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THE IMPACT OF THE MEDIEVAL CLIMATIC ANOMALY IN PREHISTORIC CALIFORNIA: A CASE STUDY FROM CANYON OAKS, CA-ALA-613/H

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This study tests the hypothesis that the Medieval Climatic Anomaly (MCA) resulted in resource stress and a decline in health in prehistoric California. Data were collected on the human remains (n = 98) from Canyon Oaks in Pleasanton, California. This analysis focuses on stature, linear enamel hypoplasias (LEH), dental caries, and evidence of violence in order to interpret patterns of growth stress, diet, and interpersonal violence in relationship to climatic changes. Statistical treatment reveals little diachronic change in the occurrence of stature, LEH, or interpersonal violence. However, the prevalence of dental caries shows significant temporal and sexual differences. These results suggest a substantive shift in diet during the MCA, without accompanying changes in growth stress or violence. It appears that this population mitigated stress through cultural and social means of buffering environmental changes. These findings underscore the role of the environment in prehistory, and the complexity of human responses to stress and climate.

STUDIES ON PALEOCLIMATE have identified post-glacial warming periods in many parts of the world during the Middle Ages, called the medieval warm epoch, or Little Optimum (Lamb 1977). On the west coast of the United States, these changes were characterized by warmer temperatures and associated droughts lasting from approximately A.D. 800 to 1350. Multiple lines of evidence have been used to verify these intense, long-scale droughts, including analyses of pollen (Adam and West 1983; Davis 1999), tree-rings (Graumlich 1993; Cook et al. 2004), carbon isotopes (Ingram 1998; Li et al. 2000), and giant sequoia fire scars (Swetnam 1993). Due to the abnormal nature and timing of these climatic changes, this period has been termed the Medieval Climatic Anomaly or MCA (Stine 1994).

Archaeological evidence suggests that significant cultural changes occurred among native populations throughout the areas affected by these droughts, and in fact climate may have been a driving force behind these cultural responses (Moratto 1984; Raab and Larson 1997; Jones et al. 1999; deMenocal 2001). Moratto and colleagues (1978) have suggested that social disruptions

among prehistoric California populations—such as increased violence, population dispersals, a breakdown of political organization, significant decreases in trade, and changes in subsistence—were concomitant with a warming climate and drought-like conditions. Similarly, studies of Channel Island Indians have shown that a variable climate, as well as population increases in a constrained environment, resulted in increased violence (Walker 1989) and emerging social complexity (Arnold 1987, 1992). Furthermore, Walker (1986) has established a connection between the climatic anomaly and lowered nutrition. An increase in the occurrence of porotic hyperostosis among island Indians was attributed to a lack of fresh water and other resources directly related to changes in the climate.

While it is difficult to establish the ultimate causality of these cultural changes using the archaeological record, these studies have relied on a synchrony of events to support their conclusions (Jones et al. 1999). Other researchers have criticized this method as being environmentally deterministic, and instead stress models of economic intensification (Cohen 1977, 1979; Basgall

1987; Broughton 1994, 1997). Population growth during this time is believed to have been the prime mover—driving market concentration, and ultimately leading to changes in social structure and subsistence, leaving the environment to play only a minor role, if any at all.

The aim of the present study is to examine the effects of the environment, specifically the MCA, on prehistoric peoples. This work tests the hypothesis that the extreme drought associated with this climatic anomaly would have led to severe resource stress resulting in declined health. For this study, health is defined as a state of total mental, social, and physical well-being, recognizing it as more than the mere presence or absence of disease. Therefore, a decline in health would manifest itself in both physiological and cultural disruptions.

This study employs a bioarchaeological approach to evaluate health as revealed through temporal changes in skeletal remains. Physiological disruptions in development and growth are identified through data collected on stature and linear enamel hypoplasias, and social disruptions are studied through changes in diet and interpersonal violence. It is believed that changes in these specific behaviors could have arisen as cultural buffers adopted in response to climatic instability. This hypothesis was tested using the human remains from the Canyon Oaks site (CA-ALA-613/H) in Pleasanton, California (Fig. 1). This site was well suited to such a study for two reasons: first, it was occupied continuously for approximately 3,600 years, spanning the period before, during, and after the climatic changes under consideration; second, studying the skeletal remains from a single site permitted an analysis of climate and human responses at a local level.

SKELETAL MARKERS OF HEALTH

To catalogue general health, various skeletal markers were chosen for analysis. This approach is emphasized by Larsen (1997:8), who recognizes health as an aggregate of “nutrition, disease, and other aspects of life history.” Health and stress represent a process, as opposed to an event, and may be expressed in any number of ways. To obtain a thorough understanding of health and cultural adaptation it is necessary to study multiple health indicators. These include data on stature, linear enamel hypoplasias, dental caries, and interpersonal violence.

