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Osteoporosis in a prehistoric bay area population

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OSTEOPOROSIS IN A PREHISTORIC BAY AREA POPULATION

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by

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OSTEOPOROSIS IN A PREHISTORIC BAY AREA POPULATION

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ABSTRACT

OSTEOPOROSIS IN A PREHISTORIC BAY AREA POPULATION

By Melynda Leigh Atwood

Modern resource analysis of the cultural environment provides a rich database to help us understand physiological processes in ancient human societies. This study uses evidence retrieved through the environmental impact process to determine the osteoporosis rates experienced by a prehistoric, semi-sedentary San Francisco Bay Area native Ohlone population of hunter-gatherers. Bone mass may be affected by sex, age, diet, activity, or genetics. To study the influence of these factors, cortical bone mass ratios were measured in a skeletal collection, CA-ALA-329, and compared with those from Wharram Percy, a medieval English, agriculture-based population.

Results from the CA-ALA-329 population mirror those of other archaeological and modern studies: Females have more cortical bone in youth, and then lose bone earlier and eventually more over time than males. When comparing this population with Wharram Percy, bone mass was found to be higher in CA-ALA-329, regardless of sex and age, indicating that the skeletal health of this hunter-gatherer population was generally better than that at the agriculture site, Wharram Percy. Dietary insufficiencies at Wharram Percy may be the cause for this difference.

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I. INTRODUCTION

Prehistoric California research would have been difficult, if not impossible, had it not been for the passage, adoption, and subsequent effects of the state's environmental laws, specifically CEQA, the California Environmental Quality Act, as well as federal statutes (e.g., American Antiquities Act of 1906 [16 USC 431-433]; National Historic Preservation Act [NHPA; Public Law 89-665]; 16 USC 470 *et seq.*; and PL101-601 Native American Graves Protection and Repatriation Act of 1990 [NAGPRA]).

Due to the adverse impacts of Spanish colonization, much of our knowledge about San Francisco Bay Area Native Americans' aboriginal lifeways is greatly diminished. The rich and detailed oral traditions and culture of the local tribes had primarily been lost by the advent of ethnographic techniques, introduced in America, especially California, during the late 19th and early 20th centuries. The use of ethnohistoric documentation (e.g. Spanish expedition diaries and mission archives) does illuminate some aspects of Bay Area prehistoric populations' culture and lifeways, however these resources are limited. While references to many aspects of aboriginal cultural behaviors and adaptations were included in their notations, the writings of these historic authors were, unfortunately, often not comprehensive and may be chronicling changes to the original California Native American lifeways as they responded to the pressures of colonization, rather than the original culture itself. It is due to this selectivity in the ethnohistoric documentation that information about pre-contact

California Native populations' lifeways, diet, and health is often derived from archaeological sites, including cemeteries, such as CA-ALA-329. A multitude of analyses conducted on the human remains, as well as the cultural and ecological assemblages found in the sites, allow scientists to reconstruct these past lifeways.

Particular to this study, the protection and preservation of Ca-ALA-329, under California's environmental laws, has allowed meaningful archaeological research to be conducted on this population, expanding our current knowledge about these indigenous peoples. For example, CA-ALA-329 was once interpreted to be a "shellmound/refuse heap" and a "habitation site," even though over 500, and as many as 3000, burials were found within the soils. Archaeological research has since indicated that the site is actually an earthmound and that the population did not use it as a habitation site, but rather as a cemetery site that was also used for performance of rituals, such as funerary rites and mourning anniversaries (Leventhal 1993). The preservation of CA-ALA-329 has also allowed other researchers to conduct inquiries into the lifeways of San Francisco Bay Area Native populations, answering questions related to such diverse issues as: Intra- and inter-tribal aggression (warfare), dental health, age-related diseases, such as osteoarthritis and osteoporosis, linear growth of subadults (health status), and populational health status stability (Jurmain 1990, Elliott 1992, Leventhal 1993, Nechayev 2007).

Additionally, through the passage of environmental laws, many archaeological sites, such as CA-ALA-329 locality, are listed with the National Registry of Historic Places. The National Registry coordinates both public and private efforts to recognize, assess, and preserve national archaeological sites. It is also responsible for the dissemination of information on the sites' locations and provides educational resources for both public and academic study.

While archaeologists and physical anthropologists reconstruct the behaviors and culture of prehistoric peoples, it is the local Tribes that are truly empowered by these federal and California State environmental/human rights laws: They have greater oversight over the treatment of their ancestral remains and may receive additional protections for their ancestral archaeological sites. Consequently, these laws are not only supportive of, but also supported by, the local tribes.

The deployment of a bio-anthropological and environmental science multi-disciplinary approach to archaeological research has resulted in a greater understanding of health and the physiological stress issues that manifested within prehistoric California Indian populations, in particular, those recovered from CA-ALA-329. The specific requirements under CEQA and federal laws, and punishment for violating these laws, ensures that discovered sites are neither disregarded by developers and public agencies nor subjected to devastating impacts prior to appropriate scientific study.

II. BACKGROUND

This study measured the prevalence of osteoporosis in a Costanoan/Ohlone skeletal collection to determine whether prehistoric San Francisco Bay Area Native American populations exhibit the same rates of osteoporosis as historic populations. The populations that will be used include: 1) CA-ALA-329, a California prehistoric Costanoan/Ohlone population dating from 130 BC to 1770 AD and 2) Wharram Percy, a medieval English village cemetery dating from the eleventh to the sixteenth century AD.

This study had multiple aims. It endeavored to increase knowledge concerning osteoporosis by examining factors that affect osteoporotic development throughout an individual's life. A comparison between temporally and culturally distinct populations will aid in the development of theories to explain similarities or disparities of osteoporosis rates noted.

Osteoporosis and osteopenia are age-related skeletal conditions that are characterized by an increase in bone resorption (the removal of old bone) that surpasses bone apposition (the creation of new bone), which leads to bone fragility and susceptibility to fracture. Throughout life, bone cells called osteoblasts add bone tissue, while bone cells known as osteoclasts remove old bone, with peak bone mass achieved in young adulthood, or after complete fusion of long bone epiphyses (Nelson et al. 2003). Whole-body bone density is achieved by the age of 30 years and does not normally increase after this time, although peak bone mass is achieved at variable times in different locations throughout the body (Peel et al. 1995, Stini 2003). Without the influence of injury or disease, these rates of apposition and removal after adulthood are proportional until about the fourth or fifth decade of life, when osteoclastic activity increases and removal rates outpace apposition rates (Ericksen 1982, Ruff et al. 1982). This age-related metabolic change leads to decreased bone density and subsequent increased susceptibility to skeletal fracture. The presence and accumulation of bone microdamage sustained throughout life is also considered a possible contributor (Burr et al. 1997).

Factors that influence the development of osteoporosis include: age, sex, genes, lifestyle, smoking and alcohol use, and chronic disease. Due to the multiple etiological factors influencing osteoporosis, it is classified into two categories: primary and secondary. There are three subcategories of primary osteoporosis: Type I, Type II, and idiopathic. Type I refers to postmenopausal osteoporosis and is, therefore, restricted to females, while Type II refers to age-related osteoporosis and is experienced by both males and females. Osteoporosis experienced by either sex prior to 50 years of age is identified as idiopathic (Peel et al. 1995). Secondary osteoporosis is associated with one known etiology, or cause, such as cancers, drugs, or diseases and conditions of the following systems: endocrine, gastrointestinal, and rheumatological (Peel et al. 1995, Grynpas 2003).

The types of osteoporosis that were studied in this thesis include only Type I and Type II primary osteoporosis. Since smoking and alcohol consumption were either absent or experienced in negligible amounts by prehistoric California Native Americans and medieval English peasants (Mays 1996), these factors were not considered in this analysis. Also, since this study's aims were to determine the "normal" osteoporosis rates of a prehistoric San Francisco Bay Area population, as well as to determine possible genetic and lifestyle factors that significantly impact bone density, the inclusion of idiopathic and secondary osteoporosis would be inappropriate. Individuals that experience osteoporosis due to disease are necessarily health-compromised and have experienced an exacerbation of the bone density loss that is normally age-related. Their inclusion in this study, consequently, would have misrepresented the "normal" age-related osteoporosis rates found within their community and, thus, were excluded.

The use of diverse populations in this study aided the assessment of osteoporosis factors and their importance. While the Native American prehistoric population from CA-ALA-329 was primarily semi-sedentary, with hunter-gatherer subsistence methods and some forms of land management (burning), the English Wharram Percy population was sedentary, with pre-industrial agriculture-based subsistence. Through the analysis of osteoporosis expression in both populations with different genetics, lifestyles, and subsistence patterns, this thesis endeavored to hypothesize on the factors that lead to osteoporosis and their importance in its expression.

III. RELATED RESEARCH

Both the mechanical processes of osteoporosis and the differences in its expression, such as age at onset and severity, have been studied in multiple disciplines, e.g., clinical medicine, physical anthropology, and archaeology (Nelson et al. 1991, Melton 1997, Mays 1998, Lau et al. 2001). To more fully understand these aspects of osteoporosis, researchers segregate their populations by age and sex, including studies that concentrated on other species (DeRousseau 1985, Hindeland et al. 1997, Nagy 2001), as well as numerous examples of work with human archaeological samples (Mole et al. 1998, Mays 2000, Mays 2001, Mays 2006, Brickley 2002). The inclusion of these independent variables allows researchers to investigate similarities, as well as differences, in the patterning, such as primary loci, as well as prevalence and severity of osteoporosis, between male and female subpopulations over time.

