A community in transition: Analysis of health and well-being in people living during and following aridification

Alyson C. Caine[1,2], Charlotte A. Roberts[3], Derek Kennet[3]

[1] Department of Anthropology and Heritage Studies, University of California, Merced, CA
[2] Current Address: University of California, Merced, UC Merced, 5200 N. Lake Rd. Merced, CA 95343, USA (acaine@ucmerced.edu)
[3] Department of Archaeology, Durham University, South Road, Durham, DH1 3LE, England (c.a.roberts@durtham.ac.uk; derek.kennet@durham.ac.uk)

***Correspondence to:** Alyson C. Caine, MSc, Interdisciplinary Humanities Graduate Group, School of Social Sciences, Humanities, and Arts, UC Merced, 5200 N. Lake Rd. Merced, CA 95343, USA (acaine@ucmerced.edu**)**

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Abstract

Objectives: This paper considers skeletal and dental lesions to assess the effects of aridification on two skeletal samples from the Bronze Age in what is now the United Arab Emirates (UAE), located on the eastern end of the Arabian Peninsula. This paper hypothesized that the sample from QAH tomb 6 would show a greater prevalence of skeletal and dental lesions in comparison to that from QAH tomb 5, because QAH tomb 6 dates to a period of aridification when compared to the wetter Wadi Suq period (~2000 B.C.).
Materials: The skeletal remains from two tombs from Qarn al-Harf (QAH) cemetery are studied: one dated to the transition period from the Umm an-Nar to Wadi Suq period (~ 2000 B.C.) – tomb 6 (n=141) and one Wadi Suq period tomb (tomb 5, n=44;2000–1600 B.C.).
Methods: Skeletal and dental lesions, including carious lesions, antemortem tooth loss, dental enamel hypoplasia, periosteal new bone formation, cribra orbitalia, and porotic hyperostosis, were recorded and used to assess differential lived experience. Findings from the two tombs are compared with five contemporary sites of the Umm an-Nar and Wadi Suq periods.
Results: Fisher's exact tests found statistically significant differences in the prevalence of cribra orbitalia ($p=0.0050$) and non-adult mortality ($p=0.0118$) for the QAH tomb 6 skeletal sample than that from QAH tomb 5. No other skeletal or dental lesions were significantly different according to Fisher's exact tests.
Discussion: While not significant, periosteal new bone formation rates in QAH 6 in conjunction with cribra orbitalia rates suggests individuals were experiencing stressors that were not impacting QAH tomb 5 individuals. Skeletal and dental lesion rates are not directly attributable to climate change; however, we argue that intense aridification around 2000 B.C. caused desiccated crops and an increased reliance on marine sources for QAH tomb 6. This reliance likely promoted nutritionally deficient diets manifesting as observed higher rates of cribra orbitalia and periosteal new bone formation.

Introduction

Climate change—long term environmental alterations—is an existential crisis for living populations which is forcing many across the globe to rethink habitable spaces (Heslin et al., 2019; Islam and Khan, 2018; Moser et al., 2012; Storlazzi et al., 2015). However, climate change and human behavior have long influenced one another and has been studied through the archaeological record (Cheung et al., 2019; Parker, 2010; Parker and Rose, 2008; Preston et al., 2012; Staubwasser et al., 2003; Schug, 2011; Schug, 2021). For example, the first epidemiological transition, which occurred approximately 10,000 years ago, saw populations adapting to more stable environments, and transitioning to farming and sedentary lifestyles from hunting and foraging for food. This had consequences for the well-being of communities, including a greater potential for infectious diseases, famines, and violence (Crane-Kramer and Cohen, 2007; Harrod and Martin, 2014; Hassan, 2016:40; Goodman et al., 1988; Lambert, 2009; Roberts, 2021; Steckel and Rose, 2002). For example, adaptations to climate change, while necessary for survival, increased trade to compensate for lost crops/livestock or led to moving to new environmentally-beneficial regions (Arriaza et al., 2010; Gregoricka, 2016; Gregoricka, 2021). These adaptations present a unique opportunity for bioarchaeologists to study the impact of climate change on health and well-being in the past, providing insight into the biological, social, and economic consequences for living populations.

Various bioarchaeological methods have been used to assess the impacts of climate change on skeletal remains, including those involving biogeochemistry (Gregoricka, 2016; Gregoricka, 2021), mortality and fertility rates (Berger and Wang, 2017), rates of violence (Harrod and Martin, 2014), and skeletal indicators of stress, including stature, periosteal new bone formation (PNBF), carious lesions (Cheung et al., 2019), and dental enamel hypoplasia (DEH; Berger and Wang, 2017; Schug, 2011; Schug and Blevins, 2016). While climate change can have consequences for health, social inequality and economic changes are also concomitant factors that complicate inferring the specific etiology of those consequences (Berger and Wang, 2017; Schug, 2011; Schug and Blevins, 2016). Bioarchaeological studies have thus highlighted the difficulty in parsing consequences associated with climate change and those resulting from economic or cultural changes, particularly because climate change is frequently observed in connection with those very cultural and economic changes (Hassan, 2016:40; Martin, 2007; Schug, 2011; Weiss et al., 1993). However, bioarchaeological studies of adaptations of people living where long-term environmental changes have occurred presents the opportunity to better understand those responses to climate change (Martin, 2007).

