Dental disease and dietary patterns in coastal Phoenicia during the Roman period

Mahmoud Mardini[1], Ali Badawi[2,3], Tania Zaven[2], Raffi Gergian[2], Efthymia Nikita[1]

[1]Science and Technology in Archaeology and Culture Research Center, The Cyprus Institute, Nicosia, Cyprus
[2]Lebanese Directorate General of Antiquities, Beirut, Lebanon
[3]5th Branch, Faculty of Letters and Human Sciences, Lebanese University, Sidon, Lebanon

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Abstract
The current paper presents one of the first bioarchaeological studies on dental disease and dietary patterns in coastal Phoenicia during the Roman period, focusing on the dentition of 145 adults from the contemporary and geographically proximal sites of Byblos, Beirut, and Tyre. Pathological conditions of the oral cavity and dental wear were used to assess intra-assemblage and inter-assemblage differences. Byblos in almost all instances exhibited higher levels of dental diseases and wear than Beirut and Tyre, suggesting a greater consumption of carbohydrates but also poorer oral hygiene and greater mechanical stress (dental wear) in this community. This difference between Beirut/Tyre and Byblos may be explained by the politico-economic status of these cities as textual sources highlight the economic and political prowess of Beirut and Tyre due to their status as colonia. In addition, within each assemblage females generally exhibited higher caries (and associated periapical cavities and ante-mortem tooth loss) than males. Although dental caries may be linked to nondietary factors, these patterns may support a more cariogenic diet for females in agreement with literary accounts reciting gender-based divisions in Roman society, at least to the extent that these would manifest in dietary patterns. The findings from this study offer important insights into major and understudied communities along the Phoenician coast. Yet, further research is required, employing complementary methods (e.g., isotopic analysis and dental calculus microdebris) and including larger datasets of Roman Phoenician assemblages.

Keywords: ante-mortem tooth loss, dental calculus, dental caries, dental wear, historical bioarchaeology, Lebanon, periapical cavities, Roman Phoenicia

1. INTRODUCTION

The present paper evaluates various dental diseases and dental wear for 145 individuals from Roman-era Byblos, Beirut, and Tyre to explore potential distinctions in oral health and dietary practices along the highly urbanized and cosmopolitanized Phoenician coast. Dental diseases have been used extensively in bioarchaeological studies as proxies of past dietary patterns and food preparation methods, but also of differential access to food sources (Bertilsson et al., 2020; Buzon & Bombak, 2010; De Groote et al., 2018; Keenleyside, 2008; Pluciennik, 2001; Ullinger et al., 2015). The latter is particularly interesting as it means that the study of dental diseases may elucidate aspects of cultural dynamics because social status, gender, religion, ethnicity, and other factors have an impact on dietary choices (Rozin, 2006).

Bioarchaeological research has contributed greatly to our understanding of the dietary preferences of the Roman Empire's diverse population (Killgrove & Tykot, 2013). Nonetheless, emphasis has been traditionally given to the western empire with Rome at the center-stage, while almost no bioarchaeological palaeodietary studies have explicitly focused on coastal Phoenician cities during the Roman period. The only exception is the unpublished PhD thesis by Elias (2016), which examined the oral health of groups from Roman Berytus (modern-day Beirut) and Botrys (modern-day Batroun) as part of a broader bioarchaeological analysis, and demonstrated that individuals from Beirut exhibited good overall oral health with low frequency of dental pathologies and degree of dental macrowear.

1.1. Social status and nutrition in the Phoenician coast during the Roman period

While literary sources, inscriptions, legal code declarations, and archaeological evidence have reconstructed various aspects of the economic framework of coastal cities like Byblos, Beirut, and Tyre, there is little information on the dietary habits and consumption profile of the people living along the Phoenician coast. The epigraphic record and archaeological evidence show that Phoenician coastal communities derived their wealth from a variety of activities, including but not limited to (a) agricultural production and trade, (b) artisanal activities and trade, and (c) the Roman law school in Berytus (Hall, 2001; Jidejian, 1969; Joukowsky, 1992).

Literary evidence on the dietary profile of the local populace in the Phoenician coast includes mentions to some types of foodstuffs in addition to lists of crops (e.g., grapes, olives, wheat, barley, oats, and several varieties of legumes) being produced in different coastal cities (Hall, 2004). In addition, epigraphic evidence for Roman-era Phoenicia documents the existence of dietary and nutritional distinctions based on socio-economic factors. For example, the late antique bureaucrat Theophanes, who traveled from Antioch to Egypt in the 4th century AD, mentioned the types of bread and fresh produce sold in Beirut (Hall, 2004, p. 17). The list of fresh produce included wine, grapes, figs, peaches, apricots, and pumpkins/squashes, in addition to “pure white” bread for the officials and “coarse” bread for the servants.

For the Roman world more broadly, literary sources document the existence of differences between communities but also within communities in association with gender and social ranks (Revell, 2005). For instance, texts from the Roman period suggest that status differences between men and women may have affected diet; notably, men sometimes enjoyed “high status” foodstuffs, such as meat, fish, and other marine products (Beer, 2010). Other texts from historians in antiquity recommended different foods to men and women due to differences in energy and nutritional requirements between them (Garnsey, 1999). Bioarchaeological research, including stable isotope studies of Roman assemblages, has given mixed results as in some groups it has identified dietary differences between sexes, which may have had implications for the overall well-being (e.g., Moles et al., 2022), while in other cases no dietary differences were found between males and females or among other adult age groups (e.g., Dotsika & Michael, 2018). Given the variability that characterized the Roman world, it is important to examine diet and its implications in a context-specific manner.