Toward this end, researchers have been able to explore some of the possible biological mechanisms of osteoporosis, such as the primary locus, or loci, of bone loss. Ericksen (1979) studied the Terry collection, comprised of black and white individuals of both sexes, dating from the late 19th to the early 20th century. Her research showed that bone loss is most evident in the expansion of the medullary cavity of long bones (Ericksen 1979). Ruff's research, in 1982, supports her findings. In his study of a late prehistoric/protohistoric Pecos Pueblo population, he found age-related increases in the area measurements of the medullary cavity in both sexes, as well as age-related increases in the total area within the subperiosteal bone surface (Ruff et al. 1982). Another researcher, AJ Perzigian, looked at the primary loci of bone loss while researching two Native American populations, Indian Knoll and Hopewell, dated 2500-2000 BC and 50 BC – 250 AD respectively. It was discovered that trabecular bone loss outpaced cortical bone loss in both populations (Perzigian 1973). Supporting this conclusion, Legrand and colleagues studied the bone mineral density, trabecular microarchitecture, and vertebral fracture patterns in a group of modern French men and found that vertebral fractures were more strongly associated with the changes and decreases in trabecular connectivity than with bone mineral density (Legrand et al. 2000).

As previously stated, researchers have also studied osteoporosis rates in multiple mammalian and nonhuman primate species, and have found similarities and disparities between their osteoporosis rates and those of humans. Hindeland and MacLean (1997) tested a moose cranium and metatarsals from two moose for evidence of osteoporosis. They found that moose, similar to humans, evinced age-related cortical bone thinning, as well as increased osteoporotic lesions, in both sexes (Hindeland et al. 1997).

DeRousseau (1985) studied osteoporosis in normally locomoting nonhuman primates, adult rhesus monkeys, and found osteoporosis patterns both similar and different to those seen in humans. The results indicated that only females showed a statistically significant decline in cortical bone indices, but only in the second metacarpal. The males showed increased cortical bone indices in long bones, such as the humerus and femur, with age, while female long bone cortical indices showed no significant relationship to age at all (DeRousseau 1985). The author concluded that the data do show a sex- and age-related osteopenia, which may indicate that loss of bone density may be considered a primate characteristic (DeRousseau 1985). Another nonhuman primate study looked at bone density in a group of female macaques, a third of which had been ovariectomized almost two years prior to death (Bowles et al. 1985). Bowles and colleagues (1985) found that the ovariectomized macaques had lower mean bone densities in all spinal column measurements. The authors concluded that the study indicated a similar, sex-related loss of bone density in female humans and macaques: Substantial bone loss in the vertebral column after the onset of menopause (Bowles et al. 1985). In sum, the data of these researchers do support a theory of sex- and age-related bone density loss in mammalian and, specifically, primate species, such as that seen in humans.

Both anthropological and clinical research have also shown that human female subpopulations do experience earlier and more severe osteoporosis than human males due to hormonal changes occurring throughout life, especially the menopausal and postmenopausal years, aggravating age-related bone loss (Plato 1982, Burr et al. 1983, Ericksen 1979, Drusini et al. 2000). Drusini and associates (2000) performed work in northeast Italy on the femora of a Longbard population and found that the female samples from this population had a higher cortical bone ratio than the males until the fifth decade, but that female osteopenia then increased and outpaced that of the males. Research by Mays (2006) on a late-Roman population from England found that the onset of cortical bone loss in the females corresponded with the onset of menopause. In this population, the females aged 50 years and older showed a decrease in cortical index measurements when compared with the younger females (Mays 2006). Another study on modern Guamanian and matched Caucasian populations found males from both groups had more overall bone mass and lost less bone mass with age that the females from either population (Plate et al. 1982). Additionally, Ericksen's study of the Terry collection (1979) found that not only did both black and white females evince a greater loss of cortical bone density with age than males, but females also have larger medullary cavity diameters at all ages.

Further research continues to show that, regardless of the geographic or genetic makeup of the populations, females do experience earlier and more severe age-related osteoporosis than males. Agarwal and associates (2004) studied trabecular bone in a medieval peasant population from North Yorkshire, England, and found that, while both males and females showed age-related decreases in vertebral bone quality, the females exhibited the losses earlier than the males. Martin and colleagues (1979) study of age-related osteoporosis in a Sudanese Nubian population found that the females' decrease in cortical bone thickness after the fortieth year was over three times the bone loss seen in the males.

It should be noted that, besides menopause- and postmenopause-induced aggravation of age-related female bone loss, parity and lactation are also variables that may be possible contributors to changes in bone mass in female subpopulations. For example, clinical research has attempted to understand the role of pregnancy in bone loss by measuring and comparing the bone mass of females before (if possible), during, and after pregnancy. Cross and associates (1995) measured bone mineral density in the distal radii of white, American, expectant mothers at the end of each trimester. They reported that, while there was increased bone turnover measured in the third trimester, statistical analysis indicated no significant differences in bone mass density measurements between any of the three separate trimester measurements (Cross et al. 1995). In another clinical study, Drinkwater and colleagues (1991) compared bone mineral density measured three separate times in white, Australian females: prior to pregnancy, six weeks after parturition, and six months after breastfeeding. Their results showed significantly decreased bone mineral density in the femoral neck and radial shafts of their subjects during pregnancy. Both of the studies, however, are hampered by their small sample sizes (10 pregnant and 10 control females, and six pregnant and 25 control females, respectively) and the subsequent inability to generalize their findings to the larger populations (Drinkwater et al. 1991, Cross et al. 1995). Using a more robust sample of 40 pregnant and 40 control Australian females, Ken and associates (1993) found no significant bone density increases or decreases in the distal forearm during pregnancy. The results of these studies indicate that bone loss may occur during pregnancy, perhaps dependent upon the specific element or the type of bone being evaluated, such as cancellous or cortical.

Research has also been able to verify the impact of lactation and weaning on female bone density. Drinkwater and colleagues (1991), who found significantly decreased bone mineral density in the femoral neck and radial shafts of its subjects during pregnancy, also found that, after six months of lactation, while bone loss in the radial shaft had returned to pre-pregnancy levels, the bone loss in the femoral neck continued. The previously mentioned research by Kent and associates (1990 and 1993), while finding no significant bone density decreases during pregnancy, also reported increased bone turnover and cancellous bone loss during lactation (Kent et al. 1990, Kent et al. 1993). It was further stated that the bone loss had not recovered by six months of breastfeeding but had by 4-6 months postweaning (Kent et al. 1990, Kent et al. 1993). In another study that measured bone density at three days and at three, six, and twelve months postpartum in 36 Italian women, 18 breastfeeding and 18 bottle-feeding, it was found that there was a significant decrease in bone mineral density in the lumbar vertebrae and distal radii during breastfeeding, which was only partially recovered six months postweaning (Affinito et al. 1996).

Affinito and colleagues (1996) suggest that multiple pregnancies that lead to multiple periods of prolonged lactation over a female's reproductive lifetime, in quick succession, may be a risk factor for postmenopausal osteoporosis by creating an increased net bone loss. This is supported by Sowers' review (1996), a synthesis of osteoporosis literature, which states that females who breastfeed three or four children may have lower bone density than women who breastfeed one or two. This is, however, contradicted by the work of Lopez and associates (1996). Their research on 56 European females (30 breastfeeding and 26 controls who had not had any children 2-3 years prior to the study) found that bone mineral density recovered after weaning was not related to age, bone mass indices, parity, or frequency or length of nursing episodes (Lopez et al. 1996). Sowers and associates (1995 and 1996) found that the resumption of menses, which is encouraged by weaning, was uniformly associated with the time of bone density recovery. In summary, while pregnancy may increase bone loss, lactation and amenorrhea do significantly increase bone loss, and it is not recovered for multiple months postweaning.

While indicating that females do experience earlier and more severe osteoporosis, previous research has also shown that there is variability in the types of osteoporosis expression seen between the sexes. For example, the element, or bone, used for testing has shown variability in the expression of female bone loss. Lynnerup and colleagues (1997) found in their study of two medieval Greenland Norse populations that, while there was no age-related bone loss evident in the mandibles of the Norse males or females, the median female bone mineral content (BMC) was proximately 11% lower than that of the median male. Another example of female osteoporosis variability may also be seen in the study of Burr and associates (1983). While examining the correlation between osteoarthrosis/arthritis and osteoporosis, the researchers found that there is no correlation between osteoarthritis and osteoporosis in males, but that females with increased levels of osteoarthrosis also indicated an increased incidence of osteoporosis (Burr et al. 1983).

Researchers have also looked at differences in the rates of conditions secondary to osteoporosis, such as bone fractures, and found that females do experience higher rates of these conditions than do males. Melton and associates (1997) looked at osteoporosis fractures in males and females of three races (black, white, and all others combined) and three age categories (45-64, 65-84, and 85+) and found that regardless of fracture type (hip, spine, forearm, and all other sites combined), female groups had a higher incidence of fractures than male groups (Melton et al. 1997). Also, in the European Prospective Osteoporosis Study Group (2003) research, 207 modern men and women were studied and it was found that men had half the new fracture rate than females per annum. Additional research by De Laet and colleagues (2002) was also conducted on 7983 elderly men and women from the Netherlands. Their study found that the average male hip fracture risk was much lower than that of the females (De Laet et al. 2002).

While these studies do show more females involvement with osteoporosis due to menopause, and possibly pregnancy and lactation, it should not be concluded that males are immune to experiences with severe osteoporosis.

