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Full Length Research Paper

Sex and the agricultural transition: Dental health of early farming females

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This research considers the long-term relationship between women's oral health and the transition to agriculture by examining dental caries and tooth loss in a prehistoric skeletal sample. Archaeological research indicates that women in many early agricultural communities experienced more severe dental pathology than male counterparts. Dentition was examined in an Early Agricultural skeletal sample from the La Playa site in Sonora, Mexico. Frequencies of caries and antemortem tooth loss (AMTL) were analyzed to test the hypothesis that in an early agricultural population undergoing major cultural changes, females experienced increased oral disease burden due to changes in the oral microenvironment resulting from greater reproductive stress. Adult females and males had similar caries rates, however, there were significant sex-differences in AMTL (p = 0.02). Comparisons across age groups indicate that La Playa women had substantial increases in AMTL, losing considerably more teeth than men. These findings, in light of dental research on oral health and pregnancy, provide an important temporal component to understanding the evolution and history of oral health and agriculture. The results suggest a dynamic process in the development of oral health trends as a function of the shift to agriculture and the burden of increased childbearing that females undertook during this transition.

Key words: Oral health, tooth loss, pregnancy, agriculture.

INTRODUCTION

This investigation considers changes associated with the transition to agricultural subsistence and effects to women's oral health, using a prehistoric skeletal sample from the archaeological site of La Playa (SON F:10:3), Sonora, Mexico. The Early Agricultural residents of La Playa were forager-farmers, occupying the site between 1600 B.C. to A.D. 200. Analyses focus on sex-variation in dental pathology rates to explore the health impact that the subsistence transition had in the lives of La Playa women.

Although the prehistoric transition to agriculture has been well studied for many regions of the world, the associated effects to maternal health have been frequently overlooked (Cohen and Armelagos, 1984; Steckel et al., 2002). A massive population expansion associated with the advent of agriculture, known as the 'Neolithic demographic transition' (Ndt), has been consi-dered a consequence of rising fertility rates that occurred in association with a more sedentary farming lifestyle and decreased birth intervals (Armelagos et al., 1991; Bandy, 2005; Bar- Yosef and Meadow, 1995; Boquet-Appel and Naji, 2006; Cowan and Watson, 1992; Eshed et al., 2004; Roth, 1985). Thus, the cultural process of amplified reliance on agricultural subsistence would have imposed biological stresses (that is, pregnancy, parturition, lactation) specific to Neolithic females (Bridges, 1989; Martin, 2000).

It has long been recognized that female reproductive biology places additional demands on women's bodies

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and oral health is not isolated from these effects. The American Academy of Periodontology (2009), states that women have greater risk of developing oral health problems than men due to physiological and hormonal changes that occur during their lifespan. The growing awareness that female reproductive physiology impacts oral health adds to a greater understanding of the complex nature of human health. Findings reported here focus on the evolutionary history in support of the argument that physiological changes during a woman's reproductive years alter the oral environment and impact dental health. These data add much-needed temporal and spatial components to understanding trends in oral health by looking at populations that lived in the past during a period of rapid cultural change.

Oral health in early farming populations

The foraging- to-farming transition occurring over the last 10,000 years has brought far-reaching and often negative consequences to human health (Cohen and Armelagos, 1984; Larsen, 1987, 1995; Steckel et al., 2002; Steckel and Rose, 2002). In the New World, agricultural populations generally exhibit higher rates of dental pathologies compared with pre-agricultural groups (Bridges, 1989; Larsen, 1987, 1995; Turner, 1979), while in Old World populations, an unambiguous association between the onset of Neolithic agriculture and rising rates for dental caries has not been found (Hillson, 1979; Eshed et al., 2006). A wide-range of studies comparing dental pathology rates for pre-agricultural males and females have shown caries occurrence to be relatively equal. With growing dependence on agricultural subsistence, however, the oral health of women was found to decline more than that of men (Bridges, 1989; Larsen, 1981, 1995; Lukacs, 1996, 2008; Lukacs and Largaespada, 2006; Steckel et al., 2002; Watson et al., 2009). Nevertheless, Lukacs (1996) cautions that higher dental pathology in agricultural females is not a universally recognized pattern, indicating the need to consider local conditions. Conventional explanations for male-female differences in dental pathology have largely focused on cultural behaviors. There is an assumption that women tend to "nibble" on carbohydrates more frequently while preparing foods (Larsen, 1987, 1995), but this explanation assumes a collective female behavior and food preference. More importantly, it fails to consider sex-specific physiological effects to oral health.