This paper argues that aridification at the end of the Umm an-Nar period (~2000 B.C.) resulted in differential experiences for individuals living during the transition from the Umm an-Nar to the Wadi Suq period (~2000) compared to those living squarely in the Wadi Suq period (~1900-1600 B.C.). Individuals from the Qarn al-Harf (QAH) cemetery in Ra's al-Khaimah (Figure 1), one of seven modern day emirates in the United Arab Emirates (UAE), present an important opportunity to investigate this hypothesis by recording skeletal and dental lesions in response to climate change between the two tombs, QAH tomb 5 and 6, predominantly represent two distinct climatic phases (Table 1). Aridification at the transition between the Umm an-Nar and Wadi Suq period would result in a dry climate for QAH tomb 6; however, QAH tomb 5 which is dater to later in the Wadi Suq period would have a wetter climate with more regular rains (Parker et al., 2006). To contextualize any differences observed between QAH tomb 5 and 6, five archaeological sites from the Umm an-Nar (2500–2000 B.C.) and Wadi Suq (2000–1600

B.C.) periods are used as comparators, and include Sharm (Wadi Suq), Shimal tombs 102 and 103 (Wadi Suq), Shimal tombs UNar 1 and UNar 2 (Umm an-Nar), al-Sufouh (Umm an-Nar), Hili (Umm an-Nar), and Mowaihat (Umm an-Nar; Table 2). These five archaeological sites are represented in the published literature as a result of research conducted in the UAE (Figure 1) and represent expected patterns for pathological alterations for individuals living during the Umm an-Nar and Wadi Suq periods, although localized variations need to be taken into consideration. We hypothesize that individuals interred in QAH tomb 6, the construction of which is dated to the transition between the Umm an-Nar and Wadi Suq periods (~2000 B.C.; de Vreeze, 2016), experienced more stress, manifested skeletally as carious lesions, antemortem tooth loss (AMTL), DEH, PNBF, porotic hyperostosis (PH), and cribra orbitalia (CO). In comparison, individuals interred in QAH tomb 5, which reflects individuals living during the wetter phase of the Wadi Suq period, experienced less stress and fewer carious lesions, AMTL, DEH, PNBF, PH, and CO in their skeletal remains.

Figure 1 Location map of research area, Ra's al-Khaimah, UAE, with all the sites from the study marked with white dots.

Table 1 Skeletal Samples from the QAH cemetery

Table 2 UAE comparator sites used in the study from the Umm an-Nar and Wadi Suq periods

Table 3 Umm an-Nar and Wadi Suq period tombs from the UAE. Key: DE – diagnostic elements; *MNI calculation is not clear in citation

Background

This section contains background information to relevant climate data for this study, and a consideration of the range of stress markers identified in the skeleton, and their potential causes, with separate dialogues on stressors affecting the teeth and bones.

Climate Context of the Bronze Age in the Arabian Peninsula

Since 10,000 cal yr BP, climatic shifts across the Arabian Peninsula have impacted human activity, including settlement and subsistence practices (Preston et al., 2012; Parker et al., 2006; Parker and Goudie, 2008; Parker and Rose, 2008; Rosenberg et al., 2011; Parker, 2010; Potts, 2009). Indeed, they continue to impact the UAE which has had an arid climate with an average of 107.7 mm of rain fall annually over the last 45 years (Sherif et al., 2014). Precipitation fluctuations from the south-west Indian Ocean Monsoon system have influenced these climate shifts and are supported by palaeoecological data, including that from phytoliths, paleolakes, and archaeological sites (Parker et al., 2004; Preston et al., 2012). Climate changes in Ra's al-Khaimah are well documented through data from the Awafi paleolake, for which sediment sequences highlight variability in climatic shifts and the importance of short-term climate changes on ecology and human occupation in the northern UAE (Fleitmann et al., 2007; Parker et al., 2006; Parker et al., 2004). During the Bronze Age, for example, it has been argued that climate change coincides with cultural shifts, including the advent of date palm cultivation (Al-Jahwari, 2009; Méry, 2013), fishing practices that include offshore large species (Beech, 2003), changes in trade networks (Cleuziou and Méry, 2002; Cleuziou and Tosi, 2021), and rises and falls in population numbers (Magee, 2014). The Hafit Period (3200-2500 B.C.), characterized by increased evidence of human activity including settlements and above ground stone tombs, marks a shift to more pluvial conditions and increased precipitation that followed an extended period of aridity in the region (Preston et al., 2012). These pluvial conditions continued into the Umm an-Nar period (2500-2000 B.C.), during which mortuary complexes, regional exchange networks, and agricultural practices flourished, as evidenced by archaeobotanical and archaeological remains, including foreign materials and large communal mortuary complexes (Cleuziou and Méry, 2002; Cleuziou and Tosi, 2021; Parker and Rose, 2008; Potts, 2003; Potts, 2009). However, declining trade contacts, fewer known settlements, changes to mortuary practice, and changes in subsistence practices, characterize the subsequent Wadi Suq period (2000-1650 B.C.; Beech, 2003; Carter 1997a; Carter, 1997b; Gregoricka, 2016; Potts, 2009). While scholars debate the primary cause of these major cultural and economic changes, the transition from the Umm an-Nar to Wadi Suq period (~2000 B.C.) coincides approximately with the retreat of the Indian Ocean Monsoon which reduced rainfall and led to intense aridification across much of the Middle East[1] (Cleuziou and Tosi, 2021; Méry, 2013; Parker et al., 2006; Parker and Goudie, 2008; Staubwasser et al., 2003; Weiss et al., 1993). Palaeoecological data from the Awafi paleolake suggests intense aridification dated to 4200 cal yr BP, and this was followed by a short lived wet phase corresponding with the end of the Wadi Suq period, between 4000 and 3000 cal yr BP (Parker et al., 2006). While palaeoecological studies have found evidence of aridification around the transition from the Umm an-Nar to Wadi Suq period, consequent alterations to health[2], as seen in the remains of the people who could have been affected, have not been explored in the context of these climatic shifts.