Males do experience age-related osteoporosis even though they do not undergo the same hormonal changes associated with menopause, pregnancy, and lactation. For example, while both Melton and associates' and De Laet and colleagues' studies did state that females have a higher fracture risk than males, they both also indicate increased age-related fracture risks for men, at the same bone mineral density, and suggest clinical interventions for osteoporosis for both men and women (Melton et al. 1997, De Laet et al. 2002). Similarly, while the European Prospective Osteoporosis Study Group's research 92003) indicated increased new osteoporosis-related fracture rates in females when compared to males, it also showed that males do have an increased incidence of fractures that is also age-related.

Additional studies have also been performed specifically to identify and understand male osteoporosis expression. Mays (2001) studied cortical bone loss in a group 18th-19th century British men and found age-related bone loss patterns, such as stable subperiosteal deposition coupled with increased endosteal resorption beginning in middle age, similar to those seen in modern European male populations. Another study looked at the bone mineral density, trabecular microarchitecture, and vertebral fractures in male osteoporosis (Legrand et al. 2000). Legrand and associates (2000) found that the trabecular microarchitecture in male vertebra is a significant determinant of fractures in these elements in men with age-related osteopenia.

Besides sex and age, two other interacting factors that influence the presence and severity of osteoporosis are the activity patterns and diets of the studied populations. Both are known to be important to the accrual of bone mass: 1) Weight-bearing exercise is known to be beneficial, however, the specific type, intensity, and duration of appropriate exercise is still under investigation and 2) an appropriate diet, sufficient in Calcium and Vitamin D, is also critical for peak bone mass; Vitamin D, created by the ultraviolet irradiation of ergosterol (a cholesterol in the skin), is necessary for maximum absorption of Calcium in the stomach (Lanham-New et al. 2007).

To further explain the role of activity patterns, it is essential to describe Wolff's law (also known as bone functional adaptation). Wolff's law states, "...that bone adapts to its mechanical environment during life, and...that differences in morphology can be used to investigate differences in past mechanical environments (Ruff et al. 2006)." This means that constant strains or pressures placed on individual bones through usage patterns will cause the body to create more bone at the site of the strain, in an effort to prevent breakage of the bone. For example, research measuring multiple anatomical sites for bone mineral content differences between cross-country runners and sedentary groups found that there was a statistically significant increase in the bone mineral content of the runners (Meade 1989). Following the rationale of bone functional adaptation, populations that lead physically demanding lives, such as peasants, should experience less osteoporosis than other, less physically active populations. A study by Agarwal and associates (2004), conducted on a medieval English population, Wharram Percy, interpreted bone loss by assessing vertebral trabecular architecture changes. This research found that age-related trabecular changes were seen, but contrary to modern populations, a continuation of the trabecular changes was not seen between middle- and old-age in the medieval population (Agarwal et al. 2004). The authors suggest that this may be due to the increased activity rates seen in the population throughout life, as well as prolonged lactation in medieval populations (Agarwal et al. 2004).

As Wolff's law posits that physical activity may be protective against bone loss, modern clinical research does indicate that physical activity-related therapies in multiple and diverse populations do appear to ease symptoms of bone loss; symptoms, which themselves, can also vary between populations (Sievert 2001). Symptoms can range from hot flashes in the United States, to "muscle-joint-bone pain" in Turkey and shoulder stiffness and ringing in the ears in Japan, and therapies that rely on activity appear to aid in easing these symptoms in many populations (Sievert 2001). Proactive remedies in the form of exercise and weight-bearing activities in Japan may account for their low rate of symptoms ascribed to menopause and the lifelong physical activity of Mayan women may increase their flexibility and muscular strength, which could compensate for low bone mineral density and prevent fracture (Sievert 2001).

However, it should be noted that research has also recently indicated that, since activity is just one of many factors that is involved in bone remodeling, Wolff's law may be overestimating the strength of activity alone on bone remodeling (Pearson et al. 2004). In support of this, a study by Mays (2001) looked at the effects of age and occupation on bone loss measured in a group of 18th-19th century British men. Using a single male population that could control for sex- and dietary-related differences, the author found no disparities in age-related bone loss patterns between men of manual and nonmanual professions (Mays 2001). Also, in another study on postpartum Caucasian and Asian females, the authors found that environmental factors, such as physical activity, had little influence on the levels of bone density loss or recovery measured (Sowers et al. 1995).

With these new questions about Wolff's law, it is possible that dietary requirements and other factors, such as parity and lactation, may have a stronger impact on osteoporosis than activity patterns. A study performed on a medieval English population, Wharram Percy, measured age-related bone loss in the femur and found that it exceeded that of modern populations (Mays 1998). According to Mays (1998), although the increased physical demands of the medieval peasants' lives should have protected them from severe bone loss, these results may be an effect of the extreme dietary fluctuations experienced by this agricultural society. The lack of adequate nutrition in their diets negatively impacted their peak bone growth during childhood and young adulthood, which would have caused an increase in the severity of osteoporosis once it appeared in individuals affected by childhood malnutrition (Mays 1998). Another study by the same author looked at past and current osteoporosis rates between medieval and modern English and Norwegian populations (Mays 2006). The medieval English and Norwegian populations evinced similar peak bone mass density and age-related patterns of bone loss, although modern Norwegians have lower bone mineral density measurements and higher rates of osteoporosis fractures than modern English populations (Mays 2006). Mays (2006) states that this suggests a recent origin for the differences in modern bone mineral density seen between these two populations and hypothesizes that it is caused by medieval females' poor nutrition and their resultant difficulties in regaining bone mass following pregnancy and lactation.

As mentioned earlier, peak bone mass is achieved by young adulthood and the "peak" is entirely predicated upon good nutrition and exercise (Nelson et al. 2003). Research on the Terry Collection (a black and white, male and female skeletal population) indicated that the 19th and 20th century black males in this population experienced increased bone loss similar to that seen in the population's females (Ericksen 1982). While white males retained bone mass until the fifth decade before experiencing bone loss, black males began to lose bone mass in the third and fourth decades, similar to the population's black and white females (Ericksen 1982). This difference in white and black male osteoporotic onset and severity may be the result of 19th and 20th century socio-economic differences between the races in America. It is possible that a higher incidence of childhood or young adulthood malnutrition in the black population and increased rates of multiple diseases, such as diabetes and tuberculosis, may have caused the black males to mimic black and white female osteoporosis rates (Ericksen 1982; Jurmain, personal communication).

Another example of dietary influence in osteoporosis can be seen in a study comparing populations found in the Canary Islands (Velasco-Vazquez et al. 1999). The population from El Hierro, with a marine dietary emphasis, exhibited only one example of osteoporosis, while the population from Gran Canaria, a population with an agriculture-based diet, experienced high numbers and increased severity of osteoporosis, including young adults with measurable bone loss (Velasco-Vazquez et al. 1999). This marine diet protection from osteoporosis can also be seen in Ericksen's study (1976) of three populations: a 18th-20th century Eskimo population with a marine diet emphasis, a 16th-17th century American Southwest Pueblos population with a primarily vegetarian diet, and a 16th-19th century South Dakota Arikaras population with a horticultural and bison-hunting dietary emphasis. While all populations evince sex- and age-related bone loss, Eskimo males have a significant cortical thickness advantage over other males at all age levels and Eskimo females have greater cortical thickness than other females in youth and middle age (Ericksen 1976). However, it must be emphasized that, due to the variability seen in Ericksen's populations, genetic differences may also be responsible for the increase in Eskimo cortical bone thickness.

Studies examining the possible influences of genetics on osteoporotic expression are seen in both archaeological and clinical research. Plato and associates (1982) measured second metacarpal cortical bone loss in modern Caucasians and Guamanians and found that, while both showed increased medullary widths after the age of forty, the speed and ratios of loss were much different between the groups and the sexes. Until the age of 35 years, Guamanians had larger medullary widths than the Caucasians, but the reverse was seen after the ages of 50 to 60 years, and white females lost more cortical width than Guamanian females after 40 years of age (Plate et al. 1982). In a more recent study, Mays reported on his comparisons between a 3rd and 4th century, late Roman, English population and a modern Finnish study (Mays 2006). His research chronicles an increase in osteoporosis and related fracture rates in the Romano-British subjects compared to both the modern and other archaeological samples and Mays theorizes that a genetic contribution may be responsible for the significant increases seen in the population (Mays 2006).

Another study looking at possible genetic influences on bone loss, Mensforth and associates (1989) studied osteoporosis fractures found in black and white males and females from the Hamann-Todd collection. They found that white females experiences higher frequencies of all fracture types (distal radius, proximal femur, vertebral, and sacral) over all other groups and that the rank order for all fracture types studied was: white women, white men, black women, then black men (Mensforth et al. 1989). Nelson and colleagues (1991) also looked at black and white females; they performed a clinical trial on modern black and white American females and measured the effects of body size and composition on bone density (Nelson et al. 1991). After analyzing their results, the authors theorized that the significantly greater bone densities seen in the black females may be explained by the increased body mass and body fat (which stores estrogen and Vitamin D) found in black females compared to white females (Nelson et al. 1991). Another clinical study on osteoporosis and its expression in females of multiple ethnicities looked at 7784 black, 1912 Asian, 5973 Hispanic, 1708 Native American, and 180471 white females for similarities or differences in age-related osteoporosis (Barrett-Connor et al. 2005). Barrett-Connor and associates (2005) determined that there were no significant differences in age-related bone loss found between the ethnicities. Fracture patterns also showed an age-related increase in all groups, although black and Asian women had the lowest fracture rates in each age group and white and Hispanic women had the highest (Barrett-Connor et al. 2005).