Self-identification in the Phoenician coast during the Roman period was influenced by a multitude of factors including cultural, geographical, economic, social, religious, legal, and linguistic constructs, which combined to shape individual and group identities in coastal cities such as Beirut, Tyre, and Byblos (Hall, 2004). It is the aim of this study to explore dental diseases and an intra-assemblage and inter-assemblage level in order to disentangle aspects of these identities and their impact on past dietary patterns.

1.2. Dental diseases as palaeodietary proxies

Dental diseases have been used extensively in bioarchaeological studies as palaeodietary proxies. Similarly, dental macrowear can offer information on dietary processing and the presence of inclusions in food. In this section, we briefly present the key causative factors of the conditions examined in the current paper and their link to diet.

Dental calculus deposits are remnants of food debris, pollen, bacterial plaque, and other environmental materials, which accumulate in the deepest layers of living plaque (Lieverse, 1999) (Figure 1a). High alkalinity in the oral environment and diets rich in protein appear to facilitate calculus formation, but the condition is also affected by salivary flow rate, mineral and silicon content in food and water, plaque accumulation, and other factors (Lieverse, 1999). Therefore, the macroscopic study of calculus can give broad information on protein consumption, while microfossils extracted from dental calculus can aid in the reconstruction of past cultural practices, lifestyles, and human adaptation to changing environmental conditions (Buckley et al., 2014; Salazar-García et al., 2021).

Dental caries results from the progressive chemical dissolution of the dental hard tissues by acids released from the fermentation of carbohydrates by bacteria of the genus Streptococcus (Fejerskov et al., 2015) (Figure 1b). It is a process initiated particularly in the presence of sugars, thus providing insights into the consumption of carbohydrates (Lukacs, 2011). However, multiple factors, intrinsic and extrinsic, such as tooth morphology, age, sex, mouth pH, dental hygiene, and food preparation processes affect caries formation (Fejerskov et al., 2015).

Periapical cavities are recognized around the tooth roots and they belong to different types, such as abscesses, granulomas, and cysts (Dias & Tayles, 1997). Because of their similar clinical and radiographic appearance, distinguishing periapical granulomas, cysts, and abscesses can be difficult. This is particularly problematic in skeletal remains, where the lack of soft tissue components makes diagnosis even more difficult. One of the most frequent causes of periapical lesions is caries-induced infection of the pulp cavity. The pulp cavity may also be exposed to bacteria by severe attrition, resulting in infection. In human skeletal material, it can be difficult to determine the etiology of periapical lesions.

Antemortem tooth loss (AMTL) is the loss of teeth during the lifetime, and it is characterized by the resorption of alveolar bone and socket filling (Lukacs, 1989) (Figure 1c). It is difficult to identify the cause of AMTL when examining skeletal remains, but there is an association between AMTL and periodontal disease, carious lesions, abscesses, trauma, intense attrition, and scurvy, in addition to cultural or ritual ablation (e.g., purposeful extraction) (Lee et al., 2019; van der Merwe et al., 2011).

Dental macrowear is the progressive loss of dental hard tissues (Figure 1b) (Scott & Turner, 1988). It has been utilized by bioarchaeologists to examine dietary habits in skeletal assemblages under the premise that the mechanical and physical characteristics of consumed food will affect the chewing process and will manifest in the wear patterns seen on the tooth surfaces (Lee et al., 2019).

2. MATERIALS AND METHODS

This study encompasses 145 adult skeletons recovered from five archaeological sites in Byblos (71 skeletons), Beirut (32 skeletons), and Tyre (42 skeletons) (Figure 2). The assemblages from Byblos in Northern Lebanon were retrieved from the rescue excavation sites Byb-418 and Byb-470 by the Lebanese Department of Antiquities under the direction of Mrs. Tania Zaven and the scientific supervision of Mr. Georges Doumet. The sites delimited the fringes of the hinterland in Byblos and have been dated to the 1st–4th century AD (Zaven et al., 2023). The site of Ashrafiye-5313 was discovered in the eastern outskirts of the Roman city of Berytus (modern-day Beirut) and dates to the 1st–3rd century AD. Ashrafiye-5313 was excavated in the context of rescue excavations by the Lebanese Department of Antiquities under the direction of Dr. Raffi Gergian and the scientific supervision of Mr. Georges Doumet. Finally, rescue excavations of two sites from Tyre in Southern Lebanon (Tyre-1087 and Tyre-2036) were conducted under the direction of Dr. Ali Badawi, from the Lebanese Department of Antiquities and the Lebanese University (5th branch). The sites in Tyre have been also dated to the 1st–3rd century AD. As there was no contextual basis for assuming that these sites represent distinct communities, Byb-418 and Byb-470 were grouped together as “Byblos” and Tyre-1087 and Tyre-2036 were grouped together as “Tyre.”

The overall preservation of the skeletal remains was very good. All skeletal assemblages had moderate to excellent bone surface preservation (often >75% of the cortical bone surface was well preserved), with mild to no weathering. The degree of bone fragmentation was generally low, except for fragile skeletal elements such as the os coxae and crania. However, Beirut overall exhibited poorer preservation compared to Tyre and Byblos. Regarding teeth, which are the focus of this paper, the enamel was generally found to be intact, and there was no surface damage or deposits that might inhibit the recording of dental conditions. Dental disease frequencies were examined and are reported both at the tooth and individual levels in order to reduce any potential biases resulting from variations in post-mortem tooth loss.

