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Assessing forearm fractures from eight prehistoric California populations

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ASSESSING FOREARM FRACTURES
FROM EIGHT PREHISTORIC CALIFORNIA POPULATIONS

A Thesis

Presented to

The Faculty of the Department of Environmental Studies
San Jose State University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by

Diane Marie DiGiuseppe

August 2009

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SAN JOSE STATE UNIVERSITY

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ASSESSING FOREARM FRACTURES FROM EIGHT

PREHISTORIC CALIFORNIA POPULATIONS

by

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ABSTRACT

ASSESSING FOREARM FRACTURES

FROM EIGHT PREHISTORIC CALIFORNIA POPULATIONS

By Diane DiGiuseppe

Cultural resource management strategies under the California Environmental Quality Act (CEQA) provide mechanisms that allow for the preservation and mitigation of prehistoric sites. Many San Francisco Bay Area sites have provided greater understanding about Native American prehistoric population interaction, including evidence of interpersonal aggression. Previous research on ulna fractures has been interpreted by bioarchaeologists as a specific type of behavior indicating intentional trauma. However, bioarchaeologists have begun to question this interpretation and have developed a more thorough methodological approach that offers greater accuracy in reconstructions. This study analyzes both ulnar and radial fractures from eight prehistoric Native American sites in the San Francisco Bay Area to determine whether fracture type indicate trauma. Transverse fractures have often been assumed to be caused by intentional trauma, whereas oblique fractures have been assumed to be due to accidents. Side, location of fracture, age, sex, other trauma indicators, and secondary pathology were correlated with the fracture type to determine whether transverse fractures were more likely related to intentional trauma than oblique fractures. Chi-square results indicated that fracture types were not randomly distributed for two tests. One of these tests provided results that did not support the hypothesis and were counter to expectations.

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I. INTRODUCTION

Prehistoric cultural resources are an integral part to the environmental impact assessment report process. A critical question for that assessment then is the significance (as defined under the California Environmental Quality Act (CEQA)) of a site or a specimen's position within that definition, with the cultural context as key to determining this significance. This thesis addresses the cultural interpretation of physical evidence from eight sites from the San Francisco Bay Area as it relates to the etiology of forearm fractures and its relationship to intentional versus unintentional trauma.

During the past century of research conducted on California's Native Americans, early anthropological ethnographic studies articulated the concept that Central California people living in the greater San Francisco Bay Area were a docile and relatively passive group of individuals who lived in peace with their neighbors and environment. University of California, Berkeley pioneer anthropologist, A. L. Kroeber, once suggested that, "...with scarcely an exception they were unwarlike..." (Kroeber, 1923). Since those early days of research, the examination of skeletal remains found in California archaeological sites has dispelled some of these preconceived ideas of a "passive" society. On the contrary, evidence of traumatic lesions found in their skeletal remains include cranial depressions, embedded projectile points, parry fractures, peri-mortem modification, and scalping (Andrushko et al., 2005; Grady et al., 2001; Jurmain, 1991, 2001; Jurmain et al., 2009; Lambert, 1993, 1994, 1997; Nelson, 1997; Price et al., 2006; Walker, 1989). Yet, even with the overwhelming evidence of interpersonal aggression, the propensity for misunderstanding empirical evidence exists. Specifically, while

conducting osteological research in the San Francisco Bay Area, researchers encountered incidences of trauma in the form of forearm fractures that they assume and classify as a result of interpersonal aggression between tribes.

By the 1970s and 1980s, the identification and inference of forearm fractures, specifically those identified as parry fractures, were generally accepted as indications of interpersonal aggression (Armstrong, 1977; Lahren and Berryman, 1984; Ortner and Putschar, 1981; Wells, 1964; Wood, 1979). Over time, California archaeological site reports continued to interpret forearm fractures, specifically involving ulnae, as indications of interpersonal aggression (Cartier et al., 1993; Hylkema, 2007; Jurmain, 1993, 1996, 2001, 2007). More recently, the interpretation of forearm fractures as evidence of interpersonal aggression in these ancient populations has come into question. New interpretations suggest that forearm fractures can be explained more accurately as either a result of intentional or unintentional trauma. Several studies that focused on the etiology of forearm fractures support the hypothesis that a percentage of the identified fractures in skeletal populations are associated with accidents and are not exclusively the result of interpersonal aggression, specifically when only the ulna is involved (Alvrs, 1999; Grauer and Roberts, 1996; Judd and Roberts, 1999; Judd, 2004, 2008; Jurmain, 1991; Kilgore et al., 1997; Smith, 1996; Standen and Arriaza, 2000).

At this point it is important to understand the biological design of the forearm and the dynamics between the radius and ulna that contribute to the interpretation of possible fracture causation. The forearm consists of two elements, the ulna and the radius. When the forearm is held in the correct anatomical position, the radius is positioned laterally to

the body and the ulna is medial. The ulna acts as a simple hinge in conjunction with the humerus at the elbow, which allows the forearm to bend at the humeroulnar joint (White, 1991). Along with the radius, the ulna acts as a lever to lift and pull in the supinated position (Evans, 1955; Kitchen, 1948; Koskinen et al., 1997; Sinha et al., 1999; White, 1991). The radius acts as a saddle joint, where it both flexes and rotates at the elbow. In the motion of twisting from a supinated to pronated position and back, the axis rotation is through the proximal radius and the distal ulna (White, 1991).

The inference of an ulnar fracture that is caused by interpersonal aggression is usually the result of parrying a blow (from a club or baton) aimed at the head of an individual. As the weapon strikes down, the reflex is for the individual to lift his/her arm in protection. The fifth digit is facing outwards away from the face and the ulna is thus the element closest to impact with the medial edge coming into contact with the weapon (i.e., club) first. Of the two elements in the forearm, the ulna is the longest and thinnest, making it vulnerable to fracture upon impact (Galloway, 1999).

The skeletal reaction to impact depends upon the forces enacting upon the bone and/or the amount of loading (loading refers to the amount of pressure or force that is placed upon the bone). When a bone fractures, three forms of loading are placed upon the element: compression, tension and torsion. Compression is expressed as loading on the element from both the proximal and distal ends that pushes towards the center. The bone has greater resistance to compression loading in the event of fracture than it does to tension. Tension is expressed as loading that occurs by pulling from both ends away from the center. The greatest force of a fracture to the ulnae or radii begins on the tensile

side, specifically, fracture begins on the side of the bone that is under tensile loading and then moves across the bone to the area of compression. Basically, the bone begins to break at the point where tensile loading (pulling) occurs (Galloway, 1999).

Torsion occurs when force is placed on the element due to twisting or rotation of a portion of the bone along its long axis. The resulting break due to a torsional fracture results from the twisting of the element and appears as a spiral line in the forearm, sometimes involving both elements. When both elements are involved, it is referred to as an ipsilateral or paired rotational fracture (Judd, 2008; Key and Conwell, 1942). Besides both elements being fractured, it can be further recognized by angulation and rotational deformity associated with torsional loading (Yochum and Rowe, 1996).

Additionally, the importance of fracture types relative to the direction of force applied to the element needs to be understood. Galloway (1999) describes a variety of fracture types, such as, transverse, oblique, and spiral, and the type of force necessary to break the element. With regard to the forearm, two types of force are applied to the bone creating a specific fracture type, either direct or indirect. When the forearm receives a direct force blow, the resulting fracture type is classified as transverse. This is recognized by the perpendicular fracture that runs at right angles to the long axis of the bone (Galloway, 1999; Yochum and Rowe, 1996). In most cases, the direct force is the result of the forearm coming into direct contact with another object, such as a club or a stationary rock. Galloway (1999) states “direct trauma is induced when an object strikes the non-moving or slowly moving body or when the moving body strikes a stationary or slower moving object.”

The second type of force described by Galloway in reference to forearm fractures is indirect force that results in an oblique break (1999). This is recognized by the diagonal fracture line that usually occurs at a 45 degree angle with blunted ends and generally is the result of an accidental fall (Galloway, 1999; Yochum and Rowe, 1996). The most common way for an oblique fracture to occur is by an accidental fall onto an outstretched hand. The indirect force of the fall radiates up the element inducing a fracture line to move diagonally across the bone. Spiral fractures also appear similar to oblique fractures and are produced by a “combination of angulation and rotation of the forearm” with the ends of the break pointed like a pen (Galloway, 1999, Yochum and Rowe, 1996). Specifically, when the forearm is twisted, the radius moves across the ulna creating stress. This stress can cause a fracture to the radius that puts pressure on the ulna inducing a spiral fracture to both elements; when the spiral fracture is due to indirect force, the breaks often occur at different levels with the ulna fracture generally at a lower level than the radius (Key and Conwell, 1942). Again, this type of fracture is referred to as an ipsilateral or paired rotational break. A way to visualize this type of fracture is to imagine the hand is stationary and the twisting of a forearm caused by a body in motion that places excessive stress upon the bones causing the trauma. The stress and forces of the twisting create a spiral fracture. By understanding bone dynamics and forces that are applied to the forearm, a clearer understanding of the processes that cause the fracture can be made about the specific fracture types and their etiology.

The purpose of this research is to apply a specific methodology suggested by researchers in the examination of forearm fractures in an attempt to clarify whether the

specific forearm lesions seen on skeletal remains occur more likely from intentional (i.e., interpersonal aggression) or unintentional (i.e., falls) causes. To make such determinations, fracture types are recorded for both ulnae and radii. As our understanding of direct and indirect force suggests, as described by Galloway (1999), Grauer and Roberts (1996), and Judd (2008), the amount of force that impacts the element can help in determining whether the fracture was caused by intentional or unintentional trauma. Furthermore, other factors are examined in this study to determine if there is a relationship between fracture types (transverse or oblique) and other indicators of either intentional or unintentional trauma, as well as the influences of secondary pathology (degenerative disease).

II. RELATED RESEARCH

Bioarchaeological Research of Forearm Fracture

Over the last few decades, bioarchaeological studies of skeletal populations have evolved from a generalized and assumptive methodology, to a more scientific analysis of paleopathological trauma (Armstrong, 1977; Galloway, 1999; Grauer and Roberts, 1996; Judd, 2000, 2002, 2004, 2006, 2008; Jurmain, 1991, 1993, 1996, 2000, 2001, 2007; Lahren and Berryman, 1974; Ortner and Putschar, 1981; Wells, 1964; Wood, 1979). Previous studies usually provide information such as: skeletal elements being examined, the sex and age of the individual, followed by a statistical analysis (Armstrong, 1977; Jurmain, 1991, 1993, 1996, 2000, 2001, 2007; Lahren and Berryman, 1974; Ortner and Putschar, 1981; Wells, 1964; Wood, 1979). In many cases, specific methodology for determining forearm fractures as indications of intentional trauma was not provided and assumptions regarding the etiology were given an interpretation that was not necessarily accurate (e.g., Armstrong, 1977; Jurmain, 1991, 1993, 1996, 2000, 2001, 2007; Lahren and Berryman, 1974; Ortner and Putschar, 1981; Wells, 1964; Wood, 1979).

For example, a generalized methodology of reporting on trauma is presented in many California site reports, e.g., CA-SCL-68, CA-SCL-137, CA-SCL-690, and CA-SCL-732 (Cambra et al., 1996, Cartier et al., 1993, Hylkema, 2007; Jurmain, 1993, 1996, 2000, 2007). The paleopathology sections in these reports interpret the presence of forearm fractures as indicators of interpersonal aggression with the methodological criteria for determination based on macroscopic review of the element, location of the fracture on the ulna, and the presence of other intentional trauma indicators, such as,

embedded projectile points and cranial depressions. It should be noted though, that these intentional indicators are not necessarily found on the same individual (Cambra et al., 1996; Cartier et al., 1993; Hylkema, 2007; Jurmain, 1993, 1996, 2000, 2007).

Radiographs were also taken to support the macroscopic determination that a fracture was indeed present on the element. Though fracture lines were visible on some radiographs, no identification of a fracture type was included in the analysis of the involved elements.

Outside of California, Lahren and Berryman's (1974) study examined a prehistoric population from the Chucalissa site in western Tennessee and interpreted fractures to the forearm as signs of interpersonal aggression, though the central hypothesis for this study was to determine activity patterns between high and low status individuals as reflected in their fracture patterns. This study examined fracture patterns found in 80 individuals. The postcranial elements examined included the femur, forearm, clavicle and humerus. Chi-square tests were run for sex distribution of the sample to determine if there was a significant difference between males and females of different social status's and the number of fractures observed. The results indicated that forearm fractures had the highest rate of fracture involvement at 46.2% followed by the clavicle at 30.8% and that the majority of post-cranial involvement was found in high status males. The observations made at this site concluded then that individuals with forearm fractures could only have received them from an aggressive encounter with another person, while the interpretation for clavicle fractures was that they were indications of accidents (Lahren and Berryman, 1974).

Interpretations that forearm fractures are indicators of interpersonal aggression were similarly expressed by other researchers during the 1960's through the 1980's (Armstrong, 1977; Ortner and Putschar, 1981; Wells, 1964; Wood, 1979). Wood (1979) wrote that fractures found on the ulna could only be "reasonably explained" as resulting from parrying a blow aimed at the head. His conclusions were that no natural causes could explain how the ulna could be fractured. Additionally, Angel's (1974) study identified the most common site of fractures as located in the forearm, which was again interpreted as interpersonal aggression. In all three studies mentioned above, one factor needs to be considered in support of their interpersonal aggression interpretation. In all the studies, forearm fractures were more prevalent on the left side. Common knowledge indicates that right-hand dominance in the world outweighs the percentage of left-hand dominant individuals. This understanding is then extrapolated to imply that prehistoric and historic populations would raise their non-dominant left arm in a defensive move because the right hand would be carrying a weapon. Moreover, the victim would more frequently be facing a right-handed foe that would strike the opponent on the left side and, in most cases, this concept holds true. A study by Jurmain (2001) of a Central California population (CA-SCL-38) on patterns of trauma indicated that 80% of the individuals with ulna fractures were located on the left side for both male and females, thus supporting the right-hand dominance perspective.

In California, a study conducted by Jurmain (1991) of the Ryan Mound (CA-ALA-329) used differential diagnosis (macroscopic and radiographic) to consider overall trauma to the skeletal remains. The results indicated that the 248 individuals in this study

did sustain various fractures that were related to both accidents and interpersonal aggression and that parry fractures (ulnae fractures) were identified as a result of interpersonal aggression (Jurmain, 1991). Support of this interpretation was the recognition that 60% and 62% of the ulnae and radial fractures, respectively, were located on the left side. Additionally, Jurmain (1991) documented a high incidence of degenerative disease found in the hands and feet that was believed to be associated with recurrent trauma to these joints that probably involved fractures to either or both forearm elements. Radiographs were used to verify the location of fractures after macroscopic analysis was completed. No determination for fracture type to the forearm was provided in Jurmain's review of skeletal trauma for the Ryan Mound (1991).

The study by Jurmain (1990) at CA-ALA-329 focusing on degenerative disease did state that the most common location on the peripheral skeleton for incidence was the hands and feet with 31% of the adults with wrist/hand involvement equally divided between males and females and about 5% of the individuals with involvement to the elbow on each side. Additionally, those individuals exhibiting degenerative disease of the wrist/hand, the oldest age category over 40 had the largest expression at 56% for males and 64% for females.

