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Original Article

Social strata and oral pathologies: A comparative study in two co-localized, temporally disjunct burial sites of ancient Egypt

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Abstract *Background/purpose:* Oral pathologies in ancient human remains provide a unique glimpse into the lifestyles, health, and societal norms of past civilizations, including ancient Egypt. However, comprehensive paleo-odontological studies accounting for temporal and sociodemographic variations remain scarce. We address this gap by analyzing oral pathologies in the remains of 68 and 57 adult individuals, respectively, unearthed from two adjacent yet temporally and socioeconomically diverse burial sites, representing the XIth dynasty (2160–1985 BCE) and the XXVth-XXVIth dynasties (948–525 BCE), at Luxor's Thutmose III Funerary Temple.
Materials and methods: We examined dental wear, carious and periapical lesions, periodontal disease, and temporomandibular joint alterations, hypothesizing that dental wear correlates with age, lifestyle, and diet. We also postulated a link between higher caries frequency and elevated social status and posited the enhanced efficacy of evaluating interdental septa over measuring the alveolar bone-cementoenamel junction distance for periodontitis assessment.
Results: Our findings confirm pronounced dental wear in both sites, with the XIth dynasty showing more severe wear, indicating differing dietary habits. While similar across the younger age groups, the later dynasties showed a significantly higher caries frequency than the XIth dynasty, in the older age groups. Furthermore, our results underscore the superior accuracy of evaluating interdental septa for periodontal disease assessment.
Conclusion: Variations in oral health, sociodemographic, and dietary trends across the studied burial sites, deepen our understanding of human health trajectories. Additionally, our methodology emphasizes paleo-odontology's vital role in deciphering the nuanced health-environment relationship in ancient societies, laying a foundation for subsequent investigations.

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Introduction

Oral pathologies in past civilizations, notably ancient Egypt, offer invaluable insights into dietary habits, socioeconomic conditions, and cultural practices. These pathologies provide a unique and enduring glimpse into the health-environment interactions of these populations. However, there remains a gap in the comprehensive understanding of oral pathologies rooted in paleoodontological principles, especially regarding variations over time and across social divides. Addressing this gap is important because oral pathologies, including dental wear, carious lesions, periapical lesions, periodontal disease, antemortem tooth loss, and temporomandibular joint disorders, have the potential to provide a detailed understanding of past health conditions and human health evolution.

We address this less-explored aspect of ancient Egyptian life within the Temple of Millions of Years, also known as the funerary temple of Pharaoh Thutmose III (circa 1550/1549 to 1292 BCE), built as his eternal mansion on the Nile's west bank opposite Luxor. Although the ravages of time have left their imprints on this esteemed archaeological site, its significance remains undiminished. Archaeological exploration and preservation efforts at this location began in 2008 under the Thutmose III temple project, a collaborative effort involving the Ministry of Tourism and Antiquities of Egypt, the University of Seville, Spain, and the Institute of Evolutionary Medicine of the University of Zurich, Switzerland.[1] In our research, we selected two burial locations situated in proximity to the temple, primarily due to their temporal separation spanning over a millennium and the divergent social strata to which the interred individuals belonged.

We propose three core hypotheses surrounding dental wear, caries prevalence, and periodontitis assessment in these ancient remains:

1. We hypothesize an increase in dental wear scores with age, anticipating distinct wear patterns across the two burial sites due to variances in lifestyle and diet.
2. Our second hypothesis connects caries prevalence with social standing, suggesting that individuals with elevated social status and a refined diet might exhibit more caries.
3. Regarding periodontitis assessment, we posit that examining interdental septa offers more accuracy than measuring the gap between the alveolar bone and the cementoenamel junction, as the former is less impacted by dental wear.

In summary, our exploration of two disparate ancient Egyptian burial sites seeks to uncover patterns in oral pathologies, emphasizing dental wear, caries, and periodontitis. We aim to elucidate the complex interplay of oral health conditions within varying temporal and societal scenarios, deepening our understanding of ancient Egyptian health dynamics and providing a robust foundation for studying oral health in past civilizations.

Material and methods

The two examined sites correspond to the XIth dynasty (2160–1985 BCE) (XI) and the XXVth and XXVIth dynasties (948–525 BCE) (LP) (Fig. 1). The earlier burial site, XI, located northeast of the temple, primarily encompasses simple burials of individuals from a social class engaged in physical labor. In contrast, the later LP burial site features tombs with intricate architectural designs, likely the resting places of individuals from a middle social stratum, such as priests or mid-ranking Cushite or Saite officials.

