6)	139	107	272	43 (14.0)	30	235	308
Molars	Females	53 (32.3)	23	88	164	48 (66.7)	5	19	72
	Males	28 (25.0)	12	72	112	116 (49.2)	8	112	236
	All	81 (29.3)	35	160	276	164 (53.2)	13	131	308
Total	Females	86 (15.1)	289	194	569	81 (32.1)	21	150	252
	Males	38 (9.8)	192	159	389	183 (22.2)	93	550	826
	All	124 (12.9)	481	353	958	264 (24.5)	114	700	1,078

*AMTL percentages were calculated using evaluable positions as the denominator; consequently, they may differ from the preservation-status percentages in Table 2, which use expected positions as the denominator.

**Total evaluable positions comprise present teeth, AMTL, and PMTL; non-evaluable positions were excluded. AMTL, antemortem tooth loss; PMTL, postmortem tooth loss. Individual sample sizes were Pixoy: n = 69, including 41 females and 28 males; and Xoclán: n = 77, including 18 females and 59 males. Frequencies are descriptive because multiple positions originated from the same individual.

At least one recorded dentin-involving carious lesion was observed in 44/69 individuals (63.8%) in Pixoy and 62/77 (80.5%) in Xoclán, representing a statistically significant difference ($\chi^2 = 5.13$, df = 1, p = 0.023). At the tooth level, dentin-involving carious lesions were recorded in 78/353 teeth (22.1%) in Pixoy and 209/700 (29.9%) in Xoclán. These tooth-level frequencies are presented descriptively because individuals contributed different numbers of teeth, and multiple teeth originated from the same individual.

In the descriptive sensitivity analysis restricted to retained mandibular first and second molars, dentin-involving caries was recorded in 80/131 molars (61.1%) in Xoclán and 63/160 molars (39.4%) in Pixoy (Table 4). Thus, the direction of the interassemblage difference persisted when the comparison was restricted to retained mandibular molars. No inferential tooth-level comparison was performed because multiple molars originated from the same individual.

Within Pixoy, dentin-involving caries affected 26/41 females (63.4%) and 18/28 males (64.3%), with no statistically significant sex difference ($\chi^2 = 0.01$, df = 1, p = 0.941). In Xoclán, caries affected 17/18 females (94.4%) and 45/59 males (76.3%) (Fisher's exact test, p = 0.170). When stratified by sex, dentin-involving caries was more frequent among females from Xoclán, affecting 17/18 individuals (94.4%), than among females from Pixoy, affecting 26/41 (63.4%; Fisher's exact test, p = 0.023). Among males, caries affected 45/59 individuals (76.3%) in Xoclán and 18/28 (64.3%) in Pixoy, a difference that was not statistically significant ($\chi^2 = 1.37$, df = 1, p = 0.243).