Stature has been used in archaeological contexts to study cultural transformations within populations. However, interpreting stature data can often be complex, as there are many environmental and genetic factors to consider (Larsen 1997). While genes play a role in stature, there is a strong relationship between childhood stress and adult height. Evidence from modern populations has indicated that short stature can be the result of disease or poor nutrition during childhood (Lambert 1993; Larsen 1997). Based on what is understood about terminal height, temporal changes in stature can be used to indicate resource abundance and the disease load within a skeletal population (Walker and Lambert 1989).

Enamel hypoplasias are dental defects associated with the developmental disruption of enamel matrix secretion. This defect can manifest itself in a number of ways, the most common of which is the “furrow-type defect,” or linear enamel hypoplasia (LEH) (Hillson 1996). The development of hypoplasias is considered non-specific and the result of any number of stressors, such as disease or poor nutrition. These defects are not subject to subsequent remodeling after their initial formation, and therefore serve as important indicators of childhood growth interruption (Hutchinson and Larsen 1988). This makes analyses of enamel hypoplasias particularly suited to studies of temporal changes in stress (Goodman and Rose 1991).

During the MCA, members of the Canyon Oaks population may have been forced to modify their diet in order to cope with limited resources. Such changes in subsistence were assessed through the prevalence of dental caries among the Canyon Oaks population. The development of dental caries is a disease process characterized as the destruction of cement, dentine, and enamel of the tooth due to the bacterial fermentation of consumed carbohydrates. The etiology of dental caries is not entirely known; however, several factors have been linked to the progression of the disease, such as dental plaque, bacterial flora, contact of the teeth with the oral environment, and diet. There are also a number of modifying factors linked to dental caries, such as tooth morphology, age, heredity, sex, and periodontal disease, to name only a few (Larsen 1997). Among all of these factors, diet has been found to strongly influence the development of carious lesions among human populations (Hillson 1992). Therefore, temporal changes

