Health and Nutritional Status at CA-SOL-451 (Encinosa Site): Biological Interpretations and Regional Comparisons

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Abstract

This study examines evidence of nutritional and disease-related stress indicators in 33 human burials excavated from CA-SOL-451 (Encinosa site), a late Holocene site (2450–1530 cal BP) located in Vacaville, California. We hypothesize that the prevalence of nutritional stress indicators (cribra orbitalia, porotic hyperostosis, linear enamel hypoplasia) and infectious disease (tibial periosteal lesions, dental caries) will be lower at SOL-451 than in contemporaneous Middle Period site components from the more densely settled lower Sacramento Valley and San Francisco Bay Area. Results indicate that levels of nutritional stress vary between sites, with SOL-451 showing a significantly lower prevalence of cribra orbitalia and porotic hyperostosis compared with Bay Area groups. The prevalence of linear enamel hypoplasia defects was also significantly lower at SOL-451 compared to groups from the Valley and Bay Area. The prevalence of dental caries at SOL-451 was similar to other Bay Area populations but was significantly lower compared to populations from the lower Sacramento Valley. Tibial periosteal lesions, while common at SOL-451, were not significantly different between sites. Overall, these results support the central hypothesis that nutritional stress and infectious disease were more prevalent among the more densely settled communities of the lower Sacramento Valley and San Francisco Bay Area.

Introduction

Human skeletal remains provide a unique window into ancient patterns of health, nutritional status, diet, migration, and violence (Larsen 1997). In prehistoric California much attention has focused on bioarchaeological patterns in the Santa Barbara Channel (Walker 1986, 1989, 1997; Walker and De Niro 1986; Walker and Lambert 1989; Lambert 1993, 1994, 1997), the Central Valley (Schulz 1981; Bartelink 2006; Broughton et al. 2010), and the San Francisco Bay Area (Jurmain 1990a, 1990b, 2001; Bartelink 2006, 2009; Pilloud 2006; Bartelink et al. 2013; Beasley et al. 2013). Despite a growing body of literature on skeletal health in prehistoric central California, little bioarchaeological research has been conducted in the northern San Francisco Bay Area. In this study we examine indicators of nutritional status and skeletal pathology in a series of human burials excavated from CA-SOL-451 (Encinosa Site), a Middle Period occupation dated to 2450–1530 cal BP (Whitaker and Carpenter 2010:1). The burials from SOL-451 date to a narrower interval than the site as a whole, and they show two distinct episodes of interment during the Middle Period (ca. 1840 BP and ca. 1520 BP).

Demographers and archaeologists have proposed that California had the highest population densities in North America at the time of European contact, with an estimated 310,000 persons (Cook 1976). Evidence of significant late Holocene population growth in central California has been identified by the number of dated sites, site components, and burials, as well as by evidence of intensive use of the landscape by more sedentary communities (Schulz 1981; Basgall 1987; Beaton 1991; Broughton 1999). The archaeofaunal and archaeobotanical records further indicate declines in the relative abundance of low-cost, high-ranked taxa relative to higher-cost, lower-ranked resources, such as small fauna, acorns, and small seeds

(Wohlgemuth 1996; Broughton 1999). These lines of evidence have been used to argue that late Holocene human population increase had significant impacts on the local fauna and flora throughout central California, likely reflecting resource stress (Broughton 1999). However, the density of sites and site components varied dramatically between regions, with generally higher population numbers in the Central Valley and San Francisco Bay Area than in the Pleasants Valley region where SOL-451 is located (Milliken et al. 2007). Research on sedentary communities of the past and present has also identified a relationship between high population density and prevalence of infectious disease (Inhorn and Brown 1990:94), as well as other indicators of stress, such as evidence of anemic response (cribra orbitalia and porotic hyperostosis), dental enamel hypoplasia defects, and reduced stature (Larsen 1997).

Using comparative bioarchaeological data from Middle Period site components in the Sacramento Valley and eastern San Francisco Bay Area, we hypothesize that the prevalence of nutritional stress and disease indicators represented on bones and teeth will be lower at SOL-451 than in the more densely settled Sacramento Valley and Bay Area. In this paper we first address skeletal health status in the SOL-451 population and then address broader health patterns throughout central California.

Site Context

SOL-451 is located within Pleasants Valley in the city of Vacaville, Solano County, California (Figure 1). The site is situated adjacent to Encinosa Creek in close proximity to foothill, oak woodland, valley floor grassland, and riparian habitats (Whitaker and Carpenter 2010:5). Paleobotanical and archaeofaunal data suggest that the site was used year-round, with a heavy emphasis on vegetal foods (especially small seeds and acorns) in addition to animal resources such as artiodactyls, waterfowl, and fish (Whitaker and Carpenter 2010:59). Middle Period (2450-1530 cal BP) occupation at SOL-451 is categorized as a hamlet, which developed into a larger village during the Late Period. The site appears to have been used year-round during the Middle Period, but only seasonally in the fall during the Late Period (960-200 cal BP) (Whitaker and Carpenter 2010:78, 81). SOL-451 falls within the ethnographic territory of the Patwin tribe (Milliken et al. 2007:100).

Materials and Methods

Archaeological investigations at SOL-451 were conducted in 2008 prior to construction of a flood detention basin for the city of Vacaville and resulted in the excavation of 33 human burials (Whitaker and Carpenter 2010:1). Osteological analyses were conducted in the Human Identification Laboratory at California State University, Chico, from 2008 to 2009. This study focused on several bioarchaeological indicators of skeletal health, including stature, cribra orbitalia, porotic hyperostosis, linear enamel hypoplasia, periosteal bone reaction, oral pathology, osteoarthritis, and trauma. Preservation and completeness of the burials varied substantially, with approximately half of the individuals commingled likely due to rodent bioturbation, prehistoric disturbance of graves, and initial site testing. For this study the focus was on the primary individual; therefore, data collected on isolated, commingled remains were not included in prevalence calculations.