By the 1990's, researchers were developing a more rigorous scientific/clinical approach to understanding forearm trauma in skeletal remains. Grauer and Roberts (1996) examined the patterns of traumatic lesions on long bone fractures from a medieval site, St. Helens-on-the-Wall in Britain to determine the patterns of healing and evidence of treatment. As part of this study, they examined long bones from 1014 individuals for

fracture type. As suggested by other bioarchaeologists, fracture type (e.g., transverse, oblique, spiral) may provide a method for identifying causation (Bennike, 1985; Galloway, 1999; Judd and Roberts, 1999; Judd, 2000, 2004, 2008). In their examination of fractures at St. Helens-on-the-Wall, Grauer and Roberts (1996) were able to determine distinct differences between fracture types. Their methodology included both macroscopic and radiographic analyses. They recorded fracture type, healed or unhealed fractures, shortening, angular deformation, and apposition (a horizontal shift of the element at the fracture point) in an attempt to determine the causative factors leading to the trauma. Additionally, they sexed and aged all skeletons, looked for the presence of degenerative joint disease usually represented as osteoarthritis in the wrist, which can be an indicator of fracture trauma to the arm, and secondary pathology (periostitis or osteomyelitis) (Bennike, 1985; Grauer and Roberts, 1996). Based on the analysis of fracture types, the majority of individuals at St. Helens-on-the-Wall with ulnar fractures were interpreted as resulting from accidental injury caused by falls or similar occurrences. This applied methodology and interpretation of causative factors contributes to the understanding of the nature of forearm fractures found in prehistoric populations.

Other studies have agreed with Grauer and Roberts's (1996) assessment of fracture types and have employed the same methodology in an attempt to recognize these differences in forearm fractures (Galloway, 1999; Judd, 2000, 2004, 2008; Judd and Roberts, 1999). Kilgore and colleagues (1997) examined two cemetery populations from Kulubnarti, Sudan, comprised 146 individuals (66 males and 80 females) for trauma and

determined that the majority of fractures these individuals incurred probably occurred because of accidental falls. Indications of intentional trauma, such as embedded projectile points or a high number of cranial depressions, were not found on these skeletal remains. One individual did have a suspected cranial depression, but upon review it was determined that it was probably not a depression and therefore not caused by aggression (Jurmain, 2006). Thus, Kulubnarti is an interesting case study since there are a large number of forearm fractures present in this population with no other indications of interpersonal aggression. Of the 260 ulnae present, 34 (13.1%) had fractures (18 left and 16 right) (Kilgore et al., 1997). Chi-square tests were run for significance levels between cemeteries showed little difference in prevalence between males and females or between left- and right-side involvement. The only significant finding was the “higher rate of fracture of the left radius” for females compared to males at 12.8% to 1.6%, respectively. Additionally, Kulubnarti had a very high prevalence of ipsilateral (the paired elements of the ulna and radius located on the same side) fractures to the forearm (23.1%) that supports the inference made recently by Judd (2008) on the “Parry Problem,” that these types of paired rotational breaks may indicate an etiology of accidental trauma. Though the authors state that intentional trauma should not be completely dismissed from consideration, the fracture pattern found at Kulubnarti suggests a hypothesis that these individuals received their fractures from accidental falls due to the harsh environment and terrain. Kulubnarti is located in the Sudan in the region of *Batn el Hajar*; known as the “belly of rock,” and is a harsh and hostile environment that lies between the second and third cataracts along the Nile River (Adams, 1977; Alvrus, 1999; Kilgore et al., 1997; van

Greven et al., 1981; Wendorf 1968). Due to the location of Kulubnarti, it has been suggested that its relative isolation from other populations may have been one of the reasons that so little evidence of intentional trauma is present in these skeletal remains (Adams, 1977; Alvrus, 1999; Kilgore et al., 1997; van Greven et al., 1981; Wendorf 1968). Thus, the environmental conditions and harsh terrain may provide the best explanation for the high number of individuals associated with forearm fractures. Future research utilizing radiographs and documenting fracture type may further support the hypothesis that these fractures occurred through accidental trauma.

Cemetery research by Judd and Roberts (1999) on the rural farming community of Raunds from medieval Britain was compared to another rural farming community (Jarrow Abbey) as well as three urban sites for patterning and frequencies of long bone fractures, including the ulna. The sample size for the rural sites was 170 individuals for Raunds and 140 for Jarrow Abbey. The urban site samples numbered 212 for St. Helens-on-the-Walls, 532 for St. Nicholas Shambles, and 212 for Blackfriars (Judd and Roberts, 1999). They identified parry fractures due to swelling between the distal and middle third of the shaft and classified these as either transverse or oblique fracture type. The swelling described by Judd (1999) in this study referred to the formation of a callus over the fracture site. A callus is woven bone that forms a bridge between the two pieces of fractured bone (Adams, 1983). The results of this study indicated that there was a higher frequency of ulnar and radial fractures in females ($n = 12$) compared to males ($n = 2$) in the group, which in the rural environment was interpreted as caused by tripping or short falls associated with female related chores, i.e., “procuring, transporting, and processing

items, associated with farming activities” (Judd and Roberts, 1999). Additionally, breaks were more prevalent in the rural vs. urban populations. The high fracture prevalence in the rural populations was again argued to be related to the activities surrounding a farming community. This interpretation was supported by the high number of individuals that exhibited oblique fractures compared to transverse (Judd and Roberts, 1999).

In 2002, Judd examined two Nubian populations (a rural population with 55 individuals and an urban population with 223 individuals) from the Kerma Classic Period (1750-1500 BC) of Ancient Nubia for an assessment of accumulated injuries, which in clinical research is termed “injury recidivism.” “Injury recidivism” in clinical studies refers to individuals that have repeat incidents of trauma. Judd’s (2002) study sought to define multiple injuries, differences in injury patterns, and association with intentional and/or accidental trauma. Chi-square tests were run to determine significant differences between individuals with one or more injuries between the two populations. Results indicated that there were no significant differences in the number of injuries between populations, while the rural population had a higher rate of multiple injuries at 61.8% compared to 18% for the urban population. One limitation in using archaeological samples for studies on “injury recidivism” is determining when an individual received an injury. Multiple injuries could have occurred during one episode or at different times during the individual’s lifetime. Judd’s (2002) study does suggest that when examining multiple fractures for causation, that other fractured elements may help in solidifying an etiology. Specifically, fractures of the femur, lower vertebrae, and tibia, are generally associated with accidents, while fractures of the cranium and ulnae are generally

interpreted as indications of intentional trauma. This interpretation can be extrapolated to the current study when examining skeletal remains from the San Francisco Bay Area. Skeletons that have forearm fractures need to be examined for additional fractured elements to help in determining the etiology of trauma (intentional or unintentional).

Research conducted by Mays (1996) focused on determining whether loss of bone occurs in either sex with the advancing of age and whether bone loss weakens the element sufficiently so individuals become susceptible to fractures. Mays' (1996) study examined a medieval peasant group of 154 individuals from Wharram Percy in England and a modern population from Finland. The methodology included accurately sexing and aging skeletal remains and selecting individuals with the second metacarpal intact with no soil erosion or breaks. Measurements were taken of the 2nd metacarpal at the mid-shaft using radiographs. Cortical indices were also taken from radiographs measuring the total bone width minus the medullary width divided by total bone width times 100. The results of this study indicated that males displayed no significant changes in bone loss for the three age categories Mays used in this study or between-group differences using a one-way ANOVA. Results for females though established a different pattern compared to males. Specifically, modern females showed more fractures to the hip area than medieval females. Mays hypothesized that this was due to the different types of ground surfaces that the females came into contact with, specifically women in the medieval sample would not break their hips as readily as modern women since the ground would be more giving than concrete (1996).

Research by Lovejoy and Heiple (1981) examined a population from the Libben Site, Ottawa County, Ohio that further demonstrated the possibility that older individuals are more likely to bear healed fractures. Using survivorship curves constructed for the entire sample for each element, Lovejoy and Heiple were able to determine specific age ranges that were at greater risk of fracture. The results indicated that the greatest number of individuals fell into two age categories: 10-25 and over 45. They attributed the higher rate of long bone fractures in the first age range to be caused by normative activities associated with adolescence. Warfare was not believed to be a contributing factor since there appeared to be no sex differential in this age range from those individuals with long bone fractures. The second age range included individuals over the age of 45 who were hypothesized to be the victims of accidental trauma, due in part to the location of most of the forearm fractures, e.g., Colles', with only two individuals from the population with "parry" fractures of the ulna (Lovejoy and Heiple, 1981). This was further supported by the high frequency of Colles' fractures located on the right radius and "assumed dominance of right-handedness in this population" (Lovejoy and Heiple, 1981). The population also had a high number of clavicle fractures at 5.8% that Lovejoy and Heiple (1981) suggested was not surprising since it is one of the most frequently fractured bones in modern populations, though in other archaeological context, involvement of the clavicle has not been recorded as high. Specifically, at CA-ALA-329, Jurmain (1991) found only 1% of the population with clavicle fractures that he associated with accidental causation. Thus, identification of other fractured elements such as the clavicle can highlight the possible etiology associated with forearm fractures.

Additionally, Lovejoy and Heiple (1981) looked at Buhr and Cooke's study (1959) that hypothesized that males were more likely to have fractures clearly associated with work-related accidents during their wage-earning period that conformed to the Libben fracture patterns. Overall, the research supports the conclusion that the majority of fractures found in the Libben population were caused through accidental trauma and not by intentional means.

In a 2008 article Judd focused on issues similar to the ones that this research seeks to explore, "The Parry Problem." One of the important aspects of this paper includes specific criteria for identifying parry fractures: "1) the absence of radial involvement, 2) a transverse fracture line, 3) a location below the midshaft, and 4) either minor malalignment ($\leq 10^\circ$) in any plane or horizontal apposition from the diaphysis ($< 50\%$)" (Judd, 2008). Additionally, Judd suggests that when fractures to the ulna do not fit within these criteria, the term "parry" should not be used, but rather refer to the fracture as an isolated fracture of the ulnar shaft (2008). Another aspect of this study was the definition of paired rotation or ipsilateral fractures. Judd (2008) describes the paired rotation fractures as the result of a fall "on the outstretched hand, where the force of impaction is transmitted up the bone shaft to produce an oblique line" and are the results of indirect force. These definitions and criteria for recognizing parry fractures from ulnar shaft fractures are useful for the present study, since besides looking at fracture type, the location of the fracture on the element and the absence of radial involvement further supports the hypothesis that transverse fractures are indications of intentional trauma, while oblique fractures express evidence of unintentional causation.

Clinical Research of Forearm Fractures: A Review

As forearm fractures are represented in archaeological context, so too are they recorded in modern populations. “Nightstick” fractures have been recorded from various areas of the world, but predominantly in Africa. In a study by DeSouza (1968) of 456 patients examined for patterns of trauma from the Malugo Hospital, Kampala, Uganda, 191 were recorded with fractures and another 116 with head injuries. From the 191 individuals with fractures, 52 were recorded as occurring by “assault or bodily violence” and of those, 30 were recorded to have been assaulted with a stick. The 166 head injuries recorded had 60 that were associated with assaults and 24 caused by blows from a stick. A summary of his findings indicated that the majority of fractures from assaults were greater than traffic-accident-related injuries with the most common weapons used, the panga (long knife) and the stick. A study from Pretoria determined that 69% of their patients were assaulted with a wooden baton called a knobkerrie and that 67% of the victim’s injuries occurred on the left side (Du Toit and Grabe, 1979).

Further research on “Nightstick” fractures continues to identify a high number of individuals that are assaulted with sticks. In the Basotho Community, Lesotho, of the Republic of South Africa, 184 men and 70 women were assaulted by men or women with sticks (van Geldermalsen and Van der Stuyft, 1993). The results of these attacks showed that head wounds were more prevalent than fractures for this population at 41% and 11%, respectively, with the majority of assaults on individuals between the ages of 20 to 30 (van Geldermalsen and Van der Stuyft, 1993). The inference for the higher incidences of head wounds found in this population among males between the ages of 20 to 30 is the

role the Basotho stick plays in this society. For young males, the stick is regarded as a status symbol with encounters between combatants considered a noble sport, thus it is not surprising that head wounds outnumber fractures in this population (van Geldermalsen, 1993). An additional study by van Geldermalsen (1993) from the Lesotho community indicated that the predominant age for male assaults was 25 to 29 while in females the age ranged from 30 to 34. Butchart and Brown (1991) found similar results with their study in Johannesburg-Soweto, Africa, that recorded higher incidents of violence peaking between the ages of 20 to 24 for males and declining until approximately 55 and females peaked between the ages of 25 to 34 before declining. Overall the assaults from sticks in these societies continue to be recorded in the clinical literature and provide some possible insight into the history of forearm fractures found in archaeological context.

Another aspect of clinical research on forearm fractures focuses on the links between high incidences of distal radial fractures due to age related factors, i.e., osteoporosis and falls. Beringer et al., (2005) study examined 1147 females between the ages of 40-75 with low-trauma forearm fractures in an attempt to propose treatment options to reduce the onset of osteoporosis and secondary fracture prevention. Of the 1147 females, 365 participated in bone mineral density testing. The results from the testing indicated that 32% of the women had osteoporosis at the forearm, which was higher than the percentage for both the hip (14%) and spine (29%). Risk factors identified in the study indicated that early onset menopause, previous hysterectomy, and smoking increased the amount of bone loss found in the females examined. Though this study focuses on aspects of osteoporosis, the indications of forearm trauma associated

with these individuals suggests that we should see a greater number of fractures to the distal radius than either the hip or spine in older females (Beringer et al., 2005).

Thus, research on the forearm suggests that there is a relationship between distal radial fractures and older individuals with the primary etiology to be due to falls rather than osteoporosis (Brogren et al., 2007; Lofthus et al., 2007; Nordvall et al., 2007).

Nordvall's et al., (2007) study of 93 women and 5 men from Luleå, Sweden over the ages of 45 and 60, respectively, suggested that osteoporosis was not the main risk factor for low-energy (low-energy radial fractures are described as fractures due to falls that occur from a sitting or standing position) distal radial fractures, but that as the individuals aged they became more susceptible to falls. Using two groups (patients with recorded radial fractures and a control group) the research tested individuals for bone mass density (BMD). The study found that the BMD became equally lower in both groups (patient and control) as the individuals aged. The main risk factor then leading to fractures was falls. The study found that falls were attributed to the patient group's previous fall history, lower level of physical activity, and impaired balance and that they were "more likely to occur in patients over 65 with a radius fracture" (Nordvall et al., 2007).

Consequently, individuals over the age of 65 had higher incidents linked to previous falls and were at higher risk for future fracture trauma. Exercise and increased mobility was the recommendation for reduced incidence of future hip fracture in the elderly (Nordvall, 2007). An earlier study by Buhr and Cooke (1959) also concluded that falls were more likely to occur in older women than men and that men were more susceptible to fractures during their wage earning years as opposed to women (Buhr and Cooke, 1959).

In agreement with Nordvall's et al., (2007) conclusions, Lofthus et al., (2007) also found that most of the distal radial fractures of their older individuals were more likely caused by other factors than osteoporosis. Lofthus et al.'s. (2007) study examined ethnic Norwegians and Asian immigrants that lived in Oslo, Norway for a one year period. The hypothesis was that forearm fractures were a precursor to future hip injuries. To test this hypothesis, the researchers looked at two time periods. The first included data recorded and tabulated from 1979 for individuals with forearm fractures over the age of 20 who were residents of Oslo and the second period was from 1998 to 1999 (one year) (Lofthus et al., 2007). The results produced two significant conclusions, first it indicated in the 1998/1999 period that distal forearm fractures in women between 40 to 65 rose exponentially and once they reach 65+ the rate of increase became more linear. Men for the same period followed a more general linear increase over the entire age span (20 to >90). The second indication was that ethnic Norwegians had a high rate of forearm fractures, while the Asian immigrants had a lower incidence that may be a result of recent immigration to Norway. Their conclusions noted that osteoporosis was present in the older individuals in their study population, but that the causes for high distal forearm fractures in ethnic Norwegians were inconclusive and possibly linked to environmental factors, such as diet and nutrition during their formative years (Lofthus et al., 2007).