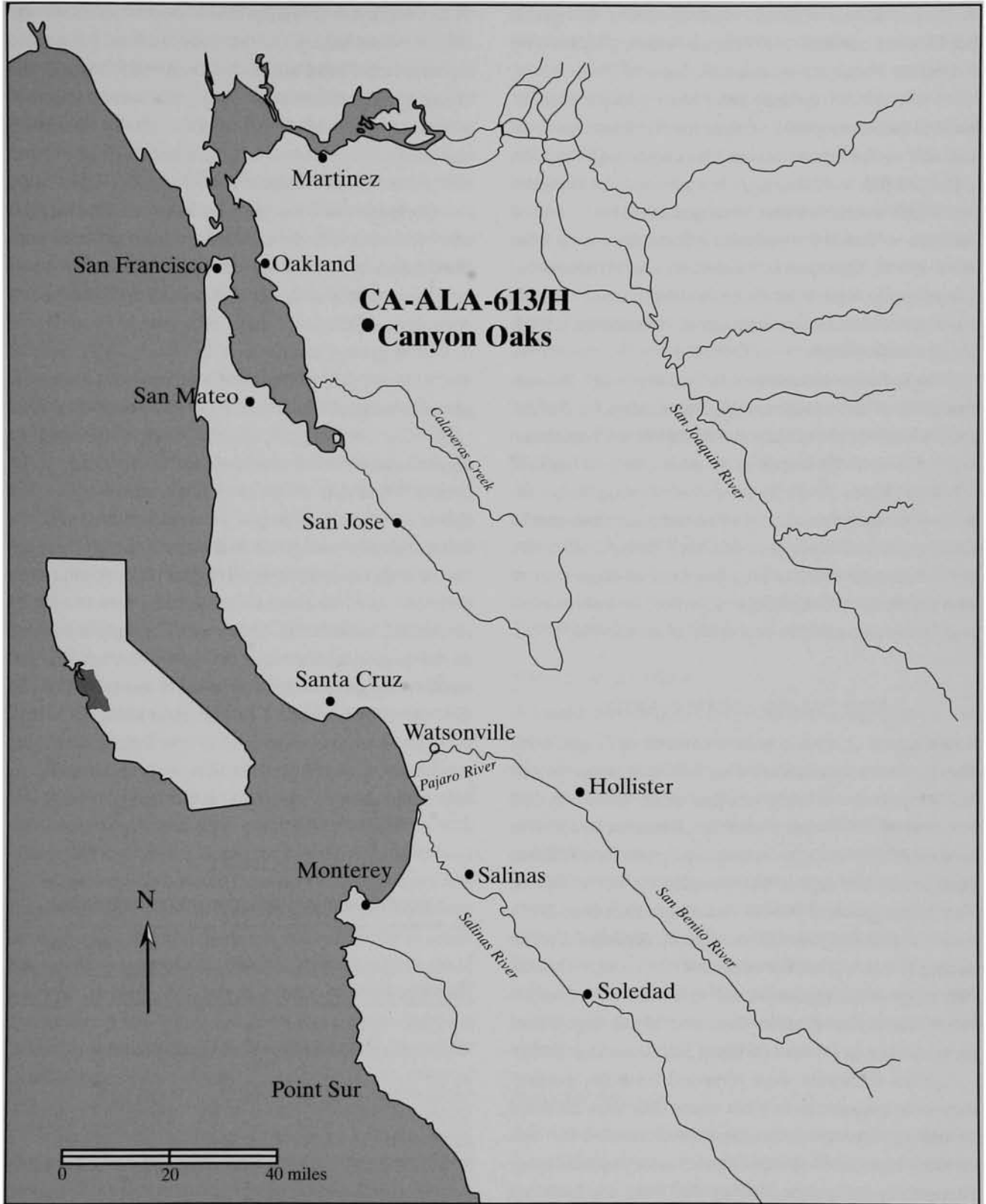


Figure 1. Location of Canyon Oaks, CA-ALA-613/H.

in the prevalence of carious lesions among prehistoric populations can indicate changes in diet (Walker and Erlandson 1986; Larsen et al. 1991; Larsen 1995).

Violent behavior may have been another possible cultural buffer adopted to secure limited resources in an unstable environment. Walker and Lambert (1989) have suggested that food shortages and resource stress caused by climatic conditions may have accounted for increased violence at Ven-110, a prehistoric cemetery dating from A.D. 100 to 1100 that is located 95 km. northwest of Los Angeles. Additional studies on the Channel Islands have also documented increases in violence during the MCA (Walker 1989).

Such violent behavior may be categorized through evidence left on skeletal remains. For example, fractures of the midshaft of the ulna (parry fractures) are considered defensive wounds sustained by attempting to fend off a blow (Ortner 2003). Bone can also retain projectile points or show evidence of perimortem cut marks (Auferhide and Rodriguez-Martin 1998). Additionally, cranial trauma is considered evidence of some sort of aggression; this includes depression fractures of the vault and facial fractures (Jurmain and Bellifemine 1997).

MATERIALS AND METHODS

The Canyon Oaks site was discovered in August 2002 during construction activities for a housing development. Full-scale data recovery resulted in the discovery and removal of 473 Native American skeletons, in addition to a wealth of artifacts, ecofacts, and prehistoric features. Historically, this region was occupied by the Ohlone or Costanoan group of Native Americans (Kroeber 1925), and it is presumed that this same group resided at the site during its occupation between 1,890 B.C. and A.D. 1760. This range of occupation, as well as the number of burials recovered, makes Canyon Oaks one of the largest sites found to date in the area (William Self Associates 2005).

After skeletons were removed from the ground, they were transported to a lab where data were collected by one of three observers. Age was estimated through various observations of skeletal morphology: metamorphic changes in the pubic symphysis (Todd 1921, 1921b; Brooks and Suchey 1990); degenerative changes to the auricular surface (Lovejoy et al. 1985); dental eruption (Ubelaker 1999); dental attrition (Dreier 1978); closure

of the epiphyses (McKern and Stewart 1957); and the closure of the sutures of the endocranium, palate, and ectocranium (Todd and D.W. Lyon 1925; Meindl and Lovejoy 1985; Mann et al. 1987). Sex was determined based on observations of several sexually dimorphic characteristics of the pelvic girdle and skull (Brothwell 1981; Buikstra and Ubelaker 1994; Bass 1995; White 2000).

Skeletons were assigned an absolute date through one of three methods: accelerated mass spectrometry, shell bead typology, or obsidian hydration band measurements and X-ray fluorescence (William Self Associates 2005). Once assigned a date, skeletons were placed in groups in relationship to the MCA. Several studies of the paleoclimate of California have placed the climatic changes of the MCA at varying dates (Graumlich 1993; Stine 1994; Ingram 1998; Li et al. 2000); however, they tend to fall within the range acknowledged by Jones et al. (1999) of A.D. 800 to 1350. This is the range that was chosen for this study, as it is the most inclusive series of dates, and also corresponds to the established chronology for the area (Bennyhoff and Hughes 1987). A total of 98 skeletons could be assigned an absolute date in relation to the MCA (Table 1). Unfortunately, only a fraction of the total available skeletal material from this site could be assigned a date and used for the present study. This research requires a fine-grained analysis of time period, and any inconsistencies in date assignments could potentially skew results. Therefore, only those skeletons with a firm date were included in this study.