Sex and Age Estimation

Sex estimation of the sample focused on the use of non-metric methods described in Buikstra and Ubelaker (1994). For the adult sample, sexually dimorphic features of the pelvis and skull were assessed. When these indicators were unavailable, Dittrick and Suchey's (1986) metric sectioning points for femora and humeri were used for sex estimation, which are comparable in accuracy to

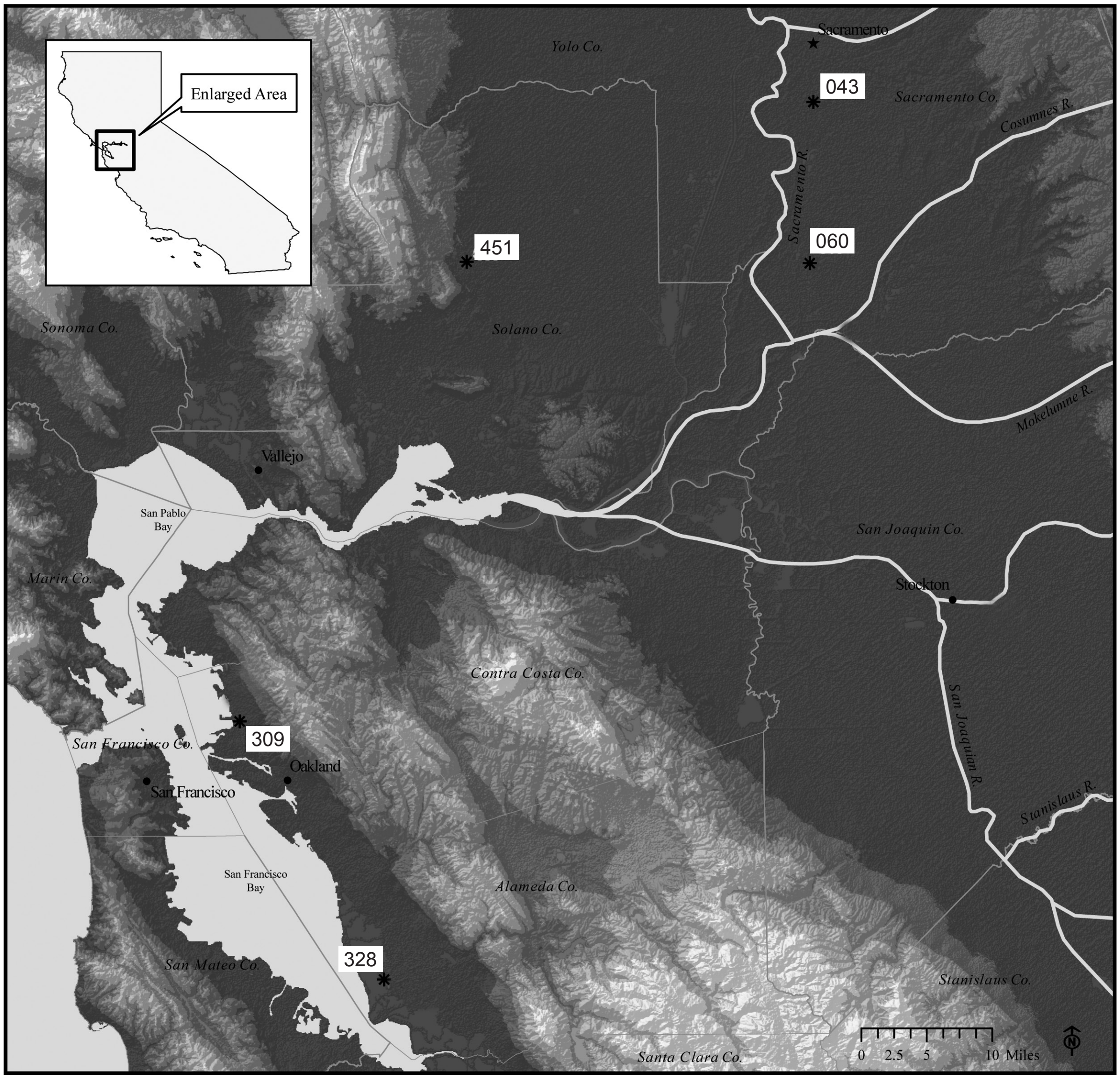

Figure 1. Map showing approximate location of CA-SOL-451 (Encinosa site). Additional sites featured include: CA-SAC-43 and CA-SAC-60 from the Sacramento Valley and CA-ALA-309 and CA-ALA-328 from the San Francisco Bay Area.

cranial indicators for prehistoric central California populations.

Age-at-death estimation was conducted also following procedures outlined in Buikstra and Ubelaker (1994). For adults the morphological changes of the pelvis provide the most reliable information for age estimation (Lovejoy et al. 1985; Katz and Suchey 1986; Brooks and Suchey 1990). Other age indicators, such as cranial suture closure (Meindl and Lovejoy 1985), vertebral osteophytosis, and dental attrition (Scott 1979; Smith 1984) were also assessed to clarify age estimates. For subadults, age estimation involved the assessment of sequences of dental eruption, dental maturation, epiphyseal union, and diaphyseal length (Buikstra and Ubelaker 1994; Scheuer and Black

2000). Radiographs were taken to aid in examination of dental eruption and dental development of subadult individuals.

Paleopathology

Bioarchaeological indicators of health can be classified as non-specific or specific, and each condition provides different levels of information regarding stress events or disease processes (Ortner 2003; Waldron 2009). Non-specific indicators, such as short stature, cribra orbitalia, porotic hyperostosis, and linear enamel hypoplasia, provide possible evidence of nutritional stress or disease that occurred in infancy or childhood (Larsen 1997; Aufderheide and Rodríguez-Martín 1998; Goodman and Martin 2002; Ortner 2003). Periosteal lesions are commonly associated with bone infection, although smaller, focal lesions may result from trauma that has disrupted the periosteum (Ortner 2003:207–209; Weston 2012). Other pathological conditions, such as osteoarthritis and trauma, may be linked to physical activity or injury during life (Waldron 2009). Dental caries is often linked to heavy consumption of carbohydrate-rich diets, especially those that are high in sugar content (Larsen 1997), although expression of the disease is complex (Lukacs 2012). In this study prevalence of pathological conditions is reported as the number of individuals affected divided by the total number of individuals assessable for a given condition. Subadults were excluded from the analysis of osteoarthritis, vertebral osteophytosis, and dental caries as these conditions are rare prior to adulthood.