To analyze the remains, we utilized a workflow to study heavily fragmented and commingled skeletonized or mummified ancient Egyptian human remains.[2] Comprehensive photographic documentation was conducted, and radiological images were captured using a portable digital X-ray unit.[3] Initially, we aimed to examine 110 individuals from site XI and 147 from site LP. However, many skeletal elements had to be excluded due to poor preservation. The concluding analysis encompassed 68 sex-determined individuals aged over 19 from site XI and 57 from site LP.

Age estimation for younger individuals was derived from tooth development and eruption patterns.[4] For older individuals, age was determined using the Brothwell chart and ectocranial suture closure techniques.[5,6] Sex was estimated based on cranial features.[7] When the postcranial skeleton was available, it was used to corroborate the initial sex estimation. Four age groups could be distinguished in terms of age at death: 19–25, 26–35, 36–45, 46+. For the further procedure, the first two were combined into the group of "young" individuals, the latter two into the group of "old" individuals. Teeth were classified according to their condition as outlined in Table 1 : "expected" refers to the anticipated count in a complete dentition; "present" designates teeth with visible crowns suitable for examination; "present but non-observable" denotes teeth unsuitable for scoring, predominantly due to extensive crown fractures; "missing" teeth had either been lost before death, termed "ante mortem tooth loss" (AMTL), or posthumously, labeled as "post mortem tooth loss" (PMTL). The loss of support zones in the posterior region was also documented.[8]

We evaluated dental wear, caries, periodontitis, tooth fractures, and other pathologies. Dental wear, often pronounced in ancient Egyptian dentitions,[9,10] was scored using the Smith and Knight tooth wear index,[11] and caries were assessed based on visible cavitations,[12] also in X-ray images. For dry skulls, the severity of marginal periodontitis was gauged by measuring the loss of alveolar bone, quantified as the distance from the cementoenamel junction (CEJ) to the alveolar bone crest (AC) in millimeters,[13] termed Method 1 (M1). An alternative method (M2)