Although there have been numerous dental health indicators investigated in archaeological remains, this study focuses on dental caries and AMTL, as these provide quantifiable measures of dental health known to be associated with varying subsistence practices (Larsen, 1995; Turner, 1979). The increase in caries observed in agricultural populations has been associated with diets that are high in sticky, processed carbohydrates (e.g., maize), which are more likely to adhere to dental surfaces (Hillson, 1979, 2001; Larsen, 1987, 1995). Additionally, the associated reduction in occlusal wear commonly seen in the dentition of early agricultural groups, compared to hunter-gatherers (Deter, 2009; Smith, 1984), would have allowed for bacterial colonies to proliferate in plaque biofilm, leading to increased incidence of dental disease.

According to Larsen (1995), a pattern of increased AMTL typically corresponds with the escalating caries rates recorded for agriculturalists. Antemortem tooth loss, which is highly age related, provides an indication of overall health as it relates to declining oral conditions and the progression of dental disease. Factors that contribute to the loss of teeth during life include caries, periodontal disease, trauma, dental attrition and factitial cultural practices (Hillson, 2001; Turner, 1979). External mitigating factors that can affect the occurrence of caries and tooth loss in a population include mineral content (such as, fluoride) present in the soil or water supply and the amount of dietary grit that can result in dental attrition and abrasion. Additional factors that can contribute to tooth loss in a population include cultural behaviors, such as using teeth as tools (e.g., processing fibers through the teeth). Watson (2005) observed limited evidence for this in the La Playa dental sample, with nine individuals (6 females, 2 males, 1 sex undetermined) exhibiting signs of grooving on their teeth, but the small sample size limited any cultural interpretation for the population (Watson, 2005).

Farming, fertility and females

Fertility is affected by the interaction of numerous factors and varies by subsistence strategy as well as by individual (Ellison, 2003, 2008). Since the early Holocene, wherever groups adopted agriculture, population expansion has occurred (Larson, 1995; Bocquet-Appel and Bar-Yosef, 2008). Research findings imply a relationship between an increasingly sedentary lifestyle, greater carbohydrate consumption, and a rise in fertility rates. Armelagos and colleagues (1991) propose that birth intervals decreased concomitant with agriculture as groups became more sedentary. In the Levant, Eshed and colleagues (2004) suggest that the Neolithic brought an earlier onset of menarche leading to an increased number of births. The authors discuss the implications of their findings for Neolithic women who, contrary to earlier Natufian women, had a lower mean age at death than their male counterparts (Eshed et al., 2004). The authors argue that the lower age at death for Neolithic females likely was due to more frequent childbirth and associated risks.

In a cross-cultural analysis of subsistence mode and fertility rates by Sellen and Mace (1997), an increase in fecundity was seen in association with greater dependence on agricultural foods. The researchers suggest three mechanisms may be involved: more predictable food supply, changes to activity levels, and readily available foods for weaning (that is, cereal grains). Breastfeeding practices are known to influence fertility rates, as lactation suppresses ovulation. In foraging societies that are highly mobile, women breastfeed for long intervals, often feeding on demand for several years (Ellison, 2003; Pennington, 1992; Schultz and Lavenda, 2004; Sellen and Mace, 1997). It is believed that the longer intervals between births maintain energy balance for women of childbearing age and may have evolved as a function of physiological response to energy demands (Ellison, 2003; Schultz and Lavenda, 2004). These studies show that female reproductive processes adjust in response to energy availability and are therefore affected by varying subsistence regimes (Ellison, 2008).

Clinical dental research

Clinical studies have shown that physiological changes during pregnancy can affect maternal oral health in critical ways (Bobetsis et al., 2006; Boggess and Edelstein, 2006; Burakoff, 2003; Krejci and Bissada, 2002; Laine, 2002; Lieff et al., 2004; Offenbacher et al., 1996, 1998; Silk et al., 2008). During the second trimester of pregnancy, the placenta assumes regulation of hormone production and hormonal levels in bodily tissues rise with an attendant vascularization (Laine, 2002). The associated vascularization of gingival tissues can result in an inflammatory response (known as, pregnancy gingivitis) (Laine 2002), as the expansion of gingival blood vessels makes tissues more permeable and sensitive to microbial irritants, increasing susceptibility to oral disease (Laine, 2002; Neville et al., 2009; Silk et al., 2008). Moreover, gingival edema from fluid retention can lead to loosening and extrusion of teeth from alveolus. In addition to the effects to gingival tissues, rising progesterone levels reduce salivary alkalinity, diminishing the ability to neutralize acids (Laine, 2002). With an acidic oral microenvironment, dental surfaces are more vulnerable to demineralization and decay and cariogenic microbes proliferate. Studies have shown increased salivary levels of a highly cariogenic bacteria, *Streptococcus mutans,* in the mouths of pregnant compared to non-pregnant women (Laine, 2002) . The increased presence of cariogenic microbes can facilitate cariogenesis (Laine, 2002).