The tombs used in the studied assemblages were typical of those commonly found in cemeteries along the Lebanese coast (De Jong, 2014-2015; Stuart& Curvers, 2013). The tombs included: (a) Pit-graves, which were either dug in the soil or cut into bedrock and covered with stone slabs; (b) cist-graves, in which the buried individuals were placed on a limestone platform or in a pit and then covered or roofed with limestone slabs; (c) limestone sarcophagi, which were rectangular stone enclosures carved out of local limestone and roofed with a single large slab of stone; (d) terracotta sarcophagi; (e) wooden coffins; (f) lead sarcophagi, which could be plain or decorated with intricate designs. Lead sarcophagi were found exclusively in Beirut, whereas terracotta sarcophagi were present only in Tyre and Beirut, and limestone sarcophagi were used in all three sites. Single inhumations were the predominant burial practice in all three sites, though Byblos had burials that featured multiple inhumations. The funerary practices in the three locations were typical of the urban communities living along Lebanon's coast and represented a blend of indigenous cultures, Hellenistic traditions, and Roman influences (De Jong, 2001).

All adults with at least one surviving tooth or socket were included in this study. Juveniles were eliminated because dental diseases and wear progress with increasing age, so their inclusion in the study would create a bias. In addition, the number of juveniles in the assemblages under study was particularly low, so even if they had been included, no reliable comparisons could have been drawn. The sex of all adults was estimated using a combination of morphological features. The pelvis was examined for physical characteristics that are typically used to distinguish the sexes, such as size and shape, as per the standards set by Bruzek (2002) and Phenice (1969). In addition, the skull was evaluated for sexually dimorphic traits, as outlined by Walker (2008). If neither cranial nor pelvic markers were available, bone measurements of metacarpals, metatarsals, and tali were used to infer sex, using standards developed specifically for Eastern Mediterranean populations (Manolis et al., 2009; Mountrakis et al., 2010; Nathena et al., 2017; Peckmann et al., 2015). Refer to Table S1 for a list of the bone measurements.

The categories suggested by Buikstra and Ubelakerm (1994) for adult age-at-death were adopted (young adult-YA: 18–35 years; middle adult-MA: 35–50 years, old adult-OA: over 50 years). Estimates of adult age-at-death were based on degenerative alterations to the pubic symphysis and iliac auricular surface (Brooks & Suchey, 1990; Buckberry & Chamberlain, 2002). The degree of closure of cranial sutures (Meindl & Lovejoy, 1985) and rib end morphological changes (Iscan et al., 1984) were used for age-at-death estimation in the absence of pelvic bones. Table 1 presents the demographic distribution of the sample under study from Tyre, Beirut, and Byblos, along with the number of alveoli and teeth by sex and age group.

Dental diseases were originally recorded according to their location and degree of expression, as detailed below. However, due to the rather small sample size, the recorded data (except for dental wear) were converted into dichotomous (presence/absence) scores prior to statistical analysis. Dental calculus was assessed based on the location, size, and thickness of the deposit following Dobney and Brothwell (1987). It is important to acknowledge that the frequent postmortem loss of dental calculus deposits represents a potential source of bias in bioarchaeological studies. Therefore, it is essential to approach the results with caution. We are currently exploring options for the microscopic analysis of the calculus deposits, in order to extract dietary and environmental debris from them, which will maximize the interpretative potential of this material. However, relevant analyses are still at a very early stage. Regarding caries, lesions were classified as carious if a discernable cavity in the enamel was present, unless this was the result of taphonomic agents. The location and degree of expression of carious lesions were recorded following Hillson (2001). Note that while Hillson (2001) also records enamel discolorations as an early caries stage, however, we decided to omit them in order to avoid misclassifying taphonomic damage (soil-related discolorations) as caries. The location, size, and wall texture of periapical cavities were recorded based on the method described by Dias and Tayles (1997). However, due to the small sample sizes and difficult diagnosis, no distinction was made between periapical granulomas, periodontal cysts, or periapical abscesses; instead, all lesions were analyzed collectively as periapical cavities. Ante-mortem tooth loss was considered to have occurred if there was any trace of remodeling in the socket or alveolar process of the missing tooth (Freeth, 2000). The overall degree of dental wear of each tooth was recorded following Smith's (1984) system for the incisors, canines, and premolars, and Scott's (1979) for the molars.

The frequency of each dental disease was estimated per individual and per tooth. Chi-squared or Fisher's exact tests were applied to examine the association between each condition, sex, and assemblage. Because dental wear was recorded in an ordinal scale, the Wilcoxon rank-sum test was used to compare inter-site and male–female values. All statistical analyses were performed using the free statistical software R (version 4.0.0). Statistical significance was set at $\alpha = 0.05$. Because the age-progressive nature of dental diseases and wear may cause biases when comparing groups with different demographic structures, we ran the statistical tests both for pooled age groups and separately for young adults (which were the largest age category in the sample).

3. RESULTS

3.1. Inter-site patterns

Calculus was most frequent in Byblos, followed by Tyre, while Beirut showed a much lower frequency, both when the frequencies were estimated per individual (Byblos: 57.7%, Tyre: 52.4%, Beirut: 9.4%; Tables 2–4) and per tooth (Byblos: 22.2%, Tyre: 16.7%, Beirut: 3.4%; Table S2). When analyzing these data per individual, the difference between Beirut on the one hand and Byblos and Tyre on the other was statistically significant for males whether all age groups were pooled or only young adults were examined (Table S5). The same applied for the comparison between Beirut and Byblos for females, but now the comparison between Tyre and Beirut was significant for pooled age groups, whereas the comparison between Tyre and Byblos emerged as significant among young adults (Table S5). When analyzing the data per tooth, all inter-site comparisons were statistically significant for both sexes, except for Tyre vs Beirut for females when pooling all age groups (Table S6). When performing the inter-site comparisons per tooth type, mandibular teeth were the only ones exhibiting patterns of significant difference (Tables S3 and S9).