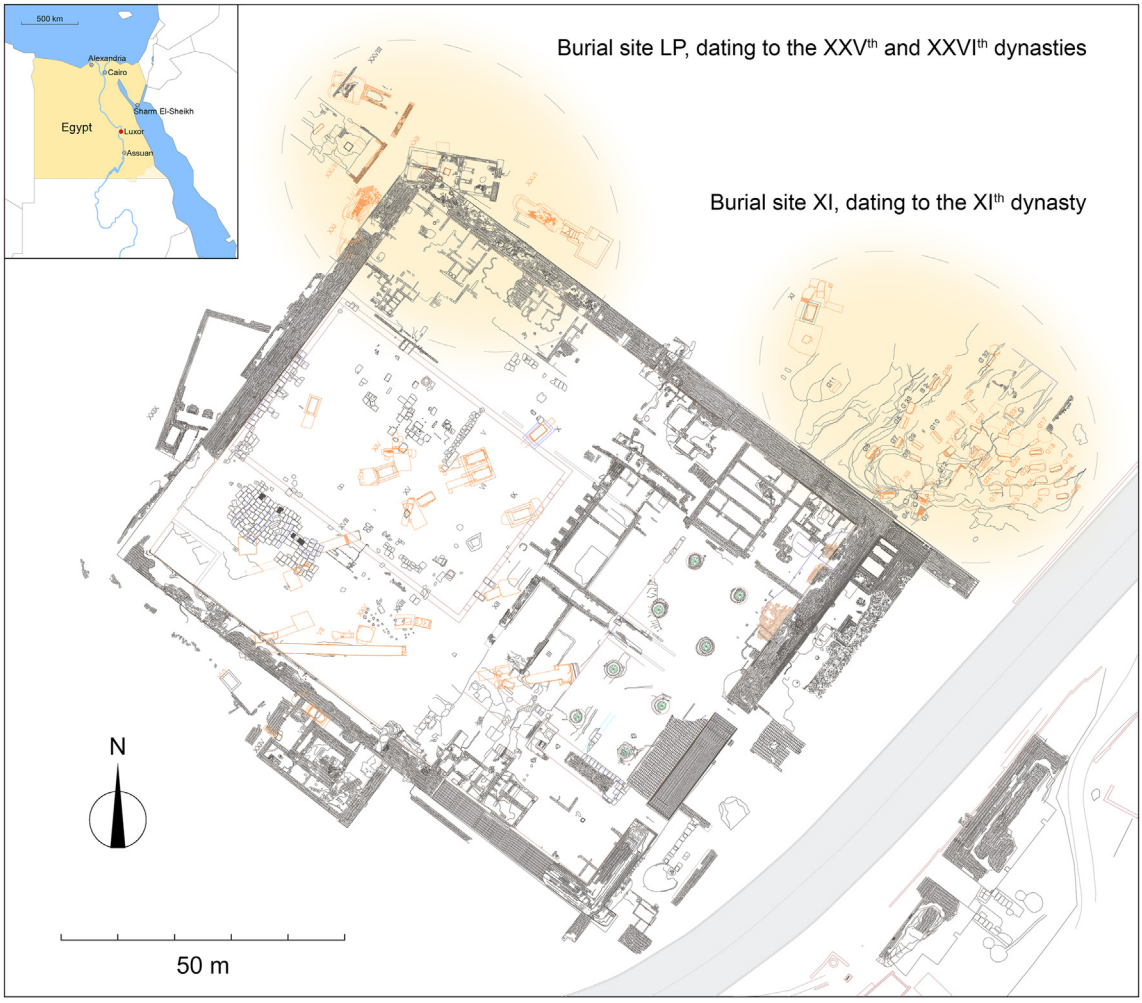

Figure 1 Detailed map (2019) showcasing the Temple of Millions of Years of king Thutmose III (1479-1425 BCE) - situated in Luxor West Bank (Egypt). Surveyor: J. Tre Garcia; drawing: E. Úbeda @ Thutmosis III Temple Project. The map illustrates the locations of the two neighboring burial sites under investigation for oral pathologies.

assessed marginal periodontitis by applying an established alveolar crest morphology scoring method with specific adaptations.[14,15] This methodology was employed for a subset of 45 out of the 68 skeletonized skulls from the XI population, specifically where the interdental septa were distinctly observable. Periapical bony lesions were identified through direct visual inspection or radiographs.[16] The temporomandibular joints were examined using guidelines for a binary osteoarthritis (OA)/non-OA diagnosis to evaluate changes in the articular surface of the condyles,[17] combining inspectorial and radiological criteria. Our goal was to determine if specific dentoalveolar pathologies could impact the conditions of the temporomandibular joint.

Descriptive statistical analyses were conducted using Microsoft Excel, whereas RStudio software was used for additional analyses, testing our three main hypotheses, and generating plots.

1. We tested the hypothesis that dental wear scores increase with age and that the two sites have distinct dental wear patterns. The Spearman's rank correlation test was utilized to examine the relationship between age groups and dental wear scores. The Wilcoxon rank sum test (Mann—Whitney U test) was applied to compare dental wear scores between the two burial sites. A violin plot was then generated to illustrate the relationship between age groups and dental wear scores, incorporating a linear regression line with a 95 % confidence interval to show dental wear score trends across age groups.
2. Caries assessment used a four-level scoring system: a healthy tooth (scored as 0), minor enamel issues (scored as 1), evident dentinal caries (scored as 2), and a substantial cavity reaching the pulp (scored as 3). Soil staining and taphonomic effects present challenges that often hinder the identification of initial caries, which can be almost invisible in X-ray imaging. Therefore, for this study, caries lesions were classified into a binary yes/no system, considering teeth with scores of $\geq$2 as having caries. This ensured only cavities with evident defects, visible in X-ray images, were counted as having caries. The chi-squared (χ^2) test was used to compare caries prevalence between the defined groups.

Table 1 Tooth related data of XI and LP. The table shows the values of the various categories of tooth recording for the sexes and age groups in both populations.[a]

Teeth:	observable	non observable	AMTL	PMTL	missing	present	expected	preserved
XI								
Male	499	58	74	193	267	557	824	750
Female	488	36	220	297	517	524	1041	821
Total XI	987	94	294	490	784	1081	1865	1571
Age group:								
Young	672	58	30	220	250	730	980	950
Old	315	36	264	270	534	351	885	621
Total XI	987	94	294	490	784	1081	1865	1571
LP								
Male	486	41	96	62	158	527	685	589
Female	478	78	136	76	212	556	768	632
Total LP	964	119	232	138	370	1083	1453	1221
Age group:								
Young	499	80	38	56	94	579	673	635
Old	465	39	194	82	276	504	780	586
Total LP	964	119	232	138	370	1083	1453	1221

[a] AMTL: Ante mortem tooth loss. LP: Necropolis of the XXVth and XXVIth dynasties (948–525 BCE). PMTL: Post mortem tooth loss. XI: Necropolis of the XIth dynasty (2160–1985 BCE).