Stress and the Skeleton

Stress and its direct link to poor or good 'health' has been problematized particularly following the osteological paradox (Pilloud and Schwitalla, 2020; Edinborough and Rando, 2020; Lambert, 2009; Wood et al., 1992). For example, Pilloud and Schwitalla (2020) show that biological responses to stress change through time and with different cultural practices. Therefore, carious lesions, AMTL, DEH, PNBF, PH, and CO, which reflect biological adaptive responses, were selected. This is because they were hypothesized to reflect the consequences of climate changes for QAH individuals. Climate change has direct consequences to subsistence strategies, for example crop failure, and evidence for changed subsistence patterns might therefore be expected in QAH individuals. In the dentition, carious lesions, AMTL, and DEH reflect changes to subsistence strategies, and specifically the adoption of agriculture (Cheung et al., 2019; Cucina et al., 2011; Cucina and Tiesler, 2003; Munoz, 2017; Lambert, 2009; Tayles et al., 2000; Temple and Larsen, 2007); date palm agriculture practiced during the Umm an-Nar period is likely to have changed during the transition from Umm an-Nar to Wadi Suq period (Méry, 2013; Munoz, 2017; Potts, 2009). In skeletal remains, PNBF, CO, and PH, reflect environmental stressors including trauma, infections, and nutrient deficient diets (Brickley, 2018; DeWitte, 2014; Pilloud and Schwitalla, 2020; Walker et al., 2009; Weston, 2012), for example increased consumption of fish, and loss of small-scale agricultural practices and subsequent nutritionally deficient diets during the transition from Umm an-Nar to Wadi Suq period (Beech, 2003; Charbonnier, 2015; Potts, 2009).

Dental stress markers

Carious lesions result from behavioral and biological differences, with people's diets, occupational practices, and sex hormones influencing respective prevalence of tooth decay

[1] Middle East is defined as the region spanning Egypt and most of western Asia.
[2] Health as defined by the World Health Organization "is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (World Health Organization 2020), recognizing that today there is much debate about this definition (e.g. Leonardi 2018; Fallon et al. 2019).

(Lukacs, 2008; Sheiham and James, 2015). Subsistence strategy and the diet people consumed have been indicated as the impetus for a high frequency of carious lesions (Cucina et al., 2011; Munoz, 2017; Tayles et al., 2000; Temple and Larsen, 2007), particularly when dietary sugars promote selective bacteria in dental plaque that lead to a low oral pH (Hillson, 2005:290; Sheiham and James, 2015).

AMTL, identified as complete resorption or 'filling in' of the tooth socket with new bone, can be attributed to a number of factors, including the destruction of the tooth by carious lesions, subsequent loss of the tooth due to periodontal disease, dental attrition, and trauma, or direct extraction (Littleton and Frohlich, 1993; Kinaston et al., 2019). Because AMTL is closely associated with other dental diseases it has been useful in assessing changes in subsistence strategies (Cucina and Tiesler, 2003; Liu et al., 2010).

DEH reflects a deficiency in enamel thickness, seen as pits, lines or grooves in the enamel surfaces of teeth during enamel formation (*in utero* to ~15 years, (Cunningham et al., 2016:168-169; Kanchan et al., 2015). A specific cause for DEH is difficult to determine, especially for ancient populations, because a multitude of factors, including periods of nutritional stress, heredity, and infection (Goodman et al., 1988; Kanchan et al., 2015).

<u>Skeletal stress markers</u>

Porosity on the cranial vault and orbital roof surfaces, are associated with CO and PH (Brickley, 2018; Chaichun et al., 2021; Rivera and Mirazón Lahr, 2017), and the outer table becomes thinner as the diploic space enlarges. While the etiology of these lesions has been debated (Brickley, 2018; Oxenham and Cavill, 2010; Stuart-Macadam, 1987; Walker et al., 2009), they are typically associated with deficiencies of dietary iron due to undernutrition and infection, alongside additional factors such as an inheritance (sickle cell anemia and thalassaemia), excessive blood loss through, for example menstruation, a deficiency in vitamin B12 resulting in megaloblastic anaemia, and infectious disease can contribute to poor absorption of iron in the blood stream (Brickley, 2018; Oxenham and Cavill, 2010; Perri et al., 2018; Stuart-Macadam, 1987; Walker et al., 2009). Porosity may also be caused by normal variation across different human groups, what might be called a pseudopathology (Wapler et al., 2004).

Finally, disruptions to the periosteal surface of bone caused by inflammation, trauma, or other conditions such as metabolic diseases like scurvy (Brickley and Mays, 2019:539; Chen et al., 2012), promotes osteoblastic activity and the deposition of reactive new bone. When discussing bony changes to the periosteum of bones, PNBF should be described as periostosis (rather than periostitis), which represents pathological changes to the periosteum that can result from a variety of stimuli, including trauma, infections, fluorosis, and neoplasms (Roberts, 2019; Weston, 2008). Debates on the meaning of periosteal reactions with respect to physiological stress response have complicated interpretations of these bony changes (DeWitte, 2014; Pilloud and Schwitalla, 2020; Weston, 2012).

Bioarchaeological Methods

Skeletal remains from both tombs were identified from diagnostic elements, using characteristic features of individual bones and teeth. However, disarticulation, commingling, and fragmentation of skeletal remains from the QAH cemetery limited the potential of producing disease profiles because a skeletal distribution of lesions was not possible. Sex, age-at-death, and the presence of skeletal and dental lesions were observed for all skeletal elements (isolated bones and teeth).