Table 1

DEMOGRAPHIC DISTRIBUTION OF EACH TIME PERIOD

Time Period	Subadult		Male		Female		Indeterminate Sex		Total n
	n	%	n	%	n	%	n	%	
Prior to MCA									
1,890 B.C. - A.D. 800	2	8.3	10	41.7	8	33.3	4	16.7	24
During MCA									
A.D. 800-1350	9	16.1	28	50	16	28.6	3	5.3	56
Post MCA									
A.D. 1350-1760	3	16.7	9	50	5	27.8	1	5.5	18

Stature

Stature can be estimated in a number of ways; however, long bones are generally used as a correlate to height.

The most accurate measurement, and the one most often used, is the maximum femur length (Bass 1995). Due to the lack of complete femora among the burials with an accurate date, stature was estimated using any and all complete long bones, including ulnae, radii, humeri, femora, tibiae, and fibulae. Stature estimates were calculated for each individual using the regression equation established by Genovés (1967). Once stature was determined for all available adult remains, the sample was divided between males and females to control for sex-related differences in height.

Linear Enamel Hypoplasias

To study the prevalence of LEH at Canyon Oaks, a dental inventory was taken to determine the total number of observable teeth. Any tooth below its occlusal third was disregarded from this count, as heavily worn teeth can interfere with the researcher's ability to adequately identify enamel defects. It has also been suggested that a high degree of antemortem tooth loss can indicate that a population was subject to greater degrees of stress, which can also interfere with results (Hutchinson and Larsen 1988). However, in the Canyon Oaks population there was a small amount of antemortem tooth loss, which when present was always associated with old age. Therefore, no measures were taken to account for this potential bias in the sample.

Enamel defects were analyzed in two ways. First, the number of individuals with the defect were counted and compared to the total number of individuals with observed dentition. Second, in order to differentiate systemic and localized stress, Hillson (1996) has suggested that it is important to identify enamel defects on several teeth forming at the same time for a single individual. A table was devised in which matches could be made to observed defects based on developmental categories. Only when matches were found could a defect be determined systemic, and scored as present for an individual.

Dental Caries

The presence of dental caries was recorded as either present or absent for each observable tooth based on a macroscopic investigation of all tooth surfaces, including the cemento-enamel junction. No distinction was made based on lesion type, location, number per tooth, or

size (Sciulli 1997). Noncarious pulp exposure caused by attrition was not included. Periapical lesions were also not included, as they were found to occur almost exclusively with the presence of noncarious pulp exposure or dental caries. The teeth were subdivided into two types, anterior and posterior. Anterior teeth were defined as the first and second incisors, as well as canines, and posterior teeth were the third molar to third pre-molar. This was done to account for the bias inherent in each tooth type; posterior teeth are more likely to develop dental caries and to be lost postmortem (Hillson 1996). Teeth were further separated by age and sex, as both can influence the progression of dental caries (Walker and Erlandson 1986).

The data on dental caries were analyzed in two ways. First, the total number of carious lesions observed per tooth type in each age and sex group was calculated as a percentage of the total number of teeth. This analysis was based on the assumption that within these groups, each tooth will express carious lesions independently. Second, to address the potential influence of individual oral environment on lesion progression, which may affect the independence of these data, an analysis was done on the number of individuals displaying carious lesions per time period.

Interpersonal Violence

Evidence for violence was inferred from the presence of parry fractures, cranial fractures, perimortem cut marks, or embedded projectile points. All skeletons displaying such evidence showed only one instance of a violent encounter, and data for interpersonal violence were either recorded as present or absent for each individual. No further measures were taken to account for the amount of preservation of each element, as there is a clear bias during the later periods towards preservation. Therefore, only the number of individuals affected in relation to the number of individuals from each time period was used to calculate the rate of interpersonal violence.

Statistical Analysis

All data were subject to statistical tests of significance using the statistical package Minitab 14. Stature estimates for each sex and time period were compared using ANOVA ($p \leq 0.05$). Chi-square analyses were employed for all other lines of data to evaluate temporal differences in relation to climatic changes ($p \leq 0.05$).

RESULTS

Female stature was at its lowest during the MCA, while that of males was at its lowest before the MCA. The average stature for both males and females was at its greatest during the latest period (Table 2). However, these temporal changes were slight, and no significant temporal differences were found among females ($p = 0.801$) or males ($p = 0.586$).