An analysis of previous research on prehistoric and historic osteoporosis rates indicates that there are multiple factors that influenced the age at onset of osteoporosis and its severity in past populations. These factors, listed in this author's order of the strength of their influence, are: sex, age, diet, genetics, and activity. Besides determining and comparing the osteoporosis rates of a California prehistoric Native American and a medieval English population, the results of this study were also intended to shed further light on the importance of individual factors that affect osteoporosis rates.

IV. RESEARCH OBJECTIVES AND HYPOTHESES

This research was intended to increase current knowledge regarding the effects of age, sex, genetics, activity levels and patterns, and diet on the expression of osteoporosis. While researchers are aware that these factors impact bone mineral density, the significance or strength of each factor on the development and severity of osteoporosis has not been determined. Through the inclusion of distinct populations in this study, the significance of each of these factors on osteoporosis was examined.

Both specific and generalized questions about osteoporosis were addressed in this study, such as: 1) do cortical index measurements differ between the sexes and among the different ages at each site, as well as between sites? 2) did hunter-gatherer or pre-mechanized agriculture subsistence strategies protect or aggravate bone mineral density loss? 3) did the variety and density of prehistoric food resources in California protect California Native Americans from osteoporosis? 4) did hard labor required for pre-mechanized agriculture subsistence protect, as Wolff's law would predict, or adversely affect the population's bone health, such as by speeding up normal biological degenerative changes? 5) did the malnutrition or increased infectious disease rates associated with pre-mechanized agriculture significantly increase osteoporosis rates in affected populations?

Previous research has shown that female subpopulations do experience earlier and more severe osteoporosis than their male counterparts (Ericksen

1979, Burr et al. 1983, Drusini et al. 2000, Agarwal et al 2004), both populations studied in this research were expected to follow this pattern. Additionally, as age is also considered a predictor of osteoporosis severity (Plato 1982, Drusini et al. 2000, Agarwal et al. 2004), the older age categories for both males and females in both populations were expected to display increased bone mineral density measurements when compared to the younger age categories.

Due to the increased malnutrition and hard labor associated with early, pre-mechanized agriculture subsistence, the medieval English population was expected to show increased levels of osteoporosis when compared to the semi-sedentary, hunter-gatherer California Native American population.

V. MATERIALS AND METHODS

Study Sites

The CA-ALA-329 population was exhumed from a shellmound found along the eastern shores of the San Francisco Bay, in Coyote Hills, in Alameda County, California. An historic representation of San Francisco Bay Native Americans can be seen in Figure 3. Located approximately three kilometers north of the Newark Slough, this area was the territory of the Penutian-speaking, East Bay Costanoan/Ohlone tribes during the time when the site was in use (Jurmain 1990). The site has been dated to within the Middle Period to Late Period Phase 2, or 550 AD to ca. 1700 AD (Leventhal 1993, Groza 2002). Archaeological research on San Francisco Bay Area Native American populations found that groups dating from the Middle to the Late Period were hunter-gatherers that were expert at subsisting on forager-adapted and collector strategies that exploited both coastal and bayshore ecosystems (Hylkema 1991). Due to their usage of agricultural techniques, e.g. irrigation, pruning, planting and harvesting, they have also been described as proto-agriculturalists (Bean et al. 1990). Examples of the diverse plant food resources available to the population include acorns (a food high in fat and calcium), buckeyes, sage, seeds, fruits (such as berries and cacti), and certain plant roots (Pierce 1982, Bean et al. 1990). Studies have also found that the Ohlone were adept at exploiting the hundreds of animal species within the population's environment and lived well on a protein-rich diet of shellfish, fish, reptiles, birds, insects, sea mammals and land mammals, such as elk, antelope, deer, and hare (Pierce 1982, Bean et al. 1990). While there is both archaeological and ethnohistoric evidence of stratified status among the Ohlone, there is also ethnographic evidence that this stratification did not create inequalities in food distribution within the population (Vayda 1973, Bean et al. 1990).

As semi-sedentary, hunter-gatherers with prodigious vegetal and wildlife resources, the Ohlone would still have probably experienced sporadic food resource insufficiencies due to natural climactic fluctuations, such as drought, flooding, or freezing temperatures (Kroeber 1925, Cook 1957). To ameliorate the effects of deficient food resources on the population, systems of trade and reciprocity were established, similar to descriptions of Pomo trade feasts (Vayda 1981, Bean et al. 1990). Pomo trade feasts redistributed food surpluses among multiple groups; tribes experiencing famine could use bead wealth to trade for food with other tribes experiencing food surpluses (Vayda 1981). The resource diversity of the multiple ecosystems in the San Francisco Bay Area, e.g. oak woodlands, marshland, seashore, etc., helped ensure that adequate food resources could be available to multiple, separate populations through this trade system (Heizer et al. 1980).

In summary, the lifestyle of the Ohlone would have been physically demanding while hunting, gathering, and preparing food, with time of leisure experienced as well. Health stresses due to food resource fluctuations may have been eased by trade and reciprocity systems and the population's time spent out-of-doors and in the sunlight, such as when hunting and collecting foodstuffs, would have likely protected the population from experiencing Vitamin D deficiency.

The Wharram Percy population was recovered during excavations at the deserted village, Wharram Percy, in Yorkshire, England, and date mainly to the eleventh to sixteenth centuries AD, or the medieval period (Mays 1996). A medieval society comprised of primarily pre-mechanized agriculture peasants, this population would have produced their own food for consumption, with both winter, e.g. wheat and rye, and spring and summer crops, e.g. barley, oats, potatoes, and legumes (Handlin 1973, Hilton 1973, Pirenne 1973). Examples of additional food resources that were available to the population include nuts, berries, roots, fruits and vegetables, such as apples, pears, cherries, cabbage, lettuce, leeks, spinach, and wild and domesticated animals, including rabbits, hare, cattle, pigs, sheep, goats, and chickens (Handlin 1973, Hilton 1973, Pirenne 1973, Gies et al. 1990). As with the Ohlone, there is ample archaeologic and historic evidence of social stratification within medieval populations, however, unlike the Ohlone, this did lead to an unequal distribution of food resources amongst the citizens (Hilton 1973, Gies et al. 1990).

Medieval European societies were socially stratified, with an hierarchy that included lords, church men, rich and average peasants (both working plots on the lords' lands), craftsmen, such as metallurgists, potters, carpenters, thatchers, tilers, ploughmen, etc., and day laborers (Hilton 1973, Gies et al. 1990). Each peasant family had to produce food, which included both crop and animal foodstuffs, to reimburse the lord for the use of his land, for their own consumption, as well as to create a surplus to buy additional incidentals for themselves, e.g. salt, farm equipment repairs, etc. (Handlin 1973). Poor peasant families often had to rely on work as day laborers to survive (Gies et al. 1990). To illustrate the differences between the diets of various social strata, individuals of higher status, such as the lords and abbots who lived within manor sites and monasteries rather than villages, had diets that could include larks, ducks, boar, geese, bacon, beef, cheese, beans, butter, and eggs, and their servants' diets, while not as rich, could consist of bacon, cheese, beans, butter, and large amounts of grain products (Hilton 1973, Gies et al. 1990). In comparison, the diet of the average peasant family consisted primarily of grain products, such as bread and porridge, or pottage, with small quantities of bacon or peas added when available for protein, and occasional supplies of milk, cheese, butter, and eggs from the family cow, ewe, and chicken (Gies et al. 1990). According to Gies and associates (1990), diets of medieval peasants contained insufficient levels of lipids (fat), protein, calcium, and vitamins A, C, and D.

Again, similar to the California Ohlone, medieval English villages also experienced climatic-induced crop failures that would have seriously compromised their supply of food resources. While there is evidence that, in times of need, lords would occasionally pay neighboring villages for surplus food goods, this is of questionable help to the population since, in general, surpluses were rare and food distribution would have been prone to social status inequalities (Pirenne 1973). There is evidence that local weekly markets did exist in medieval England, although they may, again, not have been of substantial value during times of hunger. The local markets did not trade with other, distant populations, populations that may not have experienced the same food production insufficiencies, and they were primarily used by the peasantry to sell their surplus goods in times of plenty, buy basic necessities, and socialize (Handlin 1973, Pirenne 1973). Additionally, the sale and purchase of products may not have been considered normal by the population, but rather may have been used only when people were obligated by necessity (Pirenne 1973). Seasonal fairs that included peddlers from throughout Europe also occurred in medieval England, but would also have been unhelpful during times of agricultural failure since they were primarily restricted to professional traders dealing in cloth, silk, spices, and metal goods (Pirenne 1973).

In summary, the Wharram Percy population lived a life of heavy toil in the fields, with little time for leisure, were unlikely to experience Vitamin D deficiency as a result of their daily exposure to sunlight while working in the fields, and also had a diet sufficient in calcium as deduced from geological tests and archaeological artifacts found at the site (Mays 1998). They did, however, experience possibly frequent bouts of food resource insufficiencies, a health stress which did not appear to have been eased to any degree by existent trade and reciprocity systems.

Study Design

To study the development and expression of osteoporosis, the osteoporosis rates, or cortical indices, in 62 members of a California Native American hunter-gatherer population, CA-ALA-329, were measured and compared with 126 records from a medieval English agricultural community cemetery site, Wharram Percy (See Table 1).