Although the epidemiology of dental disease is highly complex, clinical research continues to clarify the dynamic connection between oral and bodily health (AAP, 2009). Recent studies demonstrate the importance of maternal oral hygiene in the health of the mother and her fetus (Halpern, 2008; Laine, 2002; Lieff et al., 2004; Offenbacher et al., 1996, 1998; Silk et al., 2008). The October 2006 JADA presented research (Bobetsis et al., 2006) implicating oral infectious disease in systemic bacterial invasion. Findings indicate that women with mature biofilm are at increased risk for complications during pregnancy as established microbial clusters become increasingly pathogenic. Bacteria that invade systemically can breach the placental barrier and may provoke an inflammatory response in the fetus (Bobetsis et al., 2006). Additionally, Boggess and Edelstein (2006) found transmission of streptococcal bacteria from mother to child via saliva, thus predisposing children to oral infectious disease. In both of these studies, low socioeconomic status was a contributing factor to disease prevalence and severity. These findings are of particular importance for women in underserved communities, as they may be especially vulnerable to negative health outcomes (WHO, 2008).

MATERIALS AND METHODS

The dental sample from 142 skeletons from the archaeological site of La Playa, Mexico was evaluated to determine whether significant sex-differences in caries and AMTL rates could be identified. The La Playa skeletal collection represents the largest and earliest burial collection in the American Desert West and was chosen for this study as a representative sample of the Early Agricultural Period (1600 BC - AD 200) in the Sonoran Desert. Radiocarbon dates from excavated burials provide a range between 3720 $\pm$ 320 to 1530 $\pm$ 40 BP (3100 B.C.-A.D. 620 cal.), making the La Playa burial sample well suited for analyses into the effects of the transition to agriculture (Watson, 2005). In general, skeletal remains from the sample exhibit signs of adequate nutrition, low incidence of infectious disease and teeth tend to be well preserved and in good condition (Watson et al., 2006).

The site of La Playa lies in the northeast sector of the Sonoran Desert and is considered part of the southern Arizona archaeological sequence (Figure 1). Archaeological investigations at the site have recovered and preserved vast assemblages of artifacts associated with the Early Agricultural period (Carpenter and Villalpando, 2002; Watson, 2005). The Early Agricultural period is characterized by larger settlement size, growing populations and increased reliance on domesticated cultigens (e.g., *Zea mays*) (Huckell, 1995). At La Playa, the Early Agricultural period is marked by evidence for growing populations and increased local investment seen with ubiquitous groundstone and maize remains, extensive site use, numerous burials and detritus from a shell industry dating to this period (Watson, 2005).

The methods used in this study are based on the premise that the dentition of archaeological populations can provide insights into prehistoric behavior, diet, economy, environment and health (Scott and Turner, 1988). Data collection followed Standards for Data Collection from Human Skeletal Remains developed by Buikstra and Ubelaker (1994). Data collection included macroscopic assessment for the presence or absence of dental pathologies. Carious lesions were recorded only where decay of the tooth surface(s) or root(s) was observed (Figure 2). When necessary to aid in caries identification, a magnifying glass and dental probe were utilized. The following were recorded for each carious lesion observed: the location of the tooth in the dental arch (maxilla or mandible), the