Results

Sample Demographics

The sex and age distribution of the sample is provided in Table 1. Of the 33 burials analyzed, 14 (42.4 percent) are male, 7 (21.2 percent) are female, 6 (18.2 percent) are adults of indeterminate sex, and 6 (18.2 percent) are subadults (<17 years of age). Adult individuals and subadults (<17 years of age) that lacked sexually dimorphic characteristics are categorized as indeterminate sex. Five individuals (15.2 percent) are categorized as young adults (18–29 years), two (6.1 percent) as middle adults (30–39 years), ten (30.3 percent) as older adults (40+ years), and 7 (21.2 percent) as subadults (<17 years of age). Seven (21.2 percent) individuals are classified simply as adult (18+ years) due to the lack of more specific adult aging criteria. No age assessment could be conducted for three incomplete burials.

Stature Estimation

Stature estimation is an important indicator of health status for past populations (Larsen 1997). Auerbach

Table 1. Demographics of the CA-SOL-451 Sample.

	Total[a]	Male	Female	Indeterminate	Subadult
18-29 years (young)	5/33 (15.2)	4	4	0	–
30-39 years (middle)	2/33 (6.1)	1	1	0	–
40+ years (old)	10/33 (30.3)	7	7	1	–
18+ years (ind. adult)	7/33 (21.2)	2	2	2	–
0-17 years (subadult)	7/33 (21.2)	–	–	–	6
Indeterminate age	3/33 (9.1)	–	–	3	0
Total	33	14/33 (42.4)	7/33 (21.2)	6/33 (18.2)	6/33 (18.2)

[a]Number of individuals within each age category (percent of individuals in parentheses).

and Ruff (2009) recently published population-specific stature formulae for California populations. Bicondylar femoral length and maximum tibial length were used for stature estimation (recorded to the nearest millimeter).

Table 2 presents stature estimation data for the four male and four female burials with complete femora and/or tibiae (♀ = B. 2, 5, 5A, 20; ♂ = B. 13, 21, 28, 29). The mean stature is 160.95 cm for females and 168.58 cm for males (mean difference = 7.6 cm). One female (B. 5) had a stature estimate that fell within the spread of the male sample. Mean femoral lengths at SOL-451 are comparable to those found in Middle Period samples from the Central Valley and San Francisco Bay Area (Bartelink 2006:239), although small sample size limits interpretation of this measure of health in the sample.

Porotic Hyperostosis and Cribra Orbitalia

Porotic hyperostosis and cribra orbitalia are considered non-specific indicators of skeletal health that occur during infancy or early childhood (Stuart-Macadam 1985, 1987a, 1987b, 1989). Traditionally, these lesions have been interpreted as an anemic response due to iron deficiency, but more recent research suggests that vitamin B_{12} and folic acid deficiencies are more likely causes of megaloblastic anemia (Walker et al. 2009). Other conditions, such as scurvy or trachoma, may cause lesions of the superior eye orbit in certain contexts (Walker et al. 2009:120). Megaloblastic anemia may occur through vitamin B_{12} or folic acid deficiencies from the diet or due to deficiencies caused by parasitic infestation (Walker et al. 2009). In the healed state, porotic hyperostosis appears as small "pin prick" sized lesions on the cranial vault (especially on the parietal and occipital bones), whereas cribra orbitalia lesions show a similar pattern in the superior border of the eye orbit. All lesions in the SOL-451 sample are healed and showed an expression ranging from involvement of only the external table of the skull to coalescence of foraminae and cranial vault thickening. Table 3 presents the distribution of lesions and indicates 31.2 percent of crania are affected by cribra orbitalia and 28.0 percent by porotic hyperostosis. This suggests that at least one-third of the

Table 2. Stature Estimation in the CA-SOL-451 Sample.

Burial No.	Element	Length (mm)	Stature (cm) ± (SE)
Females			
2	femur	415	155.61 ± (2.58)
5	femur	465	168.96 ± (2.58)
5A	femur	413	155.07 ± (2.58)
20	femur	447	164.15 ± (2.58)
Mean			160.95
SE			6.8
Males			
13	tibia	357	159.47 ± (2.81)
21	femur	448	166.64 ± (2.55)
28	femur	472	172.74 ± (2.55)
29	tibia	410	175.48 ± (2.81)
Mean			168.58
SE			7.1

Note: SE = standard error.

individuals in the sample likely experienced nutritional stress during early growth and development.

Linear Enamel Hypoplasia (LEH)

Linear enamel hypoplasias (LEH) are tooth enamel defects that result from acute stress events during dental formation (Goodman et al. 1987; Goodman and Rose 1990; Larsen 1997; Goodman and Song 1999). These defects are observed as circumferentially depressed rings around the tooth crown (Hillson and Bond 1997:91). Teeth were only included in the LEH sample if there was at least one-third of the enamel available for observation. Non-linear hypoplastic defects were not observed in the sample. Table 4 presents the distribution of LEH defects in the sample. Overall, 23.5 percent (4/17) of burials showed at least one canine LEH, including three males and one subadult. The defects occurred on the RC_1 of Burial 1 (defect age = 2.9 years); the LC^1 of Burial 13 (defect age = 4.2 years); the LC_1 (defect age = 3.0 years) and RC_1 (defect age = 1.6 years) of Burial 21; and the LC^1 (defect age = 3.4 years) and RC^1 (defect age = 2.8 years) of Burial 29, a total of six defects. The average age of LEH formation is approximately 3 years, with the youngest defect occurring at 1.5 years and the oldest defect occurring at 4.2 years of age (Table 5). The data suggest that these four individuals experienced

Table 3. Distribution of Cribra Orbitalia and Porotic Hyperostosis in the CA-SOL-451 Sample.

	Total[a]	Male[a]	Female[a]	Indeterminate[a]	Subadult[a]
Cribra orbitalia	5/16 (31.2)	3/10 (30.0)	0/2 (0.0)	0/2 (0.0)	2/2 (100.0)
Porotic hyperostosis	7/25 (28.0)	5/11 (45.5)	1/5 (20.0)	1/3 (33.3)	0/6 (0.0)

[a]Number of individuals with CO or PH divided by the number assessable (percent of individuals affected in parentheses).

Table 4. Distribution of Linear Enamel Hypoplasias (LEH) of Canine Teeth in the CA-SOL-451 Sample.

	Total	Male	Female	Indeterminate	Subadult
Enamel hypoplasia	4/17 (23.5)[a]	3/10 (30.0)[a]	0/2 (0.0)[a]	0/1 (0.0)[a]	1/4 (25.0)[a]
No. of assessable teeth	33	14	7	6	6

[a]Number of individuals with LEH divided by the number assessable (percent of individuals affected in parentheses).