Table 2
MEAN STATURE ESTIMATES

Time Period	Male			Female		
	Mean Stature ^a	N	SD ^b	Mean Stature	N	SD
Prior to MCA 1,890 B.C.-A.D. 800	164.38	4	2.41	157.8	2	4.67
During MCA A.D. 800-1350	164.99	15	3.24	157.19	13	3.13
Post MCA A.D. 1350-1760	166.44	4	1.61	158.30	3	1.06

^aMeasurements are in centimeters.
^bSD is standard deviation.

The prevalence of linear enamel hypoplasia was low in all three time periods. When it did occur, it was restricted to the anterior teeth almost exclusively, with only one instance on a maxillary third premolar and another on a maxillary second molar. A comparison of individuals displaying the defect revealed no significant temporal change ($\chi^2 = 1.764$, $p = 0.414$) (Table 3). Using the approach proposed by Hillson (1996) to catalog systemic stress, only one individual at Canyon Oaks displayed this defect: a male estimated between the ages of 35 and 39, dated to the MCA.

Table 3
ADULT INDIVIDUALS WITH LINEAR ENAMEL HYPOPLASIAS

Time Period	Affected Individuals	N	%
Prior to MCA 1,890 B.C.-A.D. 800	1	13	7.7
During MCA A.D. 800-1350	10	33	30.3
Post MCA A.D. 1350-1760	3	11	27.3

Prevalence of dental caries decreased significantly through time among all male posterior teeth ($\chi^2 = 6.058$, $p = 0.048$), and male anterior teeth ($\chi^2 = 18.070$, $p = 0.000$). However, female posterior teeth showed a significant

peak in carious lesions during the MCA ($\chi^2 = 6.005$, $p = 0.050$), with a similar pattern observed among anterior teeth. Unfortunately, chi-square approximation was invalid for this set of data due to low expected cell counts resulting from observed zero values both before and after the MCA (Tables 4 and 5). Similar trends were observed among counts of individuals displaying carious lesions (Table 6). However, these changes were not significant among males ($\chi^2 = 0.758$, $p = 0.685$), and could not be defined for females, again due to the zero values. No carious lesions were observed on subadult dentition.

Table 4
**ANTERIOR TEETH WITH CARIOUS LESIONS
AMONG ADULTS AGED 18-39**

Time Period	Male			Female		
	Affected Teeth	N	%	Affected Teeth	N	%
Prior to MCA 1,890 B.C.-A.D. 800	5	34	14.7	0	67	0
During MCA A.D. 800-1350	1	128	0.1	3	106	2
Post MCA A.D. 1350-1760	0	50	0	0	12	0

Table 5
**POSTERIOR TEETH WITH CARIOUS LESIONS
AMONG ADULTS AGED 18-39**

Time Period	Male			Female		
	Affected Teeth	N	%	Affected Teeth	N	%
Prior to MCA 1,890 B.C.-A.D. 800	8	90	8.9	0	48	0
During MCA A.D. 800-1350	10	237	4.2	16	177	9.0
Post MCA A.D. 1350-1760	1	95	1.1	0	20	0

Table 6
ADULT INDIVIDUALS AGED 19-39 WITH CARIOUS LESIONS

Time Period	Male			Female		
	Affected Individuals	N	%	Affected Individuals	N	%
Prior to MCA 1,890 B.C.-A.D. 800	3	10	30	0	5	0
During MCA A.D. 800-1350	4	25	16	5	13	38.5
Post MCA A.D. 1350-1760	1	8	12.5	0	5	0

Violent encounters appeared to have decreased from nearly 18% during the period prior to the MCA to approximately 6% afterwards (Table 7). However, this reduction was not temporally significant ($\chi^2 = 1.062$, $p = 0.588$). It is important to note that all of the skeletons displaying evidence of violence, from the entire population of 473 individuals, were assigned an absolute date and included in this study. Therefore, these averages are elevated in this analysis. Also, since it is not known how the rest of the population was distributed through time, it is difficult to say whether these percentages are an accurate reflection of temporal changes in violence.

Table 7
INDIVIDUALS DISPLAYING EVIDENCE OF INTERPERSONAL VIOLENCE

Time Period	Affected Individuals	N	%
Prior to MCA 1,890 B.C. - A.D. 800	4	23	17.4
During MCA A.D. 800 - 1350	6	56	10.7
Post MCA A.D. 1350 - 1760	1	17	5.9

DISCUSSION

The results of the statistical analyses revealed no significant diachronic changes in stature, linear enamel hypoplasias, or interpersonal violence. Conversely, the prevalence of dental caries among adult males and females changed notably through time. The small sample size in this study likely affected the ability of the statistical tests to detect a difference, bringing the validity of these findings into question. It is therefore important to put them into context through comparisons with other studies on prehistoric California populations.