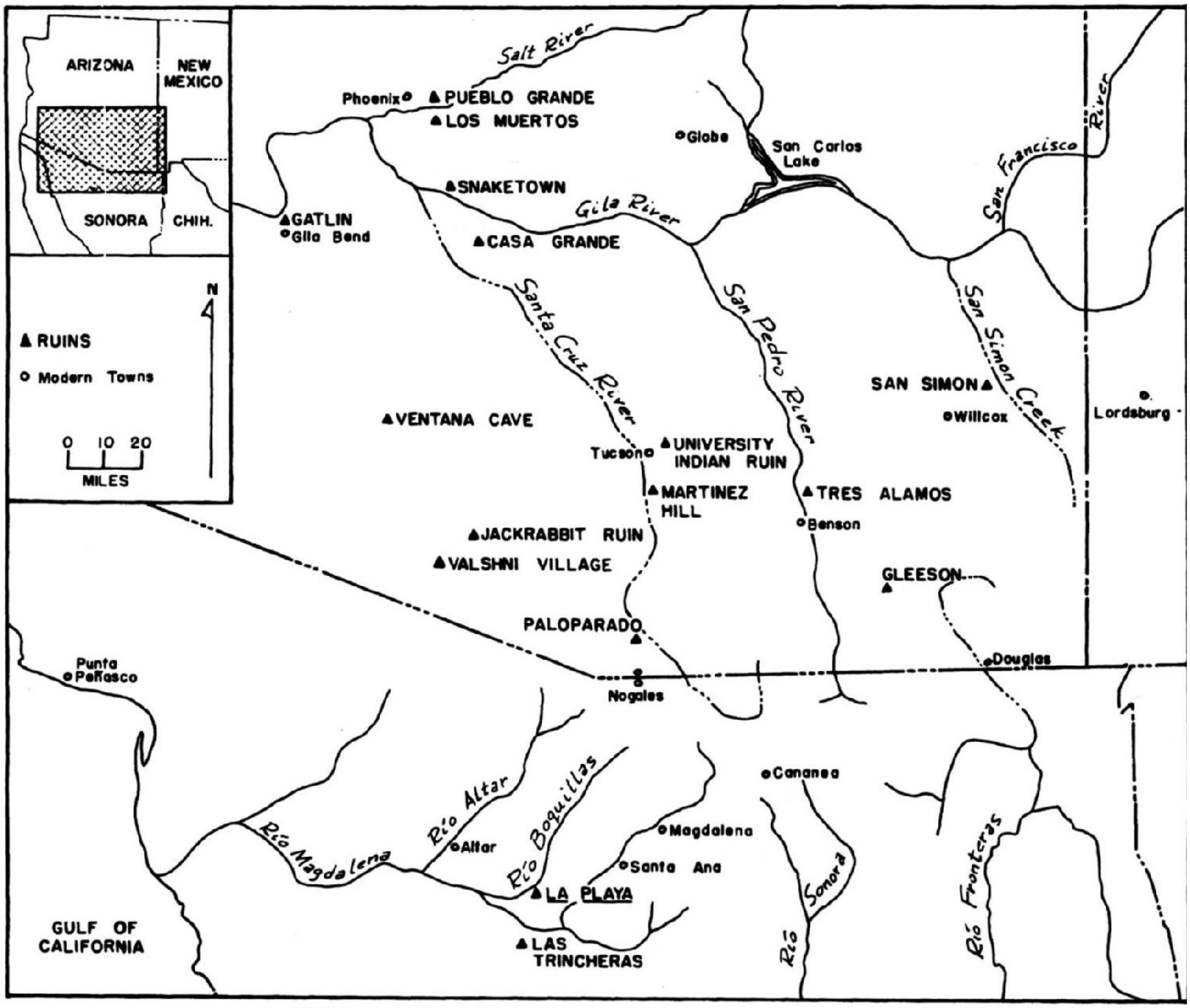

Figure 1. Archaeological sites of southern Arizona and Sonora (Johnson 1963).

specific tooth effected (incisor, canine, premolar or molar) and the initiation site or tooth surface(s) involved (occlusal, interproximal, buccal, lingual, cemento-enamel junction, root). Antemortem tooth loss was recorded only when alveolar bone remodeling, with either partial or complete alveolar resorption, was observed (Figure 3). If the alveolar socket was open, the tooth was recorded as post-mortem (Figure 3). When neither the tooth nor alveolar segment was present, the tooth was recorded as missing with no associated alveolar bone, reducing interpretive problems from inflated pathology rates. Use of these standardized methods has been shown to be reliable and to limit inter- and intra-observer error (Hillson, 2001; Lukacs, 1989).

The sample is comprised of an equal number of males (n = 71) and females (n = 71) ranging in age between 15 and 55 years. Sex and age at death were previously determined based on assessment of crania, dentition and pelves in analyses conducted by Osteo-logists J. Watson and E. Barnes (after Buikstra and Ubelaker, 1994; Brothwell, 1989). A test for intra-observer error was conducted eight months after the original assessments and all individuals were estimated similarly. Age categories for the study sample were assigned to control for age-related effects to dental health over the lifespan: ages 15 - 24 as young adults (n = 15), 25 - 34 as adults (n = 35), 35 - 44 as mature adults (n = 48) and 45-55 (n = 44) as post-reproductive. Individuals 15 years and older were considered near or of reproductive age. Individuals 45 - 55 years of age included post-menopausal women and men considered reproductively senescent. As such, the age range from 15 to 55 provides a sample that spans pre-, peak- and post-reproductive years. The sample is largely age-matched by sex between relatively homogeneous age groups (Chi-square: $p = 0.81$) including young adults with 8 females and 7 males, adults with 15 females and 20 males, mature adults totaled 25 females and 23 males and the post-reproductive group included 23 females and 21 males.