Dental caries was moderately frequent in Tyre (42.9%) and Beirut (31.3%) per individual, and very frequent in Byblos (71.8%) (Tables 2–4). The same relative pattern among sites is attested per tooth (Byblos: 11.3%; Tyre: 4.4%; Beirut: 3.8%), although all frequencies decrease notably (Table S2). None of the comparisons between Tyre and Beirut was statistically significant. In contrast, Byblos always exhibited significantly higher frequencies compared to the other two sites (Tables S5 and S6). When examining caries per tooth type, only the molars exhibited significant patterns (Tables S3 and S9).

The frequency of periapical cavities was moderate in Byblos (29.6%), and low in Beirut (12.5%) and Tyre (11.9%) (Tables 2–4). The condition was almost negligible in all assemblages when its frequency was estimated per alveolus (Byblos: 1.8%, Beirut: 1.3%, Tyre: 1%) (Table S2). For pooled age groups, no significant difference was identified between sites either for males or females, whether analyzing the condition per individual or per alveolus. When focusing exclusively on young adults, significant differences were seen between Byblos and Tyre (Tables S5 and S6). No significant differences were found when the comparisons were performed per tooth type (Tables S3 and S9).

In Byblos, 76.1% of the individuals had lost at least one tooth during their lifetime, compared to Tyre's 33.3% and Beirut's 28.1% (Tables 2–4). AMTL followed the same relative trend when estimated per alveolus, though the frequencies now were much lower (Byblos: 25.2%, Tyre: 11%, Beirut: 6.7%) (Table S2). When examining this condition per individual, the difference between Byblos on the one hand and Tyre and Beirut on the other was statistically significant, both when pooling age groups and when testing only young adults, for males, whereas for females only the comparison between Byblos and Tyre was significant for pooled age groups and the comparison between Beirut and Byblos for young adults (Table S5). When using alveolus frequencies, all inter-site comparisons reached statistical significance except for young adult males and females between Tyre and Beirut (Table S6). Performing the intersite comparisons per tooth type showed that most significant differences involved the posterior teeth and the maxilla (Tables S3 and S9).

As for dental wear, in the pooled age groups, Byblos had the highest wear scores, with Beirut and Tyre having lower average scores (Tables 5 and S4). Males from Byblos and Tyre showed significant wear differences in most maxillary and mandibular teeth (Table S10). Significant wear differences between males from Beirut and Tyre were mostly present in the maxillary anterior teeth and premolars, while Byblos and Beirut showed a single statistically significant difference in the left mandibular M2 (Table S10).

Females exhibited no wear differences except for the right mandibular M1 and left maxillary M3 when comparing Beirut and Tyre, and the right mandibular M1 when comparing Byblos and Beirut (Table S10). When dental wear patterns were compared among sites focusing only on young adults, a greater distinction was seen between the males and females from Byblos and Tyre in multiple maxillary and mandibular teeth, as well as between females from Beirut and Byblos in the posterior maxillary and mandibular teeth, while the anterior teeth and premolars of males between Tyre and Beirut also showed multiple significant differences (Table S11). It must be noted that in Table S11, the right and left teeth have been combined to enhance the sample size, otherwise the statistical comparisons would have been based on very small numbers of teeth.

3.2. Sex differences

The frequency of dental calculus was very similar in males and females per site (Tyre: M-54%, F-50%; Beirut: M-8.3%, F-10%; Byblos: M-57.5%, F-58%) (Tables 2–4). None of the sex differences was statistically significant (Table S7). This similarity also characterized the frequencies per tooth (Tyre: M-18%, F-14%; Beirut: M-4.2%, F-3.2%; Byblos: M-22.9%, F-21.3%) (Table S2). Now, the comparison between males and females identified a significant difference between young adults from Beirut (M: 0%, F: 4.6%; $\chi2 = 5.675$, $p = 0.01$) (Table S8). When exploring sex differences in dental calculus frequency per tooth type (Table S3), no significant difference was found.

Both per individual and per tooth, Byblos and Tyre had overall similar caries frequencies for males and females (Tyre: M-41.6%, F-44.4%; Byblos: M-72.5%, F-70.9%), while females in Beirut were more often afflicted by caries than males (M-16.7%, F-40%) (Tables 2–4). Per individual, there was a significant difference only between young adult males and females from Tyre (M: 31.3%, F: 0%; Fisher's test; $p = 0.05$) (Table S7). Per tooth, there was a significant difference between males and females when pooling age groups from Tyre (M: 3%, F: 7.2%; $\chi2 = 6.889$; $p = 0.01$), Beirut (M: 1.6%, F: 5%; Fisher's test; $p = 0.05$), and Byblos (M: 9.6%, F: 13.8%; $\chi2 = 4.785$; $p = 0.03$), as well as between young adult males and females from Byblos (M: 8.5%, F: 14.1%; $\chi2 = 5.087$; $p = 0.02$) (Table S8). Per tooth type (Table S3), the only significant difference between sexes was identified for the mandibular M1 from Byblos (M: 7.3%, F: 31.6%; $\chi2 = 4.388$; $p = 0.03$).