Minimum number of individuals

The minimum number of individuals (MNI) for each tomb was calculated following McKinley (2004:14). Landmarks of diagnostic bones/parts of bones were used for the remains from each tomb (e.g., petrous portion of temporal bone or distal lateral epicondyle of femur). The remaining unidentifiable skeletal elements lacked discernible features for sex, age-at-death, or disease and were simply quantified.

Sex and age-at-death

Sexually dimorphic features of bones from the pelvis and skull, and measurements of long bone epiphyses, including the humeral and femoral heads, were used to estimate biological sex in adult bones following criteria outlined by Bass (1987:21-22). Whenever possible, sex was estimated using one or two sexually dimorphic traits present on single skeletal elements (e.g., the glabella and supraorbital ridge of the frontal bone). Sex was not estimated for non-adult skeletal remains because of unreliable estimates associated with morphological analyses of non-adult skeletal remains (Cunningham et al., 2016:17).

Age-at-death in adult remains based on individual relevant bones was estimated using degenerative changes of the pubic symphysis and auricular surface, dental attrition, and cranial suture closure in semi-articulated skulls (Brooks and Suchey, 1990; Lovejoy et al., 1985; Lovejoy, 1985; Meindl and Lovejoy, 1985). Epiphyseal fusion and dental eruption were used to estimate age in non-adult skeletal remains (e.g., on individual bones and dentitions; Buikstra and Ubelaker, 1994:39-46; Cunningham et al., 2016:11-13; Moorrees et al., 1963). Although less accurate than dental eruption or epiphyseal fusion data (Cunningham et al., 2016:301), metrical analyses (e.g., long bone length), as outlined by Schaefer, Scheuer, and Black (2009), were also used to estimate age for non-adult bones. Given the state of preservation of the human remains studied, age-at-death assessments were generally limited to “adult” or “non-adult”.

Pathological conditions

Abnormal bone changes were described following criteria outlined by Roberts and Connell (2004:35), including the documentation of skeletal elements and/or parts of the bone or tooth affected, the nature of the abnormality (e.g., destructive vs. forming), evidence of healing, measurements of the lesion, and distribution of the abnormality, where possible. For dental indicators of stress, all teeth recovered (e.g., loose teeth and teeth in mandibles and maxillae) were assessed for carious lesions (Moore and Corbett, 1973), DEH (Buikstra and Ubelaker, 1994:56-58), and AMTL (Buikstra and Ubelaker, 1994:48-49; Kinaston et al., 2019). Carious lesions, AMTL, and DEH were recorded according to tooth position in the oral cavity and their morphology (Buikstra and Ubelaker, 1994:55; Hillson, 1996:229). Because PNBF commonly affects long bones, particularly tibiae (Weston, 2012:492), available long bones were assessed for lesions, with lesions measured and, where possible, evidence of active (reactive bone deposits) versus healing (lamellar bone) lesions documented (Weston, 2008). CO was recorded by side, with orbits requiring a completeness of 25% or more for observation. The presence of CO in orbital roofs and expansion of the diploic space/porosity on the ectocranial surface of the cranial vault bones (PH) was recorded following Stuart-Macadam (1985) and, where possible, age-at-death was estimated to discern if lesions were residual from childhood into adulthood or reflected active stress responses.

True prevalence of bone/dental elements affected by skeletal and dental lesions was calculated based on the number of elements affected out of the total elements recovered. To assess significance of differences observed in the prevalence of skeletal and dental lesions between QAH tombs 5 and 6, one-tailed Fisher's exact tests were used. Fisher's exact tests were selected because of their efficacy for small sample size analysis (Drennan, 2010:193). There were inconsistencies in analyses and subsequent data collected between QAH and the five comparative samples. This is because osteological analyses completed for the comparative sites has not been comprehensive, and methods used for recording, analysing and interpreting pathological lesions have emphasized dental health with relatively little discussion of other disease processes (Blau, 1999; Blau, 2007; Littleton and Frohlich, 1993; Vogt et al., 1985; McSweeney et al., 2010). While not uniform, health profiles compiled of these contemporary sites help to contextualize the results from the QAH cemetery with environmental conditions.

Materials

Qarn al-Harf Cemetery

In 2012-2013 six communal tombs were excavated from the Wadi Suq period cemetery of Qarn al-Harf (QAH) in Ra's al-Khaimah, one of the seven United Arab Emirates (UAE). The human remains from QAH tombs 5 and 6 were studied because each comprised large assemblages of diagnostic skeletal remains and represent two distinct phases of the Wadi Suq period. Tomb architecture and associated material culture, specifically pottery, suggest different construction times for each tomb (Table 1; de Vreeze, 2016). While it is not possible to know how long each tomb remained in use, it is most probable that QAH tomb 6 would have ceased use either before the construction of QAH tomb 5, or during the earlier part of its use. In the latter case there may be some chronological overlap between the two populations. Unfortunately, poor preservation of collagen in bones from both tombs has prohibited ^{14}C dating and therefore more constricted use of each tomb is not possible. The right temporal bone, specifically the petrous portion, was the most frequently identified element and was used to estimate the MNI for both tombs. A minimum number of 185 individuals were recovered from QAH tomb 5 and 6 (Table 3). Because the skeletal remains excavated were disarticulated, fragmented, and poorly preserved (Figure 2), the diagnostic bone/tooth elements identified represent a very small portion of the total human remains recovered. There were 529 diagnostic elements identified from 28,737 skeletal elements excavated from QAH tomb 5 (1.8%) and 2,780 diagnostic elements identified from 92,458 excavated from QAH tomb 6 (2.9%). Ten semi-articulated individuals were recovered, for which more extensive analyses were possible. However, these individuals are likely later intrusive interments and not contemporary with the transition period from the Umm an-Nar to the Wadi Suq period; therefore, they are excluded from the present discussion. MNI patterns for Umm an-Nar period tombs are usually based on large samples (i.e., hundreds of interments; e.g. Blau, 2001a), while Wadi Suq period tombs are comprised of smaller samples (i.e., less than one-hundred interments; Potts, 2009; Table 3). Scholars argue that smaller samples of skeletal remains associated with Wadi Suq tombs reflect smaller populations sizes and site abandonment (Carter, 1997b; Gregoricka, 2021; Magee, 2014).