A summary of dental caries is presented in Table 1. Antemortem

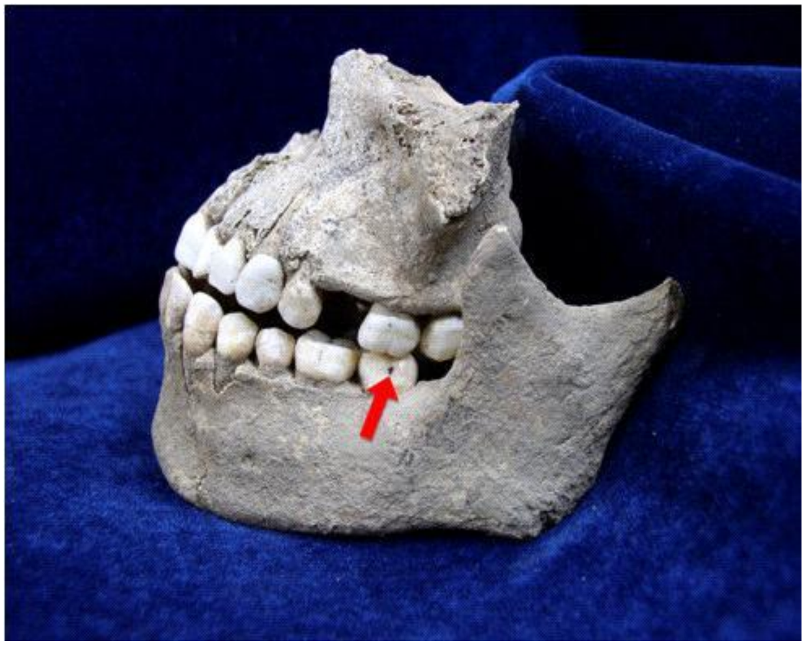

Figure 2. Dental caries seen on buccal surface of mandibular second molar.

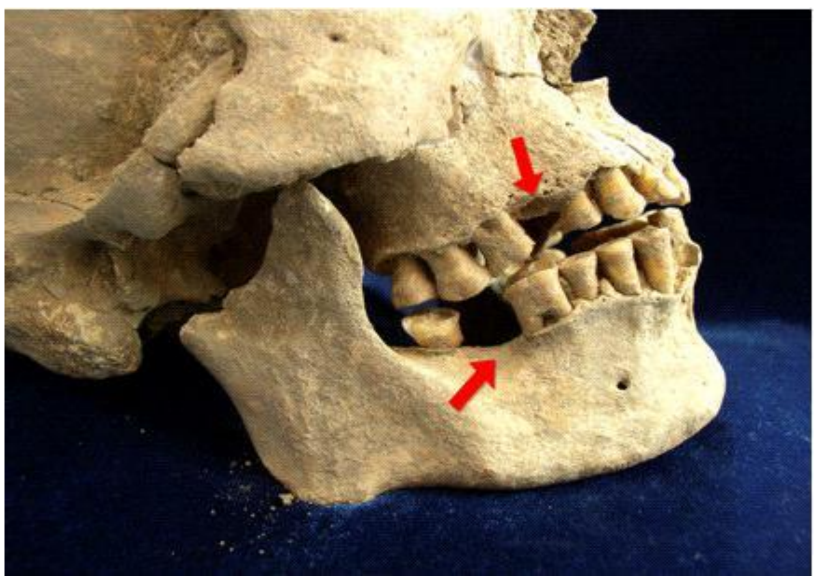

Figure 3. AMTL shown with alveolar remodeling on mandibular second molar. Open socket seen at maxillary second premolar would not be recorded as AMTL.

Table 1. Caries frequency rates for La Playa sample.

Variable caries	Sample (n)	Indvdls w/ Caries (n)	Carious teeth (n)	Total # of observed teeth (n)	Indvdl caries rate	Carious teeth per mouth (n)	Observed caries rate
Males	71	41	134	1099	57.7%	1.89	12.2%
Females	71	45	116	1127	63.4%	1.64	10.3%
Total	142	86	250	2226	60.6%	1.76	11.2%

Table 2. AMTL frequency rates for La Playa sample.

Variable AMTL	Sample (n)	Indvdl with AMTL (n)	AMTL (n)	Obsrvd Teeth (n)	AMTL Intensity	Indvdl AMTL frequency	AMTL per mouth	Sum of caries and AMTL	Caries and AMTL rate
Males	71	33	134	1099	12.2%	46.5%	1.89	268	24.4%
Females	71	35	263	1127	23.3%	49.3%	3.70	379	33.6%
Total	142	68	397	2226	17.8%	47.9%	2.80	647	29.1%

tooth loss data are presented in Table 2. Statistical tests were performed using SPSS 14.0 Version for Windows.

RESULTS

The La Playa burial assemblage can be treated as a random sample of site inhabitants, whose remains were deposited during and are therefore representative of the Early Agricultural period. Recorded observations resulted in quantitative data that were analyzed for statistically significant patterns relating to the dental health of La Playa men and women. The analyses attempted to identify differences in the occurrence of dental pathologies when grouped by independent variables for sex and age category.

Frequency rates

This study employed the following standardized frequency calculations used for reporting caries and AMTL rates in archaeological populations (Buikstra and Ubelaker, 1994; Lukacs, 1989, 1995).