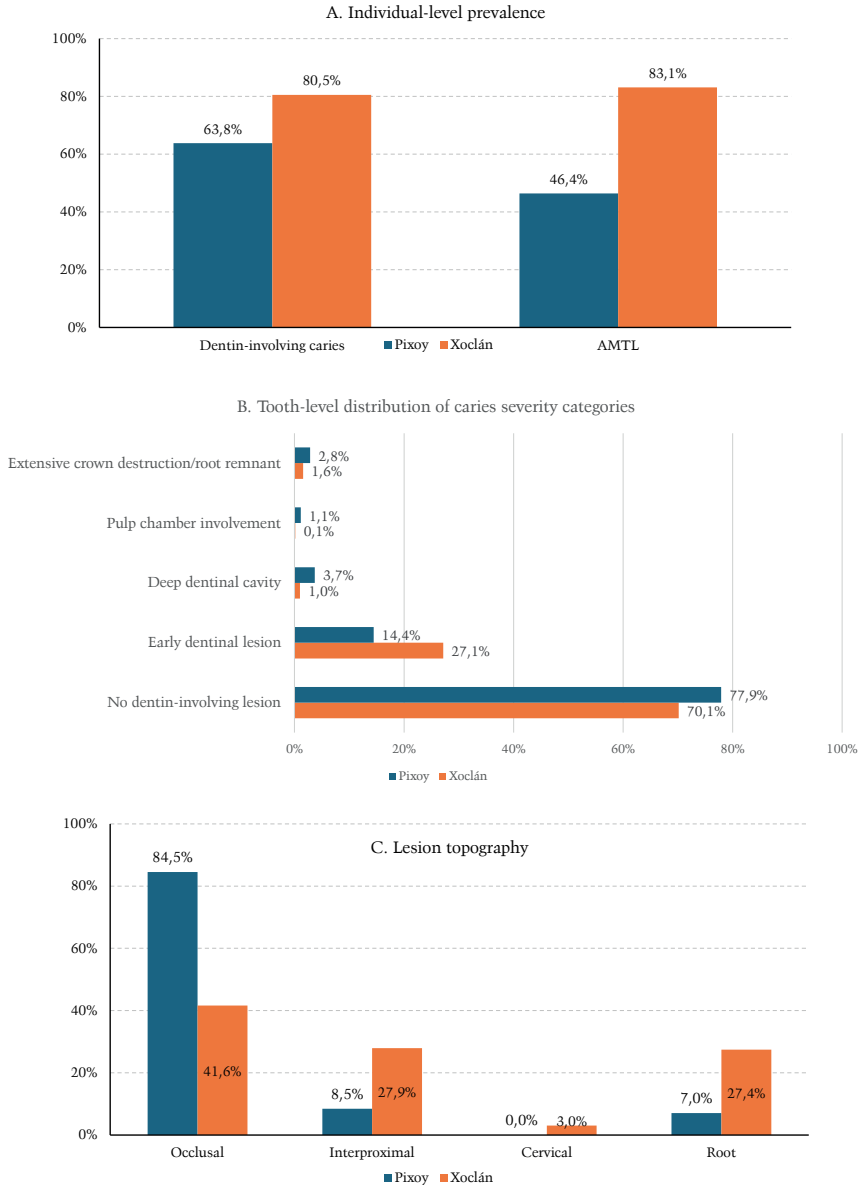


Figure 2. Comparative oral-health outcomes in the Pixoy and Xoclán assemblages. (A) Individual-level frequency of dentin-involving caries and antemortem tooth loss (AMTL). (B) Tooth-level distribution of caries severity categories among present mandibular teeth assessed for caries; teeth without visible lesions and those with enamel-only lesions were grouped as having no recorded dentin-involving carious lesion. (C) Distribution of anatomically distinct lesion locations. Panels B and C present aggregated tooth- and lesion-level distributions, respectively. Observations in panels B and C are clustered within individuals because each individual could contribute multiple teeth or lesions; therefore, these distributions are presented descriptively.

Table 4. Tooth-level frequencies of dentin-involving caries by dental region, sex, and assemblage

Dental region	Sex	Pixoy			Xoclán		
		Available teeth	Teeth with dentin-involving caries	%	Available teeth	Teeth with dentin-involving caries	%
Anterior teeth	Females	54	2	3.7	83	14	16.9
	Males	32	2	6.3	251	39	15.5
	All	86	4	4.7	334	53	15.9
Premolars	Females	52	5	9.6	48	24	50.0
	Males	55	6	10.9	187	52	27.8
	All	107	11	10.3	235	76	32.3
Molars	Females	88	42	47.7	19	19	100.0
	Males	72	21	29.2	112	61	54.5
	All	160	63	39.4	131	80	61.1
Total	Females	194	49	25.3	150	57	38.0
	Males	159	29	18.2	550	152	27.6
	All	353	78	22.1	700	209	29.9

Note: percentages were calculated by dividing the number of present teeth with at least one dentin-involving carious lesion by the number of teeth present and multiplying by 100. Individual sample sizes were Pixoy: n = 69, including 41 females and 28 males; and Xoclán: n = 77, including 18 females and 59 males. Frequencies are presented descriptively because multiple teeth originated from the same individual and individuals contributed different numbers of present teeth.

Within Xoclán, documented chronological age was not significantly correlated with the individual proportion of present teeth affected by dentin-involving caries (Spearman's $\rho = 0.19$, $p = 0.098$, $n = 77$). In contrast, chronological age showed a significant positive correlation with the individual proportion of evaluable mandibular positions affected by AMTL (Spearman's $\rho = 0.33$, $p = 0.004$, $n = 77$).

The assemblages showed different descriptive distributions of dentin-involving caries severity (Table 5). Early dentinal lesions accounted for 51/353 teeth (14.4%) in Pixoy and 190/700 (27.1%) in Xoclán, whereas advanced lesions—including deep dentinal cavities, pulp chamber involvement, and extensive carious crown destruction or retained root remnants showing evidence of carious destruction—accounted for 27/353 (7.6%) and 19/700 (2.7%), respectively (Figure 2B). Because each tooth was assigned to a single category based on its most advanced lesion, these percentages represent the maximum recorded severity per tooth. No inferential tooth-level comparison was performed because multiple teeth originated from the same individual.