The frequency of periapical cavities in all three sites was higher in females when examined per individual and per alveolus (individual frequencies: Tyre M-8.3%, F-16.7%; Beirut M-8.3%, F-15%; Byblos M-20%, F-41.9%; alveolar frequencies: Tyre M-0.7%, F-1.3%; Beirut M-1%, F-1.4%; Byblos M-1.2%, F-2.7%) (Tables 2–4 and S2). However, the only significant sex difference was traced for Byblos when pooling age groups (per individual: $\chi2 = 4.035$; $p = 0.04$; per alveolus: $\chi2 = 4.625$; $p = 0.03$) (Tables S7 and S8).

In terms of AMTL, females were more affected in Tyre and Beirut, while males were more affected in Byblos (individual frequencies: Tyre: M-25%, F-44%; Beirut: M-16.7%, F-35%; Byblos: M-87.5%, F-61.3%; alveolar frequencies: Tyre: M-7.8%, F-16.7%; Beirut: M-3.1%, F-8.7%; Byblos: M-26.6%, F-22.9%) (Tables 2–4 and S2). When examining AMTL per individual, the only statistically significant difference between males and females was found in Byblos for pooled age groups ($\chi2 = 6.588$; $p = 0.01$) (Table S7). When examining AMTL per alveolus, Tyre ($\chi2 = 15.538$; $p < 0.0001$) and Beirut ($\chi2 = 6.339$; $p = 0.01$) were the ones showing significant differences for pooled age groups (Table S8). Per tooth type, only the mandibular M1 from Tyre showed a significant difference between males and females (Fisher's test; $p = 0.007$).

Males from Byblos and Beirut often had higher average wear scores than females, but this pattern was reversed in Tyre, where females showed greater wear scores (Table S4). Potential biases may arise from the differential preservation of teeth, but as can be seen in Table S4, where the dental wear is given by sex, age, and tooth type, males consistently have higher average wear scores than females. This pattern holds true for both maxillary and mandibular anterior and posterior teeth, with few exceptions. The only significant difference between the sexes was in the mandibular P3 at Tyre ($W = 45.5$, $p = 0.04$). For young adults, a similar pattern was observed, but the only significant differences between males and females were in Byblos for mandibular M3 ($W = 81.5$; $p = 0.01$) and maxillary P3 ($W = 238.5$; $p = 0.02$) (Table S11).

4. DISCUSSION

In the Roman period, Beirut (colonia Iulia Augusta Felix Berytus) and Tyre (colonia Septimia Tyrus) were major administrative and commercial centers along the Levantine coast, and by the late Roman period, they were characterized by high degrees of urbanization. Being regarded as microcosms of the Roman government, Beirut and Tyre adapted accordingly their political organization, religious activities, and entertainment functions and were characterized by a cosmopolitan environment with a great deal of diversity in terms of linguistics, politics, culture, and religion (Hall, 2004; Paturel, 2019). In addition, the city of Berytus, settled by the veterans of the Battle of Actium, was known as “the mother of laws” for establishing one of six law schools in the Greek East, which educated a large number of local and foreign legal, administrative, and religious officials (Mouterde, 1925, p. 88; Pharr, 1939, p. 261). Although archaeological evidence from Byblos indicates that the city prospered and was part of the highly urbanized network during the Roman period, it was largely overshadowed by its coastal neighbors, Beirut and Tyre. Byblos was not credited as a colonia neither was it politically and financially as stable as Tyre and Beirut during the Roman period; however, it was frequently referenced in literary sources as having participated in the same production activities as the two main coastal cities. For instance, the expositio totius mundi et gentium, written by an unknown author, attests to Byblos' large-scale participation in the Phoenician textile industry and wine production (Hall, 2004, p. 27).

The current bioarchaeological study focused on dietary patterns within and between these three Phoenician cities as food is affected by cultural, economic, and environmental factors. As shown in Section 3, all dental conditions examined (calculus, caries, periapical cavities, AMTL) generally exhibited the highest frequencies in the assemblage from Byblos and the lowest frequencies in Beirut. These differences, especially between Byblos and the other two sites, were very often statistically significant. For dental wear, Byblos was again the assemblage exhibiting the highest scores. For males, many of the differences between Byblos and Tyre but also Beirut and Tyre were statistically significant, while females from the three sites rarely differed significantly in dental wear scores. These patterns highlight that diet was different in Byblos compared to Beirut and Tyre, reflecting the abovementioned sociopolitical distinctions between these cities. In particular, the diet in Byblos was more cariogenic and/or dental hygiene practices were poorer in this coastal Phoenician city. Finally, the higher degree of dental wear in Byblos may relate to the consumption of less processed and lower quality foods.

In what concerns gender divisions (though acknowledging that our skeletal data refer to sex and this may not always equate with gender), the frequency of dental calculus was very similar in males and females in all cities. Caries frequencies were also comparable between males and females in Byblos and Tyre but higher in females in Beirut; however, in all cases where significant differences were identified in all three sites, females were most commonly affected by the carious lesions. Similarly, periapical cavities were more frequent in females in all three sites. Finally, in terms of AMTL, females were more affected than males in Tyre and Beirut, while males were more affected than females in Byblos. These patterns suggest a similar intake of protein-rich foodstuffs (e.g., meat, dairy, and marine fauna) between males and females but higher consumption of carbohydrates among females in all sites. The higher affliction of females by caries characterizes several modern and historical populations (Lukacs, 2011; Shaffer et al., 2015; Vergidou et al., 2021). However, additionally to dietary practices, this pattern has also been linked to physiological variations between males and females (e.g., different reproductive and physiological systems) (Ferraro & Vieira, 2010; Lukacs, 2011). The most common presence of periapical cavities and AMTL in females is also likely linked to the higher frequency of caries in this demographic, as periapical cavities and AMTL are often the result of carious lesions. The most common affliction of males by AMTL in Byblos, contradicts the above pattern and may suggest a different etiology for some of the lost teeth (e.g., tooth wear). Indeed, males from Byblos and Beirut often had higher average wear scores than females, whereas in Tyre females showed greater wear scores. Nonetheless, the only significant difference between sexes was found for a single tooth type (P3) at Tyre, supporting actually minimal differences in dental wear between sexes. These results partly agree and partly contradict Roman literary sources that support the presence of dietary differences between men and women, whereby the former had greater access to high-quality foodstuffs. Similarly, they partly agree and partly contradict published isotopic studies suggesting that the dietary patterns between males and females in the Graeco-Roman world were broadly comparable (Keenleyside et al., 2006, 2009).