Figure 2 Example of preservation of human skeletal remains from QAH cemetery

An even distribution of males and females (both 42.9%) was observed in the bones from QAH tomb 5, but in QAH tomb 6 females represented 46.3% of bones assessed for sex while males represent 27.7%. A portion of bones from QAH tomb 5 (14.2%) and 6 (26%) either did not possess features assessable for sex or possessed features of both sexes and account. Age-at-death from bones and teeth varied by tomb with 54.6% of age estimates from QAH tomb 5 assessed as adults while 57.2% of age estimates from QAH tomb 6 were non-adults. According to a Fisher's exact test, the non-adult prevalence represented in the skeletal sample from QAH tomb 6 is statistically significant in comparison to the non-adult prevalence in QAH tomb 5, p=0.0118. Fragmentation and disarticulation, which is also prevalent in contemporary skeletal samples from the Arabian Peninsula (Blau, 2001a; Blau, 2001b; Williams and Gregoricka, 2019; Table 3), frequently results in small samples of diagnostic elements that can be used for sex and age-at-death estimation and therefore patterns in sex and age-at-death are variable between sites. Notably, non-adults represent a statistically significant proportion of the sample from QAH tomb 6, which could indicate a population that did not have the resources to sustain infant life and/or that the stresses of the lived environment affected the very young (Lewis, 2007:84). Similar patterns in age-at-death were seen at Hili (McSweeney et al., 2010), where 43% of the sample were non-adults, and at Shimal 103 where non-adults represented 58% of the sample (Schutkowski and Herrmann, 1987).

Results

Table 4 Summary of skeletal and dental lesion frequency rates from QAH and contemporary cemeteries in the UAE; *indicates true prevalence

Dental Lesions

Loose teeth comprise the majority of evidence for dentitions recovered from QAH cemetery. Anterior teeth (incisors and canines) represent 44.1% (n=193) and 36.5% (n=274), respectively, while posterior teeth (pre-molars and molars) represent 56% (n=193) and 63.5% (n=274), respectively, of teeth from QAH tombs 5 and 6. From QAH tomb 5, four teeth (2.1%, n=193) were recorded with carious lesions. From QAH tomb 6, seven teeth had carious lesions (2.6%, n=274; Figure 3). A Fisher's exact test found that the different prevalence rates for carious lesions in QAH tombs 5 and 6 was not statistically significant (p = 0.4958). In comparison to Umm an-Nar sites, carious lesion rates were variable by site but UNar 1 has the closest rate for carious lesions (3.9%, n=279) to the QAH cemetery (Blau, 1998a; Blau, 2007). A similar pattern of variability by site is seen for the Wadi Suq populations (Table 3; Blau, 1999).

DEH was recorded in eight teeth (4.1%, n=193) from QAH tomb 5 and twelve teeth (4.4%, n=274) from QAH tomb 6. A Fisher's exact test found that the different prevalence rates of DEH in QAH tombs 5 and 6 was not statistically significant (p = 0.5481). In comparison to DEH data from contemporary sites, DEH prevalence in people buried in the QAH tombs, was lower than that found at all the other sites no matter whether they dated to the Umm an-Nar or Wadi Suq periods (Table 3). The closest prevalence of DEH to that observed in the QAH tombs was seen in Umm an-Nar tombs (Blau, 1998a; Blau, 2001a; Blau, 2007): UNar 2 (3.8%, n=53) and Al-Sufouh (3.3%, n=304).

AMTL was observed in 66% (n=3) of mandibular fragments from QAH tomb 5. When accounting for tooth sockets affected, 22.7% (n=22) exhibited evidence of remodeling. AMTL was observed in 26 of 50 mandibular fragments from QAH tomb 6 (52.0%, Figure 3). Remodelling of the tooth sockets was recorded in 32.5% (n=317) of sockets preserved. No maxilla fragments were identified from QAH tomb 5, and AMTL was not observed in maxilla fragments from QAH tomb 6. A Fisher's exact test found that the different prevalence rates of AMTL according to tooth sockets from QAH tombs 5 and 6 were not statistically significant (p = 0.2420). When compared to contemporary sites, there is site variability in AMTL rates (Table 3);

however, the presented comparative AMTL rates represent crude prevalence rates, and not the true prevalence of sockets affected by AMTL, as in the current study (Blau, 1998a, Blau, 1999; Blau, 2007; McSweeney et al., 2010; Schutkowski and Herrmann, 1987; Vogt et al., 1985).

Figure 3 Superior view of mandible from QAH tomb 6 with occlusal surface carious lesion (circle) on the left 3rd molar, and bilateral AMTL located at the sites of the 1st and 2nd molars and the right 2nd premolar (boxes). Note: the right 3rd molar exhibits postmortem damage, and not carious lesion.