The assemblages also showed different descriptive patterns in the anatomical location of dentin-involving carious lesions. In Xoclán, 82/197 anatomically distinct lesion locations (41.6%) were occlusal, 55/197 (27.9%) interproximal, 6/197 (3.0%) cervical, and 54/197 (27.4%) root-surface lesions. In Pixoy, 60/71 lesion locations (84.5%) were occlusal, 6/71 (8.5%) interproximal, 0/71 (0.0%) cervi-

cal, and 5/71 (7.0%) root-surface lesions (Figure 2C). Because lesion observations were clustered within teeth and individuals, these distributions were interpreted descriptively rather than tested as statistically independent observations.

Table 5. Tooth-level distribution of dentin-involving caries severity categories by sex and assemblage

Category	Pixoy females	Pixoy males	Pixoy total	Xoclán females	Xoclán males	Xoclán total
A. No recorded dentin-involving carious lesion	145/194 (74.7%)	130/159 (81.8%)	275/353 (77.9%)	93/150 (62.0%)	398/550 (72.4%)	491/700 (70.1%)
B. Early dentinal lesion	31/194 (16.0%)	20/159 (12.6%)	51/353 (14.4%)	52/150 (34.7%)	138/550 (25.1%)	190/700 (27.1%)
C. Deep dentinal cavity	10/194 (5.2%)	3/159 (1.9%)	13/353 (3.7%)	4/150 (2.7%)	3/550 (0.5%)	7/700 (1.0%)
D. Pulp chamber involvement	4/194 (2.1%)	0/159 (0.0%)	4/353 (1.1%)	0/150 (0.0%)	1/550 (0.2%)	1/700 (0.1%)
E. Extensive carious crown destruction or retained root remnant showing evidence of carious destruction	4/194 (2.1%)	6/159 (3.8%)	10/353 (2.8%)	1/150 (0.7%)	10/550 (1.8%)	11/700 (1.6%)

Note: Values are presented as n/N (%), where N corresponds to the total number of present teeth assessed for caries within each sex and assemblage category. Each tooth was assigned to a single severity category based on its most advanced recorded lesion. Teeth without visible lesions and teeth with enamel-only lesions were grouped as having no recorded dentin-involving carious lesion. Distributions are presented descriptively because multiple teeth originated from the same individual and individuals contributed different numbers of present teeth.

Qualitative evidence of dental treatment was observed in the Xoclán sample, including amalgam and resin restorations, crowns, and fixed partial prostheses. Because these interventions were not systematically quantified, no frequency estimates or inferential comparisons were performed.

Discussion

The recorded individual-level frequencies followed the hypothesized direction: Xoclán showed higher frequencies of dentin-involving caries and AMTL than Pixoy. The lesion-location distributions were also descriptively consistent with the expected pattern, with greater proportional representation of interproximal and root-surface lesions in Xoclán and a predominance of occlusal lesions in Pixoy. Caries severity showed a different pattern: early dentinal lesions were proportionally more frequent in Xoclán, whereas advanced lesions represented a greater proportion of present teeth in Pixoy.

The direction of the observed difference in caries persisted when the descriptive sensitivity analysis was limited to retained mandibular first and second molars. This suggests that differences in the anatomical composition of the retained dentition did not entirely explain the pattern, although the analysis did not account for age, selective antemortem tooth loss, differences in M1–M2 representation, or the clustering of teeth within individuals.

Xoclán had a documented predominance of older adults (Chi-Keb et al., 2015), whereas the age distribution of Pixoy could not be estimated using comparable methods. AMTL generally increases with age (Walkup et al., 2023), and within Xoclán, older age was associated with a higher proportion of mandibular positions affected by AMTL. In contrast, age was not significantly associated with the proportion of present teeth affected by dentin-involving caries. An age-related effect may nevertheless remain because severely affected teeth could have been lost antemortem and were therefore unavailable for examination.

Dental wear did not resolve this age-related non-equivalence. In the small, preservation-selected Xoclán subset, Lovejoy wear phase showed no statistically significant association with documented age. Accordingly, the wear-derived categories in Pixoy were neither treated as chronological age groups nor used for age-standardized comparisons. The lower frequencies recorded in Pixoy should therefore be interpreted cautiously because the age distribution remains uncertain. Selective mortality and differential susceptibility to disease provide additional sources of uncertainty in skeletal comparisons (Wood et al., 1992).

Historical changes in Yucatán provide context for the Xoclán findings. From the 1970s onward, the crisis of the henequen agroindustry contributed to rural-to-urban migration and the rapid expansion of Mérida (Quezada, 2001). These changes coincided with the increasing availability of industrially processed foods, which transformed urban food environments (Tiesler et al., 2020). Research in northern Yucatán has documented higher caries prevalence in Maya communities with greater market integration and access to processed foods and sugar-rich sodas (Vega-Lizama & Cucina, 2014). Although national oral health programs expanded during this period, the utilization and coverage of dental services remained unequal across social groups and urban and rural settings (Medina-Solís et al., 2006).