Despite the geographic proximity between Tyre, Beirut, and Byblos, our study indicates that these socially and politically heterogeneous communities on the Phoenician coast experienced different dietary habits and associated lifestyles. This difference is particularly marked between Byblos on the one hand and Beirut and Tyre on the other. Although historical and archaeological evidence indicate that Byblos was a prominent city on the Phoenician coast during the Roman period, it may not have been as significant as other cities like Beirut and Tyre, as suggested by our findings of a diet high in cariogenic foods and/or poor oral hygiene practices among the population. These results complement those of a previous study by our team where, using pairwise interindividual biodistances, we found that the population at Byblos was less heterogeneous compared to Tyre and Beirut and rather distinct from that of the other two assemblages, supporting different patterns of regional mobility (Mardini et al., 2023). In respect to intra-site male–female differences, diets were characterized by a higher consumption of carbohydrates by the latter, though other contributing factors to higher caries rates in females cannot be excluded.

Regarding the current study's limitations, more research on diet and oral pathologies in Roman Phoenicia and the region is needed before the results can be generalized. In this direction, further investigations utilizing stable isotope analysis and dental calculus microdebris as well as analysis of dental microwear can advance our understanding of the observed patterns of dental pathology between males and females and along the Lebanese coast during the Roman period. Understanding the diversity of ancient human diets requires reconstructing local nutritional histories that take into consideration cultural, environmental, and temporal changes. The current study is an initial but decisive step in this direction.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

All data are given in the manuscript tables and in the supporting information tables.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

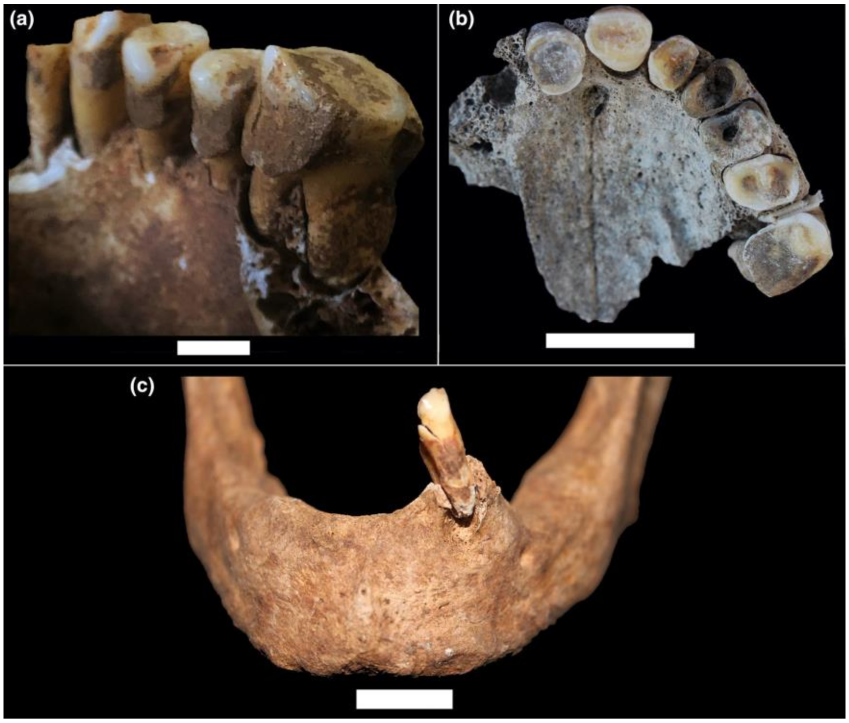

FIGURE 1. (a) Dental calculus deposits covering a large part of the mandibular crowns of the right premolars and first molar in a middle-aged male from Byb-418 (scale: 1 cm); (b) extensive wear on all maxillary teeth in addition to carious lesions on the left canine and first premolar of a middle-aged female from Tyr-1087 (scale: 2 cm); (c) antemortem tooth loss of all mandibular teeth except the left canine, and complete resorption of the alveolar bone in a middle-aged female from Byb-418 (scale: 2 cm).