Skeletal Lesions

CO was not identified on the 16 orbits recovered from QAH tomb 5, while 35 orbits (17 right and 18 left) from QAH tomb 6 were recorded with CO, representing 30.2% of the orbits recovered (n=116). Age-at-death was estimated in four individuals with CO, two non-adults and two adults, but age-at-death was not estimated for the remaining frontal bones because of a lack of age estimation features. One frontal bone with CO in a right orbit also exhibited diploic expansion (PH; Figure 4). Evidence of PH was not observed in any further cranial fragments from QAH tomb 5 or 6. A Fisher's exact test found statistical significance in the difference of CO prevalence between QAH tombs 5 and 6 ($p = 0.0050$). There is site variability in the prevalence of CO, with Umm an-Nar period comparative sites having the highest rates (Table 3; Blau, 1998a; Blau, 2001a; Blau, 2007).

Figure 4 Anterior view of a frontal bone from QAH tomb 6 with bilateral CO

PNBF was not identified in the 215 long bones from QAH tomb 5 (Table 3). PNBF was recorded on 15 long bones (0.9%, n=1662) from QAH tomb 6, with 67% (n=10) of lower limb bones affected (Figure 5) and 55.6% (n=8) active at the time of death. A Fisher's exact test did not find the different rates of PNBF observed in QAH tomb 5 and 6 to be significant ($p = 0.1601$). The prevalence of PNBF on bones from QAH tomb 6 was higher than at other Umm an-Nar populations (Table 3; Blau, 1998a, Blau, 2001a; Blau, 2007).

Figure 5 Fragment of a tibia from QAH tomb 6 with PNBF on its antero-lateral surface (indicated by oval)

Discussion

Health and well-being in response to climate change

Using the five comparative sites, the QAH results are now contextualized alongside those previously recorded for the Umm an-Nar and Wadi Suq periods. Differences in the prevalence of skeletal and dental lesions in the QAH individuals and cultural periods indicates potential differences in environmental stressors, including aridification at the transition from the Umm an-Nar to the Wadi Suq period. However, differences observed are likely also attributable to regional variations, particularly with regard to dietary practices. Dietary practices from QAH have been assessed isotopically in dental enamel (Montgomery et al., 2014), suggesting C_4 plants and/or marine resources comprised diets for people from both sites; however, poor collagen preservation prohibited isotopic analyses of carbon and nitrogen, which could differentiate plant from animal sources.

Dental Lesions

Dental lesions from QAH tomb 5 and 6 suggest that people were exposed to similar stressors. Low rates of DEH could indicate that many individuals died prior to developing DEH or were not severely stressed during childhood development (Lambert, 2009; Wood et al., 1992). In comparison to contemporary tombs, DEH and carious lesion rates were variable with no pattern apparent according to cultural period. Because diets likely differed by region and period (Munoz, 2017), variable rates of carious lesions and DEH may reflect local dietary differences, and not the result of environmental stress due to factors such as climate change. High fluoride levels in ground water has also been clinically demonstrated to buffer enamel from being predisposed to carious lesions (Carey, 2014; Mei et al., 2014), and could explain variation observed across cultural periods. This situation has also been hypothesized archaeologically, and specifically at sites in the UAE (Blau et al., 2002; Hillson, 1996:171; Littleton, 1999). Studies on archaeological dentitions from northern UAE sites have found lower fluoride levels in comparison to that of southern sites (Blau et al., 2002). Fluoride levels from the QAH cemetery were not analyzed in the current study.

Agricultural practices, including date palm cultivation, are evidenced by the presence of wells (Charbonnier, 2015), date stones (Potts, 2003), and barley and wheat grains (Parker et al., 2004; Willcox, 1995) and the consumption of all these foods has been associated with high carious lesion rates, dental attrition and subsequent tooth loss in the UAE, predominantly in Umm an-Nar samples (Blau, 2007; Littleton and Frohlich, 1993; Munoz, 2017). While subsistence strategy during the Wadi Suq period is debated, and was possibly much more regionally varied, high rates of DEH were observed and have been attributed to diets dependent on marine sources (Beech, 2003; Blau, 2007). While individuals at QAH were likely consuming marine sources (Montgomery et al., 2014), DEH rates do not signal deficiencies that impacted dentitions. Marine diets, specifically in the Arabian Peninsula (Littleton and Frohlich, 1993; Munoz, 2017), have been attributed to high rates of AMTL. This is attributed to sand and grit from the environment and associated with marine foods promoting heavy attrition of teeth, and eventually resulting in pulp exposure, carious lesions, and loss of teeth (Blau, 2007; Cucina and Tiesler, 2003; Kinaston et al., 2019; Littleton and Frohlich, 1993). This is supported at the QAH cemetery, where AMTL was observed in most mandibles from QAH tomb 6. Varying fluoride levels between northern (QAH, Sharm, and Shimal) and southern sites (al-Sufouh and Mowaihat, excluding Hili which does not fit this pattern) or through the consumption of fish (Sigler and Nuehold, 1972), could explain observed rates of carious lesions and subsequent AMTL. Alternatively, rates of carious lesions, DEH, and AMTL from the QAH cemetery may be the result of the nature of dentitions/teeth recovered, which represented mostly posterior teeth or, in the case of carious lesions, teeth with carious lesions could have been lost antemortem.