Table 1. Samples for comparison

Region	Subsistence	Study Population
Ca-Ala-329, CA, USA	Hunter-gatherer	62
Wharram Percy, UK	Agricultural	126

Costanoan/Ohlone skeletal remains from CA-ALA-329 are currently housed at San Jose State University in San Jose, California. This population was previously sexed and aged by Jurmain and colleagues (unpublished 1985). Sex was determined by: pelvic and cranial morphology, humeral and femoral head measurements, and size or robusticity of skeletal elements. Age was determined using pubic symphyseal phases from Todd, as published by Bass (1995), epiphyseal union, dental attrition and dental eruption, and the degree of degenerative joint changes, such as osteoarthritis. Of the approximately 280 adult males and females and subadults from this San Francisco Bay Area site, 62 adults were assessed as appropriate for inclusion in this study: older than 18 years, with the right metacarpal present and complete, and no macroscopic indications of postmortem damage seen.

Raw data from Dr. Simon Mays' osteoporosis study (1996), which assessed bone loss using the second metacarpal of adult skeletons from a medieval English site, will be used as a comparison for this study. This pre-mechanized agricultural population was recovered from the church and churchyard of Wharram Percy, a medieval English village, and all burials were dated from the eleventh to the sixteenth centuries AD. The ages of the population range from 18 to 50+ years old, as assessed from mortuary records. This site was chosen as an appropriate comparison to CA-ALA-329, due to its use in previous osteoporosis studies using the same methodology, the ability of researchers to accurately sex and age the collection, and the availability of the raw data, which was generously provided by Dr. Mays for this endeavor. Using the same criteria as listed above for CA-ALA-329, 126 individuals from this site were determined as appropriate for inclusion in this study.

CA-ALA-329 and Wharram Percy were each sorted by sex and grouped into three separate age groups: 18 to 29 years old, 30 to 49 years old, and 50 years and older (Table 2). The use of both sexes, multiple age ranges, and diverse sites is intended to allow an assessment of: 1) the amount of cortical bone loss in each population's male and female subpopulations over time, 2) the rates of cortical bone loss over time between populations as compared between different sexes and ages, and 3) the influence of multiple factors, such as diet, genetics, and activity, on osteoporosis.

Table 2. Sample size by age and sex per site

SEX	AGE	Ca-Ala-329	Wharram Percy
F	18-29	11	14
F	30-49	22	34
F	50+	0	12
M	18-29	5	9
M	30-49	23	34
M	50+	1	23

Data Collection

X-Rays

All adult second metacarpals from CA-ALA-329 were radiographed at the Student Health Center at San Jose State University. Only right elements were used since previous research on second metacarpals was unable to find statistical differences between right and left sides (Ives et al. 2004). Radiographs, as well as a gross examination, were used to exclude elements that showed indications of trauma or disease from this study. The inclusion of elements that have undergone other than average bone apposition and resorption activities may cause either an overestimation or underestimation of normal, age-related cortical bone loss.

Second Metacarpal Measurements

Radiographs were taken of the entire element in the antero-posterior position, with the element laid directly on the film cassette. Standard radiographic film was used with a tube-to-film distance of 100 cm to minimize radiographic magnification. The exposures were made at 2 milliampere-seconds at 50 kilovolts.

An acetate sheet was placed over the radiographs to protect them from damage and, using a Mitutoyo digimatic caliper, the following second metacarpal measurements were taken: total length, midpoint, total width, and medullary width. The measurements were used to calculate the cortical thickness and cortical index for each element. Following Mays (1996), the cortical index measures the percentage of bone width comprised of cortex and, consequently, normalizes for size:

$$\text{Cortical index} = \frac{\text{total bone width} - \text{medullary width}}{\text{total bone width}} \times 100$$

Data Analysis

All data analyses, e.g., histograms, 2-way ANOVA, 3-way ANOVA, and interaction graphs, were performed using SPSS (version 15.0). All data used in this study (age, sex, and CI in each site) were tested for violations of parametric assumptions and were found to be appropriate for parametric testing. Histograms were performed on each site and verified normal distributions in both. Also, Levene statistic test was used to test for homogeneity of variance within the cortical indices of both sites ($P = < 0.05$) and cortical indices were found to be homogeneous ($P = 1.52$).

To investigate cortical index differences between CA-ALA-329 and Wharram Percy, a 3-way ANOVA was performed. To further investigate the interactions of sex and age on cortical indices in each population, a 2-way ANOVA was performed on both CA-ALA-329 and Wharram Percy, individually. Due to the dearth of individuals in the 50+ age category at the CA-ALA-329 site ($n=1$), another 2-way and 3-way ANOVA, analyzing only the 18-29 and 30-49 age categories, were performed. To further explain the significant findings in the age and sex and sex and site interactions (the effects of age and sex and sex and site on the sites' cortical indices), interactive graphs were then created.

VI. RESULTS

CA-ALA-329 was the only site to show significant differences in how the sexes experienced age-related bone loss, and this result was restricted to the age and sex interaction, which is the differential effect of age on the two sexes' cortical index measurements within the population (Table 3). Another two-way ANOVA, analyzing only the 18-29 and 30-49 age categories, was performed and also found significance restricted to the age and sex interaction. The pattern of bone loss for females is contrary to the pattern exhibited by the male subpopulation in the California population (Figure 5). Female cortical indices drastically decrease between the 18-29 to 30-49 age categories, while the male cortical indices increase between the 18-29 to 30-49 age categories.

Table 3. 2-way ANOVA results for CA-ALA-329: interaction of age and sex in expression of cortical indices (n-62).

	Sum of Squares	df	Mean Squai	F	Sig.
Age	38.61	2	19.31	.38	.69
Sex	108.28	1	108.28	2.13	.15
Age * Sex	220.41	1	220.41	4.33	.04
Residual	2904.22	57	50.95		
Total	3620.79	61	59.36		

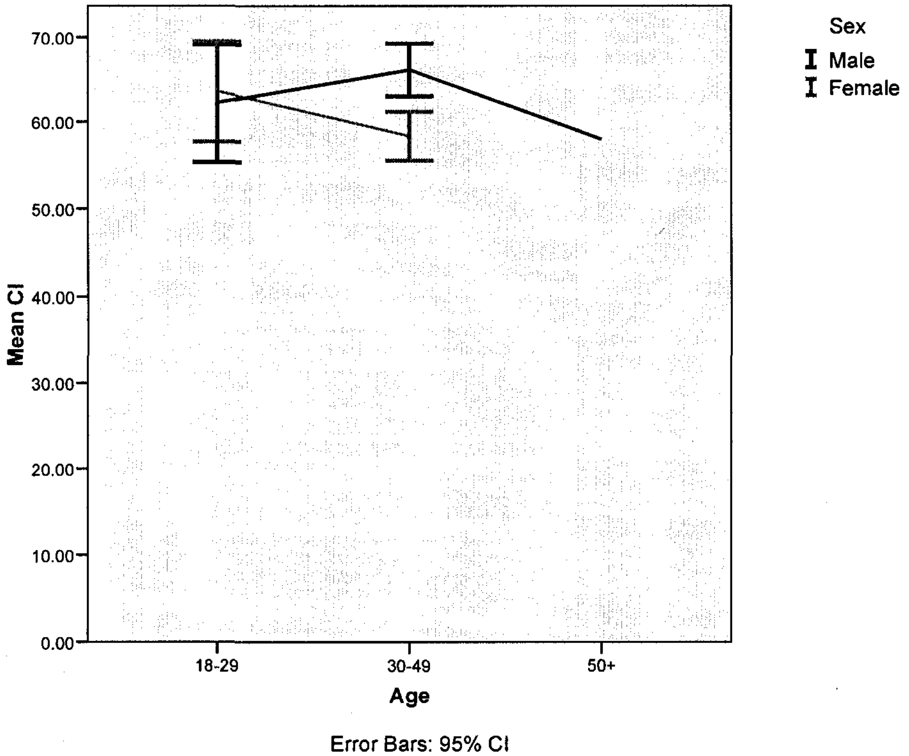


Figure 1. Interaction of age and sex in expression of cortical indices in CA-ALA-329 (n=62)

The 2-way ANOVA found no significant effects of age, sex, or age and sex interactions in the Wharram Percy population (See Table 4).

Table 4. Interaction of age and sex in expression of cortical indices: 2-way ANOVA results for Wharram Percy population (n-126).

	Sum of Square:	df	Mean Squ	F	Sig.
Age	122.20	2	61.10	.90	.41
Sex	155.29	1	155.29	2.28	.13
Age * Sex	261.05	2	130.52	1.92	.15
Residual	8173.32	120	68.11		
Total	8699.67	125	69.60		

The differences among the sites' cortical indices can be seen in their measured ranges (See Table 5). CA-ALA-329 shows an increase in its cortical indices, in all age ranges, when compared to Wharram Percy. While CA-ALA-329 has cortical index means in the high fifties to the mid-sixties, Wharram Percy cortical index means range from the low to high forties (See Figure 6).

Table 5. Cortical index means by site, sex, and age.