Differences in age structure, sampling, examination protocols, and outcome definitions complicate direct comparison with contemporary clinical studies. Moreover, the absence of a contemporaneous Yucatecan skeletal sample examined using the same protocols and stratified by socioeconomic circumstances precludes determining whether Xoclán's oral-health profile differed from that of the broader regional population. The findings must therefore be interpreted in light of the available historical evidence.

The lesion distribution in Xoclán may reflect the combined influence of age, cumulative exposure to cariogenic environments, periodontal disease, and different treatment histories. The high frequency of periodontal bone defects and increased cementoenamel junction–alveolar crest (CEJ–AC) distances previously documented in this assemblage indicate that alveolar bone loss was common and may have increased the exposure of root surfaces susceptible to caries (Noriega Muro et al., 2026). In a Mexican clinical sample, dental caries and periodontal disease were the principal indications for tooth extraction (Bernal-Sánchez et al., 2023). These processes may have contributed to the high frequency of AMTL in Xoclán, although the available evidence cannot determine whether individual tooth loss resulted from caries, periodontal disease, or therapeutic extraction. AMTL is therefore interpreted as a cumulative and context-dependent outcome rather than as a diagnostic marker of poverty (Walkup et al., 2023).

Qualitatively observed restorations and prosthetic appliances demonstrate that some Xoclán individuals received dental care. Their coexistence with untreated disease and substantial AMTL indicates heterogeneous treatment histories but does not show how frequently or consistently dental care was received. This interpretation is consistent with evidence that socioeconomically disadvantaged populations frequently experience a disproportionate burden of untreated oral disease and restricted access to preventive and restorative care (Peres et al., 2019).

The interpretation of sex-stratified findings is limited by the small number of females in Xoclán and the unequal sex composition of the assemblages. AMTL affected a greater proportion of females than males in both assemblages, although neither difference was statistically significant. In descriptive comparisons, dentin-involving caries was more frequent among females than males in Xoclán, whereas its frequency was similar between the sexes in Pixoy. Differences in caries experience between females and males may reflect a combination of biological and socially mediated factors. Proposed biological mechanisms include tooth-eruption timing, salivary physiology, hormonal changes, and reproductive history (Lukacs & Largaespada, 2006). Potential socially mediated pathways include gendered differences in food-related exposures, control over household resources, caregiving constraints, and access to preventive and restorative dental care (Lukacs & Largaespada, 2006; Peres et al., 2019). The available individual information did not permit these mechanisms to be evaluated.

In Pixoy, the predominance of occlusal lesions may partly reflect both the molar-weighted composition of the retained dentition, resulting from disproportionate postmortem loss of anterior teeth and premolars, and the greater susceptibility of molar occlusal surfaces to caries (Cucina et al., 2019). Advanced lesions represented a greater proportion of retained teeth in Pixoy, although selective antemortem tooth loss, particularly in Xoclán, complicates interpretation of this difference.

Historical evidence situates Pixoy within a rural food environment organized around agriculture, milpa cultivation, and access to communal lands, with maize and other locally produced staples forming important components of subsistence (Granados Vázquez et al., 2025; Hoil-Gutiérrez, 2019; Quezada, 2001). Although these foods provided fermentable carbohydrates, free sugars, and industrially processed products were probably less available than in the later market-integrated environment represented by Xoclán. This interpretation is consistent with research associating greater market integration and access to processed, sugar-rich foods with higher caries frequencies in contemporary Maya communities in Yucatán (Vega-Lizama & Cucina, 2014). Agrarian pressures and the Caste War subsequently disrupted access to land, food production, and settlement continuity in eastern Yucatán (Granados Vázquez et al., 2025; Hoil-Gutiérrez, 2019). Because the assemblage spans the eighteenth and nineteenth centuries and is mainly formed by a prewar component, these conditions characterize the historical setting of Pixoy but cannot be assigned to the dietary experience of individual members of the assemblage. The observed pattern is therefore considered within a rural food environment that remained potentially cariogenic.

Applying the same mandibular criteria permits a contextual, although not epidemiologically equivalent, comparison between the assemblages. Oral health is shaped by socioeconomic, historical, and structural conditions, including material resources, neighborhood-level deprivation, food environments, and access to preventive and restorative care (Bastos et al., 2018; Medina-Solís et al., 2006; Peres et al., 2019; Rodriguez et al., 2023). Considered together, caries and AMTL provide complementary information on disease experience and tooth loss that can be interpreted alongside the demographic, preservation, and sociohistorical characteristics of each assemblage.

