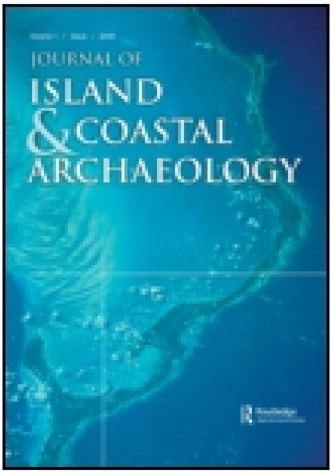

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ABSTRACT

Previous investigation of health and lifestyle in the Mariana Islands indicated that the prehistoric inhabitants living on the smaller islands of this archipelago experienced more stress than those living on the larger islands. This article expands on previous research by using one of the largest datasets (N = 385) now available for examining the health of prehistoric skeletons from the Mariana Islands. A total of 13 indicators of health are investigated, including cribra orbitalia, linear enamel hypoplasia, stature, trauma, infection, and dental disease. There is considerable inter-island variability for many of the indicators but, in general, the highest frequencies of stress are often associated with skeletons from the smaller islands. The sole exception is Rota, the smallest island that reveals levels of stress similar to Guam, the largest island. For several indicators (e.g., stature, long bone fracture, spondylolysis, alveolar defect) there were no significant differences among islands. Cultural habits such as chewing areca (betel) nut, environmental factors, and other cultural differences are examined to explain these differences.

Keywords betel nut, bioarchaeology, Chamorro, dental pathology, Mariana Islands, paleopathology

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INTRODUCTION

Previous investigation of health and disease in the Mariana Islands suggested that the prehistoric Chamorro on smaller islands such as Rota and Saipan experienced higher levels of specific as well as non-specific indicators of stress, including dental enamel hypoplasia, cribra orbitalia, and treponemal infection than the prehistoric Chamorro living on the largest of the islands, Guam (Pietrusewsky et al. 1997). The reason for this island difference was hypothesized as the smaller islands' greater susceptibility to environmental perturbations which would affect human health because of smaller land mass, remoteness, lower rainfall, freshwater lens, slightly cooler temperatures, narrow and non-continuous fringing reefs, earthquakes, volcanic eruptions, and sea-level fluctuations (Hunter-Anderson 2010). It is also possible that small sample size and temporal provenience may account for some of the observed differences. This article re-examines the question of inter-island variability in health and lifestyle of precontact Chamorro using recently excavated human skeletal series from Tinian, Saipan, and Rota. Although there have been studies of health using skeletons from the Mariana Islands (e.g., Douglas et al. 1997; Stodder 1997), there have been few regional syntheses of accumulated data that address the health in the Mariana Islands (e.g., Pietrusewsky et al. 1997, 2010, 2011; Roy 1989).

MARIANA ISLANDS

Located between 13° and 21° North latitude in the northwestern Pacific, the Mariana archipelago consists of 15 volcanic islands and numerous much smaller geologic outcroppings (Russell 1998) (Figure 1). Guam, Rota, Tinian, and Saipan, located in the southern group, are the largest islands in the archipelago; places where people have preferred to live in prehistory and the present. Geologically, the islands of the southern portion of the Mariana chain (Guam, Tinian, Saipan, and Rota) are a combination of volcanic and raised coralline deposits surrounded by a fringing reef. The least populated northern islands are of recent volcanic origin.

Guam, at 549 km^2, is the largest island of the Mariana Islands and in Micronesia followed by Saipan (115 km^2), Tinian (101 km^2), and Rota (85 km^2). Today, the climate of the Mariana Islands is classified as marine tropical, or humid tropical, with a pronounced summer monsoon often associated with heavy downpours, tropical storms, and typhoons, especially during the second half of the year (Hanson and Butler 1997). Although all of the southern islands receive high annual rainfall (2000–2500 mm) serious drought conditions can occur during the dry season, which is often prolonged by the El Niño/Southern Oscillation (ENSO) phenomena. With the exception of Guam, surface water on the southern islands is scarce, which can lead to serious water shortages. The Mariana Islands' susceptibility to droughts, severe tropical storms, and cyclones causes periodic devastation of reef systems and terrestrial vegetation, contamination of fresh water sources with seawater, and damage to other resources (Hunter-Anderson 2012).

CHAMORRO PREHISTORY AND SUBSISTENCE

When the first Europeans arrived in 1521, they found the islands inhabited by a single group of people who spoke Chamorro, an Austronesian language similar to those spoken by people in the Philippines and much of Island Southeast Asia (Blust 2000). In addition to linguistic similarities, close cultural relationships between the Marianas and the Island Southeast Asian late Neolithic cultures have been suggested (Bellwood 1997; Kirch 2000). Hung et al. (2011) have further identified the northern Philippines as a possible source of the earliest human settlements in the Mariana Islands. Based on archaeological and palaeoenvironmental evidence, human occupation of the Mariana Islands began approximately 3500 BP (Athens et al. 2004; Hunter-Anderson 2010; Hunter-Anderson and Butler 1995). Recent