Research by Sharma et al., (2008) examined fractures in males with osteoporosis. The focus of the study was to highlight the effects and risk factors of osteoporosis in older men that are under reported by the medical community (Sharma et al., 2008). It is recognized from the research into osteoporosis that patients that have low-energy

fractures of the wrist, hip, humerus, or ankle “have a fourfold greater” risk of future fractures. Specific risk factors for osteoporosis were 1) smoking, 2) alcohol excess, 3) a body mass index of <21 , and 4) a family history of osteoporosis. The study determined that men who had sustained “a fracture of the radius/ulna” had almost twice the risk of future hip fractures. Additionally, research indicates that radius/ulna fractures usually occur approximately 15 years prior to hip injuries and warn of high risk of the latter (Lofthus et al., 2007; Nordvall et al., 2007; Sharma et al., 2008). Based on the research into the relationship between forearm fractures found in the elderly, the main risk factors suggest a higher percentage are due more to accidental falls than osteoporosis. Researchers hypothesized that the sedentary lifestyle of the elderly was more detrimental to the increase risk of falls than the effects of osteoporosis.

The recognition of different types of forearm fractures associated with modern populations, (e.g., Monteggia, Galeazzi, Colles’, and fatigue) can also help in determining a possible etiology for individuals found in archaeological contexts. Thus, when examining forearm fractures in the archaeological sample, dislocation of the radial head with resulting ulnar fracture may be an indication of a Monteggia fracture. Monteggia fractures, named for the Italian physician who first recorded this type of fracture in 1814, is described as a fracture of the shaft of an ulna with a dislocation of the radial head and has generally been associated with a parrying blow by the forearm (Babb and Carlson, 2005; Bado, 1967; Eglseder and Zadnik, 2006; Galloway, 1999; Merbs, 1989; Ring et al., 1998). Dislocations are characterized by a partial loss of contact between the joint components. The dislocation associated with Monteggia fractures is

recognized by a separation between the head of the radius and the distal end of the humerus on the lateral portion of the body (Merbs, 1989). Methodologically, this type of fracture provides another way to recognize possible causative factors for forearm fractures when ulnar fractures are present. In archaeological populations determining radial dislocations may prove difficult for several reasons: 1) bone changes may not be present or extremely subtle, 2) post-mortem damage to the portion of the bone that is necessary for determining dislocation, and 3) element simply missing which in archaeological context is not unusual due to taphonomic influences once the individual is buried.

Bado (1969) classified Monteggia fractures into four distinct types: 1) Type 1 is described as an anterior (to the front or forward) dislocation of the radial head with an anterior fracture of the ulna; 2) Type 2 is similarly described, except that the dislocation and fractures occur posteriorly (to the back) of the elements involved; 3) Type 3 is described as a lateral (moving away from the body) dislocation with either an anterior or posterior fracture to the ulna; and 4) Type 4 is a combination of anterior dislocation and fracture of the radial head along with the main fracture of the ulna (Bado 1967).

Babb and Carlson's (2005) study described all four distinctive types of Monteggia fractures as being associated with direct impact. But previous research by DeSouza (1968) that examined 456 cases of trauma over a 60-day period from the Mulago Hospital, Kampala in Uganda, recording 191 individuals with fractures that suggested a different interpretation to the four Monteggia fracture types. In this study he indicated that the Monteggia fractures with anterior dislocation (Type 1) to the radial heads and

associated ulnar fractures were the outcome of trying to ward off blows while the other three types were associated with accidents (DeSouza, 1968). Even though this study, like most clinical research, has the ability to access living individuals and medical records, the task of understanding the cause of fractures is very difficult.

Clinical examination of Monteggia fracture information has presented two issues. One issue is that only seven percent of forearm fractures are Monteggia, thus reducing the likelihood that this type of fracture survives in the archaeological record (Babb and Carlson, 2005). The second issue is the dislocation of the radial head associated with the ulnar fracture would require some kind of reduction or splinting for the fracture to heal properly. In modern populations fractures such as these generally requires surgery and the placement of pins or plates to aid healing, which was not practiced in ancient cultures, though evidence of splinting in some populations has been noted (Babb and Carlson, 2005; Bado, 1967; Eglseder and Zadnik, 2006; Merbs, 1989; Ring et al., 1998). Clinicians even recommend that when individuals present with ulna fractures that examination of the proximal radius for dislocations would be advisable (Key and Conwell, 1942).

Another type of fracture that may provide insight for archaeological trauma is Galeazzi fractures. Galeazzi fractures are described as breaks to the radial shaft that occur in the distal or middle third of the diaphysis and cause a disruption to the radioulnar joint (Galloway, 1999). These types of fractures have been referred to as a reverse Monteggia fracture, as well as Piedmont or Darrach-Hughston-Milch fractures (Galloway, 1999). Galloway (1999) states that these fractures are relatively uncommon and thought

to be the result of axial loading on the hyperpronated forearm. Interestingly, the fracture type is usually transverse or “short oblique and angulated dorsally” and is associated with falls while the position of the hand is under “extreme pronation,” when falling from a height or in motor vehicle accidents (Galloway, 1999). Galeazzi fracture patterns were first recognized in 1822 by Sir Astley Cooper (Mikic, 1975). Several decades later, Ricardo Galeazzi in 1934 reported on 18 fractures of the radial shaft with associated dislocation of the radioulnar joint. From that point, radial fractures with dislocation of the radioulnar joint have been associated with his name (Ertl, 2007).

Mikic (1975) treated 125 patients with Galeazzi type fractures of which 92 were male and 33 female. The study determined that the Galeazzi fractures were most probably caused by a fall onto the outstretched hand similarly described above by Galloway (1999). Mikic (1975) further states that, “rotational stresses on the forearm would seem to be essential for dislocation of the distal radio-ulnar joint”. Though the main purpose of this study examines the pathology, diagnosis, and treatment of the 125 cases, Mikic (1975) found that the majority of cases were due to an accidental etiology, i.e., traffic accidents, while working on machines, or were unexplained. Similar to the limitations seen with Monteggia fractures, Galeazzi fractures are rare in clinical circumstances with only three to seven percent of all forearm fractures involved (Ertl, 2007). Thus, the possibility of recognizing either Monteggia or Galeazzi fractures in archaeological context may be difficult given the infrequency of these types of fractures. Also, the likelihood for recognition may be hindered by the normal effects of bone preservation and erosion of the cortex through the processes of taphonomy.

The issue of fatigue or stress fractures described in modern clinical studies highlights some problems when trying to determine causation in prehistoric populations. When examining radiographs of stress fractures published in clinical studies, the fractures are transverse. One of the earliest studies on upper limb stress fractures was conducted by Kitchen in 1948. Prior to this time, fatigue fractures had only been associated with skeletal elements that are weight bearing, such as the femur, tibia, fibula, vertebrae, etc, and by 1948 little had been published on fatigue fractures of non-weight bearing elements. Kitchen's (1948) study examined a young adult male farm worker who complained of pain in his left arm. Radiographs of the area taken three weeks after pain developed showed a "fusiform swelling" (callus) of the middle third of the ulna (Kitchen, 1948). A small transverse fracture line was visible on the radiograph. Kitchen (1948) hypothesized that the injury was caused while using a pitchfork during moving of farmyard manure. The "pitchforking" action of the arm would have entailed the left hand serving as a fulcrum and the left forearm serving as support of the downward thrust of the right hand and pull of the resisting load. The constant strain on the left forearm would be considerable enough to stress the bone and cause the element to fracture.

Evans (1955) study examined two cases of stress fractures that were found in individuals that had described pain in their forearms after performing specific tasks associated with their jobs. In the first case study, a male farm laborer experienced pain in his left wrist while lifting; at no time did he experience any pain in his arm. After swelling developed three months later in the middle of the arm, the farm laborer sought medical attention. The radiograph displayed a healed non-union of the ulna with

hypertrophic bone growth and examination indicated that the fracture line was transverse. The second case involved an ulna fatigue fracture developed in a female cook while lifting a heavy pan. A week after the incident with the pan swelling developed in the arm. Again, the radiograph indicated that the fracture line of the ulna was transverse with angulation. In both cases, stress was placed on the ulna during repetitive actions causing the fracture to develop (Evans, 1955).

The majority of clinical research regarding stress fractures of the upper limb though focuses mostly on athletes (Anderson, 2006; Fines and Stacy, 2002; Hsu et al., 2005; Jones, 2006; Koskinen et al., 1997; Lee, 2004; Maffulli et al., 1992; Reid, 2003; Sinha et al., 1999). In a study conducted by Anderson (2006) that looked at the mechanisms associated with upper limb stress fractures, he described ulnar shaft fractures caused by two forms of stress. The first form of stress is “torsional”, caused by “repetitive alteration between extremes of pronation and supination,” as seen in pitching and two-handed backhand tennis players (Anderson, 2006). Stress fractures caused by this motion are concentrated in the midshaft of the ulnae because this is the area where the shaft is the narrowest portion of the element, the cortex is the thinnest, and the bone shape is more triangular, thus the weakest part of the ulna (Anderson, 2006). The second form described by Anderson (2006) is “bending”, caused by repetitive flexion of the elbow with loading on the shaft. The factor that contributes to the stress fracture occurs as a result of bending at the midshaft, an area where the bone changes shape rapidly due to normal pressures placed upon the element (Anderson, 2006). In all of the reviewed clinical literature on sports and activity related stress fractures of the upper limb where

the radiographs were published, they show the fracture line as horizontal to the element, i.e., what defines a transverse fracture.

Additionally, research by Hsu et al. (2005) on a “Spinner Bowler” and Jones (2006) on the mechanisms of sports injury suggests that the fractures of the elements occur at the point of muscular attachment to the bones. Hsu et al. (2005) described the stress fracture of a spinner bowler where the arm was used in a pronation motion to spin the ball forcefully. The fracture occurred in the middle to distal third portion of the element possibly due to the repetitive stress on the flexor digitorum profundus muscle. Hsu et al. (2005) suggested that the spinning motion of the wrist dorsiflexion with forearm supination in backswing to forearm pronation in forward release developed stress at the location of muscle attachment, thus causing the element to fracture. Jones (2006) also concluded through research that stress fractures found in pitchers, tennis players, volleyball players, riflemen, etc., were also located at the point of muscle attachment.

Ongoing examination of forearm fractures in skeletal and living populations continue to intrigue researchers as more data is being gathered and published. Past research provides information on the number of individuals with forearm fractures as well as modern clinical records, with analytical schemes and methods being developed. Thus, specific types of forearm fractures can potentially be linked to accidental falls or interpersonal aggression in the archaeological record. Using the information published in the bioarchaeological literature by Galloway (1999), Grauer & Roberts (1996), Judd (2008) and Judd and Roberts (1999) and the clinical data on fractures, this research

attempts to synthesize and employ these methodologies and analyses to examine and clarify the fractures from eight prehistoric California populations with greater reliability.

Brief Ethnohistoric Overview of Interpersonal Aggression in Central California

An ethnohistoric overview of interpersonal aggression provides support for understanding the relationship between the number of individuals found in archaeological context exhibiting indications of trauma. Late 18th century documents from the Spanish explorers record observations of many incidents between tribes, as well as some observations of the weapons used by the native Indians in warfare. In November 1770, Spanish soldiers led by Lt. Pedro Fages left the newly established Monterey Bay based Mission San Carlos traveling north and arriving in the Santa Clara Valley where they encountered the local tribes in the area (Fages, 1911; Milliken, 2007a). The accounts described the Tamyen-speaking Ohlone (aka. Costanoan) as friendly to them while displaying substantial inter-group hostility with other neighboring tribal groups (James and Graziani, 1975; Milliken, 1983).

Causes for hostilities recorded by the Spanish within the greater San Francisco Bay Area are described as: 1) stealing of resources, 2) territorial trespass, 3) murder, 4) the theft of wives and young women, and 5) witchcraft (Milliken, 1983, 2007a; Wiberg, 2002). Of these, territorial trespass and resource theft were the most prevalent causes for hostilities between tribes. Fages recorded an observation of disputes over food resources in his diary as:

“...land also provides them with an abundance of seeds and fruits... although the harvesting of them and their enjoyment is disputed with bow and arrow among these natives and their neighbors, who live almost constantly at war with each other ([Fages, 1775, 1937], Milliken, 2007a).

Further examples of resource warfare was seen in the hostilities between the Santa Clara and the Santa Cruz Indians over cinnabar mines in Santa Clara territory and fighting that occurred between Santa Clara Ohlone and San Joaquin Yokuts for “red paint” (Heizer and Treganza, 1972).

An example of territoriality that was observed when the Spanish traveled through the Santa Clara Valley regarded crossing into another tribe’s land. They observed that when the various individuals from one village would accompany them as they traveled through the valleys, that once they reached the boundary of their territory the natives would turn and leave the Spaniards, thus not crossing into the territory of another tribe (Anza, 1930; Levy, 1978).

Warfare was also observed by the Spanish. In the Ohlone territory warfare was described as following two methods: 1) surprise attacks and 2) ritualized warfare where small groups meet on a field of battle (James and Graziani, 1975; Heizer and Whippel, 1951; Milliken, 2007a). Surprise attacks were described as short in duration and after a few of the enemy had been injured or killed, the assault was terminated and the groups would return to their previous, more peaceful relationship. Ritualized warfare involves a “duel” between combative tribes. Chiefs determined a time and place for the battle, then prepared their people. The two groups were “painted and feathered” and armed with bows, arrows, and shields. The opposing tribes then formed two lines across from each other and began the battle with songs and cries before they began shooting their arrows (James and Graziani, 1975).

The main combatants during a battle or raid were generally males. However, the Spanish describe the participation of Ohlone women and children in battle. Children from both sides were sometimes allowed to cross enemy lines and retrieve arrows that had missed their target; they would then return them to be reused by the men from their village (Bancroft, 1874). Women and children, who accompanied the men to battles, remained at a distance, to aid in escape if the men lost or to help celebrate victory if they won (James and Graziani, 1975).

The introduction of the bow and arrow arrived in California sometime after AD 500 and by around AD 900 became the most commonly used weapon by the Ohlone tribes (Fagan, 2003; Lambert, 2002; Levy, 1978; Wiberg, 2002). The Ohlone crafted their arrows from "...little reeds, very smooth, well made, and with flints, transparent and very sharp" (Anza, 1930; Cook, 1957). The land management practice of burning helped in obtaining the raw materials necessary for the production of arrows. Hazelnut shrubs when burned would shoot up straight branches that the Ohlone and Pomo utilized for arrow shafts (Anderson, 2005).

Though the Spanish diaries contain several passages where the Indians are seen carrying bows and arrows, only a few entries reference the appearance of clubs (Crespi, 1769). For example, in Southern California, "The Dieguinos especially appear to him as a cynical, unpleasant lot, and he shudders at the sight of their war clubs" expressed the feelings of the Mission Fathers as they encountered the various Native groups along their route (Crespi, 1769). This reference describes the Indians from the San Diego area that Father Crespi and other Spaniards encountered as they traveled through California.

Another area of California where Indians were encountered carrying clubs was the in San Francisco Solano (Crespi, 1769). There the natives met the Spaniards in their village “the men carried the usual bow and arrows, others war clubs, ...”. In none of the references from Father Crespi’s diary is there mention of seeing the clubs used in combat. In another reference from Father Crespi’s diary on clubs, he acknowledges the readiness of the natives for combat noting that “they all go about very much armed, with the quivers, bows, and arrow ever in their hands, and many of them carry very fearsome war clubs” (Crespi, 1769).