3. To test the hypothesis that method M2 offers a more accurate measure for periodontitis due to its lower correlation with dental wear compared to method M1, we analyzed the correlation coefficients between M1 and dental wear (DW) and M2 and DW in a subset of 45 individuals from Necropolis XI. The Pearson correlation coefficient (r) was used to determine the linear relationship between these variables. A scatterplot was generated to visualize the relationships between dental wear and periodontitis scores using both methods (M1 and M2), including linear regression lines for each method with their respective 95 % confidence intervals.

Results

The age-at-death and sex distribution differences between the two burial sites, XI and LP, are not statistically significant. In burial site XI, women tended to live longer than men; 30.88 % of females, compared to 16.18 % of males, were in the older age bracket. In contrast, burial site LP displayed a more even distribution, with 29.82 % of females and 26.32 % of males in the older age category. Table 1 presents the AMTL data. This indicator significantly increased with age within both XI and LP populations ($P < 0.001$ and $P = 0.005$, respectively) but not when comparing the same age groups across sites. Notably, women in the XI group had a higher rate of intravital tooth loss than men, a statistically significant difference ($P = 0.041$).

The frequency of dental wear was high in both burial sites. Specifically, in the younger age groups, it was 91.2 % for site XI and 89.32 % for site LP. In contrast, the older age groups showed an even higher frequency, with 97.32 % in site XI and 98.65 % in site LP. The Wilcoxon rank sum test indicates a significant difference between the dental wear scores at the two sites ($W = 1500$, $P = 0.030$), supporting our initial hypothesis that burial site XI and burial site LP differ regarding dental wear scores. We also confirmed the suspected positive correlation between dental wear scores and age at both archaeological sites, burial site XI (correlation $= 0.877$, $P < 0.001$) and burial site LP (correlation $= 0.494$, $P < 0.001$). Furthermore, in the earlier XI site, the youngest age group displays more pronounced dental wear (average $= 1.950 \pm 0.491$), but this wear progresses at a slower rate with age compared to the more recent LP site. At the LP site, the youngest age group has less dental wear (average $= 1.684 \pm 0.538$), but it increases at a faster rate, resulting in a similar level of average wear in the oldest age group for both sites (XI: 3.399 ± 0.477, LP: 3.585 ± 0.298). Fig. 2 illustrates this comparison.

Caries frequencies were calculated using tooth count and individual count methods (Table 2). Within each of the XI and LP sites, statistically, there was no notable difference in caries frequency between the younger and older age groups. Furthermore, no significant difference was observed when comparing the younger age groups of both XI and LP sites. However, when comparing the older age groups from the two burial sites, there was a significant difference ($P = 0.003$), with the LP site showing a higher frequency of caries. Also, there were no significant differences in caries frequency between males and females.

Our results confirmed our initial hypothesis: M2 is a more accurate indicator of periodontitis, as evidenced by its lower correlation with dental wear ($r = 0.634$, $P < 0.01$) compared to the correlation between M1 and dental wear ($r = 0.751$, $P < 0.01$). To better illustrate these findings, we created a scatterplot (Fig. 3), highlighting that M1 tends to overstate the periodontitis score relative to M2. Further analysis revealed that M1 has a lower intercept (0.7085) and slope (0.771) than M2, indicating significant differences