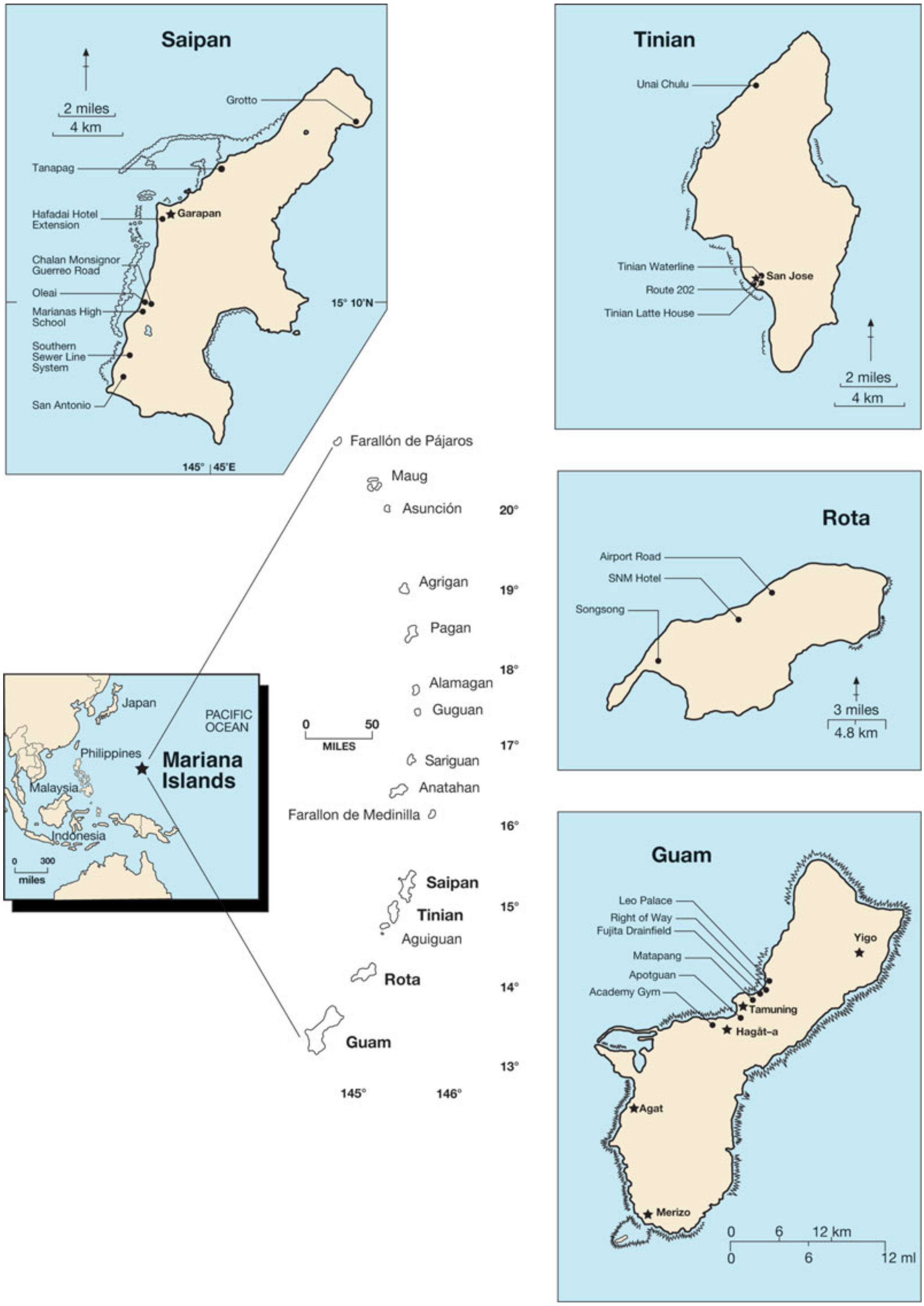

Figure 1. *Map of the Mariana Islands showing the approximate locations of the skeletal series used in the present study.*

mtDNA evidence suggests that the Mariana Islands may have been initially settled approximately 4000 years BP by a small founding group of people from Island Southeast Asia (Vilar et al. 2013). These same authors further hypothesize that this initial founding population remained genetically isolated until approximately 1000 years BP when a separate wave of migrants from Island Southeast Asia arrived. This later colonization event coincides with the introduction of *latte* structures and rice agriculture (Vilar et al. 2013).

Chamorro prehistory is traditionally divided into three periods: Pre-Latte, Transitional Pre-Latte, and Latte Periods [following Moore (1988)]. The term *latte* is applied to a form of paired stone pillars and cup-shaped capitals or capstones, which were used to support houses, meeting halls, and/or religious structures (Carson 2012; Graves 1986; Hanson and Butler 1997). On the larger southern islands, during the Pre-Latte Period (1500 BC–AD 400) population size was small, consisting of coastal villages, which relied on fishing, shellfish, and agricultural subsistence (Hunter-Anderson and Butler 1995; Moore 1983). The Transitional Pre-Latte Period (AD 400–900) designates a time of adaptive change associated with an increase in population growth and settlement expansion outward from coastal settings into the islands' interiors (Hunter-Anderson and Butler 1995). The Latte Period (AD 900–1700) is characterized by the presence of the *latte* structures in larger villages and more inland settlements (Carson 2012; Hunter-Anderson and Butler 1995). The Latte Period extends into the Proto-Historic Period, which began with Magellan's historic landfall in Guam in 1521 and culminated with significant conflicts on Saipan between the late 1600s and early 1700s with the forcible removal of the Chamorro population to Guam (Lévesque 1997; Russell 1998). Ethnographic accounts suggest that, at the time of contact, Chamorro society was a ranked society divided into descent groups marked by matrilineal clans (Hunter-Anderson and Butler 1995). A system of alliances developed between the different clans, which served to control access to resources and to redistribute resources among villages in different environmental zones. These alliances may have extended to the other islands as well (Hunter-Anderson 2012).

The precontact subsistence economies of the Chamorro included reliance on cultivated tree and root crops typical of the tropical island environment such as coconut, banana, breadfruit, taro, yam, and possibly rice—all foods high in carbohydrates. The Mariana Islanders diet was also rich in marine resources, including fish and shellfish, found in the surrounding reefs, reef flats, and deep water environments (Alkire 1977; Butler 1988). In addition to agriculture and fishing, Chamorro subsistence included gathering and hunting of endemic as well as migratory birds, fruit bats, monitor lizards, turtles, and crabs (Dixon et al. 2003; Hunter-Anderson and Butler 1995; Russell 1998). Rats arrived in the islands during the Latte period, but the common Pacific domesticated correlates—pig, dog, and chicken—do not occur in the Mariana Islands (Carson 2012).

SKELETAL SERIES

A total of 385 adult skeletons from 22 sites on Rota, Tinian, Saipan, and Guam of the Mariana Islands are included in this study (Table 1). With very few exceptions, the sites represented are coastal sites. The majority of these skeletons are from Latte Period although a few skeletons from Tumon Bay on Guam may date to the Transitional Pre-Latte Period, and a few others (e.g., Matapang and Fujita) may date to the pre-Latte Period. Overall, the skeletons used in this study date to the prehistoric (pre-1521) period, though a few may date to the time when the Chamorro were engaged in a strong resistance to Spanish rule in the 1600s.

Generally, there are more males than females in most skeletal series, and for Saipan, the sex ratio is skewed heavily toward males (Table 2). Overall, young and middle-aged adults are about equally represented; the Saipan series has an older age-at-death profile (52.6% middle or old aged) followed by the Guam series with 45.3% middle or old aged. Approximately 9% of all adults died during old age. In addition to skeletal series

Table 1. **Skeletons from Rota, Tinian, Saipan, and Guam used in the present study.**