Table 5. Regression Formulae Used to Estimate Age of Hypoplasia Defect Formation, Corrected for Buried Cuspal Enamel (Goodman and Song 1999:224, Table 9.4).

Tooth Type	Equation C[a]	Enamel Represented (in mm)[c]	Developmental Ages Represented (in Years)[d]
Maxillary			
C	Age = (-.521 x Ht)+ 6.0	4 mm	3.9–6.0 years
Mandibular			
C[b]	Age = (-.490 x Ht) + 4.5	4 mm	2.5–4.5 years

[a]Age = age in years; Ht = distance of hypoplastic defect in mm from CEJ.
[b]Assuming amelogenesis of the mandibular canine is complete by 4.5 years.
[c]Minimum cutoff for inclusion in analysis (as measured from CEJ).
[d]Developmental ages (in years) represented by each segment of enamel for each tooth type.

nutritional or disease-related stress during childhood that disrupted enamel formation.

Periosteal Bone Reaction

Periosteal reactions, also known as periostitis or periostoses, are among the most common lesions identified in archaeological skeletons (Larsen 1997; Ortner 2003). The periosteum is a thin tissue membrane that lines the external surfaces of bone. Disruption of this membrane due to infection or trauma may result in a periosteal bone reaction (Lambert 1993; Larsen 1997; Ortner 2003; Walker et al. 2005). Active lesions involve subperiosteal deposition of woven bone superficial to the external cortex and may take on an "onion-skin" appearance (Ortner 2003:53). In contrast, healed lesions may involve large areas of the bone diaphysis and are often characterized by thick layers of striated bone on the external cortex. For reasons not well understood, the tibia is the most commonly affected element (Ortner 2003:209). For this study periosteal reactions were recorded for all available post-cranial skeletal elements. However, only a few cases involved elements other than the tibia; thus, the focus will be on tibial periosteal reactions. Table 6 presents the distribution of periosteal lesions in the sample and indicates that 25.0 percent of left and 28.6 percent of right tibiae were affected. Although the presence of a periosteal reaction only indicates inflammation and not a specific cause, the majority of the lesions in the SOL-451 sample are bilateral and diffuse, suggesting an infectious origin rather than traumatic bone response.

Oral Pathology

Pathological conditions of the jaws and teeth provide insight on the diet and oral health of earlier human societies (Hillson 1996, 2001; Larsen 1997). The direct interaction between teeth and food provide the basis for studying the impact of diet on dental health, including dental caries, attrition, and alveolar abscesses. Dental caries can be defined as an infectious disease process involving the focal demineralization of tooth enamel caused through the secretion of organic acids by oral bacteria (Larsen 1997; Lukacs 2012). Bacterial fermentation of carbohydrates, especially sugars, is strongly correlated with the prevalence of dental caries (Moore and Corbett 1971; Newbrun 1982; Hunter 1988). Severe dental caries may result in complete destruction of the tooth crown, which provides a point of entry for oral bacteria (Ortner 2003). This may cause an infection of the alveolar bone, resulting in abscess and subsequent antemortem tooth loss. The factors that contribute to dental caries are complex, although diet is believed to be an important factor (Moore and Corbett 1971; Newbrun 1982; Hunter 1988). Previous research on Central Valley populations reported relatively high rates of dental caries, especially among females (Schulz 1981; Bartelink 2006; Kolpan 2009), which contrasts with the very low caries rates among populations from the San Francisco Bay Area (Jurmain 1990a; Bartelink 2006) and Central Coast (Bartelink and Yoder 2008).

Six out of 17 (35.3 percent) individuals with scorable dentitions had evidence of dental caries (Table 7). Alveolar abscesses result from infection of the pulp

Table 6. Distribution of Periosteal Reactions in the CA-SOL-451 Sample.

	Total[a]	Male[a]	Female[a]	Indeterminate[a]	Subadult[a]
Left tibia	5/20 (25.0)	1/11 (9.1)	1/4 (25.0)	0/0 (0.0)	3/5 (60.0)
Right tibia	6/21 (28.6)	2/12 (16.7)	1/4 (25.0)	0/0 (0.0)	3/5 (60.0)

[a]Number of individuals with periosteal reactions divided by the number assessable (percent of individuals affected in parentheses).

Table 7. Distribution of Dental Pathology in the CA-SOL-451 Sample.

	Total[a]	Male[a]	Female[a]	Indeterminate[a]	Subadult[a]
Dental caries	6/17 (35.3)	2/10 (20.0)	1/2 (50.0)	1/1 (100)	2/4 (50.0)
Maxillary abscess	6/22 (27.3)	5/12 (41.7)	0/4 (0.0)	1/3 (33.0)	0/3 (0.0)
Mandibular abscess	1/22 (4.5)	0/12 (0.0)	1/4 (25.0)	0/3 (0.0)	0/3 (0.0)
Max. & mand. abscess	2/22 (9.1)	2/12 (16.7)	0/4 (0.0)	0/3 (0.0)	0/3 (0.0)

[a]Number of individuals with oral pathology divided by the number assessable (percent of individuals affected in parentheses).

chamber or tooth socket and are commonly associated with dental caries or severe occlusal attrition. Abscesses were relatively common in the sample and affected 27.3 percent of maxillae and 4.5 percent of mandibles (Table 7), with 9.1 percent of burials showing evidence of abscesses in both the maxilla and mandible. The presence of carious lesions in these individuals suggests they likely consumed a diet that included significant carbohydrates, especially foodstuffs with high sugar content. When processed and cooked, root foods are a significant source of starchy carbohydrates that can contribute to dental caries. In addition, berries also show caries-enhancing properties. In contrast, acorns and small seeds are more likely to inhibit caries formation as these resources contain low amounts of sugar (Bartelink 2006; Kolpan 2009).

Osteoarthritis

Osteoarthritis (OA) is the most commonly reported pathological condition observed on human skeletal remains (Aufderheide and Rodríguez-Martín 1998:93). OA can provide unique insight on stress-related subsistence activities, sexual division of labor, and the aging process in prehistoric populations. Osteoarthritis can be defined as a "non-inflammatory disorder of movable joints characterized by deterioration and abrasion of articular cartilage, as well as by formation of new bone at the joint surfaces" (Hough and Sokoloff 1988:1571). The joint surface may be enlarged through new bone growth (osteophytes) and may show evidence of joint porosity, loss of articular cartilage, and eburnation (polishing) (Aufderheide and Rodríguez-Martín 1998:93).