The present findings stand in contrast to those from a study of the skeletal remains from CA-SJO-91, a Northern Valley Yokuts site located outside of San Jose, California, a study which also analyzed climate-related health changes. Data were collected on paleodemography, cortical thickness, trauma, and pathology among 98 individuals who lived both before and during the climatic anomaly. Significant differences were found between these two groups, leading the researcher to conclude that drought-related conditions had had adverse effects

on the overall quality of life and health (Weiss 2002). Although different skeletal markers were used in the present study, such drought-related disruptions in health were not found.

The absence of observable changes in stature may be related to sample size; this coupled with a high variance rendered the power of this test quite low, affecting its ability to detect differences between the samples. However, Dickel et al. (1984) found in a large sample from several Central California sites that stature did not vary through time despite changes in the stress experienced by native populations. Similar conclusions were drawn from an analysis of populations at three sites within 10 km. of Canyon Oaks (CA-ALA-483, -555, and -483 Extension). Stature estimates were made using the same formula employed in this study and are shown in Table 8. Each site represents a distinct time period, ranging from 3,420 B.C. to A.D. 1370; little temporal difference in stature was observed (Wiberg 1996). Conversely, Lambert (1993) published very different results based on her research on the Santa Barbara Channel Islands. In a survey of 149 individuals, she found that average height was reduced by 10 cm. from 6,000 B.C. to A.D. 1782.

Table 8

MEAN STATURE ESTIMATES FROM OTHER CALIFORNIA SITES^a

Time Period	Time Period	Male		Female	
		Mean Stature ^b	N	Mean Stature	N
CA-ALA-483	3,420 - 780 B.C.	174.2	5	164.2	1
CA-ALA-555	180 B.C. - A.D. 360	168.8	31	159.4	38
	A.D. 1430 - 1680				
CA-ALA-483 Extension	A.D. 1210 - 1370	168.0	3	154.4	3

^aFrom Wiberg (1996)

^bMeasurements are in centimeters

The rate of LEH appeared to increase during the MCA; however, these results were not significant. Other studies of hypoplasia in central California populations also found an increase around the time of the MCA. However, those samples showed a further increase into the later periods (Dickel et al. 1984), whereas the Canyon Oaks population showed a decrease. Contrary to the Canyon Oaks data, skeletal remains from coastal southern California also exhibit temporal increases in

LEH (Lambert and Walker 1991). The discrepancies in these findings may be due to small sample size, or to different methods used in recording and reporting enamel disruption. It has been argued that the width of hypoplasias offers a reasonable estimate for the duration of the stress episode (Hutchinson and Larsen 1998), as well as the number of perikymata in the occlusal walls of the defects (Guatelli-Steinberg et al. 2004). The present study did not record such distinctions, and LEH were merely recorded as present or absent.

Statistical tests indicate that the rates of interpersonal violence at Canyon Oaks appear to have remained steady through time. This is similar to findings at the nearby sites of CA-ALA-483, -555, and -483 Extension, which showed a steady rate of violence at around 10% from 3,420 B.C. to A.D. 1370. While the overall rate of violence did not change at these sites, the authors did note an increase in violence towards females during the Late period, which they attribute to either wife-stealing or spousal abuse (Wiberg 1996). Conversely, in southern California, Walker (1989) documented a temporal increase in violent behavior as evidenced by cranial injuries, which was attributed to a growing population and an unstable environment.

It is also of note that the rates of interpersonal violence at Canyon Oaks appear low for prehistoric California. Among the entire sample at Canyon Oaks ($n = 473$), only 4.5% of the population displays evidence of violence. This is less than half the reported amount of 10% at CA-ALA-483, -555, and -483 Extension (Wiberg 1996), as well as at another Ohlone site, CA-SCL-647, in Santa Clara, California, where a similar rate of 10% was reported (Andrushko et al. 2005). Although still higher, somewhat more comparable rates were found to the northeast of Canyon Oaks at CA-CCO-474/H, where violent behavior was recorded at 6% (William Self Associates 2002). At CA-ALA-329, located in the Coyote Hills south of San Francisco Bay, craniofacial injuries were found at a rate of 2.7% (Jurmain and Bellifemine 1997). Among the Canyon Oaks sample, only three individuals displayed such injuries, accounting for less than 1% of the sample.