Raids were another form of interpersonal aggression that was part of the San Francisco Bay Ohlone way of life. These more than likely occurred when one tribe crossed over boundaries in an attempt to gather subsistence resources without permission. An example of this occurred after contact during the early 1800’s when the Yokuts from the Central Valley crossed over into the territory of the “Carmel Indians (probably Costanoans)” at Monterey Bay to gather mussels and abalone. During this time, the local Ohlone Indian population was greatly reduced and protection of their territorial borders was breeched by other tribes (James and Graziani, 1975). Though no record exists describing the type or style of fighting that occurred between these two groups during such conflicts, bows and arrows and other weapons such as clubs, spears, lances and later firearms were used in warfare. The hypotheses that clubs were used in prehistoric California have been recorded for many archaeological sites from the evidence of cranial depressions and forearm fractures (Andrushko et al., 2005; Bellifemine, 1997; Jurmain, 1991, 2001; Jurmain et al., 2009; Walker, 1989). Thus, warfare was a component of

California Native Americans lifeways and evidence of this is supported by trauma found in their skeletal remains.

III. RESEARCH QUESTIONS

The previous section brings into focus the interpretations of forearm fractures in archaeological context by briefly reviewing the bioarchaeological, clinical, and ethnohistorical literature. In early bioarchaeological research, forearm fractures have been interpreted as the result of intentional trauma by the mere presence of a parry fracture, while more recent research has suggested that there may be an alternative explanations for the presence of forearm fractures (Armelagos, 1977; Galloway, 1999; Grauer and Roberts, 1996; Judd, 2000, 2002, 2004, 2006, 2008; Jurmain, 1991, 1993, 1996, 2000, 2001, 2007; Lahren and Berryman, 1974; Ortner and Putschar, 1981; Wells, 1964; Wood, 1979). The more recent of these studies (Grauer and Roberts 1996; Judd 1999, 2002, 2008; and others) have determined that fractures types -- transverse or oblique -- are associated with specific types of force, either direct or indirect. From the literature review, the research suggests that direct force trauma to the forearm is an indication of intentional trauma and indirect force is indicative of unintentional causation. Additionally, the ethnohistoric literature from diaries of the Spanish explorers for the San Francisco Bay Area document aggressive acts between tribal groups where they verify that a greater number of males between the ages of 22 to 50 were involved in warfare than women and children and that males were the main combatants during periods of warfare and surprise attacks (Bancroft, 1874; James and Graziani, 1975; Milliken, 1995). Therefore, it is expected to find a higher incidence of forearm fractures among males than females.

This present study seeks to apply the methodology from the more recent research studies that utilizes fracture types to identify particular forearm fractures as a result of intentional or unintentional trauma. Specific research questions are as follows:

1. What fracture types found in the sample study of skeletal populations support the hypothesis of evidence for intentional trauma?
 - a. Do transverse fractures support an etiology of intentional trauma as suggested by the bioarchaeological and clinical literature as evidence of direct force impacts (Galloway, 1999; Grauer and Roberts, 1996; Judd 2008)?
 - i. Does left side involvement indicate greater prevalence than the right and is it potentially more associated with transverse fractures, as the over representation of right-hand dominance would suggest from the bioarchaeological and clinical literature (Du Toit, 1979; Jurmain, 1991, 2001; Lahren and Berryman, 1984; Lovejoy and Heiple, 1981)?
 - ii. Does ipsilateral (ulnae/radii) involvement support an etiology of intentional trauma where both elements would be fractured at the same level as suggested in the bioarchaeological and clinical literature (Judd, 2008; Key and Conwell, 1942; Yochum and Rowe, 1996)?
 - iii. Does the location of the fracture on the element relate to the determination that a transverse fracture indicates an etiology of

intentional trauma, specifically when found in the mid-shaft or distal third of the element (Judd, 2008)?

- iv. What other elements evince signs of intentional trauma once a forearm fracture has been identified in a specific individual, e.g., cranial depressions or embedded projectile points (Hedges et al., 1995; Judd, 2002; Jurmain, 1991; Lovejoy and Heiple, 1981)?
 - v. Is there evidence of secondary pathology, such as osteoarthritis, in individuals with forearm fractures that are located in the wrist and elbow (Bennike, 1985; Galloway, 1999; Grauer and Roberts, 1996; Jurmain, 1990, 1991)?
2. What fracture types found in the sample study of skeletal populations support the hypothesis of evidence for unintentional trauma?
- a. Do oblique fractures support an etiology for accidental causes as suggested by the bioarchaeological and clinical literature (Galloway, 1999; Grauer and Roberts, 1996; Judd 2008)?
 - i. Does right side involvement indicate a greater prevalence than the left and is it potentially more associated with oblique fractures caused when an individual puts their hand out to stop a fall (Du Toit, 1979; Jurmain, 1991, 2001; Lahren and Berryman, 1984; Lovejoy and Heiple, 1981)?
 - ii. Does ipsilateral (ulnae/radii) involvement support an etiology of unintentional trauma where both elements would be fractured at

the different levels as suggested in the bioarchaeological and clinical literature (Judd, 2008; Key and Conwell, 1942; Yochum and Rowe, 1996)?

- iii. Does the location of the fracture on the element relate to the determination that an oblique fracture indicates an etiology of unintentional trauma caused by falling onto an outstretched hand with the indirect force radiating up the element (Judd, 2008)?
 - iv. What other elements evince signs of unintentional trauma once a forearm fracture has been identified in a specific individual, e.g. the lower limbs, vertebrae, or clavicle (Hedges et al., 1995; Judd, 2002; Jurmain, 1991; Lovejoy and Heiple, 1981)?
 - v. Is there evidence of secondary pathology, such as osteoarthritis, in individuals with forearm fractures that are located in the wrist and elbow (Bennike, 1985; Galloway, 1999; Grauer and Roberts, 1996; Jurmain, 1990, 1991)?
3. Does age and sex play a role in frequency and type of forearm fractures (Beringer et al., 2005; Butchart and Brown, 1991; DeSouza, 1968; Judd and Roberts, 1999; Lofthus et al., 2008; Lovejoy and Heiple, 1981; Mays, 1996; Mock et al., 1995, Nordvall et al., 2007; Sharma, 2008)?
- a. Are transverse fractures more prevalent in certain age ranges such as those associated with males during their wage earning years as suggested by Buhr and Cooke (1959) and Lovejoy and Heiple (1981)?

- b. Are oblique fractures more prevalent in certain age ranges such as breaks associated with normal adolescent activities (Lovejoy and Heiple, 1981)?
- c. Do females over a certain age have more ulna or radial fractures than males? If so, are these fractures indicative of intentional or unintentional trauma, specifically considering that in modern populations, females over 60 years are at risk of distal radial fractures associated with osteoporosis and falls, while men evince more fractures during their wage earning years (Buhr and Cooke, 1959; Lofthus et al., 2008; Nordvall et al., 2007)?
- d. Do males over a certain age have more ulna or radial fractures than females? If so, are these fractures indicative of intentional or unintentional trauma specifically considering that in modern populations, females over 60 years are at risk of distal radial fractures associated with osteoporosis and falls, while men evince more fractures during their wage earning years (Buhr and Cooke, 1959; Lofthus et al., 2008; Nordvall et al., 2007)?

Examination of these questions highlights current research that identifies differences in fracture types with relation to causation. Past analyses have focused on a generalized format that depends strongly on the researcher's ability to interpret the macroscopic evidence and the association of "parry fractures" as the results of intentional trauma by deflecting a blow to the head (Jurmain, 1991). Research conducted by Grauer and Roberts (1996), Judd (2002, 2006, 2008), Judd and Roberts (1999), Kilgore et al., (1997), and others have questioned the assumption that all parry fractures are associated

with intentional trauma. The current study therefore has two working hypotheses: 1) that transverse fractures are an indication of intentional trauma and 2) that oblique fractures are an indication of unintentional trauma. The null hypothesis is that fracture types are not indicative of whether cause was intentional or unintentional trauma.

IV. CULTURAL, ARCHAEOLOGICAL, AND ENVIRONMENTAL SETTINGS

This study analyzes human skeletal populations from eight Prehistoric Bay Area sites with six of these principally located in the South Bay (greater San Jose area). One site is from the West Bay (Stanford Area) and the other one site from the East Bay (Alameda County) and all located within a 15 mile radius surrounding CA-SCL-38 (Fig. 1). The sites listed in Table 1 are organized based on the availability of the burials for either macroscopic, radiographic or both types of analyses, along with the minimum number of field designated burials from each site.

Drawing: Diane DiGiuseppe

Fig. 1. Location of study sites from three counties

TABLE 1. Sites from the San Francisco Bay Area in this study

Sites	Minimum Number of Discrete Burials
Available Specimens (Macroscopic and Radiographic)	
CA-ALA-329SJ (San Jose)	284
CA-SCL-134	24
CA-SCL-287/CA-SMA-263	26
Reburied Specimens (Radiographic)	
CA-ALA-329ST (Stanford)	139
CA-SCL-38	243
CA-SCL-68	35
CA-SCL-137	79
CA-SCL-690	123
CA-SCL-732	100

Cultural Setting

The burial populations from these sites consist of prehistoric California Native Americans that resided within the greater San Francisco Bay Area spanning the past 2,500 years. These prehistoric populations are considered the direct ancestors of the modern day Muwekma Ohlone Indians who have lived in the San Francisco Bay Area prior to the late 18th century contact period with the Hispanic Empire (Harrington, 1921-1939; Kroeber, 1910; Milliken et al., 2007b; Moratto, 1984). The mission records from Mission's San Jose, Santa Clara and Dolores provide written documentation indicating

that the ancestors of the Muwekma Ohlone resided in and around the San Francisco Bay area for many generations.

The eight sites are all located within the ethnohistoric Tamyen-speaking and Chocheño-speaking Ohlone tribal groups of the West, South and East Bay. Recent research by Milliken et al., (2007c) into the various linguistic groups offers a reconstruction and distribution of the Ohlone Tribal groups surrounding the San Francisco Bay Area. Previous linguistic studies proposed that there were several different dialects of the Costanoan/Ohlone-speaking Tribal groups. Milliken et al. (2007c) has advocated that the three major Bay Area Ohlone (Costanoan) dialects, Chocheño, Tamyen, and Ramaytush, are really part of a dialectical continuum and should be considered a single language presently referred to as San Francisco Bay Costanoan, thus suggesting that there was greater affiliation between the various tribes than previous linguistic information indicated going beyond trade and marriage alliances.

Based upon time sensitive cultural assemblages (especially shell beads and ornaments) and radiocarbon assays, the temporal placement of these sites range from the Early/Middle Transition Period (c. 500 BC) to the Phase II Late Period (c. AD 1769) (Table 2). The radiocarbon assays including Accelerator Mass Spectrometry (AMS) for these sites are based on results of dating human collagen, faunal remains, charcoal, and *Olivella* beads that were all found in burial context (Bellifemine, 1997; Bennyhoff and Hughes, 1987; Cambra et al., 1996; Cartier et al., 1993; Groza, 2002; Hylkema, 2007; Morley et al., 2003). Both corrected and uncorrected radiocarbon dates provide the temporal range for these sites.

TABLE 2. Temporal assessment by site

Site	N*	Method of Determination	Temporal Assessment**
ALA-329SJ	45	<ul style="list-style-type: none"> • Radiocarbon Assay • Time Sensitive Artifacts 	Early Middle to Late Phase 2 (200 BC to AD 1800)
ALA-329ST	4	<ul style="list-style-type: none"> • Radiocarbon Assay • Time Sensitive Artifacts 	Early Middle to Late Phase 2 (200 BC to AD 1800)
SCL-38	23	<ul style="list-style-type: none"> • Radiocarbon Assay • Time Sensitive Artifacts 	Early Middle to Late Phase 2 (200 BC to AD 1800)
SCL-68	2	<ul style="list-style-type: none"> • Radiocarbon Assay 	Early Middle Period (200 BC to AD 100)
SCL-134	2	<ul style="list-style-type: none"> • Radiocarbon Assay • Time Sensitive Artifacts 	Early Middle to Middle/Late Transition (200 BC to AD 1000)
SCL-137	4	<ul style="list-style-type: none"> • Radiocarbon Assay • Time Sensitive Artifacts 	Early/Middle Transition to Middle/Late Transition (500 BC to AD 900)
SCL-287/	11	<ul style="list-style-type: none"> • Radiocarbon Assay • Time Sensitive Artifacts 	Early Middle to Middle/Late Transition (200 BC to AD 1000)
SMA-263		<ul style="list-style-type: none"> • Time Sensitive Artifacts 	
SCL-690	2	<ul style="list-style-type: none"> • Radiocarbon Assay • Time Sensitive Artifacts 	Middle Intermediate to Late Phase 1C (AD 100 to 1400)
SCL-732	13	<ul style="list-style-type: none"> • Radiocarbon Assay • Time Sensitive Artifacts 	Early/Middle Transition to Middle Intermediate (500 BC to AD 300)

*N = number of C¹⁴ run. ** Temporal placement based upon Bennyhoff and Hughes 1987 Scheme B1.

Using Bennyhoff and Hughes (1987) dating scheme B1 (Fig. 2). The types of shell beads found with burials were of several different types that collaborated the radiocarbon dates of the human remains.

Fig. 2. Alternative dating schemes for the central California archaeology sequence (Bennyhoff and Hughes, 1987)

Archaeological Context

Over the last several decades, the eight sites in this study have been excavated by several different archaeological investigators that include: academic researchers from several different universities, Cultural Resource Management firms, and the local Muwekma Ohlone, through their Cultural Resource Management Firm, Ohlone Families Consulting Services. The reasons for the excavations range from academic field schools to salvage/recovery archaeology programs implemented through mitigation requirements under CEQA for final Environmental Impact Reports (EIRs).

Excavations began in 1935 at CA-ALA-329 (Ryan Mound) when W. R. Wedel from the University of California, Berkeley conducted the first recorded excavations of the site removing 12 burials. This early work was followed by C. E. Smith from University of California, Berkeley in 1948 when 38 burials were recovered. The major excavations commenced in 1959 and continued through 1967 by B. Gerow from Stanford University when he began annual field seasons at the site. In 1962, J. Hester and D. Pritchard from San Jose State College joined Gerow and excavated at the site until 1968 (Elliott, 1992; Leventhal, 1993; Pierce, 1982). The last academic excavations at the site occurred during 1970 to 1971 field seasons by C.E. Smith from California State University, East Bay (Leventhal, 1993). Thus, the purpose of excavations at CA-ALA-329 over a 40 year period was conducted principally for research, training of future archaeologists, and recovery and preservation of the human remains. In June 1991, the Stanford portion of the burials was reinterred (Elliott, 1992; Leventhal, 1993; Pierce, 1982).

Between August 1993 and October 1994, monitoring and excavation of CA-SCL-038 (Yukisma Site) was conducted by Ohlone Families Consulting Services (OFCS) in compliance with California Environmental Quality Act (CEQA) during the construction of new inmate barracks at the Elmwood Correctional Facility in Milpitas, California (Bellifemine, 1997). Prior to this fieldwork, CA-SCL-038 was first formally recorded in 1952 by C. W. Meighan from the University of California, Berkeley (Bellifemine, 1997). Historically the site was known as the “Alms House Mound” and was described as an extensive habitation site that was 300 feet in diameter and four feet high (Bellifemine, 1997). During these earlier excavations six burials and associated artifacts were recovered and stored at Berkeley. In 1981, the Archaeological Resource Management Firm (ARM) conducted surface reconnaissance studies of particular building sites during the original development and planning stages of the Elmwood Detention Center prior to construction. In 1988, ARM returned to the site to conduct further studies by excavating two 1x1 meter units and several auger bores to discover the margins of the site, determine age of the site, and its cultural significance (Bellifemine, 1997). In 1999, the Muwekma Ohlone Tribe reburied the 243 human remains and the majority of the ground stones and artifacts (a small sampling of shell beads, mortars, and lithics were retained for educational displays and future research). Through the cooperation of the Muwekma Ohlone Tribal leadership, three San Jose State University students had full access to the burials and grave associations for the purpose of completing their Master’s Thesis work on this site. Additionally, Dr. R. Jurmain analyzed the skeletal remains and published a Technical Report that is currently on file at San Jose State University.