Caries Frequency Calculations:

1) Individual Frequency Rate: $\frac{\text{\# of individuals with caries}}{\text{total \# of individuals in the group}}$

2) Carious Teeth per Mouth: $\frac{\text{\# of teeth with caries}}{\text{total \# of individuals in the group}}$

3) Observed Caries Rate: $\frac{\text{\# of teeth with caries}}{\text{total \# of teeth in the group}}$

Table 1 displays caries data using these frequency calculations. The individual frequency rate provides information as to the prevalence of dental caries. A second frequency calculation provides the average number of caries per individual, listed as the number of carious teeth per mouth. This formula describes the severity of dental caries for each group. The total number of teeth affected with caries includes any tooth with at least one carious lesion and is irrespective of severity. Thirdly, the observed caries rate describes the percentage of caries for each group based on the number of teeth present.

The data in Table 1 show that females had slightly higher, although insignificantly (p = 0.52), individual caries frequency compared to males. Tooth loss data (Table 2) are listed by tooth count (reported as intensity), individual frequency rate and AMTL per mouth. Antemortem tooth loss by tooth count describes the severity of AMTL for each group by analyzing the number of teeth known to have been lost during life. In addition to the standard calculations used to describe pathology frequencies, as indicated below, Powell (1988) suggests reporting pooled caries and AMTL counts as combined pathology frequency, to demonstrate the magnitude of the dental pathologies combined. Counts and frequency rates for the combined pathologies are presented in Table 2.

AMTL Frequency Calculations:

1) AMTL Intensity Rate: $\frac{\text{\# of teeth lost antemortem}}{\text{total \# of observed teeth in the group}}$

2) Individual AMTL Frequency: $\frac{\text{\# of individuals w/antemortem tooth loss}}{\text{total \# of individuals in the group}}$

3) AMTL per mouth: $\frac{\text{\# of teeth lost antemortem}}{\text{total \# of individuals in the group}}$

4) Combined Pathology Rates: $\frac{\text{Sum \# of carious teeth and \# AMTL}}{\text{total \# of observed teeth in the group}}$

The incidence of AMTL for the sample indicates that almost half of the adults at La Playa had lost teeth. Females exhibited only slightly higher individual frequency than males, but the intensity value for females was far greater than for males. The sample of La Playa women lost nearly twice (3.7) the number of teeth per mouth than sample men (1.9).

Sex differences

Results from a *t*-test on caries rates indicate that there are no statistically significant differences in caries prevalence between males and females (alpha level = 0.05, t-value = - 0.64, d.f. = 140, p = 0.522). Results from a t-test for AMTL rates, however, confirm a statistically significant difference between males and females, at the .05 level (t-value = 2.32, d.f. = 140, p = 0.02). In addition, a Cohen's d test for effect indicates a strong association between sex and AMTL (d = 0.39).

A Chi-Square Goodness of Fit test was run on AMTL

Table 3. Chi-square results on AMTL.