In southern California, rates of violence were even higher. Healed cranial depression fractures were found among nearly 19% of the Chumash Indians living on the Channel Islands, and among 7.5% of those living on the mainland (Walker 1989). In the Canyon Oaks

population, only one individual exhibited similar trauma: a female aged 50–60. At CA-YEN-110 in Ventura, evidence for projectile point wounds was present in 10% of the population (Walker and Lambert 1989). In the Canyon Oaks sample, only four individuals were found with evidence of projectile point injuries.

The generally low rates of violent behavior observed at Canyon Oaks may be due in part to the volume of remains recovered; among all the sites discussed here, this yielded by far the largest sample, ranging from over twice to nearly five times as large. Additionally, this population was not subject to the pressures of a developing hierarchical society, as has been suggested to have been the case at other sites (Andrushko et al. 2005). Kennett (2005) has suggested that increases in violence among Chumash Island populations after 650 A.D. were related to population growth and environmental instability. Territories and villages were solidifying, making it difficult to forage on or colonize other parts of the small island; the result was a higher potential for violence. The population at Canyon Oaks was not subject to these same limiting factors of space as the island Indians were. They were therefore better equipped to cope with cultural and environmental changes, resulting in a steady, low level of interpersonal violence. It appears that the Canyon Oaks population was able to maintain good intra- and inter-group relations despite environmental or cultural stressors, which may help account for the duration of occupation observed at Canyon Oaks. This lack of temporal change in markers of physiological disruption and violence may speak to the relative health of the people of Canyon Oaks and to their ability to cope with resource stress.

The evidence of dental caries presented highly significant temporal variation, in contrast to the other skeletal markers used in this study. Overall, carious lesions among males decreased through time, while the rate among females was highest during the MCA. These results are contrary to what has been found in other California populations, which show either significant increases in carious lesions through time (Basgall 1987; Wiberg 1996) or little change at all (Dickel et al. 1984).

The high rate of anterior carious lesions observed in male dentition prior to the MCA is of particular interest. This is a very high rate and is suggestive of the introduction of a very specific cariogenic environment

to the mouth. One possible explanation for this rate of dental caries may be that males were using their anterior teeth as tools. A macroscopic evaluation of the dentition from Canyon Oaks revealed that three individuals had occlusal surface grooving on the anterior teeth, and two had similar grooves on the posterior teeth. All five individuals were male, and two could be assigned a date placing them both in the period after the MCA. It has been suggested that such grooving among prehistoric central California populations was related to pulling fibrous materials over and across the teeth during the production of basketry, string, cords, boats, or nets (Schulz 1977). However, such occlusal grooves in other California and Great Basin populations are generally not associated with carious lesions (Schulz 1977; Larsen 1985). Four of the five males with occlusal grooves had carious lesions in either the anterior teeth or the first and second molars.

A second type of tooth wear that coincides with a high prevalence of dental caries among cultures without agriculture is lingual surface attrition of the maxillary teeth (Turner and Machado 1983; Irish and Turner 1987). This is a disproportionate wear specific to the maxillary anterior teeth that is thought to be due to dietary practices. Studies conducted among prehistoric South and Central American populations have concluded that this wear was caused by eating and processing some type of starchy or abrasive food. It has also been suggested that shellfish consumption might be responsible for the wear (Irish and Turner 1987). A more recent study of prehistoric tooth use among the Tutu of the U.S. Virgin Islands found maxillary lingual wear and occlusal grooving in the same population—indicating that types of tooth use and wear need not be mutually exclusive (Larsen et al. 1998).

Unfortunately, wear patterns of anterior teeth were not recorded for the Canyon Oaks population, and it is not clear if such patterns may have contributed to dental caries progression. As access to this collection is no longer possible, questions regarding the origin of this high rate of carious lesions may never be resolved. What can be determined is that the activity that led to the high prevalence of male anterior dental caries stopped during the MCA, evident in the much lower rates of dental caries in the periods both during and after it.

These analyses of carious lesions show significant differences between males and females during the MCA. It appears that during the MCA a new gender-based