Site	Sex	Age	Mean	N	Std. Deviation
CA-ALA-329	Male	18-29	62.25	5	5.56
		30-49	66.14	23	7.20
		50+	57.98	1	.
	Female	18-29	63.62	11	8.79
		30-49	58.36	22	6.43
Wharram Percy	Male	18-29	41.85	9	7.42
		30-49	44.35	34	8.54
		50+	41.59	23	5.64
	Female	18-29	48.86	14	9.68
		30-49	43.44	34	9.08
		50+	43.06	12	7.93

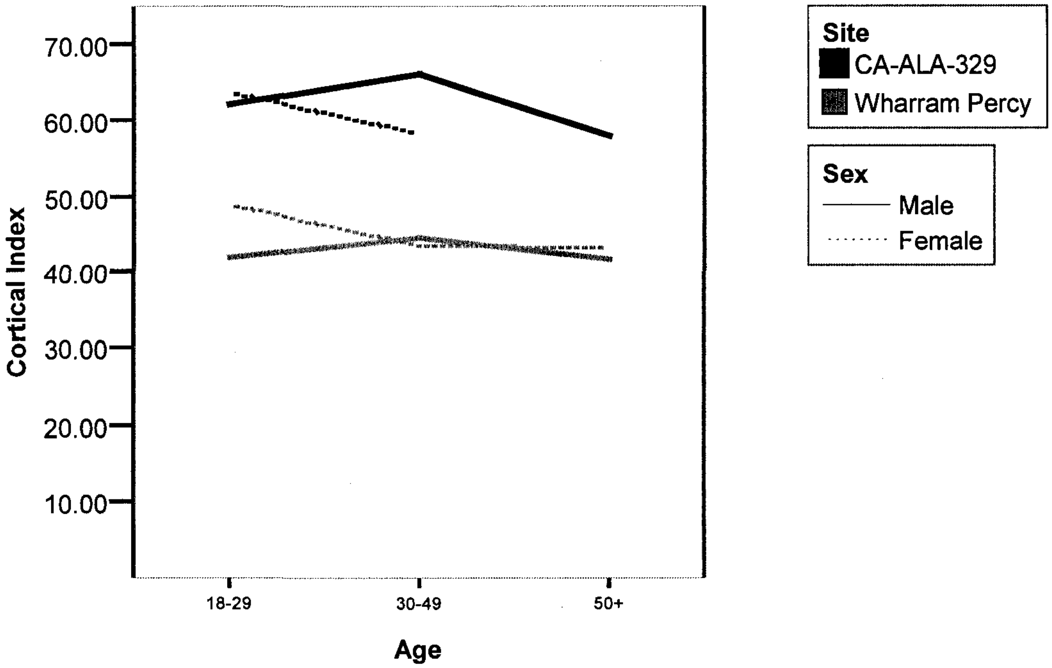


Figure 2. CA-ALA-329 (n=62) and Wharram Percy (n=126) cortical indices by age and sex

Three-way ANOVAs revealed significant differences between sites, as well as in the interactions among age and sex, and sex and site (see Table 6). Due to the minimal number of individuals in the 50+ age category at CA-ALA-329 (n=1), another three-way ANOVA, analyzing only the 18-29 and 30-49 age categories in both sites, was performed and again found significance only between sites and in the interactions of age and sex and sex and site.

Table 6. Interaction of age, sex, and site in expression of cortical indices: Three-way ANOVA results for Ca-Ala-329 and Wharram Percy

			Sum of Squares	df	Mean Square	F	Sig.
CI	Main Effects		8419.95	3	2806.65	41.72	1.83
		Age	29.69	1	29.69	.44	.51
		Sex	.16	1	.16	.00	.96
		Site	8312.96	1	8312.96	123.56	.00
	2-Way Interactions		837.09	3	279.03	4.15	.01
		Age * Sex	469.04	1	469.04	6.97	.01
		Age * Site	3.87	1	3.87	.06	.81
		Sex * Site	251.81	1	251.81	3.74	.05
							.85
	Model		13031.08	7	1861.58	27.67	.00
	Residual		9687.75	144	67.28		
	Total		22718.84	151	150.46		

Females show a steady loss in cortical indices from the youngest to the oldest age ranges (highest cortical indices at the 18-29 age range, with decreases at each subsequent age range), while males show an increase in cortical indices from the 18 to 29 to the 30 to 49 age ranges with a decrease between the 30 to 49 and the 50+ age ranges (see Figure 7).

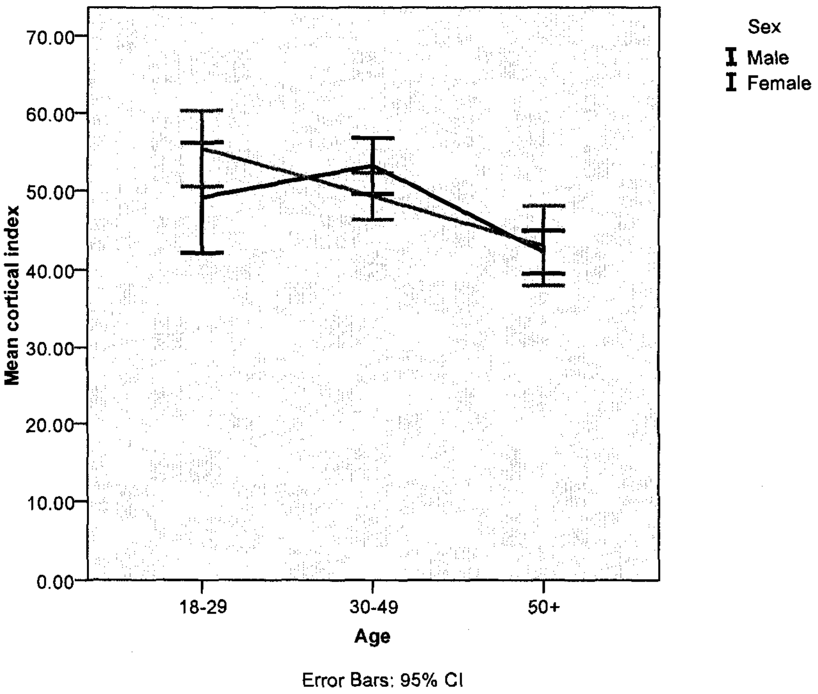
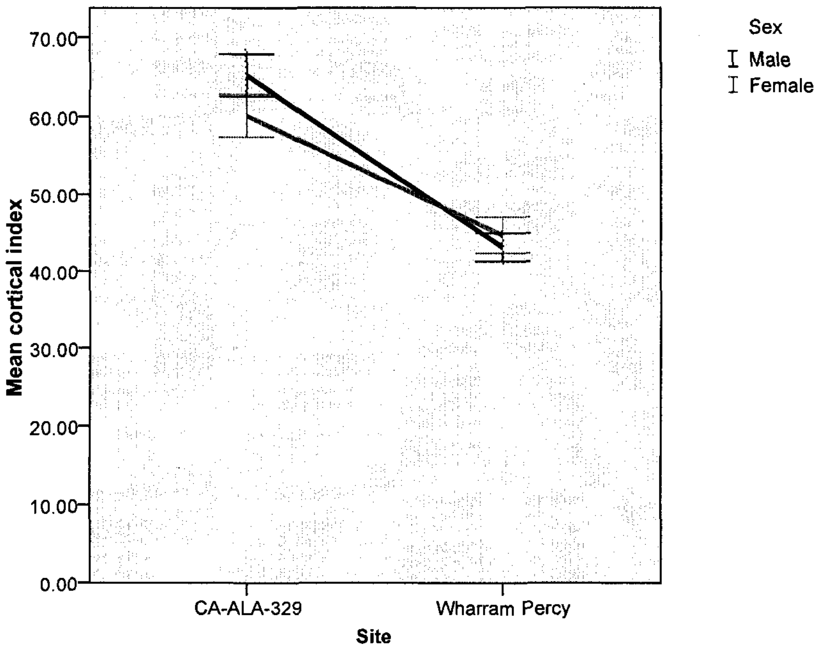


Figure 3. Effects of sex and age on cortical index measurements at both sites

Overall, CA-ALA-329 cortical indices are greater in both sexes than Wharram Percy cortical indices, with a mean in the low- to mid-sixties compared to a mean in the mid-forties, respectively (see Figure 8). Also, while males show the highest means compared to the females in the CA-ALA-329 population, the Wharram Percy males' mean is lower than the population's females' cortical index mean.



Error Bars: 95% CI

Figure 4. Effects of sex and site on cortical index measurements in both sites

VII. DISCUSSION

CA-ALA-329

Prior to comparing the population samples from the two sites, the results from each site were individually studied to determine each population's individual range of cortical bone indices. CA-ALA-329 was the only site to show any significant findings, in the age and sex interaction, a description of the effect that age and sex had on cortical index measurements in this population. Moreover, this population also showed high cortical index ratios for both sexes, reaching levels in the high-fifties to the mid-sixties. At this time, it should be reiterated that the study of this site was accomplished with a small sample size and with only one individual, a male, in the 50+ age category. Of the 126 individuals in CA-ALA-329 that were eligible for this study, 64 had to be removed from the test's sample due to age, e.g. <18 years old at time of death, the absence of the right second metacarpal, the presence of postmortem impacts on the cortical surface of the element, or evidence of antemortem trauma, such as healed or healing fractures. Of the 64 removed, none were in the 50+ age category.

Upon further examination of the site's entire population, not just those individuals included in this study, CA-ALA-329 did not have many individuals in the latter age category in its entirety (n=2; a male who was included in this study and a female who was ineligible for use due to postmortem damage to the right second metacarpal). According to Jurmain (2001), the average age at death for males and females in this population, calculated using only individuals aged over fifteen years old at time of death, is 32.2 and 37.2 years, respectively. Consequently, the lack of individuals in the oldest age category is not surprising and may be responsible for the anomalous ANOVA results for this population: Neither sex nor age variables were found to be significant in the expression of cortical index measurements. Since sex and age are both known to be significant contributors to cortical bone mass measurements in both modern and other archaeological populations (Ericksen 1979, Plato 1982, Burr et al. 1983, Drusini et al. 2000, etc), CA-ALA-329's nonsignificant ANOVA findings concerning sex and age may simply be a byproduct of this study's small sample size, as well as its lack of individuals in the oldest age category, 50+, when changes in cortical indices are often most dramatic.