Limitations

Comparable age-at-death data were unavailable for Pixoy, precluding age-standardized comparisons between the assemblages. Dental wear was recorded solely to characterize molar wear and was not used to assign biological age categories. In the small, preservation-selected Xoclán subset, mandibular molar wear showed no statistically significant association with documented age. Moreover, the absence of corresponding maxillary dentitions prevented assessment of functional occlusion; earlier loss of maxillary antagonists may have altered the progression of mandibular wear. Age therefore remains an unresolved source of non-equivalence between the assemblages.

Dental preservation differed substantially between the assemblages. Pixoy exhibited greater postmortem tooth loss, particularly in anterior and premolar positions, resulting in differences in the anatomical composition of the retained dentitions. This may have affected tooth-level caries frequencies, severity distributions, and lesion locations. Unequal tooth retention may also have influenced recorded individual-level caries frequency. Restricting the descriptive comparison to retained molars reduced differences in anatomical composition but did not correct for selective antemortem tooth loss, unequal numbers of molars contributed by each individual, differences in M1–M2 representation, or age-related cumulative exposure. Because the analysis was restricted to mandibular teeth and alveoli, the findings should not be interpreted as whole-mouth estimates.

Sex-stratified comparisons were constrained by the small number of females in Xoclán, unequal sex distributions, and differences in methods of sex assessment. In Xoclán, documented sex was compared with estimates based on pelvic morphology when preservation permitted; in Pixoy, sex was estimated from mandibular morphology.

Information on individual dietary histories, socioeconomic circumstances, use of dental services, and the timing and indications of observed dental treatments was unavailable. In addition, Pixoy's broad 18th to 19th century chronology prevents linking the documented historical processes to every individual in the assemblage.

Conclusion(s)

This study identified contrasting patterns of mandibular oral disease in two historically distinct Yucatecan osteological assemblages. Xoclán exhibited higher recorded individual-level frequencies of dentin-involving caries and AMTL and, in descriptive analyses, a greater proportional representation of interproximal and root-surface lesions. Pixoy showed lower individual-level fre-

quencies of both indicators but a greater proportional representation of advanced lesions among retained teeth and a predominantly occlusal lesion distribution. Together, these patterns show that caries frequency, lesion severity, lesion location, and tooth loss capture distinct but complementary dimensions of oral-disease experience.

The observed differences must be considered in relation to age documentation, demographic composition, dental preservation, historical food environments, and opportunities for dental care. Examining caries and AMTL together within these contexts provides a historically informed biosocial perspective on oral-disease accumulation without treating the two assemblages as stages of a simple temporal sequence.

Acknowledgements

S. Thamara Noriega Muro acknowledges the Secretaría de Ciencia, Humanidades, Tecnología e Innovación (SECIHTI, Mexico) for the postdoctoral fellowship (CVU 623333) that supported her academic stay at the Department of Human Ecology, Cinvestav. We are grateful to the Laboratorio de Bioarqueología (Dr. V. Tiesler, Universidad Autónoma de Yucatán) for granting access to the Xoclán skeletal collection.

Author contributions

S.T.N.M. Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. S.D.B. Writing – original draft, Validation.

O.D.C.C., M.P.M., and A.M.G.V. Writing – original draft, Validation, archaeological, osteological, and contextual information related to the Pixoy assemblage. A.C. Writing – original draft, Validation, Supervision, Project administration, Conceptualization.

Ethics statement

Access to the osteological collections was formally authorized, and the study complied with international ethical standards for research involving human remains. The Xoclán collection comprises documented modern individuals whose remains were not reclaimed following the expiration of temporary burial concessions and were subsequently transferred to the cemetery ossuary. Its use for academic purposes was approved through an agreement between the City Council of Mérida and the Autonomous University of Yucatán. The historical Pixoy collection, preserved by the National Institute of Anthropology and History (INAH), is not associated with any formally identified descendant community or documented descendant claim and was available for research in accordance with Mexican national regulations.

Data availability statement

Data are available upon request to the first and corresponding authors.

Financial disclosure

This work was supported by a postdoctoral fellowship (CVU 623333) from the Secretaría de Ciencia, Humanidades, Tecnología e Innovación (SECIHTI) to S.T. Noriega Muro for her academic stay at the Department of Human Ecology, Cinvestav. No additional project-specific funding was received.

Conflict of interest

The authors declare no conflict of interest.

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