	Sex
Chi-Square(a)	41.917
df	1
Asymp. Sig.	0.000

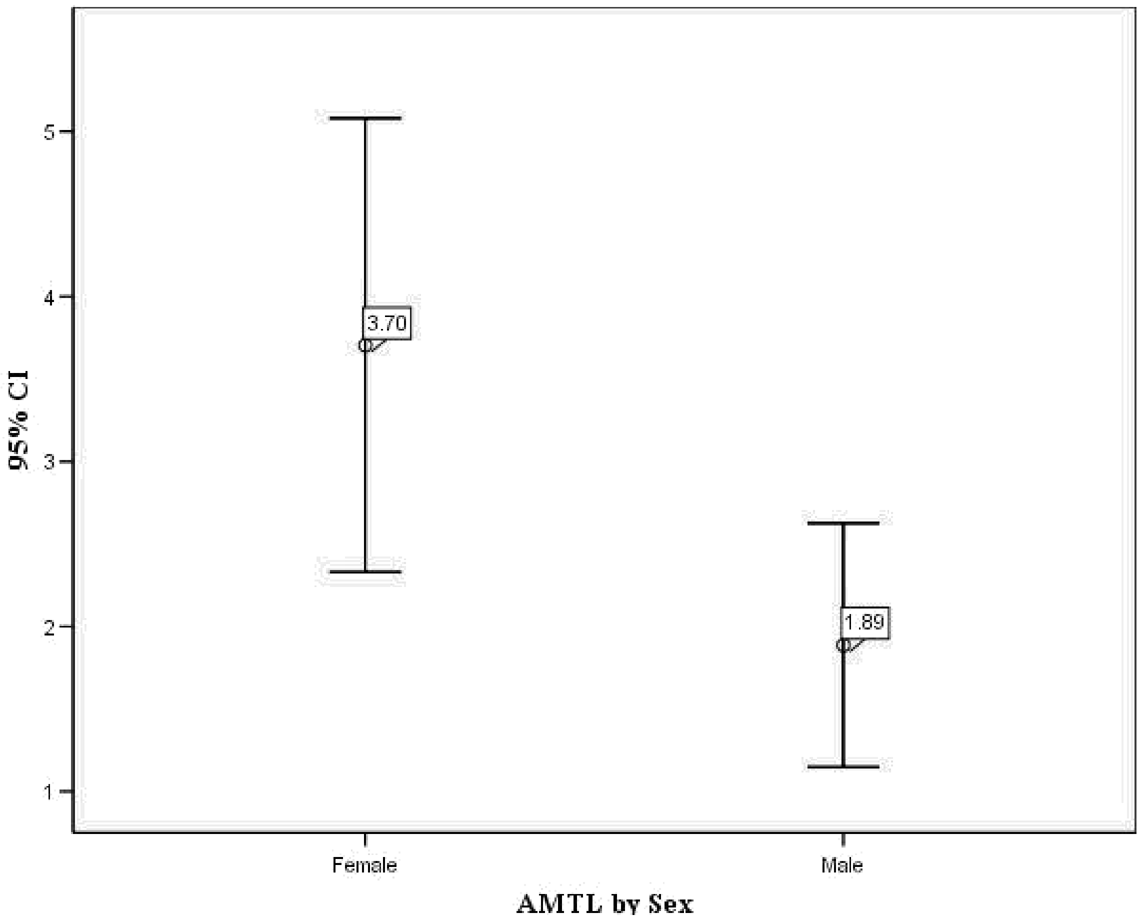

Figure 4. The error bar graph shows that La Playa females had significantly more tooth loss than La Playa males. Bars show minimal overlap between data distributions. The means (labeled by the circle on each bar) indicate that AMTL at La Playa diverged widely between the sexes.

data to evaluate whether the observed frequencies of tooth loss depart significantly from what might be expected, given an equal probability of tooth loss for both women and men. Results (Table 3) indicate statistically significant differences, even at the > 0.01 significance level. These findings suggest that the amount of tooth loss experienced by sample women was significantly greater than what would be expected ($x^2 = 41.92$, d.f. = 1, N = 397, $p < 0.0005$).

An error bar graph (Figure 4) shows the divergence in AMTL between adult men and women. Figure 5 displays data for caries and AMTL organized by sex and age category. This graph presents a visual display of changes in oral health over the reproductive lives of Early Agricultural women and age-matched men at La Playa.

DISCUSSION

This study provides insights into the health consequences of the foraging-to-farming transition, focusing on the greater dental pathology rates seen in many regions