subsistence strategy was adopted to cope with declining resources. On the basis of new evidence indicating that oceanic conditions favored high productivity during the MCA (Jones et al. 1999; Kennett and Kennett 2000), it is suggested that the population at Canyon Oaks may have begun to rely more heavily on ocean resources for subsistence as terrestrial ones were being depleted. Ethnographic reports on the Ohlone indicate that the duties of fishing in the bay and in the streams were generally relegated to men (Kroeber 1925; Font 1931; Galvan 1968; Milliken 1996). While it has been suggested that men most likely played an integral role in harvesting and gathering plant materials (McGuire and Hildebrandt 2004), they may have been torn from these duties during the MCA as changing climatic conditions necessitated an increased reliance on fishing. The dry conditions may have forced the men to travel the some 50 km. to the ocean to obtain fish, clearly giving them greater access to this high-protein food source. Not only would this high protein diet have resulted in fewer dental caries among men, it has also been shown that fish protein is high in fluoride, which would also hinder the development of carious lesions (Leverett 1982). Women, on the other hand, in the absence of male assistance and in the face of poorer climatic conditions, would have increased their foraging range and practice. The archaeobotanical remains at Canyon Oaks corroborate this hypothesis by showing a change in subsistence practices at the inception of the MCA, marked by a wider range of diet with a stronger reliance on acorns (William Self Associates 2005). This greater consumption of starchy, terrestrial-based foods would have led to an increase in carious lesions among females.

After the MCA, the prevalence of dental caries decreased in all the dentition of both sexes to the lowest rates of all three periods. In addition, the difference in observed carious lesions between men and women found during the MCA almost entirely disappeared. This suggests that gender-based subsistence strategies may have coincided more during this time as climatic conditions became more favorable. Based on these results, it would appear that the population of Canyon Oaks continued to exploit fish as a dietary staple after the termination of the MCA. One possible explanation for this continued exploitation could be the return of streams, rivers, and lakes throughout the area as a result

of the increased precipitation occurring at the conclusion of the MCA. This would have allowed fishing to occur closer to the site, providing easier access to and transport of such lacustrine resources, therefore giving females greater access to this high protein diet.

CONCLUSIONS

The results of this study indicate that the general health of the Canyon Oaks population was relatively stable through time despite changes in the climate. No significant changes were observed in stress-related growth disruption, and levels of interpersonal violence seemed to be low with no temporal changes. Based on the evidence for dental caries, as well as archaeobotanical remains, it appears that the population at Canyon Oaks was forced to develop new subsistence strategies due to climatic stress. This validates the original hypothesis only in part—as predicted cultural buffers were put into place to mitigate environmental instability, these adaptations were sufficient to avoid any accompanying disruptions in growth and development or increases in violence.

These results emphasize the role of climate change in altering culture above other economic models of change, including population growth, and can best be explained through the resource stress model. This model focuses on resource availability and criticizes population growth models for their inability to explain causality or take into account cultural buffers to curtail growth. Instead, it focuses on a group's desire to constantly seek equilibrium and their ability to adapt to resource stress in order to maintain balance. This would result in several cultural and technological developments that allowed prehistoric populations to keep an optimal balance between the cost of suffering and that of maintaining a steady population (Hayden 1981).

The inhabitants of Canyon Oaks were able to combat resource instability by increasing the diversity of their resource base, which resulted in minimal physiological stress being observed in the skeletal remains. These results also agree with the general model for the study of stress in skeletal populations proposed by Goodman and Armelagos (1989). In their model, environmental constraints represent the main source of stress for a population. These stresses are then subject to a cultural buffering system; if the culture or the individual is

unable to resist the stressor, physiological disruption will occur. However, if the buffering system put into place is adequate to resist the stress, its impact will not be seen or felt—as is the case at Canyon Oaks.

The seeming ease with which this population was able to adapt may be due in part to the flexibility ascribed to hunting and gathering. During times of climatic instability such groups are better equipped to diversify, due to their better understanding of wild foods and plant exploitation strategies (Gamble 2005). It may also have been related to a very specific set of conditions that were unique to the locality of Canyon Oaks. This may have included any number of factors, such as the degree of political complexity, population size, extent of trade networks, or the biodiversity of the area. During the MCA, a time of climatic instability, many sites within the region were abandoned (Wiberg 1996; Ingram 1998; Jones et al. 1999), and populations in the Channel Islands were facing increases in violence (Walker 1989), the frequency of periostitis, and an overall decrease in stature (Lambert 1993). However, the population of Canyon Oaks was able to remain in place and adapt to changing conditions.

Definitive cause and effect relationships are difficult to determine in prehistory; however, it appears from the Canyon Oaks sample that climate was the main cause of change. While small sample size is an inherent problem in this temporal study, analyzing health using multiple indicators, coupled with statistical analyses and comparative data, allows trends to emerge. These biological data indicate marked cultural changes occurred within this single population, specifically in relation to the MCA. This study also underscores the variety of responses to climate change present in prehistoric California. There was clearly no prescribed response to resource stress, as illustrated through comparisons of the Canyon Oaks population with other Native California groups. This study highlights the importance of the environment in prehistory, and brings to the forefront the complexity and range of cultural responses to climate.

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