Methods for scoring degenerative lesions followed Jurmain (1977, 1978, 1990b) using the following criteria: 1) marginal and osteophytic joint lipping; 2) joint porosity; and 3) joint eburnation. The degree of severity was scored for each variable using the following ordinal scale: 0) none to trace; 1) slight; 2) moderate; 3) severe; and 4) not assessable. However, all degrees of severity are grouped together for analysis (i.e., 1–3 scored as "presence of OA"). A diagnosis of OA was made for joint complexes that showed evidence of osteophytic lipping, eburnation, or either indicator in conjunction with joint porosity. Because the disease is often bilateral, presence of the appropriate diagnostic criteria in either side of the body was counted as evidence of the disease.

Vertebral osteophytosis (VOP) represents a degenerative condition of the spine that affects the fibrocartilaginous joints of the vertebral bodies (Aufderheide and Rodríguez-Martín 1998:96–97). This most commonly affects the lumbar spine and involves the development of osteophytes that project away from the margins of the vertebral body. Due to the incompleteness of most vertebrae in the sample, the presence versus absence of VOP was only scored in lumbar vertebrae.

Table 8 presents the distribution of OA in the sample by joint type. OA of at least one joint was present in

Table 8. Distribution of Osteoarthritis (OA) and Lumbar Vertebral Osteophytosis (VOP) in the CA-SOL-451 Sample.

	Total[a]	Male[a]	Female[a]	Indeterminate[a]
Total OA	7/18 (38.9)	5/13 (38.5)	1/4 (25.0)	1/1 (100.0)
Shoulder	1/10 (10.0)	1/8 (12.5)	0/2 (0.0)	0/0 (0.0)
Elbow	6/17 (35.3)	4/13 (30.8)	0/2 (0.0)	0/0 (0.0)
Wrist	2/10 (20.0)	1/7 (14.3)	1/3 (33.3)	1/1 (100.0)
Hip	1/15 (6.7)	1/11 (9.1)	0/4 (0.0)	0/0 (0.0)
Knee	3/16 (18.8)	2/11 (18.2)	0/4 (0.0)	1/1 (100.0)
Ankle	0/12 (0.0)	0/8 (0.0)	0/4 (0.0)	0/0 (0.0)
Cervical	1/10 (10.0)	1/8 (12.5)	0/2 (0.0)	0/0 (0.0)
Thoracic	0/11 (0.0)	0/8 (0.0)	0/2 (0.0)	0/1 (0.0)
Lumbar	0/15 (0.0)	0/10 (0.0)	0/4 (0.0)	0/1 (0.0)
Lumbar VOP	7/15 (46.7)	5/10 (50.0)	2/4 (50.0)	0/1 (0.0)

[a]Number of individuals with OA or VOP divided by the number assessable for a given joint (percent of individuals affected in parentheses).

39.0 percent of the sample (7/18). The highest prevalence on the appendicular skeleton was found at the elbow (35.3 percent), followed by the wrist (20 percent), knee (18.8 percent), shoulder (10.0 percent), and hip (6.7 percent). This conforms to previous studies of archaeological samples that show that elbow OA is typically the most or second most commonly affected joint (Jurmain 1991; Bridges 1992:71; Bartelink 2001; Cheverko 2013).

Although vertebrae were highly fragmented and poorly represented in the sample overall, one individual showed evidence of severe OA of the articular facets of the cervical spine (lipping, porosity, and eburnation), while VOP of the lumbar spine affected 46.7 percent of the total adult sample (7/15). VOP may represent a normal part of the aging process, and it generally affects individuals in their fifth decade of life (Aufderheide and Rodríguez-Martín 1998:96–97). The prevalence and distribution of OA and VOP in the sample is consistent with the findings in many other studies in prehistoric North America (see Larsen 1995, 1997).

Traumatic Injury

Evidence of skeletal trauma can provide insight on patterns of interpersonal violence as well as risks of injury in past populations (Larsen 1997; Ortner 2003). An adult of indeterminate sex (B. 26) had a Colles' fracture of the distal left radius that was associated with secondary osteoarthritis (Ortner 2003:138). The ipsilateral distal ulna also shows evidence of severe osteophytic lipping and moderate eburnation on the articular surface. This type of fracture is commonly the result of an accidental fall with an outstretched hand. An adult male (B. 9) had an osteoblastic growth on the medial aspect of the left humeral diaphysis near the deltoid tuberosity. The growth is consistent with myositis ossificans traumatica, an ossified hematoma resulting from a muscle injury that commonly involves the deltoid muscle (Ortner 2003:133–134). Another adult male (B. 28) showed evidence of spondylolysis of the fifth lumbar vertebra (i.e., a fracture of the neural arch showing nonunion) (Aufderheide and Rodríguez-Martín 1998). This fracture is also associated with vertebral osteophytosis of the centrum of L5.

Spondylolysis is often caused by repeated microtrauma to the lumbosacral region due to stressful activity involving the lower spine, although genetic factors likely play a role (Ortner 2003:147–148).

Concordance of Pathological and Stress Indicators

Table 9 presents the distribution of pathological conditions and nutritional-stress indicators in the SOL-451 burial sample by individual. Eleven of the 31 individuals showed evidence of two or more pathological stress or disease indicators (B. 1, 5, 12, 13, 14, 18, 21, 22, 26, 28, and 29); however, no pattern is apparent between these indicators, as some conditions occurred during different periods of life (e.g., LEH and osteoarthritis).

Comparison with Other Studies

Regional comparisons were limited to conditions that had comparative data sets available and included nutritional stress indicators (cribra orbitalia, porotic hyperostosis, linear enamel hypoplasia) and probable evidence of infectious disease (tibial periosteal lesions, dental caries). The comparative sample included Middle Period (ca. 2160–940 BP) site components from the Sacramento Valley, including CA-SAC-43 (Brazil site) and CA-SAC-60 (Hicks #1 site), and San Francisco Bay site components from CA-ALA-309 (Emeryville site) and CA-ALA-328 (Patterson site). All comparative data were collected using the same methods as used for SOL-451 (see Bartelink 2006) and are reported in Table 10.