Three sites from the South Bay included in this study are individual components of a larger project called the Guadalupe Transportation Corridor Project (Guadalupe Corridor) that was conducted in compliance with 36 CFR Part 800 (Cartier et al., 1993). The purpose of the “Guadalupe Corridor” project was for the construction of a lightrail system that originally ran from Tasman Avenue Station to Santa Teresa Boulevard Station. The first site that was excavated as part of the Guadalupe Corridor Project was CA-SCL-68 (The Narvaez Site) where the early investigations were conducted by Anderson et al. in 1973 from West Valley Community College. This was followed by Archaeological Consulting and Research Services in 1974, then by Edwards in 1978 from Cabrillo College, Chavez in 1980, Roop et al. 1982 (Archaeological Resource Services), Fong in 1988-1989 (Basin Research Associates), and Cartier et al. in 1991-1992 from the Archaeological Resource Management Firm (ARM) (Cartier et al., 1993). In 1991 to 1992 Cartier et al. (1991), conducted monitoring and excavation services during the construction of the lightrail system. The excavations recovered several burials and a variety of burial assemblage artifacts, e.g., obsidian, *Haliotis* and *Olivella* shells (Cartier et al., 1993).

The second site, CA-SCL-137 (Snell Site) was originally monitored by Cartier in 1987 for the Santa Clara Water District when a water pipeline was placed through the area. There is no mention in the records of whether burials were recovered during this first project. During construction of the “Guadalupe Corridor,” several cultural resource management firms were engaged in monitoring and recovering any burials, features, or time sensitive artifacts. Basin Research Associates monitored the site from July 1, 1988

to January 10, 1989 (Fong et al., 1989), followed by ARM from January 1989 to February 14, 1991 (Cartier et al., 1993). During this time period, a total of 88 burials were recovered as well as associated artifacts.

The third site, CA-SCL-690 (Tamien Station) that was part of the larger Guadalupe Corridor project was originally started in the 1980's when demolition of a former cannery structure uncovered significant archaeological resources (Hylkema, 2007). In early 1990, monitoring and excavation again began at the site, by Caltrans archaeologist, Mark Hylkema, with the assistance of the Muwekma Ohlone Tribal members under their Cultural Resource Management firm Ohlone Families Consulting Services, and students from the Anthropology Department of San Jose State University under the direction of Dr. Robert Jurmain (Hylkema, 2007). Again, several burials and culturally sensitive artifacts were recovered from the site. This location, though, differed from the other two in that it encompassed three transportation systems that came together: Highway 87, the lightrail system, and a stop for Amtrak's Coast Starlight Route (Hylkema, 2007). There are several other archaeological sites associated with the above three projects, but these sites did not recovery any human remains therefore they do not fit the data collection criteria used in this study.

Early investigations of CA-SCL-134 (Corvin Drive) located in the City of Santa Clara began in 1974 under the direction of Rob Edwards from West Valley Community College and was recorded as WVC-3, as part of a standard site survey project. At that time various "flakes, cores, metate, mortar and pestles" were recovered that appeared to indicate a large habitation settlement (Cambra et al., 2001). Prior to Edwards survey of

the site, in 1973 the current building was under construction and it was noted during the 1974 survey that there was evidence of human bone, lithic flakes, and two shell *Olivella* beads scattered on the surface. In the archaeological site record forms, aerial photographs taken of the site in the 1950's showed a relatively intact mound feature present and that it had remained relatively undisturbed even by farming activities. In 2001, a burial was uncovered by a demolition contractor working in the parking lot area of 3000 Corvin Drive. The 2001 project was headed by the Muwekma Ohlone Tribe, Ohlone Families Consulting Services and San Jose State University staff and students along with Susan Morley and Alan Leventhal, Principal Investigators as part of the mitigation process through CEQA. Twenty plus burials were recovered as well as *Olivella* shell beads, lithics and mortars.

There were three phases of excavation at the CA-SCL-287/CA-SMA-263 (San Hill Road, Stanford University Site) that occurred from 2000 to 2004 under the guidance of Stanford Management Company that retained Pacific Legacy, Inc. to monitor and document the archaeological components of the site (Morley, 2003). When burials were exposed during construction, the Stanford Management Company contracted Ohlone Families Consulting Services, the archaeological arm of the Muwekma Ohlone Tribe, to oversee the recovery and removal of their ancestral dead. Burial recovery Phases 1 and 2 occurred in 2000 and 2001, respectively, under the direction of Susan Morley, M.A. The purpose for monitoring and oversight of the site during Phases 1 and 2 was the widening of Sand Hill Road to create a bike path on the west side of the road. In 2004 a joint project between Stanford Management Company, Pacific Legacy, and Ohlone Families

Consulting Services, began due to the widening of Sand Hill Road that made architectural renovations to the Stanford Golf Course necessary. Twenty plus burials and culturally sensitive artifacts were recovered during all Phases of monitoring and excavation. To date no official reports have been issued to Stanford Management Company on excavations and monitoring during the different phases, though a preliminary report was available for review by this author.

In 1992, CA-SCL-732 (Three Wolves Site) located in South San Jose came under the jurisdiction of the Santa Clara County Traffic Authority, the California Department of Transportation (Caltrans), and Santa Clara County that began a project to provide a new riparian restoration basin drainage system along Highway 101 and Coyote Creek for the purpose of diverting and restoring water to the riparian wetland habitat for the Highway 85 expansion (Cambra et al., 1996). Due to the sensitive nature of the area, proximity to other recorded sites, EIR mitigation recommended monitoring of the project. Two different cultural resource management firms were contracted to begin the monitoring process, 1) Archaeological/Historical Consultants (AHC) of Oakland was hired by Caltrans and the Traffic Authority and 2) Santa Clara County independently hired Ohlone Families Consulting Services (OFCS) with the assistance of San Jose State University faculty and students (Cambra et al., 1996). Over 100 burials and cultural sensitive artifacts were recovered during excavations that the tribe made available to faculty and students for analysis at San Jose State University prior to reburial in 1994 (Cambra et al., 1996). In 2006, construction of an overpass footing from Highway 85 to Highway 101 encroached upon the 1994 burial location of CA-SCL-732 making it necessary for the

reburied remains to be recovered and moved to a new location. This portion of the project was again funded by Caltrans and the Traffic Authority that contracted with OFCS to recover, protect, and rebury their ancestral remains. With the help of San Jose State University faculty and students, the burials were re-excavated over a 21 day period. When the burials were reburied in 2006, they were placed within the original 1992 location, thus returning them to their ancestral cemetery (Leventhal et al., 2007).

Environmental Setting

The study area is bounded by the Diablo Mountain Range to the east, the Santa Cruz Mountains to the west, and the Santa Teresa Hills and the Coyote Creek Narrows to the south, forming a large sheltered valley that narrows from the north end to the southern portion (Bellifemine, 1997). The Alameda Creek/Coyote Hills Slough forms the northern boundary and the Coyote Creek, Canoas Creek, and Guadalupe River are major freshwater sources in the south. Several small hills fall within the boundaries of the project area including the Coyote Hills in Alameda County in the East Bay where CA-ALA-329 is located (Fig. 3).

The ethnohistoric Ohlone territory covers a multitude of rich environments that provided diverse habitats ranging from marine and tidal marsh to mixed hardwood and evergreen forest communities (Hylkema, 2002). The environment around these sites in the San Francisco Bay Area provided abundant resources for native communities to gather local shellfish, marine mammals, terrestrial animals, water fowl, fish, and local grain seeds and acorns providing a diverse diet (Gifford, 1916; Greengo, 1951; Leventhal, 1993).

Photo: Leventhal, 1993

Fig. 3. CA-ALA-329 located in the Coyote Hills of Alameda County

To maintain these diverse diets, the native Indians practiced land management through the use of controlled burns. A consequence of these controlled burns was the increase in the grass/seed yield that supported larger mammals such as elk, deer, and antelope. Anderson (2005) acknowledges that when underbrush was removed from an area by burning, new plants produced tender new shoot growth that encouraged grazing of larger faunal species, as well as increasing the seed yields for harvest.

East Bay environment. CA-ALA-329 is located along the southeastern shore of the San Francisco Bay in Alameda County, approximately 20 miles north of San Jose, California (Jurmain, 1991; Leventhal, 1993) (Fig. 3). The area is bounded by the Diablo Mountain Range to the east, the Alameda Slough to the north and by the Newark Slough to the

south (Leventhal, 1993) with the mound measuring 133 m X 90 m X 4 meters high (Elliott, 1992).

The environment around the East Bay indicates that there were abundant resources for the community to gather shellfish, fish, and hunt marine mammals, as well as, utilize the local terrestrial flora and fauna (Gifford, 1916; Greengo, 1951; Leventhal, 1993). Freshwater streams nearby feed into both the Alameda Slough to the north and the Newark Slough to the south supporting salmon and steelhead fish runs. The Alameda Creek located less than three miles from the site was probably a perennial stream providing freshwater year round (Gross, 1991). During the spring, the area was lined by a giant salt water estuary (Gross, 1991).

Reconstruction of paleoecological plant species from Coyote Hills in Alameda County at the time of contact indicates that this site was located in a salt marsh/wetland community (Leventhal, 1993; Mayfield, 1978). According to Wilson (1999), the adjacent Patterson Mound (CA-ALA-328) that borders CA-ALA-329 was located on the “bay marsh edge,” which supports the interpretation that the area was rich in bay/marsh resources that provided subsistence to the local tribes (Milliken et al., 2007b; Wilson, 1999). Additionally, research at the Patterson Mound identified a large variety of plant species by the presence of carbonized and uncarbonized seeds that were recovered in archaeological contexts (Hylkema, 2002).

West Bay environment. The location of CA-SCL-287/CA-SMA-263 straddles two counties crosscutting the boundaries between Santa Clara and San Mateo, on Sand Hill Road in Palo Alto between Santa Cruz Avenue and Vine Street. It is divided by the San

Francisquito Creek that is rimmed by a row of riparian trees providing freshwater to the inhabitants (Morley, 2003). To the northeast, the site is recorded as CA-SMA-263 and to the southwest the site is recorded as CA-SCL-287 (Fig. 4).

Image: Google Maps

Fig. 4. Location of CA-SCL-287/CA-SMA-263

The environment surrounding CA-SCL-287/CA-SMA-263 is very diverse. Subsistence resources came from a variety of areas, including oak savannah, chaparral, riparian, etc. (Holson et al., 2003). From these different ecological niches, food sources provided a wide variety of edible plants, and terrestrial and saltwater mammals. Levy (1978) noted that the Native Americans living in the area practiced control burning of

large areas to encourage increased production of seed producing plants, as well as acorns from the various oak trees nearby. The San Francisquito Creek that runs through the site provided fresh water, water fowl and native fish. Additionally, the native plants, such as tule, provided the material necessary for the production of nets, cordage, baskets, rafts and a variety of other useful items (Baker, 1995).

South Bay environment. The six South Bay sites are located in Santa Clara County, California. CA-SCL-038 is located in the Elmwood Correctional Facility at 701 S. Abel Street in the City of Milpitas, approximately six miles from the southern end of the San Francisco Bay, and is situated on a flood plain between the freshwater Coyote Creek and lower Penitencia Creek (Bellifemine, 1997).

Situated on the west side of Corvin Drive in Santa Clara, CA-SCL-134 lies between Central Expressway and Kifer Road and is approximately 12 to 13 acres in size. To the west, the modern Calabazas Creek drainage that originates in the Santa Cruz Mountains lies 125 meters away provided freshwater to the inhabitants of CA- SCL-134 (Cambra et al., 2001; Cartier and Reece, 1994). Other waterways nearby include the Guadalupe River to the east and Stevens Creek to the northwest (Cambra et al., 2001; Cartier and Reece, 1994).

CA-SCL-068 is found near the intersections of Capitol Expressway and Narvaez Road in Santa Clara County, California and encompasses 41 acres to the north and south of this location (Cartier et al., 1993). To the west, the Guadalupe River supplied freshwater. CA-SCL-137 is located in the City of San Jose at the intersections of Blossom Hill Road and Snell Avenue and is part of the larger “Guadalupe Corridor”

project. The size of the site at the time of excavation was considered to be between five and eight acres. Freshwater is located in three directions from the site with the Guadalupe River to the west, Coyote Creek to the east and the closest water source Canoas Creek to the southwest (Cartier et al., 1993).

CA-SCL-690 is located west of Lick Avenue between Alma and Willow Avenues in San Jose and is near the east bank of the Guadalupe River that flows through the Santa Clara Valley (Hylkema, 2007). CA-SCL-732 is located in the southern portion of Santa Clara Valley, where Highways 85 and 101 meet along the southern foothills (Cambra et al., 1996). The site is a mile north of Tulare Hill along the Coyote Creek drainage. The Coyote Creek is adjacent to the site and is part of the discharge of creeks and streams flowing out of the Diablo Range watershed (Cambra et al., 1996).

The environment of the South Bay was very diverse boasting a wide range of habitats, e.g., marshland, mountains, chaparral, oak savanna, seasonal wetlands, and riparian (Bellifemine, 1997; Cartier et al., 1993; Leventhal et al., 2009; Wu, 1999). The grasslands included species of blue wild rye, purple needle grass and melic (Edwards and King, 1974). The Valley Oaks and Douglas Firs that were part of the prehistoric landscape began disappearing during contact period when Europeans planted non-indigenous species of orchards.

Other subsistence resources utilized by the Native Indians in San Francisco Bay Area come from the large variety of terrestrial and marine mammals. During the Early and Middle periods (2000 BC – AD 900), evidence suggests that while both terrestrial and marine mammals were exploited, there was greater emphasis on terrestrial mammals

(Hylkema, 2002). By the Late Period beginning circa AD 900, the archaeological evidence begins to show changes in the types of mammals being hunted, with an increase in exploitation of marine species compared to terrestrial mammals that possibly indicated a change in available resources during this period (Hylkema, 2002). An example of this change was found at CA-SCL-690, where an increase in the number of rabbit bones recovered during excavation, considered a low ranking resource compared to deer and elk, could reflect the onset of dry conditions associated with the Medieval Climatic Anomaly (MCA) (Hylkema, 2002).

Additionally, other studies suggest that changes in subsistence resources “largely resulted from resource depression, which produced substantial decreases in foraging efficiency” (Broughton, 1994a, 1994b, 1997; Hylkema, 2007). Basically indicating that as population increases over-hunting of specific mammals occurred, creating a reduction in larger mammals (deer and elk) near village sites and shifted the hunting strategy to a greater dependency on low-ranking mammals (Hames and Vickers, 1982; Hylkema, 2007; Janetski, 1997). Broughton (1994a, 1994b) also recognized the role of the environment in subsistence adaptations that were highly variable and unpredictable, specifically noting the effects of climatic events such as El Nino and climate fluxations during the Medieval Climatic Anomaly (MCA) (Hylkema 2007).