A graph of the significant sex and age interaction seen in CA-ALA-329 does show that females and males experienced contrary cortical index patterns over time. In youth (18-29 years old), females measured their highest cortical index measurements, which then decreased over time (30-49 years old). The site's males, on the other hand, initially showed similar cortical index means to females (18-29 years old) that then decreased over time (30-49 years old), before decreasing (50+ years old; n=1) to measurements similar to the cortical index means measured in youth. While the sample size may have adversely affected the ability of this study to thoroughly analyze cortical bone loss in CA-ALA-329, the general pattern of sex- and age-related bone loss measured does appear to conform to the findings of other, more robust studies: Females have more cortical bone in youth, then begin losing cortical bone earlier and eventually lose more over time than males (Ericksen 1979, Plato 1982, Burr et al. 1983, Drusini et al. 2000, etc.).

As stated earlier, the CA-ALA-329 individuals included in this study date from within the Middle Period to Late Period Phase 2, or 550 AD to ca. 1700 AD (Leventhal 1993, Groza 2002). Archaeological research on San Francisco Bay Area Native American populations found that groups dating from the Middle to the Late Period were hunter-gatherers that were expert at subsisting on forager-adapted and collector strategies that exploited both coastal and bayshore ecosystems (Hylkema 1991). Additional studies found that the Ohlone were adept at exploiting their environment and lived well on a diet of shellfish, fish, sea and land mammals, acorns, seeds, berries, and other indigenous foods (Pierce 1982). The lifestyle of the Ohlone would have been physically demanding while hunting, gathering, and preparing food, with time of leisure experienced as well. Also, their time spent out of doors and in the sunlight, such as when hunting and collecting foodstuffs, would have likely protected the population from experiencing Vitamin D deficiency.

These data indicate that diet and exercise levels in this population were appropriate for good bone growth. Additional support for this conclusion may also be seen in a study of CA-ALA-329 and skeletal growth in its pre-pubescent subpopulation (Elliott 1992). According to Elliott (1992), long bone widths increased in proportion with linear growth, indicating little stress on this population's growth patterns in youth, when peak bone mass is achieved. The stability of the population's health status has been supported by research by Nechayev (2007), which found no evidence that CA-ALA-329 experienced health care declines from the Middle to the Late Periods, and further hypothesized that the population successfully adapted to changes in environmental and cultural changes over time.

In summary, the overall results for CA-ALA-329 suggest that this was a healthy population and that its hunter-gatherer subsistence practices, myriad and plentiful food resources, and systems of resource reciprocity may have allowed appropriate peak bone mass accrual during youth. This peak bone mass accrual allowed the population's adults to maintain bone mass ratios between the high-fifties and mid-sixties throughout life and may be responsible for the similarity to the typical sex- and age-related bone loss patterns seen in modern populations.

Wharram Percy

The fact that the 2-way ANOVA from Wharram Percy found no significant sex differences in osteoporosis primarily supports previous research using second metacarpal radiogrammetry on this population (Mays 1996). However, it should be noted that Mays was able to find significance between the different female age categories, 18-29 and 50+, after removing the 30-49 age category. Following Mays, a one-way ANOVA was also performed, subtracting the 30-49 age category from the sample size to compare the 18-29 and 50+ categories and, again, no significant results were found. As with CA-ALA-329, the population's sample size in this study may be responsible for this inconsistency. Due to incomplete records, e.g. indeterminate sex or age status or a lack of cortical index measurements on the data sheets, only 126 individuals from this population were able to be included in this study. This decrease in the overall sample size, when compared to Mays' (n=138), may be responsible for the slight variation in the results.

The pattern of sex- and age-related cortical bone loss in Wharram Percy shows no significant differences in the young male and female cortical indices (18-29 years) and similar indices are also seen in the older age categories, 30-49 and 50+; the cortical index ratios measured for both sexes were in the low- to the high-forties throughout life. Contrary to the usual pattern of female cortical bone loss (female measurements decrease more with age than male), the uniformity seen in this population's males and females from youth and into old age is atypical. Previous research on this population has suggested that this is indicative of the protection experienced by females due to this population's particular lifestyle; a lifestyle that had high levels of activity and reproductive behaviors, such as increased parity and prolonged lactation, protected the Wharram Percy females from experiencing an increased severity in age-related bone loss (Agarwal et al. 2004). When considering additional research, however, that indicates that pregnancy and lactation actually create bone loss that is not recovered until months postweaning and increased parity may adversely affect bone recovery (Kent et al. 1990, Sowers et al. 1995, Affinito et al. 1996, Lopez et al. 1996), it is possible that the reason for the anomalous results seen in Wharram Percy's female population may be connected to the population's anomalous male results. While males usually measure increased rates of bone mass that is retained longer than females, the Wharram Percy males and females maintain similar, stable measurements of cortical bone mass throughout each age category.

To further investigate the causes for this uniformity, the lifestyle of the population was studied. The medieval peasants at Wharram Percy had a physically demanding, rural lifestyle, were unlikely to experience Vitamin D deficiency due to their time spent working in the fields, and had a diet sufficient in calcium as deduced from geological tests and archaeological artifacts found at the site (Mays 1998). It is possible, however, that while the population spent hours per day outside, the cloudy conditions experienced at Wharram Percy (bright sunshine being experienced almost throughout the year at CA-ALA-329) may be a contributor to the low cortical indices measured within the population, even without causing population-wide Vitamin D deficiency. A meta-analysis on the effects of cloud cover on UV radiation found that, while UV radiation is lowered by 15-45% by cloud cover, a significant number of studies reported an enhancement of UV radiation due to the presence of clouds and the authors recommended further research to clarify these effects (Calbo et al. 2005). According to Webb and colleagues (1988), however, the amount of ultraviolet rays measured specifically in Nordic countries during the winter months was below the level required for Vitamin D synthesis, which would support this theory. Holick's research in 2004 contributes to this topic by indicating that during the spring, summer, and fall months, the body stores excess Vitamin D in body fat, to be accessed and used during the winter months. It is possible, as well, that due to the previously-stated research that indicated chronic insufficiencies of fat intake for medieval English populations, that they may have been unable to store an adequate amount of excess Vitamin D created during the spring, summer, and fall, for access and use during the English winter months. Due to the above-listed, as well as significantly higher cortical indices measured in the modern English population compared to the medieval English Wharram Percy population, diet appears to be the most significant factor in Wharram Percy's low cortical indices.

Periods of famine and possible gastrointestinal afflictions, which could have been caused by the population's known poor hygiene and constant proximity to animals, may have adversely affected cortical bone mass in this population through periodic malnourishment and negatively impacted nutrient absorption (McEwan et al. 2005). Examinations of the site's subadult collection indicate that problems attaining peak bone mass may also be responsible for both the low cortical bone ratios measured in the population and the similarities found between the site's age-related male and female bone loss. According to McEwan and associates (2005), while Wharram Percy adult stature was approximately 97% of modern adults, the subadults in the population were determined to be approximately four years behind modern populations in linear growth; a growth rate that would have detrimentally impacted cortical bone mass. As mentioned earlier, peak bone mass is achieved in youth and entirely predicated upon good nutrition and exercise (Nelson et al. 2003). Since the severity of sex- and age-related bone loss is affected by the peak bone mass attained, it is possible that the consistently low cortical bone measurements found in this population is an effect of their inability to achieve peak bone mass in youth.

These findings suggest that Wharram Percy subadults experienced negative impacts on their diets or levels of physical activity, which, in turn, negatively impacted cortical bone mass. Since even the subadults in medieval populations are known to have led physically active lifestyles, it is more likely that the known dietary fluctuations and possible diseases experienced by the Wharram Percy population may be most responsible for their inability to achieve peak bone mass and, in adulthood, to exhibit corresponding male and female cortical bone measurements throughout all age categories.

The overall results for Wharram Percy indicate that this population may have experienced deleterious dietary- and possibly disease-related impacts on peak bone mass accrual during youth, which created the consistently low bone mass ratios and the anomalous stability of the bone mass ratios throughout life.

Comparison of CA-ALA-329 and Wharram Percy

When comparing sex- and age-related cortical bone loss in CA-ALA-329 and Wharram Percy, there are many factors that clarify both the similarities and the differences seen between the populations. While neither site individually shows significant sex- or age-related results, the 3-way ANOVA shows that both sites' sex-related bone loss patterns are similar: females have higher cortical index measurements than males in the 18-29 age category, but by the 30-49 age category, the roles have reversed and males have higher cortical index measurements than females. The lack of individuals in the 50+ age category in CA-ALA-329 makes it impossible to determine how the pattern of cortical bone loss in that population compares to Wharram Percy in the oldest age range, when the majority of bone loss is usually measured. With these data, however, it is possible to say that the pattern of bone loss in both populations does mirror that of other archaeological and modern populations studied: young females have more cortical bone compared to young males, which reverses as the populations age, with older males having more cortical bone and losing less over time than older females.

Another significant finding of this study involves the differences found in the cortical ratios measured between the two populations. Both the males and females at Wharram Percy measured significantly lower cortical bone ratios throughout life than their counterparts in the CA-ALA-329 population. As previously mentioned, the Wharram Percy population had uniform cortical index ratio means, low- to high-forties, measured for both sexes throughout the population's adult life. This finding does not appear to have had a genetic influence since comparisons between both adult and subadult Wharram Percy populations and modern European adult and subadult populations found that Wharram Percy cortical ratios were consistently and significantly lower than modern (Mays 1996, McEwan et al. 2005). These results also indicate that CA-ALA-329 and modern populations are more similar in cortical index measurements than either is to the medieval Wharram Percy population.