Cribra Orbitalia and Porotic Hyperostosis

The prevalence of cribra orbitalia and porotic hyperostosis rates at SOL-451 is similar to Middle Period samples from the Sacramento Valley (e.g., SAC-43, SAC-60), as well as ALA-328 in the San Francisco Bay Area (Figure 2). However, the prevalence is substantially lower than at ALA-309. Comparisons indicate a significant relationship between cribra orbitalia prevalence and site location ($\chi^2 = 21.683$, df = 4, $p < 0.001$). For porotic hyperostosis the prevalence was similar to that of SAC-60 but was substantially lower than that found at the SAC-43, ALA-328, and ALA-309 sites. Comparisons also indicate a significant relationship between the prevalence of porotic hyperostosis and site location ($\chi^2 = 19.665$, df = 4, p = 0.001).

Linear Enamel Hypoplasia (LEH)

The prevalence of maxillary and mandibular canine LEH is substantially lower at SOL-451 than in populations from the Sacramento Valley and San Francisco Bay Area (Figure 3). Statistical comparisons indicate a significant relationship between the prevalence of LEH and site location for maxillary teeth ($\chi^2 = 6.022$, df = 2, p = .049), but not for mandibular teeth ($\chi^2 = 4.416$, df = 2, p = .110).

Tibial Periosteal Reaction

The prevalence of tibial periosteal lesions is higher at SOL-451 than in other groups from the Sacramento Valley and San Francisco Bay Area (Figure 4). However, there is no significant relationship between the prevalence of periosteal reactions and site location for either the left ($\chi^2 = 2.995$, df = 4, p = .559) or right ($\chi^2 = 6.362$, df = 4, p = .174) tibiae. Periosteal reactions may result from bacterial exposure through contaminated water sources, waste accumulation, and high levels of person-to-person contact, and they are typically associated with more densely settled communities (Walker 1986:352; Inhorn and Brown 1990:94; Lambert 1993:510, 517–518). Prevalence of tibial periosteal reactions appears to be similar between the Middle Period site components included in this study as well as in sites along the central California coast (Bartelink and Yoder 2008).

Table 9. Pathological Conditions and Stress Indicators in the SOL-451 Burial Sample.

Burial No.	**MNI**	**Sex**	**Age**	**Date**	**Stature**	**Pathological Condition**							
				BP	(in cm)	PH	CO	LEH	PR Tibia	PR Other	DC	OA	Trauma
1	2	I	13–17	1520	n/a			X	X		X		
2	2	F	17–23	1520	155.6				X	X			
3	3	M	40+	1520	n/a							X	
4	1	M	40+	1520	n/a							X	
5	3	F	35–44	1520	169.0					X		X	
5A	2	F	28–48	1520	155.1								
6	3	M	45–60	1520	n/a							X	
7	2	M	40–49	1520	n/a				X				
8	1	I	18+	1520	n/a								
9	3	M	35–44	1520	n/a								X
9A	2	M	30–34	1520	n/a	X	X						
10	1	F	18+	1840	n/a								
11	1	M	25–49	1840	n/a								
12	2	M	40+	1840	n/a	X						X	
13	2	M	19–34	1520	159.5	X		X					
14	2	M	40–44	1840	n/a	X	X						
15	1	F	30+	1840	n/a								
16	3	I	18+	1840	n/a								
17	1	F	18+	1840	n/a								
18	1	I	7–8	1520	n/a				X	X	X		
19	1	I	13–16	1840	n/a		X						
20	1	F	45–59	1840	164.2	X					X		
21	3	M	20–34	1520	166.6	X		X			X		
22	2	I	11–14	1520	n/a		X			X			
23	1	I	12–17	1840	n/a					X			
24	1	I	IND	1840	n/a								
25	1	I	IND	1840	n/a	X							
26	1	I	40+	1520	n/a						X	X	X
27	1	I	15+	1840	n/a								
28	1	M	20–35	1520	172.7						X		X
29	2	M	25–29	1520	175.5		X	X	X	X			
30	1	I	8–12	1520	n/a				X	X			
31	3	M	18+	1520	n/a							X	

Note: M = Male; F = Female; I = Indeterminate; PH = Porotic Hyperostosis; CO = Cribra Orbitalia; LEH = Linear Enamel Hypoplasia; PR = Periosteal Reaction; DC = Dental Caries; OA = Osteoarthritis.

Table 10. Prevalence of Pathological Conditions and Stress Indicators in the Comparative Middle Period Samples.

Indicator	SOL-451[a]	SAC-43[a]	SAC-60[a]	ALA-309[a]	ALA-328[a]	SacramentoValley[a]	San Francisco Bay[a]
CO	5/16 (31.2)	16/41 (39.0)	5/27 (18.5)	17/21 (81.0)	6/21 (28.6)	—	—
PH	7/25 (28.0)	25/41 (61.0)	9/28 (32.1)	19/24 (79.2)	15/24 (62.5)	—	—
LEH	2/17 (11.8)	—	—	—	—	15/35 (42.9)	8/33 (24.2)
PR left tibia	5/20 (25.0)	6/39 (15.4)	3/25 (12.0)	2/25 (8.0)	4/20 (20.0)	—	—
PR right tibia	6/21 (28.6)	3/38 (7.9)	4/24 (16.7)	2/25 (8.0)	2/21 (9.5)	—	—
Dental caries	7/251 (2.8)	—	—	—	—	53/889 (6.0)	20/829 (2.4)

[a]Number of individuals affected divided by the number assessable (percent of individuals affected in parentheses).
Note: CO = Cribra Orbitalia; PH = Porotic Hyperostosis; LEH = Linear Enamel Hypoplasia; PR = Periosteal Reaction.