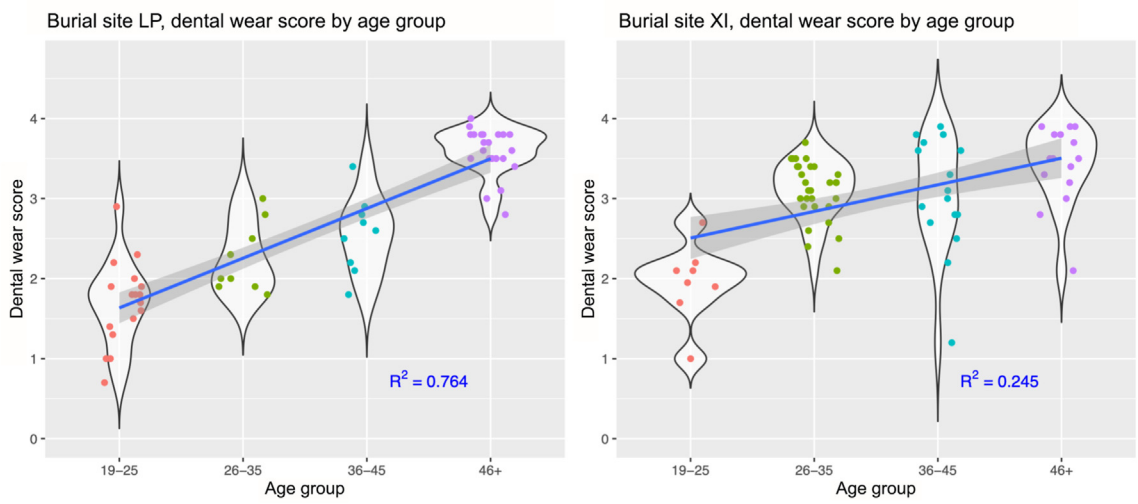

Figure 2 Comparison of dental wear scores across the four age groups (19—25, 26—35, 36—45, 46+) for burial site XI and burial site LP. The violin plots display the distribution of dental wear scores, while the individual data points are overlaid as dots. Linear regression lines (including the respective 95 % confidence interval) and their respective R^2 values are shown in blue to illustrate the relationship between age group and dental wear score at each site. Note: XI: necropolis of the XIth dynasty (2160—1985 BCE). LP: necropolis of the XXVth and XXVIth dynasties (948—525 BCE).

Table 2 The table shows the values of the observable teeth and the observable individuals of the different age groups (young/old) in both necropolis populations and the corresponding frequencies of carious lesions of the decayed teeth and the individuals with decayed teeth. From this is calculated the percentages of individuals with decayed teeth (ni/Ni) and the percentages of decayed teeth (nt/Nt), respectively, and finally the average number of teeth affected in the age groups.[a]

	XI			LP		
	Young	Old	Total	Young	Old	Total
Sum observable teeth (Nt)	672	315	987	499	465	964
Observable individuals (Ni)	36	32	68	26	31	57
Sum decayed teeth (nt)	9	18	27	18	42	60
Individuals with decayed teeth (ni)	7	11	18	5	19	24
Affected individuals: ni/Ni (%)	19.44 %	34.38 %	39.71 %	19.23 %	61.29 %	42.11 %
Affected teeth: nt/Nt (%)	1.34 %	5.71 %	2.74 %	3.61 %	9.03 %	6.22 %
Average affected teeth/age group	**0.25**	**0.56**	**0.41**	**0.69**	**1.35**	**1.02**

[a] Ni: Sum of observable individuals. Nt: Sum of the observable teeth. ni: Sum of individuals with decayed teeth. nt: Sum decayed teeth. LP: Necropolis of the XXVth and XXVIth dynasties (948—525 BCE). XI: Necropolis of the XIth dynasty (2160—1985 BCE).

between the two methods. On average, M1 overestimates the periodontitis score by 0.811.

Further analysis showed that younger individuals exhibited fewer periapical lesions at both burial sites, with 22.22 % in XI and 19.23 % in LP. In contrast, the older age group had higher occurrences, with 40.63 % in XI and 48.39 % in LP. However, this difference was only statistically significant for the LP site ($P = 0.047$). The temporomandibular joints were assessable in 43 (63.24 %) of the XI individuals and 37 (64.91 %) of the LP individuals. Osteoarthritis was diagnosed in 7 cases (16.28 %) in XI and 9 cases (24.32 %) in LP, with no significant differences between the burial sites. Age seemed to be a predictive factor for a higher prevalence of osteoarthritis in both sites (XI: $P = 0.033$; LP: $P = 0.039$). Further parameters, such as the loss of lateral support zones and the degree of dental wear, didn't markedly affect osteoarthritis in the temporomandibular joints.

Discussion

The Temple of Millions of Years of Thutmose III in Luxor's west bank provided well-defined archaeological contexts for analysis. Dental pathologies reflect external influences accumulated over a lifetime, as dental tissue has limited healing capabilities. Ante mortem tooth loss is a critical dental health indicator providing valuable information about an individual's life, diet, and overall health. The frequency of AMTL is comparable with a similar study on ancient Egyptian dentitions.[18] Various factors contributing to tooth loss can be postulated. The elderly population within the necropolis exhibits elevated occurrences of severe dental attrition, which can culminate in pulp exposure, subsequently leading to periapical conditions like granuloma, abscesses, or cyst formation, ultimately resulting in tooth loss. Conversely, the elderly individuals in LP exhibit higher incidences of carious lesions with