Climate. The climate of the San Francisco Bay Area and Central California Coast has varied through time with periods of abundant rainfall followed by years of drought. Stine (1994) presented evidence of prolonged and severe droughts in California that spanned approximately 500 years, between AD 800 and 1350 that has been termed the Medieval

Climatic Anomaly (MCA). Jones and Kennett (1999) and Jones and Ferneau (2002) suggests that the MCA may have precipitated demographic problems, i.e., settlement disruption and dietary changes. Indications of short term sea temperature changes caused by the El Niño “Southern Oscillation” (ENSO) elevated temperatures causing lower marine productivity and higher rainfall (Jones and Ferneau, 2002). Thus, the long-term effects of rising sea temperatures involved alterations to marine productivity and ultimately, changes in overall coastal climates, which would influence the availability of both faunal and flora resources for California Indians (Jones and Ferneau, 2002).

In a study of oxygen isotope readings from dated archaeological materials of mussel shells, Jones and Kennett (1999) identified three periods of sea temperature variations over the last 2000 years, for the Central Coast. Specifically, during the first period from AD 1 to 1300 seas were 1°C cooler than today, in the second period from AD 1300-1500 the seas had greater seasonal variation with extremes above and below present ocean temperatures, and during the third period from AD 1500-1700 the seas were 2-3°C cooler than today. Due to ocean currents that differ from the Southern Coastline, the Central California coastline seas temperatures provided greater stability through time. By AD 1460 to 1860, the climatic conditions changed to a cooler wetter environment termed the “Little Ice Age.” This period is represented by glacial advances in the Sierra Nevada and filling of desert lakes in Southern California and may be a reflection of the choices of habitation sites selected by the native Indians (Jones and Ferneau, 2002).

V. MATERIALS AND METHODOLOGY

Materials

Selection of the sample populations for this study was based on a combination of the following criteria: 1) skeletal populations comprising a number of individuals with forearm elements, 2) published research on sites that have examined forearm elements by descriptive analysis and/or has been included within skeletal analysis, 3) analysis of forearm fractures from sites that have been conducted, but not published, 4) radiographs of forearm fractures from sites that have been reburied, having forearm elements with clear images of fractures, and 5) the overall study area is within the Costanoan (Ohlone) territory.

In addition to the criteria discussed above, individuals were included for study if they had complete or incomplete forearms (less than two-thirds present with articular surface), known sexes and ages or elements available for sex and age determination, evidence of healed forearm fractures, and diagnostic radiographs.

Three of the sites examined in this study had skeletal remains housed at San Jose State University and were available for both a macroscopic and radiographic analyses (Table 1). From CA-ALA-329SJ a total of 284 field designated burials were recovered. For this study, a total of 163 individuals fit the methodological criteria for inclusion. From CA-SCL-134 a total of 24 burials were recovered, 15 individuals were included in this study. From CA-SCL-287/CA-SMA-263, a total of 26 burials were recovered, 16 individuals fit the methodological criteria for inclusion in this study.

Due to reburial of the human skeletal populations, the other six selected sites for this study were examined by using radiographs and documentation housed at San Jose State University (Table 1). The criterion for selection of these six sites was based upon the availability and clarity of radiographs that allowed for accurate determinations of fracture types. Skeletal inventories, pathology sheets, and the availability of technical reports also determined which remains were utilized.

The CA-ALA-329ST records housed at San Jose State University note that there were 139 field designated burials recovered. A total of 65 individuals fit the methodological criteria for inclusion in this study. At CA-SCL-038 243 field designated burials were recovered from this site from which 162 individuals were selected. For CA-SCL-68, 37 individuals were recovered. Thirteen of these individuals fit the methodological criteria for inclusion. The records from CA-SCL-137 indicated that 79 field designated individuals were recovered, of which 46 individuals were selected. The CA-SCL-690 skeletal inventory records indicated that 123 field designated burials were recovered during excavations, from which 73 individuals fit the methodological criteria. The records for CA-SCL-732 documented 103 field designated burials, of which 43 individuals fit the methodological criteria for inclusion in this report.

Table 3 provides a breakdown of the number of individuals from each site that fit the criteria for inclusion in this study and fall into the demographic categories of sex and age. Table 4 provides a compilation of the number of forearm elements that were available for inclusion in this study from each of the eight sites.

TABLE 3. Demographics of the sites

		Age Range Split by Sex Distribution								
		<25			25-40			>40		
Site	N	M	F	I	M	F	I	M	F	I
East Bay:										
CA-ALA-329SJ	163	14	16	0	55	49	3	9	16	1
CA-ALA-329ST	65	6	6	0	19	15	1	8	9	1
West Bay:										
CA-SCL-287/SMA-263	16	2	0	0	3	3	2	1	5	0
South Bay:										
CA-SCL-38	162	26	15	3	55	30	7	9	17	0
CA-SCL-68	13	1	3	2	3	3	0	0	1	0
CA-SCL-134	15	0	2	0	3	3	0	4	3	0
CA-SCL-137	46	8	5	3	9	16	1	0	4	0
CA-SCL-690	73	4	9	6	20	17	12	5	0	0
CA-SCL-732	43	4	5	3	12	9	6	1	3	0
Total	596	65	61	17	179	145	32	37	58	2

TABLE 4. Breakdown of forearm elements from each site

Site	Ulnae		Radii		Ipsilateral		Contralateral	
	lf*	rt*	lf	Rt	lf	rt	Ulnae	Radii
East Bay:								
ALA-329SJ	153	150	150	149	148	143	143	139
ALA-329ST	62	60	59	57	58	56	58	52
West Bay:								
SCL-287/SMA-263	13	11	10	8	9	8	9	6
South Bay:								
SCL-38	152	145	152	152	149	143	137	143
SCL-68	11	12	11	11	10	10	10	10
SCL-134	13	13	14	13	13	13	11	12
SCL-137	39	37	34	36	34	35	31	26
SCL-690	64	64	60	61	56	59	56	51
SCL-732	35	38	35	37	33	35	30	31
Total	542	530	525	524	510	502	485	470

*lf: left; rt: right

Methodology

Sexing and aging. Information on sex and age for these eight sites was based on macroscopic analysis and previously documented information. Two populations examined macroscopically by the present author and other colleagues (Melynda Atwood and David Grant) for sex and age determinations are CA-SCL-134 and CA-SCL-287/CA-

SMA-263 (specific methodology listed below). For CA-ALA-329SJ, sex and age was previously conducted by several anthropologists (Bizjak and Repke, 1986; Gillett, 1987; Gross, 1991; Jurmain, 1991; Leventhal, 1993; Musladin et al., 1986; Pierce, 1982). Additionally, CA-ALA-329SJ was available for the author to confirm the sex and age determinations conducted by previous researchers by examining the morphological changes of the pelvis and cranium when available or by metric measurement of the femoral or humeral heads. CA-ALA-329SJ skeletal remains are currently housed at San Jose State University. The remaining populations from CA-ALA-329ST, CA-SCL-38, CA-SCL-68, CA-SCL-137, CA-SCL-690, and CA-SCL-732 utilized previously documented information recorded on site records and skeletal inventory sheets that were all analyzed by Jurmain and those records are housed at San Jose State University, Department of Anthropology Laboratory, as well as from site and technical reports (Bellifemine, 1997; Cambra et al., 1996; Cartier et al., 1993; Hylkema, 2007; Jurmain, 1993, 1996, 2000, 2007).

Table 5 provides an overview of the sexing and aging criteria used by Jurmain for CA-ALA-329SJ, CA-ALA-329ST, CA-SCL-38, CA-SCL-68, CA-SCL-137, CA-SCL-690 (1993, 1996, 2000, 2007), and CA-SCL-732 and the author for CA-SCL-134 and CA-SCL-287/CA-SMA-263. In most cases, several different sexing and aging criteria are recorded and aggregated for greater accuracy.

TABLE 5. Sex and age criteria for each site

Site	Sex Criteria	Age Criteria
East Bay:		
CA-ALA-329SJ	Bass, 1986; Dittrick & Suchey, 1986; Ubelaker, 1978	Bass, 1986; Katz & Suchey, 1986; Lovejoy et al., 1985; Todd, 1920; Ubelaker, 1978
CA-ALA-329ST	Bass, 1986; Dittrick & Suchey, 1986; Ubelaker, 1978	Bass, 1986; Katz & Suchey, 1986; Lovejoy et al., 1985; Todd, 1920; Ubelaker, 1978
West Bay:		
CA-SCL-287/	Acsádi & Nemeskéri 1970,	Buikstra & Ubelaker, 1994;
CA-SMA-263	Buikstra & Ubelaker 1994, Phenice 1969	Lovejoy et al., 1985; Skelton, 1996; Smith, 1991; Suchey et al., 1986; Ubelaker, 1984
South Bay:		
CA-SCL-038	Bass, 1991; Dittrick & Suchey, 1986; Loth, 1996	Bass, 1991; Iscan, 1985; Katz & Suchey, 1986; Loth, 1996; Lovejoy et al., 1985; Suchey et al, 1986; Ubelaker, 1978
CA-SCL-068	Bass, 1987; Ubelaker, 1978	Bass, 1987; Katz & Suchey, 1986; Todd, 1920; Ubelaker, 1978

TABLE 5. Sex and age criteria for each site (continued)

Site	Sex Criteria	Age Criteria
South Bay:		
CA-SCL-134	Acsádi & Nemeskéri, 1970; Buikstra & Ubelaker, 1994; Phenice, 1969	Buikstra & Ubelaker, 1994; Lovejoy et al., 1985; Skelton, 1996; Smith, 1991; Suchey et al., 1986; Ubelaker, 1984
CA-SCL-137	Bass, 1987; Dittrick & Suchey, 1986; Ubelaker, 1978	Bass, 1987; Katz & Suchey, 1986; Todd, 1920; Ubelaker, 1978
CA-SCL-690	Bass, 1987; Dittrick & Suchey, 1986; Ubelaker, 1978	Bass, 1987; Katz & Suchey, 1986; Todd, 1920; Ubelaker, 1978
CA-SCL-732	Bass, 1987; Dittrick & Suchey, 1986; Ubelaker, 1978	Bass, 1987; Katz & Suchey, 1986; Ubelaker, 1978

Skeletons that were macroscopically examined from CA-SCL-134 and CA-SCL-287/CA-SMA-263 were sexed by examining morphological changes to the pelvic area (ventral arc, subpubic concavity, greater sciatic notch, preauricular sulcus) and the cranium (nuchal crest, mastoid process, supra-orbital margin, mental eminence) by both the author and other colleagues (Table 5) (Acsádi and Nemeskéri, 1970; Buikstra and Ubelaker, 1994; Phenice, 1969). When pelvic area and cranial elements for the two sites (CA-SCL-134, CA-SCL-287/CA-SMA-263) were not available for sex estimation, metric measurements of the femoral head and/or bicondular width or humeral head is used to assess the sex of the skeleton (Bass, 1987; Dittrick and Suchey, 1986) (Table 4). In all

cases where sexing is possible, an aggregate assessment was utilized to provide a more accurate evaluation of the sex. When no diagnostic elements for sexing were available, it was recorded as indeterminate.

For skeletons previously documented by other researchers (see above) the sexing of the human remains was accepted by the author. Individuals recorded as indeterminate were considered for inclusion in the study only if an age range was provided.

Skeletal remains that were macroscopically examined by the author and colleagues from CA-SCL-134 and CA-SCL-287/CA-SMA-263 were aged by examining the morphological changes of the pubic symphysis and auricular surface for adults (Table 4) (Buikstra and Ubelaker, 1994; Lovejoy et al., 1985; Suchey et al., 1988). Subadult ages were determined by dental eruption, maximum diaphyseal length of long bones, and degree of fusion of epiphyses (Bass, 1987; Skelton, 1996; Smith, 1991; Ubelaker, 1984, 1989). It is understood that for dental eruption and calcification of dentition that this methodology is the “most reliable method for age estimation in children up to age 14” (Griffin, 2007). Diaphyseal length provides a good estimation of subadult age for individuals less than 12 years (Krogman and Iscan, 1986). Subadults are only included in this study if the sex of the individual was determined. For individuals that have no elements available for clear aging diagnostics, they were classified as either subadult or adult based on the development or degree of fusion for long bones or the degree of osteoarthritis (Bass, 1987; Ubelaker, 1984). For skeletons that were previously documented, the given age ranges were accepted by the author (Bellifemine, 1997;

Cambra et al., 1996; Cartier et al., 1993; Hylkema, 2007; Jurmain, 1993, 1996, 2000, 2007).

Age ranges were divided into three categories: young adult (≤ 25), middle adult (26-40), and older adult (>40). For each of the skeletons included in this study, the mean was calculated and the individual was recorded within the appropriate age category. This was done to impose order and standardize the findings for analysis and to align the data for comparative purposes.

Data collection. An important aspect of the data collection process for this study was the availability of radiographs. Macroscopic analysis provided the data necessary for selection of the elements that needed to be radiographed for a more complete determination of the causation of forearm fractures from these prehistoric California populations. Previously documented and recorded fractures were available for three sites where macroscopic analyses was conducted, but some elements were excluded from the analysis due to post-mortem damage to the elements making radiograph analysis impossible and/or if they did not fit the age criteria. Preservation and care of the elements also dictated whether inclusion of elements could be used for this study. Three sites (CA-ALA-329SJ, CA-SCL-134, and CA-SCL-287/CA-SMA-263) were available for macroscopic and radiographic analyses. The other six sites were available through previously completed radiographs, skeletal inventory and pathology sheets, and technical reports.

Macroscopic analysis for the three available sites. Macroscopically, skeletons from CA-ALA-329SJ, CA-SCL-134, and CA-SCL-287/CA-SMA-263 that had forearms

(ulnae and radii) present were examined for fractures. Only ante-mortem (during life) fractures were accepted for inclusion in this study in order to eliminate the possibility of error between identifying peri-mortem (at time of death) and post-mortem (after death) fractures caused by taphonomic processes.

The ulnae and radii of each skeleton were examined and recorded as: 1) complete (75%+ of diaphysis with one articular surface), 2) incomplete (25%-75% of diaphysis with articular surface), or 3) fragmentary (less than 25% of diaphysis). Forearm fractures were identified in several ways, such as callus development (indicating healing), angular deformation, shortening, twisting, and other abnormal morphology in the curvature of the element when compared to the contralateral element.

When a fracture was identified, sex, age, element, and side were recorded. The position of the fracture along the element was recorded as: 1) proximal epiphyses, 2) proximal 1/3 of diaphysis, 3) mid-shaft, 4) distal 1/3, or 5) distal epiphyses (Fig. 5).

Photo: Diane DiGiuseppe

Fig. 5. Example of element divided in to the five areas

Measurements associated with the fractured element were taken and recorded using a Mitutoyo (U.K.) Ltd., Model No. CD-6" B sliding calipers and osteometric board: 1) the length, 2) the length of the contralateral element, and 3) the distance from the proximal and distal ends to the center of the fracture (Appendix A).

Healing was indicated when the formation of a callus was present or the edges of the fracture showed signs of remodeling. Macroscopically, calluses are identified by reactive vascular bone that knits and holds the broken ends in place (Merbs, 1989). Several measurements associated with the callus were taken and recorded: 1) the position of the callus from the proximal and distal ends to the edge of the callus margins, 2) the length of the callus, and 3) the width of the callus at the thickest portion (Appendix A).

Forearm elements were examined for the presence of angular deformation. When elements exhibited angulation, it was recorded as present or absent. In some cases, long standing fractures may be completely healed through remodeling, thus making determination of a fracture line impossible macroscopically. Slight angular deformity may only be a representation of human variation, but caution was taken when an element appeared to have morphological variation between the contralateral elements.