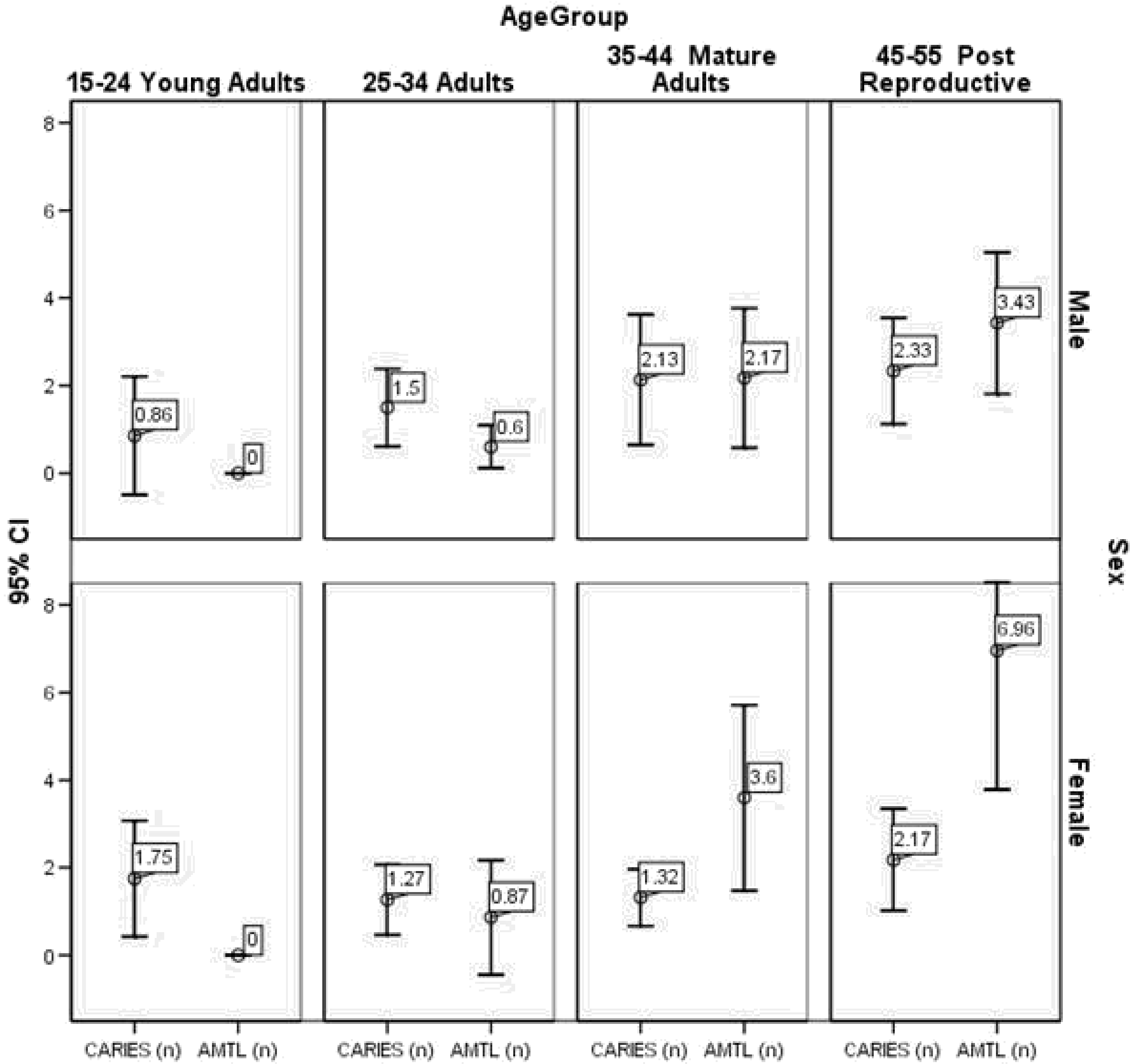

Figure 5. Pathology organized by sex and age group show the differences in dental disease occurrence across the adult lifespan of La Playa men and women.

for early agricultural females (Bridges, 1989; Hillson, 1979, 2001; Larsen, 1987, 1995; Lukacs, 1996, 2008; Lukacs and Largaespada, 2006; Steckel et al., 2002; Watson et al., 2009). Research into caries frequencies based on subsistence has shown Paleolithic hunting and gathering groups experienced minimal dental caries, with rates averaging under 2% (Scott and Turner, 1988). During the early Holocene, a mixed-economy diet of wild and cultivated carbohydrates resulted in slightly higher rates with a mean approximating 5%, while agriculturalists typically have the highest caries rates, often exceeding 10% and ranging upwards of 26% (Scott and Turner, 1988). Watson (2008) argues for a mixed-economy subsistence at La Playa that included consumption of local cariogenic plant foods along with maize, which would explain the observed caries rate for the study sample within the expected range for agriculturalists (Table 1).

In addition to the conditions necessary for cariogenesis, there are environmental factors known to modify oral health. Diets that are high in sand can reduce caries formation as the mastication of abrasive particles wear down enamel surfaces, thereby preventing or abrading carious lesions (Hillson, 2001, 2002). Watson (2005) found evidence for a moderate amount of dietary grit at La Playa likely related to food processing techniques. The amount of fluoride present in the environment is an additional modifying factor in caries prevalence. A skeletal sample from La Playa sent for fluoride analysis to the

University of Notre Dame Fluoride Dating Laboratory found elevated levels of fluoride content (Watson, 2005). Elevated fluoride levels in the soil or water supply could have had a prophylactic effect on dentition (Watson, 2005). Such modifying factors potentially would have impacted all of the site inhabitants and therefore would not be expected to skew study results.

Findings for individual caries rates show that the number of sample women with at least one carious tooth was slightly higher than for men, suggesting that the degree of tooth loss among La Playa women may have been, in part, due to advanced carious decay. Further indication of this is seen in the 45 - 55 year old age group, where men and women had comparable caries occurrence, while female tooth loss intensified to more than double that for males. Clinical research has shown that a substantial degree of tooth loss increases risk for health related issues (Abnet et al., 2005; Tu and Gilthorpe, 2005), including an association between systemic infections from invasive bacteria. Thus, it could reasonably be argued that the cumulative effects of tooth loss on La Playa females might have resulted in a number of health complications specific to women.

Results from this study indicate that the adoption of agriculture had profound consequences for the dental health of these early farming females. Prior assumptions about sex-differences in archaeological populations erred in not factoring in reproductive-related effects. Recent clinical research has corrected this oversight by emphasizing the role of physiological factors that influence dental disease prevalence in women. The awareness that oral health is critical in the lives of women and their families contributes to efforts to improve maternal health outcomes, particularly in underserved communities. Findings from this study provide additional insights into the complexity of hormone- driven oral pathology with empha-sis on the development of oral health trends through time. This research illustrates the processes of evolution and adaptation in varying environments and subsistence regimes and highlights the differential effects on oral dis-ease and tooth loss, with special implications for women of childbearing age.

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