Skeletal Lesions

There was no evidence of CO or PH in the individuals interred in QAH tomb 5. The CO prevalence rate in QAH tomb 6 was statistically significant in comparison to QAH tomb 5 ($p=0.0050$), supporting the notion that individuals interred in QAH tomb 6 were significantly stressed in comparison to those buried in QAH tomb 5. CO has been observed in other Umm an-Nar and Wadi Suq period samples, and a higher prevalence has been associated with practices in the Umm an-Nar period, including sedentism where individuals lived closer to each other and their animals, with low levels of effective hygiene and sanitation (Blau, 2007). While CO has been attributed to iron deficiency (Stuart-Macadam, 1989; Stuart-Macadam, 1987), shell mounds at Shimal (Schutkowski and Grupe, 1989) and fish remains (Beech, 2003), along with isotopic signatures of remains from QAH tomb 6 (Montgomery et al., 2014), indicate marine resources were consumed regularly. This suggests megaloblastic anaemia and/or genetic anaemias such as thalassemia, better explain the observed CO prevalence (Walker, 1986; Walker et al., 2009). While fish was likely included as a component of diets for people interred in both QAH tomb 5 and 6, aridification could have promoted a dependence on marine sources in QAH tomb 6 individuals, resulting in nutritionally deficient diets and CO, whereas QAH tomb 5 individuals, who lived in a wetter climate, were able to consume a more varied diet that was nutritionally sufficient.

The presence of PNBF in individuals buried in QAH tomb 6 suggests stress caused by a variety of etiologies caused inflammation, including trauma, vitamin deficiencies, and/or infectious diseases (Roberts, 2019:288; Weston, 2018). However, as the periosteum is easily stimulated to produce new bone, the presence of PNBF does not necessarily mean an infection was present (Roberts, 2019:288; Weston, 2018). The lower leg bones were most affected which is frequently observed archaeologically (Weston, 2012:492). The higher frequency of tibial periostosis has been debated, but proximity to the skin and therefore potential for direct trauma has been cited (Roberts, 2019). The rate of PNBF from QAH tomb 5 and 6 suggest individuals were differentially affected by causative stressors; however, this difference is not statistically significant, ($p=0.1601$). In comparison to contemporary sites, QAH tomb 6 had the highest rate of PNBF (Table 3), further supporting the notion that these individuals were exposed to different stressors, which was potentially the result of aridification.

The impact of transition

The most compelling support for the hypothesis presented in this paper is the statistical significance of differences between the CO prevalence at QAH tombs 5 and 6 ($p=0.0050$) and non-adult mortality ($p=0.0118$). While not significant, PNBF rates at QAH 6 in conjunction with CO rates, and the proportion of non-adults represented in the skeletal sample, suggests individuals were experiencing stressors that were not impacting individuals from QAH tomb 5. Combined, the results support the hypothesis that people interred in QAH tomb 6 were more chronically stressed, than those interred in QAH tomb 5. However, these differences cannot be directly attributable to aridification because dietary differences both by cultural period and regionally could explain observed skeletal and dental lesions. Although higher rates of CO and PNBF were present, this does not mean QAH tomb 6 individuals were necessarily less 'healthy' than individuals from QAH tomb 5 who did not exhibit these lesions (Lambert, 2009; Wood et al., 1992); the presence of active and healed PNBF indicates lived long enough for lesions to develop and heal before death. While observed rates of skeletal and dental lesions cannot be directly attributable to climate change, we argue that intense aridification during the transition from the Umm an-Nar to the Wadi Suq period caused failed crops and an increased reliance on marine sources for people interred in QAH tomb 6. Proximity to marine sources, approximately 9km, likely buffered subsistence changes following aridification. However, increased reliance on marine sources promoted nutritionally deficient diets manifesting as CO, AMTL, and higher rates of (trauma related) PNBF as a result of accessing marine resources, along with significant differences in non-adult mortality in the skeletal sample studied. While adapting to climate change, including accessing marine resources, enabled individuals from QAH tomb 6 to live long enough to incur skeletal alterations, skeletal and dental lesion differences with comparator sites highlight the precarity climate changes posed, and do pose, to living populations.

Conclusion

Although it was not possible to definitively link mortality and morbidity data from human remains from the two tombs at the Qarn al-Harf (QAH) cemetery in Ra's al-Khaimah with the consequences of climate change, the findings of this paper present an ongoing opportunity to gain insight to the possible health implications of past climate change in the UAE. Bioarchaeological research on commingled and disarticulated material from the Arabian Peninsula has promoted a better understanding of mortuary practices and changes through the Bronze Age (Blau, 1998b; Magee, 2019; Martin, 2007; Williams and Gregoricka, 2019). Asking nuanced questions about the lived experiences of prehistoric people of the Arabian Peninsula, who experienced centuries of vulnerability to climate fluctuation, provides insights on the costs of climate change to human health and well-being. While it is challenging to study bioarchaeological samples from the Arabian Peninsula because of imprecise chronology and poor preservation from large-scale commingled tombs (Blau, 1998b; Blau, 2001a; Brickley and Buckberry, 2015; Martin, 2007), this research benefits current understanding of how environmental change can influence cultural change and the impact on the lived experiences of individuals. While much of the data from this paper signals site variability, particularly for dietary practices, future research that explores subsistence practices and environmental conditions (e.g., fluoride levels), could further contextualize the findings discussed here and further advance understandings of the health implications of climatic shifts in the Arabian Peninsula during the Bronze Age.