Island	Site	No. adults	Site dates	Reference
Rota	Songsong Village	10	AD 1050–1530	McManamon (1989); Pietrusewsky (1988)
	Songsong Village	39		Sava (1999)
	SNM Hotel	1	Latte	Craib (1992, 1994); Pietrusewsky (1994); Pietrusewsky and Ikehara-Quebral (1995)
	Airport Road, north coast, Rota	16	~AD 1–1600	Butler (1988); Hanson (1988)
	Rota total	66		
Tinian	Tinian Rt. 202 Project (Rt 202)	10	~AD 1009–1611 ± 30	Pietrusewsky and Douglas (2010)
	Tinian Waterline Project (TWL)	10	~AD 1200–1640	Pietrusewsky and Douglas (2001a)
	Tinian Latte House (TLH)	3	AD 1000–1521	Pietrusewsky and Batista (1980)
	Unai Chulu	14	Pre-1521	Pietrusewsky (1986a); Ward and Pickering (1985)
	Tinian total	37		
Saipan	Southern Sewer Line System Project (SSLS)	10	AD 1429–1670[1]	Pietrusewsky (2006)
	Chalan Monsignor Guerreo Road Project (CMG)	8	A.D 1060–1450[2]	Pietrusewsky and Douglas (2001b)
	Hafadai Hotel Extension Project	19	pre-1521	Pietrusewsky (1986a); Ward and Pickering (1985)
	Oleai[3]	30	pre-1521	Graves (1986, 1991); Pietrusewsky and Douglas (1989)
	Tanapag	6	pre-1521	Pietrusewsky (1986a); Ward and Pickering (1985)
	Marianas High School	3	no dates	Pietrusewsky and Batista (1980); Russell (1978)
	Grotto Site	2	AD 720–210 ± 100	Pietrusewsky and Batista (1980); Russell (1978)
	San Antonio	32	AD 1230–1360 ± 100	Pietrusewsky and Batista (1980); Russell (1978)
	Saipan total	110		

(Continued on next page)

Table 1. **Skeletons from Rota, Tinian, Saipan, and Guam used in the present study. *(Continued)***

Island	Site	No. adults	Site dates	Reference
Guam	Apotguan, Tamuning, Hagåtña	101	AD 1000–1521	Douglas et al. (1997); McNeill (personal communication 1995); Pietrusewsky et al. (1992)
	Fujita Drainfield (Tumon Ball Park), Tumon Bay	24	AD 590–900	Bath (1986); Pietrusewsky (1986b)
	Leo Palace Hotel Site, Tumon Bay	16	AD 1000–1400	Davis (1990); Davis et al. (1992); Douglas and Ikehara (1992)
	Matapang Park, Tumon Bay	18	AD 770–1025[4]	Bath (1986); Pietrusewsky (1986b)
	Right of Way (ROW-A), Tumon Bay	10	AD 1480–1665	Bath (1986); Pietrusewsky (1986b)
	Academy Gym, Agana	3	pre-1521	Ikehara and Douglas (1995); Welch (1991)
	Guam total	172		
	Total (Mariana Islands)	385		

[1]Three burials from this site (Nos. 6, 24, & 24B) were dated to AD 1420–1450 (late Latte Period) and four burials (Nos. 16, 20A, 21A, & 22) were dated to AD 1640 and 1670 (Swift, personal communication February 17, 2010).

[2]This range of dates represents carbon 14 dates for eight of the burials from this site (Nos. 4, 5, 6, 7, 16, 19, 20, and 26) (Swift, personal communication February 17, 2010).

[3]The Oleai skeletons were excavated by Michael Graves and Darlene Moore in April, 1986. One individual was inadvertently excluded from the age/sex table in Pietrusewsky and Douglas (1989).

[4]The majority of the Matapang burials are from the Latte Period (AD 1000–1521), but three are dated to 1690 BC–1140 BC.

analyzed in an earlier study (Pietrusewsky et al. 1997), the present study includes new data recorded in skeletons from two sites on Tinian (Tinian Rt. 202 Project and Tinian Waterline Project) and two sites on Saipan (Chalan Monsignor Guerreo Road Project and Southern Sewer Line System), which were excavated during cultural resource management investigations undertaken by Swift and Harper Archaeological Resource Consulting (SHARC) on Saipan. This new analysis also includes new data from four separate locations in Songsong Village on Rota recorded by Sava (1999). Because of the underrepresentation of subadults in most of the skeletal series from Saipan and Tinian examined by the authors since 1997, only adults are included in the present study.

METHODS

The methods used to determine age-at-death and sex follow standard osteological procedures described in Buikstra and Ubelaker (1994) and Pietrusewsky and Douglas (2002). The 13 skeletal and dental indicators of health investigated in this paper include those that are attributable to non-specific systemic stress during growth and development (e.g., LEH, cribra orbitalia, stature) and those that suggest specific stressors (e.g., trauma,

Table 2. **Age and sex distribution of the adult skeletons from Rota, Tinian, Saipan, and Guam.**

							No. of adults by age[3]			
Island	**Skeletal series[1]**	**No. males**	**No. females**	**No. ? sex**	**Total adult**	**Sex ratio[2]**	**Y**	**M**	**O**	**A**
Rota	SNM Hotel	1			1		1			
	Songsong (Pietrusewsky 1988)	1	9		10	0.1	5	3	1	1
	Songsong (Sava 1999)	20	16	3	39	5.3	25	10	1	3
	North coast Rota (Hanson 1988)	9	4	3	16	2.3	5	2	1	8
	Rota total	31	29	6	66	1.1	36	15	3	12
Tinian	Tinian Rt 202	6	4		10	1.5	4	5		1
	Tinian Waterline	6	4		10	1.5	7	3		
	Tinian Latte House	0	3		3		1	1	1	
	Unai Chulu	8	3	3	14	2.7				
	Tinian total	20	14	3	37	1.4	12	9	1	15
Saipan	Southern Sewer Line System Project	5	5		10	1.0	4	3	2	1
	Chalan Monsignor Guerreo Rd. Project	6	2		8	3.0	3	5	0	0
	Oleai Site	19	10	1	30	1.9	9	13	2	6
	San Antonio Site[4]			32	32		15	6	6	5
	Hafadai Hotel Extension Project	12	6	1	19	2.0	4	11	3	1
	Tanapag Site	5	1		6	0.2	1	5		
	Marianas High School	1	2		3	0.5	2		1	
	Grotto Site	1	1		2	1.0	1		1	
	Saipan total	49	27	34	110	1.8	39	43	15	13
Guam	Apotguan, Tamuning, Hagåtña	53	43	5	101	1.2	38	37	13	13
	Fujita Drainfield (Tumon Ball Park)	12	9	3	24	1.3	10	4		10
	Leo Palace Hotel Site, Tumon Bay	10	5	1	16	2.0	5	5	2	4
	Matapang Site	10	8		18	1.3	5	9		4
	Right of Way (ROW-A) Site	4	6		10	0.7	2	6	1	1
	Academy Gym, Agana	2	1		3	2.0	1	1		1
	Guam total	91	72	9	172	1.3	61	62	16	33
	Total (Mariana Islands)	191	142	52	385	1.3	148	129	35	73

[1]See Table 1 for reference.
[2]Sex ratio = proportion of males to female (M/F).
[3]Y = Young adult (19–34 years); M = Middle-aged adult (35–49 years); O = Old adult (50 + years); A = Adult.
[4]The skeletons from the San Antonio site represent a mass burial of commingled remains of at least 32 adults and one subadult; the number of male and female adults represented is not known.