While CA-ALA-329 and Wharram Percy may be showing significant heterogeneity in terms of the groups' cortical bone ratios, this may be due to differences in diet (hunter-gatherer versus medieval agriculture), social mechanisms, such as systems of resource reciprocity, some genetic impacts, or differences in levels of activity or parity. Even though these factors may influence bone mass, however, the results of this study do conform to those reported in clinical research: accrual of peak bone mass in youth is crucial to bone mass levels and their retention in adulthood. Wharram Percy subadults had problems achieving peak bone mass as seen in the linear growth studies conducted. This initial cortical deficit adversely affected their bone mass ratios throughout life, while at CA-ALA-329 subadults were able to achieve peak bone mass as seen in similar linear research and the measured cortical bone mass ratios that are similar to modern levels. This result may also indicate that physical activity alone may not be able to create or aid in bone mass recovery when the diet has been impacted and bone growth adversely affected. The medieval Wharram Percy population had a heavy workload, perhaps even greater than that of the hunter-gatherer Ohlone, but it does not appear as if it was able to help the English population in achieving or retaining peak bone mass.

Overall, these results do indicate that the population at CA-ALA-329 was a generally healthier population than that found at Wharram Percy. While research that specifically provides a clear measure of overall health status of CA-ALA-329 has not yet been performed, these results do indicate that the semi-sedentary hunter-gatherer lifestyle of the Ohlone afforded the population some protection from cortical bone loss, with significantly greater bone mass, even in its older females, compared to the Wharram Percy medieval peasant population.

VIII. CONCLUSION

Misconceptions and lack of knowledge about indigenous peoples' health and well-being has sometimes contributed to modern lack of concern for protection of Native American sites. Protecting this heritage through the environmental impact process in California has proven challenging, and far less successful than analogous efforts in Europe and the British Isles. This research strongly suggests that much remains to be learned about human health and sustainable lifestyles from studying native Ohlone culture. Strong investment in cultural resource analysis and protection is critical to that endeavor. Specifically, additional studies on osteoporosis should be conducted on this and other San Francisco Bay Area populations to more fully explore the health status of these groups, as well as to verify the results of this study. While problems with sample size made a complete assessment of bone loss in this population difficult, the use of other, weight bearing or trabecular elements should be attempted. Also, the fine-tuning of additional modern techniques, such as dual energy absorptiometry, or DEXA, that are noninvasive and accurate on archaeological remains would be helpful in this endeavor.

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APPENDIX A

2nd Metacarpal Recording form – to accompany radiographs

Date:______________________________Site Number:__________________
Burial/Skeleton Number: _____________Side: _________________________
Sex:________________________________Age:__________________________

Metacarpal 2 Pathologies:

____
____
____

Metacarpal 2 Traumas:

____
____
____

Source to film:______ Object center to film:___________

Measurements on Radiographs:

Total bone length: ___________________________

Midpoint/Measurement point:__________________

Total bone width:____________________________

Medullary width:____________________________

Derived Values:

CT: ___________________________________

CI:____________________________________

APPENDIX B

Cortical Index Measurements by Site, Burial Number, Sex, and Age

WHARRAM PERCY

B#	SEX	AGE	CI
2	M	18-29	39.56
3	M	50+	37.19
3B	M	30-49	43.52
4	M	30-49	47.12
5	M	50+	47.62
6	F	30-49	37.14
9	M	30-49	32.35
11	M	18-29	29.44
11B	M	30-49	48.07
12	M	30-49	60.39
13	F	30-49	34.00
13B	M	50+	38.65
15	M	50+	30.73
15B	M	50+	48.56
16	F	18-29	33.52
16B	F	30-49	37.65
16B	F	18-29	50.32
17	M	30-49	37.38
18	M	30-49	31.46
18B	F	18-29	54.25
19	M	30-49	41.99
20	M	30-49	46.23
20B	M	30-49	56.57
21	M	50+	51.69
22	F	50+	41.89
23	F	50+	38.06
26	F	30-49	52.50
26B	F	50+	44.91
29	F	18-29	53.25
29B	F	50+	41.06
30	F	18-29	55.17
31	F	30-49	30.72
33	M	50+	42.39
33B	F	30-49	25.93
36	F	18-29	55.70
36B	F	30-49	37.84

CA-ALA-329

B#	SEX	AGE	CI
1	M	30-49	71.66
2	F	30-49	56.97
6	F	18-29	80.92
14	M	30-49	77.54
15	F	30-49	63.89
16	M	30-49	73.56
20	F	18-29	63.50
21	M	30-49	68.45
23	M	30-49	73.08
52	F	30-49	50.52
53	M	18-29	56.36
54	F	30-49	51.21
58	M	30-49	49.38
60	M	50+	57.98
62	F	30-49	53.86
64	M	30-49	62.96
71	M	30-49	54.96
74	F	30-49	61.89
77	F	18-29	49.85
86	F	30-49	61.52
88	F	30-49	60.08
93	F	30-49	53.19
94	M	18-29	64.80
96	F	30-49	55.34
100	M	30-49	67.03
106	M	30-49	74.23
108	F	30-49	60.35
109	M	30-49	54.82
111	F	30-49	71.32
118	F	30-49	57.44
122	F	30-49	49.12
125	M	30-49	60.23
133	F	30-49	51.85
134	F	30-49	68.52
143	F	18-29	68.72
158	F	30-49	69.97

APPENDIX B (continued)

Cortical Index Measurements by Site, Burial Number, Sex, and Age

WHARRAM PERCY

B#	SEX	AGE	CI
37	M	50+	44.91
40	F	50+	48.35
41	M	30-49	53.33
41B	F	30-49	59.74
43	M	18-29	54.78
43	F	30-49	43.56
44	M	30-49	38.01
45	F	50+	29.89
45B	M	30-49	41.29
46	F	50+	35.71
46B	M	50+	45.25
47	F	30-49	47.22
49	F	50+	43.84
50	F	30-49	43.48
51	M	30-49	55.50
52	M	50+	45.60
53	F	50+	50.63
56	F	30-49	39.88
59	M	50+	47.31
59B	F	30-49	36.36
61	F	30-49	44.77
66	F	18-29	40.13
68	M	30-49	47.52
70	F	30-49	42.94
71	F	30-49	68.83
78	M	18-29	50.00
80	M	30-49	60.00
87	F	30-49	43.23
88	F	30-49	51.22
94	F	30-49	35.47
99	F	30-49	40.64
102	M	50+	32.74
104	M	30-49	42.51
109	F	30-49	57.34
112	M	50+	43.53
115	M	30-49	50.35

CA-ALA-329

B#	SEX	AGE	CI
167	F	30-49	52.18
173	M	30-49	68.92
177	M	30-49	68.14
180	M	30-49	64.90
182	F	18-29	58.87
188	F	30-49	61.97
205	M	18-29	59.80
216	M	30-49	65.07
219	F	18-29	56.67
223	M	18-29	59.67
225	M	30-49	59.60
231	F	18-29	67.34
235	F	18-29	56.14
242	M	30-49	63.42
244	M	30-49	65.05
245	M	30-49	76.22
252	M	30-49	70.42
256	M	30-49	61.26
257	F	18-29	68.57
260	M	18-29	70.61
261	F	18-29	71.33
263	F	18-29	57.87
266	F	30-49	57.47
273	M	30-49	70.25
278	F	30-49	52.64
282	F	30-49	62.52

APPENDIX B (continued)

Cortical Index Measurements by Site, Burial Number, Sex, and Age

WHARRAM PERCY

B#	SEX	AGE	CI
117	**M**	**50+**	**43.22**
123	**F**	**30-49**	**43.23**
124	**F**	**50+**	**34.04**
131	**M**	**50+**	**36.50**
137	**M**	**50+**	**41.46**
138	**M**	**30-49**	**40.80**
146	**M**	**30-49**	**31.10**
149	**F**	**30-49**	**45.29**
164	**M**	**30-49**	**28.57**
167	**F**	**30-49**	**42.31**
171	**M**	**30-49**	**32.70**
176	**M**	**18-29**	**38.00**
173	**F**	**30-49**	**39.74**
181	**M**	**50+**	**43.46**
184	**F**	**30-49**	**61.02**
195	**M**	**18-29**	**45.83**
197	**M**	**50+**	**35.53**
199	**M**	**50+**	**31.92**
203	**F**	**30-49**	**27.78**
215	**F**	**18-29**	**66.67**
218	**M**	**50+**	**47.80**
233	**M**	**30-49**	**36.77**
254	**F**	**18-29**	**42.46**
265	**M**	**30-49**	**46.93**
296	**M**	**30-49**	**58.66**
297	**M**	**50+**	**40.22**
303	**M**	**30-49**	**52.17**
310	**M**	**30-49**	**44.79**
377	**F**	**50+**	**57.05**
379	**M**	**50+**	**38.92**
385	F	30-49	41.06
398	**M**	**18-29**	**40.11**
406	**M**	**30-49**	**35.95**
416	**F**	**30-49**	**44.10**
427	**F**	**30-49**	**46.63**
436	**M**	**30-49**	**41.75**

APPENDIX B (continued)

Cortical Index Measurements by Site, Burial Number, Sex, and Age

WHARRAM PERCY

B#	SEX	AGE	CI
443	F	18-29	38.12
462	M	18-29	38.38
478	F	18-29	38.04
482	M	50+	41.31
516	M	30-49	50.61
571	F	30-49	32.24
587	M	30-49	44.20
604	M	18-29	40.56
607	M	30-49	39.90
628	F	30-49	42.53
635	F	18-29	53.80
652	F	30-49	51.35
670	F	30-49	54.11
692	F	50+	51.23
694	M	30-49	47.78
746	M	30-49	41.62
747	F	18-29	42.86
760	F	18-29	59.72