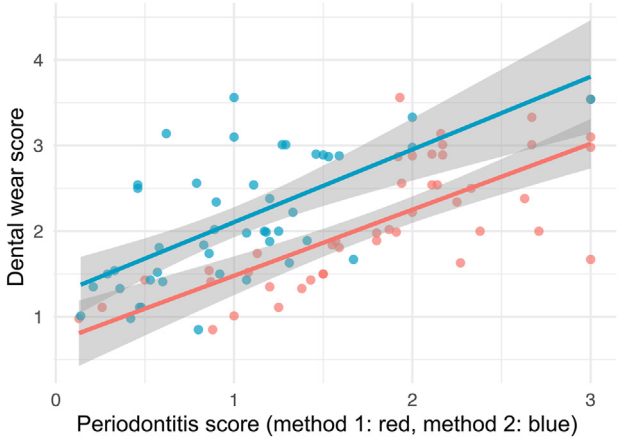

Figure 3 In a subset of 45 Individuals from burial site XI, dental wear scores (ranging from 0 to 4) are compared against periodontitis scores obtained by two methods (M1 in red and M2 in blue). The solid lines represent the respective linear regression lines, with shaded areas representing each method's 95 % confidence intervals. M1 tends to overestimate the periodontitis score compared to M2 as M1 has a lower intercept (0.7085 vs. 1.2553) and a slightly lower slope (0.7710 vs. 0.8494) than M2. Note: M1: scoring marginal periodontitis by measuring distance from the cementoenamel junction (CEJ) to the alveolar bone crest (AC) in millimeters. M2: assessing marginal periodontitis by applying an established alveolar crest morphology scoring method. XI: necropolis of the XIth dynasty (2160–1985 BCE).

comparable outcomes. Consequently, while the older individuals in both XI and LP share similar frequencies of periapical issues, the etiology differs between the two populations. Furthermore, we tested hypotheses related to dental wear, caries scores, and periodontitis assessment methods. Dental wear scores rose with age, as reported for ancient Egypt,[19] but exhibited different patterns across the two sites, in that the higher value in the group of younger people of the XI cemetery in age is evened out between the two sites. The burden of caries was more elevated in the older age group of LP. This may be explained by differences in food preparation and sweetened food availability between "workers' meals" and "nobles' meals".[20] Similarly, higher caries scores have been found in upper-status individuals.[21] Finally, differences were found between the two assessment methods for marginal periodontitis. With the second measurement method, severe periodontal disease incidence (score >2) dropped to 6.67 %, which aligns well with previous studies confirming that a small subset (5–15 %) of any population experiences severe periodontitis, regardless of dental care.[22,23] There is broad agreement in the literature that the frequency of OA is correlated with age, i.e., age is a risk factor for OA.[24–27] However, conflicting results are reported on the influence of dental wear and loss of support zones on the development of OA in the TMJ.[28] In our investigation, we substantiated the correlation between advancing age and a heightened prevalence of OA. However, this correlation did not extend to the dental pathologies under consideration.[29,30]

While our study provides novel insights into dental pathologies in ancient Egyptian populations from two distinct burial sites, there are inherent limitations. Firstly, our conclusions are based on remains from a specific region and time frame and thus may not be generalizable to other ancient Egyptian populations or broader ancient civilizations. Additionally, despite our meticulous examination, the preservation status of some remains might have affected the accuracy of our assessments, especially in cases of severe dental wear or decay. It's also worth noting that the interpretations of dietary habits and social class differences are largely speculative and are based on available archaeological and historical records, which might not capture the entirety of ancient lifestyle nuances.

In conclusion, our study successfully conducted an 'inter-cemetery comparison' of dental pathologies in ancient human remains from two co-localized burial sites in ancient Egypt, separated by nearly 1400 years and belonging to different social classes.[21] The findings provide valuable insights into the oral health status of these two populations, revealing differences in dental wear, caries frequency, and periodontitis assessment. Our results support the hypotheses that dental wear scores increase with age, distinct dental wear patterns exist between the two sites, and that assessing interdental septa offers a more accurate evaluation of periodontitis than measuring the alveolar bone-cementoenamel junction distance. Furthermore, a higher caries frequency was observed in the older age group of the more recent LP burial site, suggesting a relationship between caries frequency and social status. We hope to contribute to a better understanding of the oral health status of ancient populations, highlighting the impact of lifestyle, diet, and social factors on dental health. We also want to emphasize the importance of accurate methods for assessing periodontitis in studies on ancient human remains.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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