The length of all individual forearms from both sides was measured and recorded bilaterally to determine if shortening of an element was present. Healing may obscure an older fracture and differences in the lengths of bilateral elements could suggest a prior break. Shortening occurs when the fractured bone does not connect properly due to displacement after fracturing. Displacement of the bone depends upon whether the fracture of the element occurs above or below the pronator teres muscle (Key and Conwell, 1942). Depending upon this, different muscles and tendons which become involved determine the direction that the element will be displaced. It is noted though that shortening can occur for other reasons. It can occur in subadults from a traumatic interruption in blood supply to the bone. If injuries occur at the epiphyses, then

premature fusion at the growth plate may occur that results in a shortened bone (Key and Conwell, 1942). If both the radius and ulna were affected, the entire forearm would be shortened.

When both the ulna and radius were fractured, each element was recorded as an individual fracture yet noting its ipsilateral involvement. The ulna and radius involvement was assessed as occurring from the same incident when examination indicated that the fracture line encompassed both elements (Judd, 2008). In many cases, twisting of the element was apparent along the diaphysis. Judd (2008) terms this type of fracture as “paired rotational” breaks. Given the displacement of forces along the bone and through the interosseous ligament, co-occurring multiple fractures may take place at quite different positions on the two forearm bones (Galloway, 1999). Generally, when paired rotational (ipsilateral) fractures are involved, the breaks are often located at different levels, with the ulna break found below the radial one (Key and Conwell, 1942).

Un-united fractures were identified by the presence of highly vascular reactivity at the ends that seal the medullary cavity. When both portions of the element are present, they will both have similar appearances. An attempt was made to measure and record un-united fractures for the: 1) length of the proximal end, 2) length of the distal end, 3) length of the callus for each end if present, and 4) greatest width of the callus for each element. Due to the fact that some of these un-united fractures were only portions of one end, measurements could not be recorded. It was possible, though, to assess the fracture type for each of these elements.

Once a forearm fracture was identified and recorded, the entire skeleton was examined for additional fractures. If there were other elements fractured, they were recorded by element, side, and location on the bone. Indications of secondary pathology associated with forearm fractures were identified when present. This included the development of osteoarthritis from specific skeletal locations, such as the hand, wrist, and elbow. For two of the sites (CA-SCL-134 and CA-SCL-287/CA-SMA-263) the level of osteoarthritis was evaluated using an ordinal scaling system developed by Jurmain (1990) (Table 6). For the other sites in this study, previous documentation of the level of osteoarthritis was conducted by other researchers and accepted as accurate.

TABLE 6. Ordinal scaling system of degenerative changes

Degenerative Joint Disease	
0	none/slight
1	moderate (small osteophyte and/or pitting <10% of articular surface
2	Severe (very large osteophyte (remodeled and concave with original surface) and/or pitting >10% of articular surface or any eburnation
3	Ankylosis

Other indications of secondary pathology include periostitis and osteomyelitis. The secondary pathology information was recorded as 1) present or absent, 2) element involved, and 3) the side.

Examination of skeletons with forearm fractures was conducted for signs of interpersonal aggression in the form of cranial depressions, embedded projectile points, peri-mortem modification and scalping and recorded as 1) present or absent, 2) element

affected, and 3) side. Additionally, for CA-ALA-329SJ, previous research addressing indications of interpersonal aggression have been recently published and this information was utilized for this study (Jurmain et al., 2009).

Radiographic analysis for the three available sites. Following the macroscopic analysis, radiographs were taken of the identified fractured ulna and/or radius, as well as the ipsilateral (both elements ulna and radius, from the same side) and contralateral (same element ulna or radius, from the opposite side) elements when available using San Jose State Universities Health Services x-ray machine, the AmeriCorp LX125 Collimator 3 Phase Generator Picker GX550. For these three sites a more rigorous methodology of radiographic analysis was applied. Each ulna and radius was taken to San Jose State University Health Services for radiographic analysis. With guidance from x-ray technician, Rene Schlice-Diehl, the settings selection for use in x-raying the elements was 42 kV (kilovoltage that is the amount of penetration through an object, the amount and quality of wavelength) and 1.8 mAs per second (the milliamp resonance – length of exposure or the amount of radiation).

Elements were placed on an 11x14 inch cassette for x-ray in specific positions. The first position was the anterior/posterior (A/P) view. To maintain positions, sponges were used to hold the bones in place keeping them from moving. Sponges were chosen for use to eliminate possible distortions that other materials, such as clay, would create. The second image taken was the medio/lateral (M/L) orientation. This was done for each individual exhibiting a forearm fracture. Two burial sets were placed on each cassette, for example one film would have the A/P views taken of Burials 51 and 61 (a set is the

paired elements from both sides – one individual) and x-rayed. In the future it is recommended doing one burial per cassette and change the position from A/P to M/L between shots.

To obtain a precise image with no distortion for each set, two exposures were taken per cassette with the x-ray centered on each set of bones with the collimator opened only around the elements being radiographed. When the other side of the cassette was used, a lead sheet was laid on the previously exposed section to eliminate possible over exposure. Care was taken to make sure that the elements were placed on the cassette in anatomical orientation. In all x-rays, the anterior side was facing up when the A/P view was exposed and the lateral side was up for the M/L view.

The methodology for determining forearm fracture types follows Grauer and Roberts (1996) and Judd's (2008) interpretation that "direct force" impact causes a transverse break and "indirect force" is evidenced by an oblique fracture. The ulnae fracture types are the diagnostic criteria for this study; whereas, radial fractures are only considered when found with ulnae fractures. The radii fracture types are not of diagnostic importance. Radiographs for each skeleton were examined both A/P and M/L for indications of fracture types and recorded as: 1) transverse, 2) oblique, or 3) other. The transverse fracture was recognized by a thin line that crossed the plane of the bone at approximately $90^{\circ} \pm$ a few degrees to the long axis of the element. The oblique fracture was recognized by a similar thin line that crossed the plane of the bone at approximately a 45 degree angle. The cortex of the elements on the radiograph was examined for breaks along the long axis to assess in identifying the location of the fracture. Depending on the

placement of the element on the radiograph, A/P and M/L, the fracture type became more apparent and diagnostic.

Each fractured element was measured from both the proximal and distal ends to the fracture line using the view that provided the most accurate indications of fracture type. For both the transverse and oblique fractures, the measurement is to the center of the fracture line. Measurements of the callus are taken from the radiographs for: 1) length, 2) anterior/posterior width, and 3) medio/lateral width. In some cases the callus did not appear clearly on the radiograph and measurements were not taken. Photographs of the macroscopic and radiographic elements for each fractured ulna and radius were taken and documented (Appendix B).

Records and documentation from previously analyzed sites. Eight sites included in this study were previously examined and documented by other researchers prior to reburial (Bellifemine, 1997; Cambra et al., 1996; Cartier et al., 1993; Hylkema, 2007; Jurmain, 1993, 1996, 2000, 2007). Skeletal inventory sheets, pathology sheets, and radiographs of fractures and pathological lesions were available for examination by the author.

Each of the skeletal inventory and pathology sheets were examined to extract the following data for each individual recovered during the field excavations: sex, age, presence of forearms (complete, incomplete, fragment), forearm fractures, secondary pathology (osteoarthritis, degenerative joint disease, periostitis, osteomyelitis), indications of interpersonal aggression (cranial depressions or fractures, embedded projectile points, port-mortem modification, scalping), other fractures (upper body, lower body), radiographs taken, photographs taken.

Due to the unavailability of skeletal remains from the six other sites (CA-ALA-329ST, CA-SCL-38, CA-SCL-68, CA-SCL-137, CA-SCL-690, and CA-SCL-732) the standard macroscopic analysis was not conducted and reliance upon existing data (described above) and radiographs was made in the determination of fracture type. Once skeletons with forearm fractures were identified, radiographs were retrieved from the radiographic storage cabinets housed at San Jose State University and examined for fracture type.

There were no notes in the data sheets that identified the settings used or the procedure for taking radiographs from the Health Services department, so no determination was made about this process. It was noted that unlike the above rigorous steps taken to assure quality of the radiographs for the three sites that were available for macroscopic analysis that the previous x-rays taken on the 11x14 inch cassettes, exposed the entire film in one shot. In some instances the elements located on the outer margins of the film lost clarity and the line of the cortex appears dimmer than the elements found on the center of the film.

Identification of forearm fracture type was difficult to determine with these previously radiographed individuals. The method used to evaluate these fracture types was similar to that discussed above. Forearms were examined for fracture lines that crossed the plane of the x-ray. Breaks on both sides of the element's cortex were examined to further assist in determining whether the fracture line was transverse or oblique. Once a determination of fracture type was made, it was recorded as transverse, oblique, or other. It should be noted that if the quality of the radiograph was such that

determination of fracture type was not possible, then these individuals were eliminated from the current study (even if they had been previously documented and published as individuals with forearm fractures). To ensure accuracy in determination of fracture type in this study, assistance was requested from two observers (Dr. E. Weiss and Dr. L. Pierce) for agreement and confirmation of the author's diagnosis.

VI. STATISTICAL ANALYSES

All data generated on forearm fractures were analyzed using the statistical software program SPSS 15.0. The variables included: 1) fracture types (transverse, oblique), 2) fracture location (proximal epiphyses, proximal third, mid-shaft, distal third, and distal epiphyses), 3) determination of the number of fractured paired elements (ipsilateral and contralateral), 4) indications of intentional trauma (cranial depressions, embedded projectile points), 5) indications of other fractures which are found in the lower limbs, ribs, vertebrae, clavicle and scapula, and hands and feet, 6) secondary pathologies (osteoarthritis and inflammatory reaction), 7) age (<25, 26-40, >40), and 8) sex (male, female, indeterminate). Percentages of the frequency distribution by element were determined for all populations. For age ranges, a median number was calculated from the raw data sets for conformity of placement within the three established age range categories. Chi-square tests were run to test frequencies between fracture type and the other above variables to determine whether there were significant differences between fracture types and indicators of intentional or unintentional trauma. Yate's Correction (continuity correction) tests and Fisher's Exact tests were computed on 2x2 tables. These tests were used when samples sizes are small; the correction for small sample size compensates for the inclusion of a raw frequency of less than five in at least one cell. Additional Chi-square tests were run to determine significance when more than one value could be representative. When SPSS could not calculate constant values, hand calculations of Chi-Square analyses were performed to determine significance. The critical alpha level was set at 0.05.

VII. RESULTS

Table 7 presents the frequency distribution of fracture type and Table 8 provides the breakdown of the number of fractures compared to the number of breaks per element. A total of 596 individuals from the eight sites were examined for ulnar and radial fractures to identify fracture type of these: 483 individuals have both ulnae and 469 individuals have both radii present. Of the 596 individuals, 40 (6.7%) individuals were associated with forearm fractures, 27 (2.5%) fractures of 1072 ulnae and 24 (2.3%) fractures of 1049 radii were identified (Table 7). As mentioned previously, the ulnae fracture types are the diagnostic criteria; whereas, radial fractures are only considered when found with ulnae fractures. The radii fracture types are not of diagnostic importance.

TABLE 7. Frequency distribution by element

Element	N	n	%	Transverse		Oblique	
				N	%	N	%
Left ulna	542	18	3.32	9	1.66	9	1.66
Right ulna	530	9	1.70	3	0.57	6	1.13
Left radius	525	15	2.86	--	--	--	--
Right radius	524	9	1.72	--	--	--	--
Total ulnae & radii	2121	51	2.40	--	--	--	--

N=total number of elements, n=number fractured

TABLE 8. Distribution of fractured elements by site

Site	Ulnae				Radii			
	Left		Right		Left		Right	
	N	N, (%)	N	n, (%)	N	n, (%)	N	n, (%)
East Bay:								
ALA-329SJ	153	3(1.9)	150	3(2.0)	150	6(4.0)	149	3(2.0)
ALA-329ST	62	1(1.6)	60	2(3.3)	59	1(1.7)	57	--
West Bay:								
SCL-287/SMA-263	13	2(15.4)	11	--	10	--	8	--
South Bay:								
SCL-38	152	9(5.9)	145	2(1.4)	152	2(1.3)	152	3(2.0)
SCL-68	11	--	12	--	11	2(18)	11	--
SCL-134	13	--	13	1(7.7)	14	2(14)	13	--
SCL-137	39	1(2.6)	37	1(2.7)	34	2(5.9)	36	--
SCL-690	64	2(3.1)	64	--	60	--	61	2(3.3)
SCL-732	35	--	38	--	35	--	37	1(2.7)
Total	542	18(3.3)	530	9(1.7)	525	15(2.9)	524	9(2.3)

Contralateral and Ipsilateral Involvement and Fractures

Table 9 presents the frequency of contralateral and ipsilateral elements verses the fracture type. A total of nine individuals from the entire sample have either contralateral or ipsilateral involvement. Pearson's Chi-Square for the left ulnae and radii ipsilateral elements is significant (Table 9). Specifically, three individuals have both the left ulnae and radii obliquely fractured and one individual has a transverse fracture to both elements. Though the Fisher's Exact Test and Yate's Correction showed no significance for the left ulnae and radii oblique fractures versus transverse fractures (Table 9), this could be representative of the small sample size.

TABLE 9. Frequency of contralateral and ipsilateral elements and fracture types

Elements	Fracture Types	
	Transverse	Oblique
Contralateral		
Left and Right Ulna ¹	0	1
Ipsilateral:		
Left Ulna and Radius ²	1	3
Right Ulna and Radius ³	2	0

1. Left and Right Ulna: Chi-Square = 0.000, $P = 1.000$

2. Left Ulnae and Radius: Chi-Square = 4.000, $P = 0.046$, Yate's Correction = 0.444, $P = 0.505$, Fisher's Exact Test $P = 0.250$

3. Right Ulna and Radius: Chi-Square = 0.000, $P = 1.000$

Location of Fracture on Element

Table 10 presents the significances of fracture types and location of the fracture on the ulna. No significant results are present.

TABLE 10. Frequency of fracture type to location on element

Element/Fracture Type		Location of Fracture on Element				
		Proximal	Proximal	Mid-	Distal	Distal
		Epiphyses	1/3	Shaft	1/3	Epiphyses
Left Ulna: ¹	Transverse	0	0	4	5	0
	Oblique	0	1	1	4	3
Right Ulna: ²	Transverse	0	1	0	2	0
	Oblique	1	2	0	3	0

1. Chi-Square = 5.911, $P = 0.116$

2. Chi-Square = 0.600, $P = 0.741$

Intentional Trauma Compared to Fracture Types

Table 11 provides the frequency of fracture types and intentional trauma indicators for both ulnae. No significant results are present.

Table 11. Frequency of Fracture Type to Intentional Trauma

		Cranial	Embedded Projectile
Element/Fracture Type		Depression	Point ¹
Left Ulna: ²	Transverse	2	0
	Oblique	0	0
Right Ulna: ³	Transverse	1	0
	Oblique	0	0

1. No data

2. Chi-Square = 2.250, P = 0.134

3. Chi-Square = 2.250, P = 0.134

Unintentional Trauma Compared to Fracture Types

Table 12 provides the frequency of fracture types to unintentional and secondary pathology indicators for ulnae. Right ulnae transverse fractures are significantly related to other fractures that indicate unintentional trauma (Table 12). The Fisher's Exact Test and Yate's Correction run for small sample size also prove to be significant for right ulna transverse fractures and other fractures (Table 12).