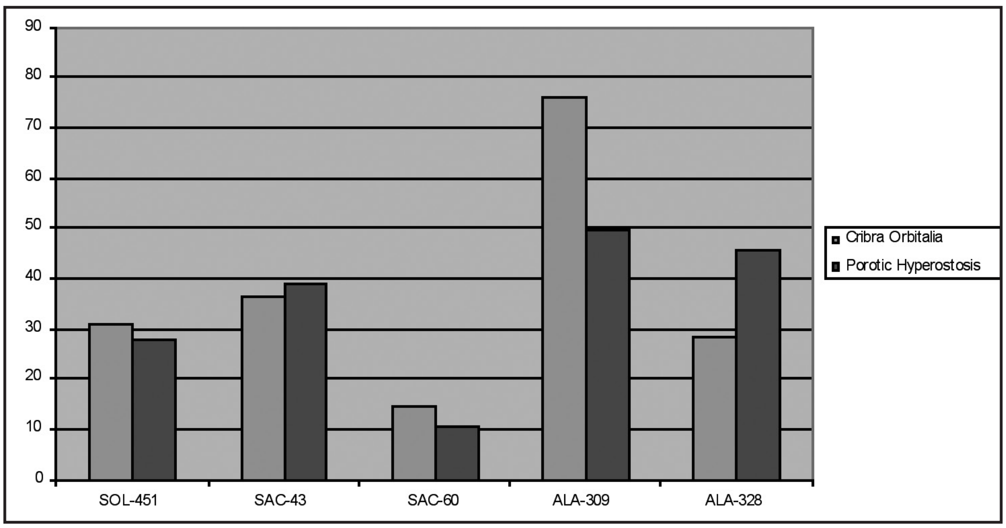

Figure 2. Regional comparison of cribra orbitalia and porotic hyperostosis.

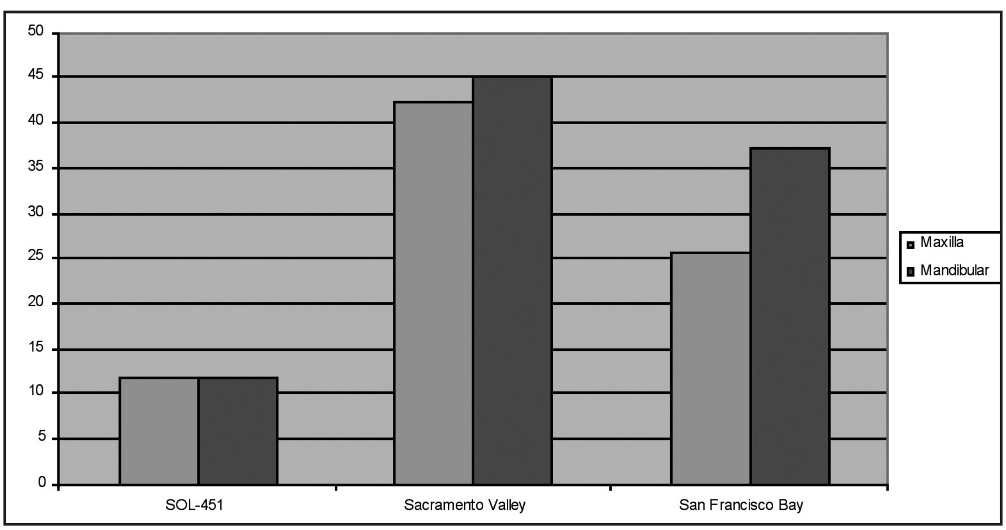

Figure 3. Regional comparison of linear enamel hypoplasia defects in canine teeth.

Dental Caries

For the purposes of comparison, the tooth count method was used to quantify the prevalence of dental caries in the comparative regional samples. The relatively low prevalence of dental caries found in the SOL-451 sample is similar to rates for other San Francisco Bay Area populations, but it is much lower than that found among groups from the lower Sacramento Valley (Figure 5). Statistical comparisons indicate a significant relationship between the prevalence of dental caries and region ($\chi^2 = 15.061$, df = 2, p = 0.001). In burials

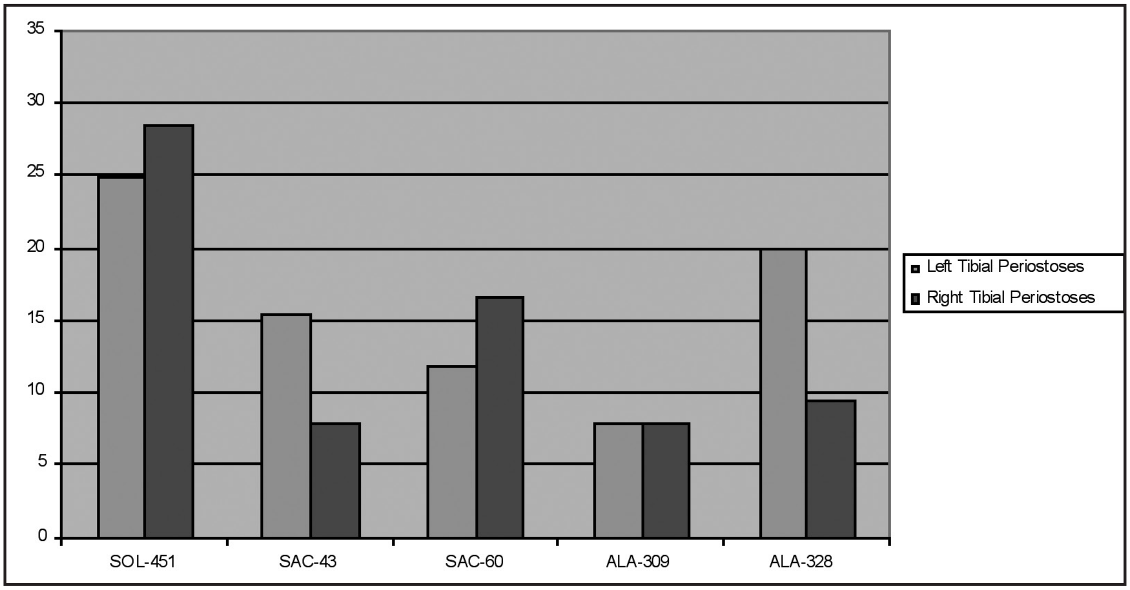

Figure 4. Regional comparison of tibial periosteal lesions.