Table 3. **Frequency of cribria orbitalia (CO) (reported by individual) and linear enamel hypoplasia (LEH) (by tooth) in the skeletons from the Mariana Islands, sexes combined.**

	CO		LEH	
Island	**A/O[1]**	**%**	**A/O**	**%**
Rota	1/18	5.6	44/158	27.8
Tinian	5/17	29.4	9/101	8.9
Saipan	11/55	20.0	45/103	43.7
Guam	3/42	7.1	161/520	31.0
Total	20/132	15.2	259/882	29.4

[1]A/O = Affected/Observed.

infection, dental disease). Most of the data presented in this paper were recorded by Pietrusewsky and, in a few instances when this was not the case, they were recorded by individuals who were trained by him, thus minimizing inter-observer error.

Additional background information on these indicators will be introduced in the appropriate section when discussing the results. Fisher's exact test was used to test for significant differences of the discontinuous data and Student's t-test for continuous data (Thomas 1986).

RESULTS

Unless otherwise indicated, the frequencies of dental enamel hypoplasia and dental pathology are reported on a per tooth/tooth socket basis. The sexes are combined in this analysis because of small sample sizes. For purposes of brevity, we report combined data for each of the four islands. More detailed data, by site, are presented as supplemental data in the Appendix (See Appendix Tables 1–12).

Cribra Orbitalia

Cribra orbitalia (CO), the sieve-like lesions that develop in the orbital roofs, is commonly attributed to iron deficiency anemia (Stuart-Macadam 1989, 1991) or megaloblastic anemia (Walker et al. 2009), although the latter attribution has been challenged by Oxenham and Cavill (2010). We report the frequency of cribra orbitalia by adult individuals, sexes combined (Table 3). The frequency of CO ranges from 5.6% (Rota) to 29.4% (Tinian). The only significant difference in the frequency of CO is the one between Tinian (29.4%) and Guam (7.1%). The combined frequency of CO in the skeletons from the Mariana Islands is 15.2%.

Dental Enamel Hypoplasia

Linear enamel hypoplasia (LEH), visible as one or more transverse furrows or grooves of varying depths on the crown surfaces of teeth, is caused by the disruption of enamel development during infancy and early childhood (Goodman and Rose 1991). Disruption of enamel production is caused by a variety of stressors affecting the mother and/or growing child including malnutrition, metabolic disorders, acute and chronic infections, physical trauma, and hereditary conditions (Goodman et al. 1984; Goodman and Rose 1991; Hillson 2008). LEH in the permanent teeth from the Mariana Islands ranged in severity in depth and width from slight to moderate grooves and often there was more than one defect per tooth. Observations of LEH are sometimes complicated by betel staining which may be thick enough to obscure the defects. When this was the case, no observations of LEH were recorded in those teeth. All teeth were scored for the presence/absence of these disruptions, but because defects are more frequent in the

Table 4. **Comparison of male and female statures[1] (cm) in the skeletons from the Mariana Islands.**

	Male			Female		
Island	***n***	**Mean**	**Range**	***n***	**Mean**	**Range**
Rota	10	172.2	167.4–178.6	17	160.5	155.8–170.6
Tinian	9	174.0	168.7–179.9	9	159.8	155.5–166.7
Saipan	19	173.9	166.1–182.1	11	160.0	153.9–164.6
Guam	20	172.5	167.8–177.1	8	162.4	156.7–168.4
Total	58	173.2	166.1–182.1	45	160.6	153.9–170.6

[1]Stature estimates using Houghton et al. (1975) on complete long bones only.

incisor and canine teeth frequencies are reported for those teeth only.

There is considerable variation in the frequencies of LEH for the four islands ranging from 8.9% (Tinian) to 43.7% (Saipan) (Table 3). The Rota (27.8%) and Guam (31.0%) LEH frequencies are not significantly different, but all other island comparisons exhibit statistically significant differences in LEH frequency. The overall frequency of LEH in adults from the Mariana Islands is 29.4%.

Stature

Because of the lack of population-specific stature formulae for Chamorro skeletons the stature estimates reported here (Table 4) are based on formulae for Maori (Houghton et al. 1975) using the maximum and/or physiological length measurements for adult males and females. If more than one stature estimate was calculated, the estimate having the least error was selected.

A comparison of male and female average statures for the four main Mariana Islands reveals no significant differences between any of the islands. The average male statures for Guam and Rota (~172 cm) are nearly identical and approximately 2 cm less than the average male statures for Tinian and Saipan. The tallest individual males are found on Saipan (182.1 cm) and Tinian (179.9 cm). The average male stature for the Marianas is 173 cm, 13 cm greater than the average for living Chamorro males from Saipan reported by Hasebe (1938).

The average stature for females from Guam is approximately 2 cm greater than the average statures for Rota, Tinian, and Saipan. The tallest individual female is found on Rota (170.6 cm). Overall, the average Mariana Island female stature is 160.6 cm, nearly 13 cm shorter than the average male stature.

Long Bone Fractures

Fractures of the adult major long bones (clavicle, humerus, radius, ulna, femur, tibia, and fibula) provide an indication of the frequency and type of traumatic, accidental or deliberate, injury in a population (Lovell 2008; Walker 1989). Although healed fractures of other bones in the skeleton are observed in Mariana skeletal series, because of difficulties in establishing frequencies in these kinds of fractures, we are concentrating on the long bones (Table 5). Fracture frequency is estimated using the corresponding number of complete, or nearly complete, bones reported.

The frequencies of long bone fractures are low (0.8% to 1.1%) and there are no statistically significant differences between the four major islands. The combined frequency of long bone fractures in Mariana Island skeletons is 0.9%, suggesting that accidental or deliberate injury, as indicated by long bone fractures, is rare in the prehistoric Chamorro.

Spondylolysis

Spondylolysis, or fracture of the lumbar vertebrae at the pars interarticularis (the

Table 5. **Frequency of long bone fractures, spondylolysis, and infection in the skeletons from the Mariana Islands.**

	Long bone fractures[1]		Spondylolysis[2]		Infection[3]	
Island	**A/O[4]**	**%**	**A/O**	**%**	**A/O**	**%**
Rota	2/234	0.9	2/92	2.2	11/53	20.8
Tinian	2/181	1.1	1/36	2.8	2/23	8.7
Saipan	2/177	1.1	1/78	1.3	13/102	12.7
Guam	5/593	0.8	10/149	6.7	14/172	8.1
Total	11/1185	0.9	14/355	3.9	40/350	11.4

[1]Observed = the number of clavicles, humeri, ulnae, radii, femora, tibiae, and fibulae.
[2]Observed = lumbar vertebrae.
[3]Observed = individuals.
[4]A/O = Affected/Observed.

narrow area connecting the inferior facets of the neural arch with the superior facets), has been related to repeated stress to the lower lumbar vertebrae by physical activities requiring flexion of the lumbar spine with the legs extended (Merbs 1996; Ortner 2003). Arriaza (1997) proposed hyperextension of the lower back under stressful conditions, such as in *latte* construction, as another explanation for spondylolysis.