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Tables

	QAH tomb 5	QAH tomb 6
Cultural Period	Late Wadi Suq Period	Early Wadi Suq (potentially transitional Umm an-Nar)
Relative Date	~1900-1600 B.C.	~2000 B.C.
Climate	Periodic precipitation	Intense aridification
Dating evidence (de Vreeze, 2016)	• Ghalilah tomb • Wadi Suq period ceramics	• Circular tomb with Umm an-Nar features • Transitional ceramics with features of Umm an-Nar and Wadi Suq period
MNI	45	144

Table 1 Skeletal samples from the QAH cemetery

Site	QAH		Sharm	Shimal				Al-Sufouh				Hili	Mowaihat
Cultural Period	Wadi Suq period		Wadi Suq period	Wadi Suq period		Umm an-Nar period		Umm an-Nar period				Umm an-Nar period	Umm an-Nar period
Relative Date	1800-1600 B.C.	2000 B.C.	1250 B.C.	1500 B.C.		2100-2000 B.C.	2300-2100 B.C.	2400-2300 B.C.				2100-2000 B.C.	2300-2100 B.C.
Tomb	5	6	N/A	102	103	UNar 1	UNar 2	1	2	3	4	N	N/A
Citation	Author's Own	Author's Own	Blau, 1999	Vogt et al., 1985	Schutkowski and Herrmann, 1987	Blau, 2001b	Blau, 2001b	Blau, 2001b	Blau, 2001b	Blau, 2001b	Blau, 2001b	McSweeney et al., 2010	Blau, 2001b

Table 1 UAE sites used in the study from the Umm an-Nar and Wadi Suq periods

Site	QAH		Sharm	Shimal				Al-Sufouh				Hili	Mowaihat
Cultural Period	Wadi Suq period		Wadi Suq period	Wadi Suq period		Umm an-Nar period		Umm an-Nar period				Umm an-Nar period	Umm an-Nar period
Tomb	5	6	N/A	102	103	UNar 1	UNar 2	1	2	3	4	N	N/A
Total DE	529	2780	2989	N/A	N/A	744	12982	1253	3789	3272	55	N/A	3307
MNI	41	144	71	121	50	212	235	13	60	59	4	700*	57
N Sex DE	7	123	307	N/A	28	N/A	1477	61	471	411	0	N/A	306
Male	42.9%	27.7%	2.61%	N/A	42.9%	N/A	3.6%	1.6%	2.8%	2.7%	0%	40%	16.7%
Female	42.9%	46.3%	2.61%	Majority	57.1%	N/A	7.4%	8.2%	14.2%	12.4%	0%	44%	6.7%
N Age DE	152	292	2989	N/A	50	N/A	11021	1245	3767	3245	52	N/A	3307
Non-Adult	45.4%	57.2%	0.6%	30%	58%	N/A	3.6%	9.56%	5.3%	6.63%	7.69%	43%	7.53%
Adult	54.6%	42.8%	98.9%	N/A	42%	97.72%	90.96%	89%	93.9%	91.99%	92.31%	N/A	87.11%
Citation	Author's Own	Author's Own	Blau, 1999	Vogt et al., 1985	Schutkowski and Herrmann, 1987	Blau, 1998a; Blau, 2001b	Blau, 1998a; Blau, 2001b	Blau, 1998a; Blau, 2001b	Blau, 1998a; Blau, 2001b	Blau, 1998a; Blau, 2001b	Blau, 1998a; Blau, 2001b	McSweeney et al., 2010	Blau, 1998a; Blau, 2001b

Table 2 Umm an-Nar and Wadi Suq period tombs from the UAE. Key: DE – diagnostic elements; *MNI calculation is not clear in citation

Skeletal Indicators of stress		**QAH Umm an-Nar/Wadi Suq Period**		Sharm Wadi Suq period	Shimal				Al-Sufouh Umm an-Nar period				Hili Umm an-Nar period	Mowaihat Umm an-Nar period
					Wadi Suq period		Umm an-Nar period							
Tomb		**5**	**6**	N/A	102	103	UNar 1	UNar 2	1	2	3	4	N	N/A
Dental	Carious Lesion	**2.1* (n=193)**	**2.6* (n=274)**	24* (n=50)	Rare to absent	N/A	3.9* (n=279)	9.1* (n=55)	0.3* (n=304)				6	0.2* (n=433)
	AMTL	**22.7* (n=22)**	**32.5* (n=317)**	30	29	21.9	16.5	43.8	9.1	15	12.6	0	64	37.5
	DEH	**4.1* (n=193)**	**4.4* (n=274)**	10* (n=50)	N/A	N/A	1.8* (n=279)	3.8* (n=53)	3.3* (n=304)				10	12.3* (n=433)
Cranial	CO	**0 (n=16)**	**30.2* (n=116)**	40* (n=56)	N/A	3.1	N/A	17.5* (n=189)	25* (n=4)	41.5* (n=41)	33.3* (n=33)	0	18-37.2	27.3* (n=11)
	PH-parietal bone	**0**	**0**	0	0	0	N/A	9.3*	0	13* (n=23)	8* (n=25)	0	18-37.2	3.4* (n=29)
	PH-occipital bone	**0**	**0**	0	0	0	N/A	6.3*	0	5.9* (n=34)	4.5* (n=44)	0	0	0
Post-cranial	PNBF	**0 (n=215)**	**0.9* (n=1662)**	0.03* (n=2989)	0	0	N/A	0.04* (n=12982)	0	0.05* (n=3767)	0.03* (n=3245)	0	N/A	0.6* (n=3307)
Citation		**Author's Own**	**Author's Own**	Blau, 1999: Blau, 2007	Vogt et al., 1985	Schutkowski and Herrmann, 1987	Blau, 1998a	Blau, 1998a; Blau, 2007	Blau, 2001a; Blau, 2007	Blau, 2001a; Blau, 2007	Blau, 2001a; Blau, 2007	Blau, 2001a; Blau, 2007	McSweeney et al., 2010	Blau, 2001a; Blau, 2007

Table 3 Summary of skeletal and dental lesion rates from QAH and contemporary cemeteries in the UAE; * indicates true prevalence