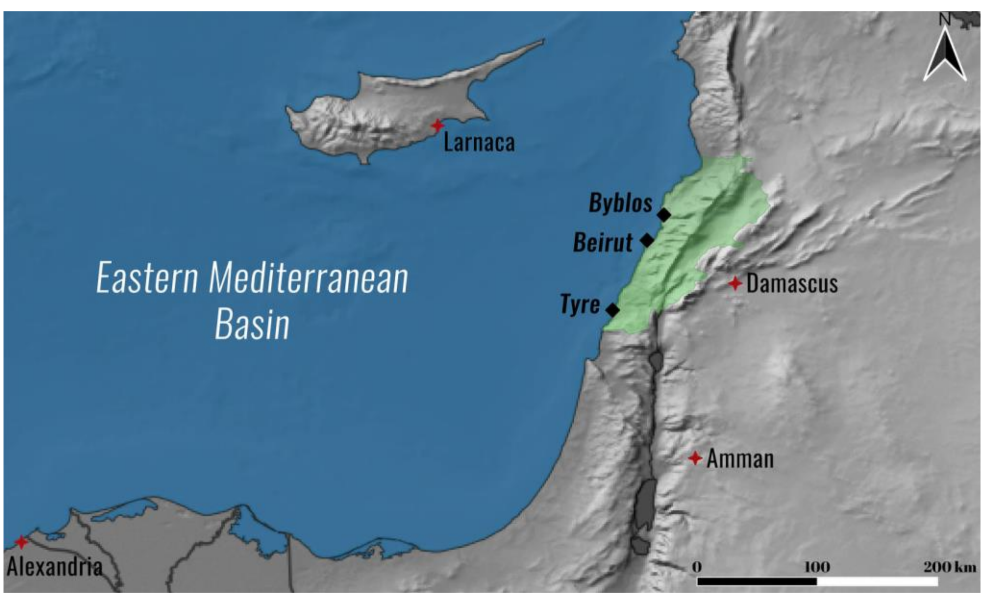

FIGURE 2. Location of Tyre, Beirut, and Byblos within the Eastern Mediterranean basin. Map created by the first author using open-source QGIS and vector map of Gray Earth 1:10 m (https://www.naturalearthdata.com/downloads/10m-raster-data/10m-gray-earth/).

TABLE 1. Age and sex distribution of the sample and number of examined teeth/alveoli.

Tyre									
	Number of individuals			Number of alveoli			Number of teeth		
Age categories	M	F	Total	M	F	Total	M	F	Total
YA	16	11	27	328	135	463	321	133	454
MA	6	5	11	164	102	266	130	73	203
OA	1	2	3	30	62	92	29	43	72
A	1	0	1	15	0	15	15	0	15
Total	24	18	42	537	299	836	495	249	744
Beirut									
	Number of individuals			Number of alveoli			Number of teeth		
Age categories	M	F	Total	M	F	Total	M	F	Total
YA	7	13	20	119	242	361	119	238	357
MA	5	6	11	76	112	188	70	104	174
OA	0	1	1	0	3	3	0	1	1
A	0	0	0	0	0	0	0	0	0
Total	12	20	32	195	357	552	189	343	532
Byblos									
	Number of individuals			Number of alveoli			Number of teeth		
Age categories	M	F	Total	M	F	Total	M	F	Total
YA	17	16	33	400	316	716	354	276	630
MA	15	11	26	357	223	580	238	133	371
OA	7	1	8	155	10	165	76	10	86
A	1	3	4	19	52	71	19	46	65
Total	40	31	71	931	601	1532	687	465	1152
Combined									
	Number of individuals			Number of alveoli			Number of teeth		
Age categories	M	F	Total	M	F	Total	M	F	Total
YA	40	40	80	847	693	1540	794	647	1441
MA	26	22	48	597	437	1034	438	310	748
OA	8	4	12	185	75	260	105	54	159
A	2	3	5	34	52	86	34	46	80
Total	76	69	145	1663	1257	2920	1371	1057	2428

Note: Key: M: Male; F: Female; YA: Young adult; MA: Middle adult; OA: Old adult; A: Adult

TABLE 2. Frequency of affected teeth by age and sex per individual—Tyre.

	M	**F**	**Total**	**M**	**F**	**Total**
Age groups	**Calculus**			**AMTL**		
YA	7/16 (43.8%)	3/11 (27.3%)	10/27 (37%)	3/16 (18.8%)	2/11 (18.2%)	5/27 (18.52%)
MA	4/6 (66.7%)	4/5 (80%)	8/11 (72.7%)	2/6 (33.3%)	4/5 (80%)	6/11 (54.55%)
OA	1/1 (100%)	2/2 (100%)	3/3 (100%)	1/1 (100%)	2/2 (100%)	3/3 (100%)
A	1/1 (100%)	-	1/1 (100%)	0/1 (0%)	-	0/1 (0%)
Total	13/24 (54%)	9/18 (50%)	22/42 (52.4%)	6/24 (25%)	8/18 (44%)	14/42 (33.3%)
	Caries			**Periapical cavities**		
YA	5/16 (31.3%)	0/11 (0%)	6/27 (22.2%)	0/16 (0%)	0/11 (0%)	0/27 (0%)
MA	4/6 (66.7%)	5/5 (100%)	9/11 (81.8%)	1/6 (16.7%)	2/5 (40%)	3/11 (27.3%)
OA	0/1 (0%)	2/2 (100%)	2/3 (66.7%)	1/1 (100%)	1/2 (50%)	2/3 (66.7%)
A	1/1 (100%)	-	1/1 (100%)	0/1 (0%)	-	0/1 (0%)
Total	10/24 (41.6%)	8/18 (44.4%)	18/42 (42.9%)	2/24 (8.3%)	3/18 (16.7%)	5/42 (11.9%)

TABLE 3. Frequency of affected teeth by age and sex per individual— Age groups Beirut.