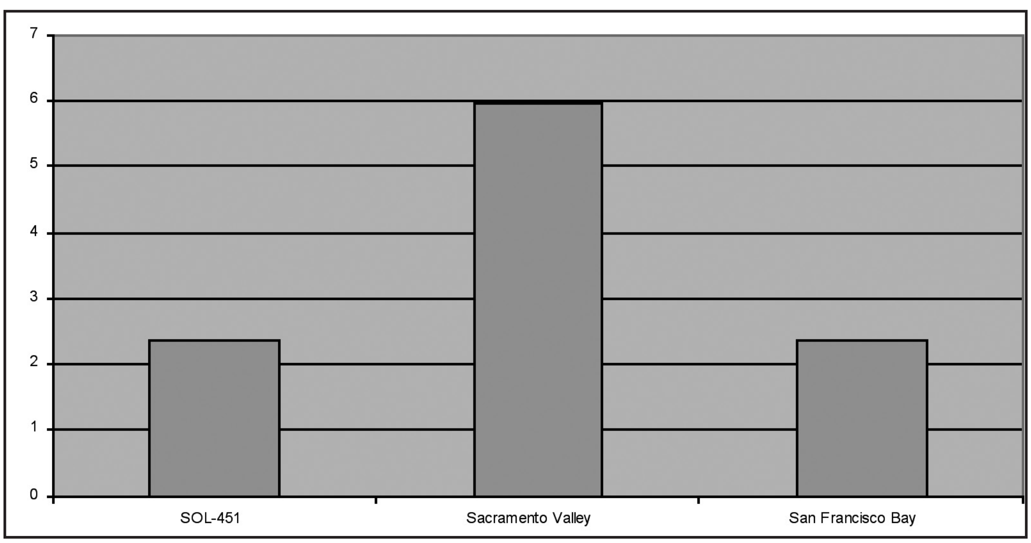

Figure 5. Regional comparison on dental caries. Tooth count prevalence was calculated using the total number of scorable teeth (≥ 2mm of enamel present).

from SOL-451, the lower caries rate is consistent with greater consumption of non-cariogenic resources such as terrestrial game, freshwater and marine fish, as well as acorns and small seeds (Bartelink 2006; Kolpan 2009).

Discussion

Comparison of the nutritional stress and disease indicators provides some support for the central hypothesis of a lower prevalence of skeletal and dental health indicators at SOL-451 than in the more densely settled lower Sacramento Valley and San Francisco Bay Area. For example, while overall prevalence rates for porotic hyperostosis and cribra orbitalia were generally similar between SOL-451 and three other sites (SAC-43, SAC-60, and ALA-328), ALA-309 showed a significantly higher prevalence. ALA-309 is a massive shellmound that was likely associated with a large human population that lived along the northeastern shore of San Francisco Bay (Broughton 1999). High population density in this area may have created the conditions for contaminated drinking water, resulting in high levels of parasitism (Walker 1986:351). In addition, marine fish and marine mammal meat consumed raw are commonly infested with parasites, such as roundworm (*Ascaris lumbricoides*) and tapeworm (*Diphyllobothrium pacificum*) (Walker 1986:351). Humans that acquire these parasites from consuming raw fish and marine mammal meat may develop megaloblastic anemia due to loss of vitamin B_{12} and folic acid through vomiting, ulceration, diarrhea, and blood in the stool (Walker 1986:351). Stable carbon and nitrogen isotope data from prehistoric humans interred at ALA-309 indicate that marine foods were important dietary resources (Bartelink 2006, 2009). Thus, parasitism seems to be a more a likely cause of the porotic hyperostosis and cribra orbitalia lesions in this population than a direct dietary deficiency.

The prevalence of LEH defects was also significantly lower at SOL-451 than in populations from the Sacramento Valley and San Francisco Bay Area, suggesting that childhood stress was a less common problem in the Pleasants Valley region. This contrasts with the tibial periosteal lesions, which showed non-significant differences between SOL-451 and the Sacramento Valley and San Francisco Bay Area. Finally, the prevalence of carious lesions was significantly lower at SOL-451 than in populations from the Sacramento Valley, but was not different from populations from the San Francisco Bay Area. This suggests that food resources consumed by the SOL-451 population were less cariogenic than those consumed by groups from the Sacramento Valley. Stable isotope data from two sites located close to SOL-451 (CA-SOL-11 and CA-SOL-69) indicate that small amounts of marine foods were consumed from brackish environments such as Suisun Marsh (Eerkens et al. 2013). If the SOL-451 population also consumed marine protein resources, this may have raised the pH of the oral cavity, thus reducing the population of oral bacteria that contribute to dental caries (Bartelink 2006). This is also supported by the similar prevalence of dental caries between SOL-451 and the San Francisco Bay Area, the latter of which is known to have consumed high amounts of marine proteins based on stable isotope data from human burials (Bartelink 2006, 2009).

Summary and Conclusions

Overall, the prevalence of nutritional stress and disease indicators at SOL-451 is comparable to that found in other studies within the Middle Period of central California, although some site and regional patterns are evident. Despite the small size of the SOL-451 sample, a number of pathological conditions were observed. Cribra orbitalia and porotic hyperostosis, two possible indicators of anemic response, were identified in approximately 25 to 30 percent of crania. The prevalence is similar to the SAC-43, SAC-60, and ALA-328 samples, but it is much lower than that found for ALA-309. Linear enamel hypoplasia is rare in the SOL-451 sample and only affected the canine teeth of four individuals (6 total teeth). The prevalence was significantly lower for maxillary teeth compared to groups from the lower Sacramento Valley and San Francisco Bay Area. Periosteal bone reactions of the tibia affected approximately 25 percent of individuals, with most cases showing bilateral involvement. This high prevalence suggests that bacterial exposure through contaminated water sources and waste accumulation may have been a health issue in the population. However, no site differences were observed in the prevalence of tibial periosteal reactions. Carious lesions were observed in 35.3 percent of individuals; however, the caries rate using the tooth count method was similar compared to San Francisco Bay Area populations but was significantly lower than populations from the lower Sacramento Valley. Osteoarthritis affected 39 percent of adults, with the greatest involvement for the elbow joint, followed by the wrist, knee, shoulder, and hip, a pattern observed in other studies on prehistoric populations. Vertebral osteophytosis of the lumbar spine also affected 46.7 percent of the adult sample, although vertebrae were significantly underrepresented. Healed fractures were observed in two cases, including a Colles' fracture of the left radius and a fifth lumbar neural arch fracture (spondylolysis). In addition, one case of myositis ossificans traumatica of the left humerus was observed.

Analysis of burials from SOL-451 has revealed important aspects of prehistoric lifeways of the northern San Francisco Bay Area. This study provides a record of stress events and pathological conditions experienced by a sample of the population. Additional studies of human skeletal remains from this area will shed additional light on variability in nutritional stress and health across different regions in central California during the Middle Period.

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