Although the frequency of spondylolysis is highest in the lumbar vertebrae from Guam (6.7%), there are no statistically significant differences in the frequencies for the four main islands (Table 5). The lowest frequency of spondylolysis is reported in the skeletons from Saipan (1.3%). The overall frequency of spondylolysis is 3.9%.

Bone Infections

Specific bone infections include tuberculosis, leprosy, treponematoses, and fungal infections. Treponemal infections include pinta, yaws, and syphilis, which are caused by the spirochete, *Treponema pallidum.* Only yaws and syphilis affect the skeleton. Infection with the organism *Treponema pallidum* may produce lesions of the cranial vault, as well as very characteristic symmetrical appositional lesions of the long bones (Ortner 2003).

As is the case for much of the Pacific, it is widely acknowledged that venereal syphilis was absent in the Mariana Islands prior to contact with Europeans (Baker and Armelagos 1988; Stewart and Spoehr 1952). Bony lesions with manifestations typical of treponemal infections from the Mariana Islands and elsewhere in the Pacific are usually diagnosed as evidence of yaws (see, e.g., Rothschild and Heathcote 1993).

Bony changes attributed to treponemal infection (e.g., periosteal reaction, gummatous osteitis and cloacae) were observed in the skeletons from the Mariana Islands (Table 5). The frequencies of treponemal infection in adult skeletons range from 8.1% (Guam) to 20.8% (Rota)—the only statistically significant inter-island difference. The fact that several of the new skeletal series were not examined in total, but rather sampled, suggests the frequency of treponemal disease is likely underestimated. Two of the highest frequencies of treponemal infection occur in skeletons from the Hafadai Hotel Extension site on Saipan (36.8%) and the Songsong Village site on Rota (21.6%) (Pietrusewsky et al. 1997). The overall frequency of treponemal infection in individual skeletons from the Mariana Islands is 11.4%.

Betel Staining and Dental Pathology

Chewing of the areca nut (*Areca catechu)*, more commonly referred to as betel nut, with or without the use of pepper leaf (*Piper betle*) and/or slaked lime, is common throughout South Asia, Southeast Asia, and the western Pacific. Regular use of betel quid causes a bright orange/red stain of the teeth and gums. Tooth staining, either as a result of chewing a quid and/or deliberate application of a mixture of betel nut and lime slurry, has been reported in adult dentitions for many archaeological skeletal series from the Mariana Islands and Micronesia (e.g., Fitzpatrick et al. 2003; Hanson and Butler 1997; Hocart and Fankhauser 1996; Leigh 1929; Pietrusewsky 1986b; Pietrusewsky et al. 1992, 1997). The staining of the tooth enamel, common among the present-day Chamorro, is usually light to dark brown/reddish brown in color.

Because there is now a substantial epidemiological literature demonstrating a link between chewing betel nut and cariostasis (e.g., Howden 1984; Möller et al. 2009; Schamschula et al. 2010) and other oral-dental pathologies including periodontal disease in living people (e.g., Chatrchaiwiwatana 2006; Trivedy et al. 2002) and a documented increase in dental attrition (IARC 2004; Kumar et al. 2004), we report the frequency of stained teeth for our skeletal series (Table 6). Although there is considerable variation in the frequency of betel-stained teeth, more than half of all adult teeth exhibit staining. The lowest frequencies are observed in the skeletons from Rota (54.0%) and Guam (54.8%), while the highest frequencies of staining are observed in the skeletons from Tinian (80.4%) and Saipan (75.3%). If all the skeletons from the Mariana Islands are combined, the overall frequency of betel-stained teeth is 60.4%.

Dental Caries

Dental caries is a demineralization of the tooth structures caused by organic acids produced by bacterial processes involved in the fermentation of dietary carbohydrates (Hillson 2008:313). The lowest frequencies of dental caries are observed in the Tinian (4.6%) and Guam (4.2%) skeletons, while significantly greater frequencies of caries are found in the Saipan (8.5%) and Rota (8.7%) skeletons (Table 6). The frequency of carious lesions in the combined Mariana Islands skeletons is 5.8%.

Alveolar Bone Loss

Two distinct types of bone loss from the alveolar process are recorded in the skeletons from the Mariana Islands. The first type, referred to in this study as alveolar resorption, is related to the removal of alveolar bone due to inflammation of the supporting tissues of the teeth associated with periodontal disease (Hildebolt and Molnar 1991; Hillson 2008). The second type of alveolar bone loss is the one concentrated around the apex of the tooth roots, originating from infections of the pulp, so-called periapical inflammation; a term that has been suggested to replace the older and somewhat less correct designation, periapical dental abscess (Dias and Tayles 1997; Hillson 2008). While we have adopted the term, alveolar defect, for this type of bone loss in the present paper, it is referred to as dental abscess in previous studies (e.g., Pietrusewsky et al. 1997; Steckel and Rose 2002).

Alveolar resorption. In this study, alveolar resorption is scored as the amount (none, slight, moderate, and marked) of tooth root exposed above the alveolar bone margin. The frequency of advanced (moderate and marked) alveolar bone resorption ranges from 24.4% in the Tinian skeletons to 60.3% in the Saipan skeletons (Table 6). Comparisons of the frequencies of alveolar resorption between the four islands were statistically significant except for the difference between Tinian (24.4%) and Guam (28.3%). The frequency of advanced alveolar resorption is 38.6%, suggesting periodontal disease was relatively prevalent for prehistoric Chamorro.

Alveolar defects. The frequency of alveolar defects in the skeletons from the Mariana Islands ranges from 3.8% in the Tinian skeletons to 6.7% in the Saipan skeletons (Table 6). Comparisons of the frequencies of alveolar defect among the four main islands are not statistically significant. The overall frequency of alveolar defects is 5.0%.