	M	**F**	**Total**	**M**	**F**	**Total**
Age groups	**Calculus**			**AMTL**		
YA	0/7 (0%)	2/13 (15.4%)	2/20 (10%)	0/7 (0%)	2/13 (15.4%)	2/20 (10%)
MA	1/5 (20%)	0/6 (0%)	1/11 (9.1%)	2/5 (40%)	4/6 (66.7%)	6/11 (54.6%)
OA	-	0/1 (0%)	0/1 (0%)	-	1/1 (100%)	1/1 (100%)
A	-	-	-	-	-	-
Total	1/12 (8.3%)	2/20 (10%)	3/32 (9.4%)	2/12 (16.7%)	7/20 (35%)	9/32 (28.1%)
	Caries			**Periapical cavities**		
YA	1/7 (14.3%)	5/13 (38.5%)	6/20 (30%)	0/7 (0%)	1/13 (7.7%)	1/20 (5%)
MA	1/5 (20%)	2/6 (33.3%)	3/11 (27.3%)	1/5 (20%)	1/6 (16.7%)	2/11 (18.2%)
OA	-	1/1 (100%)	1/1 (100%)	-	1/1 (100%)	1/1 (100%)
A	-	-	-	-	-	-
Total	2/12 (16.7%)	8/20 (40%)	10/32 (31.3%)	1/12 (8.3%)	3/20 (15%)	4/32 (12.5%)

TABLE 4. Frequency of affected teeth by age and sex per individual— Age groups Byblos.

	M	**F**	**Total**	**M**	**F**	**Total**
Age groups	**Calculus**			**AMTL**		
YA	11/17 (64.7%)	12/16 (75%)	23/33 (69.7%)	14/17 (8.2%)	9/16 (56.3%)	23/33 (69.7%)
MA	9/15 (60%)	5/11 (45.5%)	14/26 (53.8%)	15/15 (100%)	9/11 (81.8%)	24/26 (92.3%)
OA	2/7 (28.6%)	1/1 (100%)	3/8 (37.5%)	6/7 (85.7%)	0/1 (0%)	6/8 (75%)
Total	23/40 (57.5%)	18/31 (58%)	41/71 (57.7%)	35/40 (87.5%)	19/31 (61.3%)	54/71 (76.1%)
	Caries			**Periapical cavities**		
YA	12/17 (70.6%)	12/16 (75%)	24/33 (72.7%)	5/17 (29.4%)	6/16 (37.5%)	11/33 (33.3%)
MA	13/15 (88.7%)	7/11 (63.6%)	20/26 (76.9%)	2/15 (13.3%)	7/11 (63.6%)	9/26 (34.6%)
OA	3/7 (42.9%)	1/1 (100%)	4/8 (50%)	1/7 (14.3%)	0/1 (0%)	1/8 (12.5%)
A	1/1 (100%)	2/3 (66.7%)	3/4 (75%)	0/1 (0%)	0/3 (0%)	0/4 (0%)
Total	29/40 (72.5%)	22/31 (70.9%)	51/71 (71.8%)	8/40 (20%)	13/31 (41.9%)	21/71 (29.6%)

TABLE 5. Average tooth wear scores per jaw, tooth type, and side.

Tooth	Side	Tyre			Beirut			Byblos		
Mandible		N	WS	ASP	N	WS	ASP	N	WS	ASP
I1	R	23	3.39	3.40	19	4.07	3.83	41	3.69	3.83
	L	20	3.40		18	3.57		38	3.97	
I2	R	21	2.86	3.07	18	3.60	3.43	41	3.43	3.46
	L	23	3.26		17	3.23		41	3.49	
C	R	25	2.96	3.12	21	3.12	3.22	50	3.48	3.56
	L	26	3.27		20	3.33		52	3.63	
P3	R	28	2.39	2.48	20	3.27	3.26	49	3.29	3.22
	L	28	2.57		21	3.25		53	3.16	
P4	R	25	2.32	2.22	22	2.76	2.80	42	3.20	3.08
	L	26	2.12		22	2.83		45	2.98	
M1	R	24	18.42	17.96	26	15.86	16.53	38	19.59	19.79
	L	22	17.43		23	17.35		41	19.98	
M2	R	25	13.92	13.59	23	13.79	13.36	37	17.68	17.35
	L	26	13.27		20	12.79		49	17.10	
M3	R	19	8.94	9.58	15	10.57	10.43	28	14.59	15.18
	L	18	10.22		9	10.14		29	15.75	
Maxilla		N	WS	ASP	N	WS	ASP	N	WS	ASP
I1	R	23	3.26	3.02	13	4.50	4.04	27	4.17	3.98
	L	22	2.77		13	3.62		24	3.74	
I2	R	24	2.33	2.50	12	3.42	3.19	27	2.96	3.00
	L	24	2.67		10	2.89		32	3.03	
C	R	25	3.00	3.10	18	3.38	3.33	36	3.53	3.48
	L	25	3.20		14	3.27		29	3.41	
P3	R	27	2.42	2.29	14	2.83	2.77	29	2.80	2.83
	L	23	2.13		12	2.70		34	2.87	
P4	R	25	2.20	2.16	15	2.83	2.78	38	2.88	3.02
	L	24	2.13		13	2.73		31	3.19	
M1	R	25	16.32	16.86	16	16.92	16.36	25	19.26	19.41
	L	24	17.42		16	15.75		33	19.55	
M2	R	26	11.42	11.78	16	12.75	12.83	40	15.19	15.94
	L	24	12.17		15	12.91		31	16.96	
M3	R	12	5.83	6.42	10	8.70	8.81	21	11.67	12.62
	L	12	7.00		11	8.91		21	13.53	

Note: Key: N = Number of teeth; ASP = Average score-pooled; WS = Wear score