TABLE 12. Frequency of fracture type to other fractures and secondary pathology

		Other Fractures	Osteoarthritis	Inflammatory
Element/Fracture Type		(OF)	(OA)	Reaction (IR)
Left Ulna ¹	Transverse	0	6	1
	Oblique	1	5	0
Right Ulna ²	Transverse	3	1	1
	Oblique	0	4	1

1. OF: Chi-Square = 1.059, $P = 0.303$; OA: Chi-Square = 0.234, $P = 0.629$; IR: Chi-Square = 1.059, $P = 0.303$
2. OF: Chi-Square = 9.000, $P = 0.003$, Yate's Correction = 5.063, $P = 0.024$, Fisher's Exact Test = 0.012; OA: Chi-Square = 0.900, $P = 0.343$; IR: Chi-Square = 0.321, $P = 0.571$

Age Range Related to Fracture Types

Table 13 presents the distribution of fracture types and the age range for individuals with forearm fractures. No significant age differences are present (Table 13).

TABLE 13. Frequency of fracture type compared to age ranges

		Age Ranges			
Element/Fracture Type		≤25	26-40	>40	Total
Left Ulna ¹	Transverse	1	6	2	9
	Oblique	1	6	2	9
Right Ulna ²	Transverse	0	1	2	3
	Oblique	1	4	1	6

1. Chi-Square = 0.000, $P = 1.000$
2. Chi-Square = 2.400, $P = 0.301$

Sex Distribution and Fracture Types

Table 14 presents the distribution of fracture types versus sex for individuals with forearm fractures. Sex differences are not significant (Table 14).

TABLE 14. Fracture frequency to sex distribution

Element/Fracture Type		Sex		
		Male	Female	Indeterminate
Left Ulna: ¹	Transverse	3	6	0
	Oblique	2	5	2
Right Ulna: ²	Transverse	1	2	0
	Oblique	3	2	1

1. Chi-Square = 2.291, $P = 0.318$

2. Chi-Square = 1.125, $P = 0.570$

Fracture Types Compared to Age Ranges With Sex Considered

Table 15 looks at the distribution of fracture types versus age range when run for differences between sexes. No significant results are present.

TABLE 15. Fracture frequency compared to age range while controlling for sex

Element/Fracture Type		Male			Female		
		<25	26-40	>40	<25	26-40	>40
Left Ulna: ¹	Transverse	0	3	0	1	3	2
	Oblique	0	1	1	0	4	1
Right Ulna: ²	Transverse	0	0	1	0	1	1
	Oblique	1	2	0	0	1	1

1. Male: Chi-Square = 1.875, $P = 0.171$; Female: Chi-Square = 0.397, $P = 0.497$

2. Male: Chi-Square = 4.000, $P = 0.135$; Female: Chi-Square = 0.000, $P = 1.000$

In summary, two tests are significant for fracture types and the different variables.

They are fracture type verses 1) ipsilateral left ulnae and radii and 2) other fractures associated with right ulna involvement.

VIII. DISCUSSION

Research on forearm fractures has guided this study to examine the interaction between fracture types and causation. Transverse fractures have been identified by researchers as indications of direct force trauma (Alvrus, 1999; Galloway, 1999; Grauer and Roberts, 1996; Judd, 2008). As the forearm is directly impacted by a hard object (e.g., club), the break that results will occur as a visible straight line across the element on a radiograph. It is also noted that a transverse fracture can occur if the upper limb itself is in motion and comes into contact with a stationary object. An example would be if an individual rolled down a hill and the arm came into contact with a rock or tree. The force of the direct impact would cause the bone to fracture in a similar way as if the individual was struck with a heavy club when lifting one's arm in a defensive gesture.

Similarly, oblique fractures in the forearm have been described as occurring when an individual falls and reaches out with the hand in an attempt to break the fall (Galloway, 1999). The force of the impact radiates up the element causing a diagonal break. Oblique fractures usually occur at a 45° diagonal line across the element, thus indicating that the stress to the bone occurred by the indirect force of impact. Another example of indirect force is caused by twisting of the elements, whether one or both bones are involved. Twisting is represented by a longer spiral fracture down the bone. In some cases, only one element will fracture due to impact or twisting injury, but the force of the fracture on the one element can exert force and loading onto the other element and the second bone will fracture secondary to the original fracture (Galloway, 1999).

Two tests provided significant results at a 95% confidence level. The first statistically significant result was ipsilateral involvement of left oblique fractures. Specifically, three individuals had oblique ipsilateral fractures on the left forearm (ulnae and radii). Once corrected for the small sample size, the Yate's Correction Test and Fisher's Exact Test indicate that there is no significance between ipsilateral involvement and fracture type. Usually in statistical analyses, additional testing for small sample size helps show significance, but, the small sample size remained problematic when attempting to determine the etiology of forearm fractures in this study. Judd (2008) described paired rotational (ipsilateral) fractures as the result of a fall onto an outstretched hand "where the force of the impaction is transmitted up the bone shaft to produce an oblique fracture line" for both elements. As stated previously, ipsilateral fractures involve breaks that occur to both elements during the same episode. In clinical cases, a direct impact "identified by a transverse line" is rare to see because the radius generally is protected by the ulna that receives the full brunt of the force (Judd 2008). Additionally, when the fracture is due to "indirect violence," the breaks are often at different levels with the ulna fracture at a lower level than the radius (Key and Conwell, 1942). The results of this first test supported the hypothesis that ipsilateral oblique fractures are an indication of unintentional trauma resulting from falling onto an outstretched hand (Judd, 2008; Key and Conwell, 1942).

One individual with a left ipsilateral fracture was a female aged 35-44 years was found in burial 104 from CA-ALA-329SJ. The ipsilateral fractures for this individual are located at slightly different levels with the ulna fracture found closer to the distal end just

above the metaphysis at 37 mm and the radial break slightly above the ulnar fracture at 43 mm (Fig. 5). Twisting was visible on radiographs and by direct macroscopic examination. Shortening is also present on both elements, with the left radius measuring 187 mm in length and the right measuring 209 mm. Both elements are displaced proximally on the posterior side. For ipsilateral fractures, the muscles tend to influence the direction that the bones move, thus determining the displacement of the elements, though the interosseous membrane between the two elements tends to remain intact and prevents “divergence of the bones” (Key and Conwell, 1942).

Photo: Diane DiGiuseppe

Fig. 6. Left forearm ipsilateral fracture from CA-ALA-329, burial 104

The second individual with a left ipsilateral fracture is found on burial 38 from CA-SCL-38 of a male aged 45-60 years. Both of the fractures are oblique, located in the distal epiphyses, and at the same level. Since ipsilateral fractures are considered indications of accidental causation and the location in the distal epiphyses indicates a similar etiology, the hypothesis of unintentional trauma is supported. The third individual with left ipsilateral fractures is found on burial 74 from CA-SCL-38 of a female aged 35+. Both fractures are located at approximately the same level with the

radius slightly higher, twisted, oblique, and shortened (Fig. 6). This individual also had a transverse fracture of the right radius on the distal epiphysis that was previously identified as a Colles' fracture and further supports the hypothesis that this individual was involved in an unintentional traumatic event.

Photo: Diane DiGiuseppe

Fig. 7. Twisting and shortening of left radius from CA-SCL-38, burial 74

The second statistically significant result was between right ulna transverse fractures and other fractures found elsewhere in the skeleton. Specifically, three individuals with right ulna transverse fractures all had other fractures found in association. This finding did not support the hypothesis that transverse fractures are indications of intentional trauma since the other fractures supported an etiology of unintentional causation. However, it is interesting to note that this relationship was found on the right sides, which are less likely to be fractured by intentional trauma since most aggressors would be right handed and defenders would lift the left arm for protection. Judd (2002) broaches the subject of multiple injuries in her study of “injury recidivism.”

Her study followed the methodology from clinical studies that looked at “injury recidivism” patterns that present at hospitals (Buhr and Cooke, 1959; Hedges et al., 1995; Judd, 2002; Kaufmann et al., 1998, Madden et al., 1997; Reiner et al., 1990). In Judd’s (2002) study, she states that certain elements can be associated with specific types of etiology, i.e., lower limb, lower vertebrae, cervical and others that are indications of trauma due to unintentional or accidental falls. In the current study three individuals fit this pattern of interpretation.

One individual from Burial 24 from CA-SCL-134 is a female aged 45+ years with two other fractures. Besides the right ulna transverse fracture, the left radius distal epiphysis had a transverse fracture, typically identified as a Colles’ fracture and an oblique break to the T9 spinous process. The right ulna fracture was located in the distal epiphyses and corresponds to the left distal radial fracture. The combined fractures suggest an etiology of unintentional trauma caused by accidental falls (Judd, 2002, 2008). There is no evidence that all of these fractures occurred at the same time, but it does support a probability that the right ulna fracture may have occurred during the same incident that caused the other two fractures or during another incident as described in modern “injury recidivism” clinical studies. Additionally, archaeological and clinical studies have suggested that as individuals age, they are at greater risk of fractures due to falls and that the older the individual is, the more likely their skeleton will bear healed fractures. This explanation then appears to fit this older female’s pattern of fracture involvement and supports the interpretation of unintentional trauma (Brogren et al., 2007;

Buhr and Cooke, 1959; Lofthus et al., 2007; Lovejoy and Heiple, 1981; Mays, 1996; Nordvall et al., 2007; Sharma et al., 2008).

A second individual with right ulna transverse fracture located in the distal epiphysis versus other fractures comes from CA-ALA-329ST (burial 12 of a female, 25-35). Besides the right ulna fracture, this individual also displayed a right proximal tibial fracture. In modern cases, tibial fractures occur most often in traffic accidents or sports activities, i.e. in “*boot-top* injuries of skiers” (Galloway 1999). There is no mention in the records of the corresponding fibula having also been involved with the tibial fracture since, like the forearm, these are paired elements. Grauer and Roberts (1996) study of fracture trauma from St. Helen-on-the-Walls indicated that 67% of the individuals with tibial fractures had ipsilateral involvement with the fibula. Though this was not the case for this individual, the indication of the right ulna and right tibial fractures does suggest an etiology of unintentional causation, especially since Judd’s 2002 study suggests fractures to the lower limbs are generally related to unintentional trauma.

The third individual examined with a right ulna transverse fracture located in the proximal third and associated with other fracture comes from CA-ALA-329ST (burial 77, male 40+). From the skeletal inventory and pathology reports stored at San Jose State University, this individual had several additional elements that were fractured. These included a fractured left humerus, two right ribs, right fibula, and the right radius. Additionally, periosteal reaction is located on the left parietal, both tibiae and fibulae and elsewhere throughout the skeleton. The right radius was not considered for inclusion in this study since a fracture line was not visible on the radiograph. As an indication of

trauma that was incurred by this individual, the right radius is considered. In this case, the additional fractures of two right ribs, right fibula, right radius, and the left humerus, suggests a strong indication that this individual was involved in a serious incident caused by an unintentional etiology. Again this type of multiple injury pattern links back to Judd's (2002) and others "injury recidivism" studies that provide support for an etiology of unintentional trauma (Buhr and Cooke, 1959; Hedges et al., 1995; Kaufmann et al., 1998, Madden et al., 1997; Reiner et al., 1990). In bioarchaeological contexts, several researchers also recognize these trauma patterns as strong indications of unintentional causation (Alvrus, 1999; Burrell, 1986; Grauer and Roberts, 1996; Judd and Roberts, 1999; Kilgore et al., 1997; Lovejoy and Heiple, 1981).

The majority of Chi-square tests run were not significant when looking at fracture type versus the other variables. The most likely reason for this is due to the small sample size of this study. The overall number of individuals with indications of forearm fractures was 40, but when they are factored into the various categories, the number of involved cases drops to below five individuals.

IX. CONCLUSION

At the beginning of this study, two hypotheses were forwarded: 1) that ulna transverse fractures represented intentional trauma, and 2) that oblique fractures were associated with unintentional trauma, with each of the different types of breaks linked to specific types of force (direct or indirect). As the results demonstrated, these hypotheses did not always hold true.

First, the transverse fractures analyzed in this study did not clearly indicate intentional trauma. The statistical test that indicated significant results with transverse fractures of the right ulna was associated with other fractures that were indicative of unintentional trauma, with two of the breaks located at the distal epiphyses and the third located in the proximal third of those elements. In all of these individuals other fractures indicated unintentional trauma. Thus, the transverse fractures with the one statistically significant result could not be interpreted as being associated with intentional trauma.

The analysis of oblique fractures in this study did indicate unintentional trauma and thus supported the hypothesis. The one test result that supported the hypothesis indicated three individuals had left oblique ipsilateral fractures. In all three, the fractures were located close to each other with the ulna break slightly below the corresponding radial fractures and with twisting apparent by macroscopic and radiographic examination (Judd, 2008; Key and Conwell, 1942). Thus, according to Judd (2008), these types of fractures that involve both elements from the same side are generally indications of unintentional trauma.

Under the California Environmental Quality Act (CEQA), the environmental impact report (EIR) process offers a mechanism that allows for the preservation and/or mitigation of prehistoric sites, especially in reference to the studies in areas of paleoepidemiology. Paleoepidemiology includes evidence of trauma; trauma evidence can be used to analyze human behavior and lead to discussions of whether identified cases of trauma were caused by intentional or unintentional etiologies. This present study has focused on presenting a methodology that will aid in distinguishing types of fractures that were either a result of interpersonal aggression or by other types of trauma in precontact skeletal populations. Given the fact that the majority of present-day skeletal biological studies are conducted on populations derived from archaeological investigations implemented through Environmental Impact Reports/Mitigation Plans, it is important to allocate sufficient funding towards thorough and comprehensive skeletal analyses prior to reburial of human remains.

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Appendix A
Collection Data Sheet Form 1 of ____

Site No. _____ Burial No. _____
 Recorded by: DiGiuseppe Date: _____

Determined Age: _____ Criteria Used: _____
 Determined Sex: _____ Criteria Used: _____

Condition of Element: Complete _____ Incomplete _____ Fragmentary _____
 Element Fractured: _____ Side: _____
 Position: Prox. Epip. _____ Proximal 1/3 _____ Mid-shaft _____
 Distal 1/3 _____ Distal Epip. _____

Macroscopic Measurements: (measured in mm from fracture to articular ends)
 Total Length: _____ Bilatl Elem Length: _____ Prox: _____ Dist: _____
 Angulation: Yes _____ No _____ Shortening: Yes _____ No _____
 Healed: Yes _____ No _____

Callus: (measured in mm from callus margin to articular ends)
 Proximal: _____ Distal: _____ Length: _____ Width: _____
 Un-united Forearm Fracture: (measured in mm from fracture to articular ends)
 Proximal: _____ Distal: _____ Length: _____ Width: _____
 Other Elements Fractured: _____ Side: _____ Location: _____

Secondary pathology:
 OA: Yes _____ No _____ Element _____ Side _____
 Periostitis: Yes _____ No _____ Element _____ Side _____
 Osteomyelitis: Yes _____ No _____ Element _____ Side _____
 Interpersonal Aggression:
 Cranial depr. Yes _____ No _____ Element _____ Side _____
 Em. Proj. Pt. Yes _____ No _____ Element _____ Side _____
 Cutmarks Yes _____ No _____ Element _____ Side _____
 Scalping Yes _____ No _____ Element _____ Side _____

Fracture Type: (determined by radiograph)
 Transverse: Yes _____ Prox. length _____ Dist. Length: _____
 Oblique: Yes _____ Prox. length _____ Dist. Length: _____
 Other: Yes _____ Prox. length _____ Dist. Length: _____

Radiographic Callus Measurements: (measured in mm callus margin to articular ends)
 Length: _____ Anter./Post. width: _____ Med./Lat. width: _____

Comments: _____

Temporal Diagnostics: _____

Appendix B
Element Photographs

Site No. CA-ALA-329
Recorded by: DiGiuseppe

Burial No. 106
Date: 3/15/08

Macroscopic View of the Ulna and Radius

Radiographic View of the Ulna and Radius

Proximal Length to Fracture, mm: _____

Distal Length to Fracture, mm: _____

Thickness of Callus, mm: _____