Dental Calculus

Dental calculus, calcified or mineralized dental plaque, is composed primarily of

Table 6. **Frequency of betel staining, caries (by tooth), alveolar resorption, and alveolar defect in the skeletons from the Mariana Islands.**

	Betel staining		Caries		Alveolar resorption[1]		Alveolar defect	
Island	**A/O[2]**	**%**	**A/O**	**%**	**A/O**	**%**	**A/O**	**%**
Rota	429/794	54.0	69/790	8.7	199/425	46.8	38/749	5.1
Tinian	361/449	80.4	17/372	4.6	30/123	24.4	9/237	3.8
Saipan	435/578	75.3	58/681	8.5	282/468	60.3	39/582	6.7
Guam	1247/2274	54.8	98/2310	4.2	325/1148	28.3	81/1745	4.6
Total	2472/4095	60.4	242/4153	5.8	836/2164	38.6	167/3313	5.0

[1]Frequencies of advanced (moderate and marked) alveolar resorption are reported in this table.
[2]A/O = Affected/Observed.

calcium phosphate mineral salts deposited between and within remnants of formerly viable microorganisms (White 1997). Dental calculus is enhanced in high carbohydrate diets and severe dental attrition (Hillson 2008; Lieverse et al. 2007), attaching to the tooth surface at the base of a living plaque deposit. The etiology of dental calculus is dependent upon a number of factors that contribute to the mineralization of plaque including an alkaline oral environment, "salivary flow rate", hydration, calcium and phosphate levels in the blood, mineral content of drinking water, silicon content in both food and water, and plaque accumulation" (Lieverse 1999; Lieverse et al. 2007:332).

Although two forms of calculus are generally recognized (Hillson 2008; Lieverse 1999; White 1997), supragingival (on the tooth crowns and sometimes roots) and subgingival (a less obvious layer coating the surface of the root), we report only supragingival calculus in this study. In the skeletons from the Mariana Islands, dental calculus was mainly confined to the tooth crown and cemento-enamel junction. Here, we report the overall frequency of advanced (moderate and marked) calculus (Brothwell 1981:figure 6.14b) (Table 7). The frequencies of dental calculus in the Mariana Island teeth range from 11.1% (Saipan) to 22.5% (Rota). No significant differences in calculus are noted between Tinian (14.1%) and Saipan or between Tinian and Guam, but the Rota frequency is significantly greater than all the other islands. The frequency of advanced calculus build-up for the combined series is 15.8%.

Dental Attrition

Dental attrition is the physiological wearing away of the occlusal and proximal surfaces of the teeth in function (Hillson 1996). In the skeletons from the Mariana Islands, occlusal attrition was recorded on an absent, slight (enamel wear), moderate (dentin exposure), and marked (pulp exposure) gradient (Table 7).

The frequencies of advanced (moderate + marked) dental attrition are similar in the skeletons from Guam (26.3%) and Rota (28.8%), significantly less than the frequencies in skeletons from Saipan (49.9%) and Tinian (47.0%). The combined frequency of advanced attrition for the Mariana Islands teeth is 32.8%.

Antemortem Tooth Loss (AMTL)

The loss of teeth before death (antemortem tooth loss—AMTL) can be attributed to several pathological processes including periodontal disease, carious lesions, and alveolar defects (Table 7). The lowest frequency of AMTL is reported for the skeletons from Tinian (2.0%), significantly lower than AMTL frequencies from the other three island series. Saipan (7.1%), Rota (6.7%), and Guam (5.3%) cluster together, though there is a significant difference between frequencies in

***Table* 7. Frequency of dental calculus, attrition, and AMTL in the skeletons from the Mariana Islands.**

	Calculus[1]		Attrition		AMTL	
Island	**A/O[2]**	**%**	**A/O**	**%**	**A/O**	**%**
Rota	172/765	22.5	155/538	28.8	64/957	6.7
Tinian	47/333	14.1	174/370	47.0	9/450	2.0
Saipan	74/665	11.1	342/686	49.9	116/1626	7.1
Guam	315/2088	15.1	596/2265	26.3	157/2981	5.3
Total	608/3851	15.8	1267/3859	32.8	346/6014	5.8

[1]Frequencies of advanced levels (moderate and marked) of dental calculus and attrition are reported in this table.

[2]A/O = Affected/Observed.

Guam skeletons and those in Saipan skeletons. The overall frequency of AMTL for all the skeletons is 5.8%.

DISCUSSION

Previous research (Pietrusewsky et al. 1997), based on 272 adult skeletons, suggested that the precontact inhabitants of the smaller islands in the Marianas, such as Rota, Tinian, and Saipan, were less healthy than those from Guam, the largest island. This new analysis, based on 385 adult skeletons, allows a more in-depth examination of interisland differences in health and lifestyle. While the data presented in this study may be influenced by temporal differences, insufficient samples pose a greater challenge to fully examine this issue, one that will require temporally controlled samples of especially pre-Latte skeletons. Some of the differences observed in these results might be due to greater representation of males to females and age-at-death differences that are likely to influence the incidence of many of the dental indicators surveyed. Tests of statistical significance in the frequencies of 13 indicators between the four largest islands reveal the majority are not statistically different. No significant differences in adult stature, and frequencies of long bone fractures, spondylolysis, and alveolar defects were observed in comparisons between islands.

Childhood Health: Cribra Orbitalia, LEH, and Stature

Cribra orbitalia, LEH, and stature generally reflect the prevalence of stress during child development. The highest frequencies of cribra orbitalia occur in the skeletons from Tinian and Saipan. The very low frequency (5.6%) observed in the Rota skeletons may be due to small sample size. With the possible exception of Rota, there is more childhood stress in the skeletons from the more northern islands.

The frequencies of LEH exhibit considerable variation in the skeletal series surveyed. The lowest frequency occurs in the Tinian series (8.9%) and the highest in the Saipan series (43.7%) suggesting that something about this island's geography and environment (e.g., mineral content of the water and adequacy of food, susceptibility to typhoons and the aftereffects of these) may have adversely impacted the people living here.

The lack of statistically significant differences in adult stature among the islands suggests recovery from the childhood stressors signified by frequencies of CO and LEH, especially in the series from Saipan. The adult males from Tinian and Saipan are slightly taller than those from Rota and Guam, while among adult females those from Guam are taller than those from Rota, Tinian, and Saipan. The prehistoric inhabitants investigated in this study were appreciably taller than male Chamorro living on Saipan in the 1930s and Micronesians from Kosrae Ponape, Truk, Yap, and Palau, described by Hunt (1950:164) as being short to medium stature. It should be noted, however, that the Spanish forcibly removed all Chamorros living on Tinian and Saipan between the late 1600s and early 1700s and relocated them on Guam. In the early 1800s many Carolinians, especially those from Satawal, began to repopulate Saipan. The people measured by Hasebe on Saipan in the early decades of the twentieth century may have included those of Carolinian ancestry.

Adult Health: Long Bone Fractures, Spondylolysis, and Infection

Adult health and lifestyle indicators include the prevalence of long bone fractures, a stress fracture of the lumbar vertebrae, and infection. The low frequency of long bone fractures (0.9%) in these skeletons suggests very similar patterns of physical activity and little deliberate or accidental injury. The rarity of these fractures supports the view that large-scale organized warfare was largely non-existent in prehistoric times (Hunter-Anderson and Butler 1995); at least there is no physical evidence of trauma in these skeletons.

The frequency of spondylolysis, often attributed to repeated stress in the lower lumbar region, is only slightly higher in the Guam series (6.7%) relative to the three remaining island series. Arriaza (1997) suggested that the high incidence of lumbar spondylolysis in ancient Chamorros may be related to traumatic events associated with activities such as the transport of *latte* stones, a risk which seems distributed fairly equally across the archipelago. Spondylolysis is much higher in skeletons from the Marianas than in other Pacific Island series, including those from Hawai'i (Pietrusewsky and Douglas 1994). In an earlier study (Pietrusewsky et al. 1997) there was no evidence for long bone fractures or spondylolysis in the skeletons from Rota, Tinian, and Saipan but the addition of new skeletons indicates comparable frequencies of both types of trauma across the four main islands.

The highest frequency (20.8%) of bony changes attributed to treponemal infection (most likely yaws) in individual skeletons was observed in the Rota series, a finding that may be influenced by small sample size. The only significant difference observed for this indicator was that between Rota and Guam, the latter having the lowest frequencies (8.1%) of infection.

Comparisons of the overall frequencies of these selected indicators of health suggest that inhabitants of the smaller islands, especially Saipan, have greater childhood stress than inhabitants of Guam, but the disadvantage is not carried into adulthood, where stature, patterns of long bone fracture and spondylolysis are similar.

Betel Nut and Dental Pathology

The differences in the remaining indicators, which account for the majority of the significant inter-island differences, appear to be related to the use of betel nut. Although not well understood, the chewing of betel, or areca, nut is believed to confer protection against dental caries. Other research has demonstrated periodontal disease and dental calculus may be greater in areca chewers (Chatrchaiwiwatana 2006).

Using this as background, the Marianas skeletons with higher levels of betel-stained teeth are predicted to exhibit lower frequencies of dental caries, and higher frequencies of dental attrition, alveolar resorption, and dental calculus. Given their association, a lower caries rate should also result in lower frequencies of alveolar defects and AMTL.

Except for alveolar resorption and dental calculus, the frequencies of four dental pathologies in a skeletal series with a high frequency of betel staining (Tinian) and one with a low frequency of betel-stained teeth (Rota) conform to these expectations (Figure 2). The Tinian skeletons have low frequencies of dental caries, alveolar defects, and AMTL and high frequencies of dental attrition. Likewise, Rota skeletons have a higher frequency of dental caries, moderately high frequencies of alveolar defects and AMTL, and a low frequency of dental attrition.

Tinian and Saipan skeletal series have the highest rates of betel-stained teeth in this study, but the anticipated pattern of dental pathologies is not consistent between the two. The Tinian skeletons have low frequencies of dental caries, alveolar defects, and AMTL and a high frequency of dental attrition, but alveolar resorption and calculus are unexpectedly low. The Saipan skeletons have higher frequencies of dental caries and AMTL and a lower rate of calculus than expected, but the high rates of attrition, alveolar resorption and defects in this series are consistent with betel nut chewing. The greater number of older aged individuals in the Saipan series may explain some of these differences.

The Guam and Rota skeletal series have lower rates of betel staining, but again, the anticipated pattern of dental pathologies is not consistent between the two. Rota skeletons have higher frequencies of dental caries, calculus, and alveolar resorption, moderately high frequencies of alveolar defects and AMTL, but a low frequency of dental attrition. The Guam skeletons are similar to those from Tinian in that there are low frequencies of caries, resorption, calculus, and defects but slightly higher rates of AMTL and low frequency of attrition.

Although it has been shown that loss of periodontal attachment and calculus formation are greater in areca nut chewers (Ånerud et al. 1991), a WHO study on the effects of

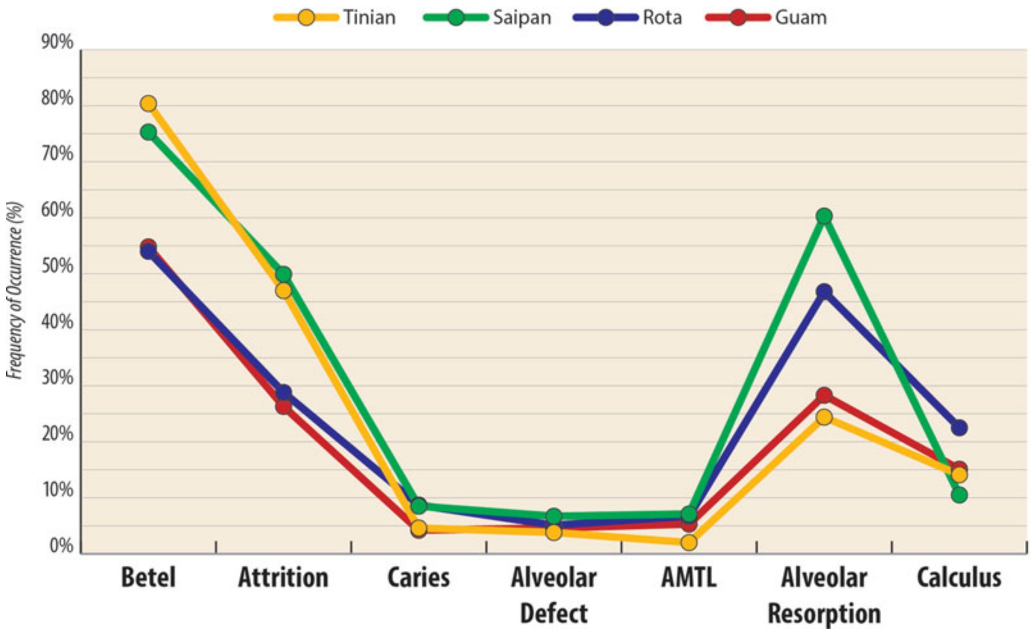

Figure 2. *Chart showing the frequencies of occurrence of betel staining and dental pathology in the skeletons from the Mariana Islands.*

betel quid and areca nut chewing (IARC 2004) found that there are a number of confounding variables such as the level of oral hygiene, dietary factors, general health, and dental status that may have a significant influence on periodontal status (e.g., 2004:174). According to the same report, areca chewers on Guam do *not* use slaked lime while chewing areca nut (pugua) (Stich et al. 1986), a practice that may help to explain the lower incidence of dental calculus and alveolar resorption in the Guam, Saipan, and Tinian series.

No significant differences in the frequencies of alveolar defects are noted among the four main islands. The frequencies of this dental pathology, which originates from infections of the pulp, correlates with the frequencies of dental caries reported for these series. The highest frequencies of alveolar defect are those reported for Rota and Saipan, which also have the highest frequencies of dental caries. Overall, the indicators of dental disease (ATML, dental caries, and alveolar defects) are uniformly low in the skeletons from the Mariana Islands. The inter-island differences in dental indicators may reflect differences in the age-at-death distribution and/or the individual variation in betel quid choice and betel chewing habits.

Island Differences

Comparisons between Rota and Guam and between Tinian and Saipan reveal significant differences in four indicators of health. Likewise, comparisons between Rota and Tinian and between Guam and Saipan reveal significant differences in seven health indicators. Overall, these results suggest greater similarities in health and lifestyle in skeletons from Rota and Guam in contrast to those from Tinian and Saipan. An analysis of Latte Period pottery by Graves et al. (1990) has demonstrated similarities for Guam and Rota and, conversely, for Tinian and Saipan. Because of its small size, the highest frequencies of skeletal and dental stress were expected to occur in the skeletons from Rota. Unexpectedly, several of the frequencies of the indicators of health observed in the skeletons from Rota were similar to those recorded in the skeletons from Guam, the largest island. Given the proximity of these two islands there is the possibility that when conditions (e.g., periods of extended droughts) on Rota became intolerable, the people left for Guam. Hunter-Anderson (2010:156) has suggested the formation of large island/small island "partnerships", such as those between Guam and Rota, may have provided a way for people living on smaller landmasses to minimize deficits and vulnerabilities that occurred in the past. Alternatively, compared to Tinian and Saipan, the relatively low population density on Rota and the existence of spring water caves (Keel et al. 2005), which today provide a reliable source of fresh mineral-infused water even during times of drought, may help to explain the lower prevalence of these disease/health indicators in the skeletons from this island.

CONCLUSIONS

Utilizing what is arguably the largest dataset of skeletal/dental indicators of stress recorded in 385 adult skeletons from the Mariana Islands allows more robust conclusions regarding the health and lifestyle of the Latte Period Chamorro. While differential preservation as well as possible temporal differences in provenience, and uneven and small sample sizes requires cautious interpretations of these results, there are fewer statistically significant differences in indicators of health among the four largest islands than previously thought. No significant differences in adult stature, long bone fractures, stress fracture of the lumbar vertebrae, treponemal infection, and alveolar defects (dental abscesses) were observed in the skeletal series.

The prehistoric inhabitants of the Marianas were relatively tall and exhibit very low frequencies of healed bone fractures, spondylolysis, and alveolar defects. Tall stature and little evidence of trauma suggest the prehistoric inhabitants of the Marianas were healthy and not prone to injuries resulting from accidents or warfare. However, there is evidence of treponemal disease, most likely yaws, in skeletons from all islands, which is likely to have negatively impacted the health of these people.

The frequencies of two childhood indicators of stress, cribra orbitalia and LEH, are significantly different between islands, with generally the highest frequencies among the skeletons from Tinian and Saipan. The significantly higher frequency of LEH in the skeletons from Saipan suggests greater childhood stress for the inhabitants of this island. Mostly lower and similar frequencies of these two childhood indicators were observed in the skeletons from Rota and Guam. Some of the observed differences in the frequencies of these indicators may reflect differences in sex, and/or environmental and nutritional differences between the main islands.

Overall, the dental health of prehistoric inhabitants of the Mariana Islands was generally good. The frequencies of dental caries, AMTL, and alveolar defects were low and advanced dental calculus and attrition were only moderately high. The cultural practice of chewing areca nut explains some of the observed variations in the pattern of dental pathology. As expected, low frequencies of dental caries, AMTL, and alveolar defect and a high frequency of dental attrition were observed in the skeletons from Tinian with the highest frequency of betel-stained teeth. Likewise, Rota, a series with the lowest frequency of betel-stained teeth, was observed to have higher frequencies of dental caries, alveolar defects, and AMTL, and a lower frequency of dental attrition.

This new analysis, while providing general confirmation of an earlier study (Pietrusewsky et al. 1997), which demonstrated that the inhabitants of the smaller islands in the Marianas were less healthy than those living on Guam, the largest island, also reveals new associations, most notably the similarities between Rota and Guam.

After Guam, the skeletons from Tinian, the third largest island investigated, and Rota, the smallest island, have the lowest levels of stress. The skeletons exhibiting the highest frequencies of stress are those from Saipan, the most northerly of the islands investigated and the one farthest from Guam. Some of the observed differences between islands may be attributed to differential access to environment and/or resource availability and the possible effects of microclimates and natural disasters on smaller more northerly islands.

Future research may address questions of intra- and interisland variability in skeletal indicators of health, temporal changes in health, and variability by sex and age. The gradual accumulation of archaeological skeletal series from all of the southern islands of the Marianas over the last several decades, the greater attention to temporal assignment (i.e., more specific than "pre-1521"), the recent discovery of pre-Latte skeletal remains, and the continued use of standardized recording methods, will, most certainly, improve our assessment of the health of early Mariana Islanders.

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SUPPLEMENTAL

Appendix Tables 1–2 are available as supplemental content at http://dx.doi.org/10.1080/15564894.2013.848959.

REFERENCES

Alkire, W. H. 1977. *An Introduction to the Peoples and Cultures of Micronesia,* 2nd ed. Menlo Park, CA: Cummings Publishing Co.

Ånerud, Å., H. Löe, and H. Boysen. 1991. The natural history and clinical course of calculus formation in man. *Journal of Clinical Periodontology* 18:160–170.

Arriaza, B. T. 1997. Spondylolysis in prehistoric human remains from Guam and its possible etiology. *American Journal of Physical Anthropology* 104:393–397.

Athens, J. S., M. F. Dega, and J. V. Ward. 2004. Austronesian colonisation of the Mariana Islands: The palaeoenvironmental evidence. *Bulletin of the Indo-Pacific Prehistory Association* 24: 21–30.

Baker, B. J. and G. J. Armelagos. 1988. The origin and antiquity of syphilis: Paleopathological diagnosis and interpretation. *Current Anthropology* 29:703–737.

Bath, J. 1986. *The San Vitores Road Project. Part 1: Final Report.* Prepared for Maeda Pacific Corporation and Maeda Road Construction Co., Ltd. Unpublished manuscript.

Bellwood, P. 1997. *Prehistory of the Indo-Malaysian Archipelago,* rev. ed. Honolulu: University of Hawaii Press.

Blust, R. 2000. Chamorro historical phonology. *Oceanic Linguistics* 39:83–122.

Brothwell, D. R. 1981. *Digging up Bones,* 3rd ed. Ithaca, New York: Cornell University Press.

Buikstra, J. E. and D. H. Ubelaker (eds.). 1994. *Standards for Data Collection from Human Skeletal Remains*. Fayetteville, AK: Arkansas Archaeological Survey Research Series No. 44, Arkansas Archaeological Survey.

Butler, B. M. (ed.). 1988. *Archaeological Investigations of the North Coast of Rota, Mariana Islands*. Micronesian Archaeological Survey Report No. 23. Carbondale: Southern Illinois University at Carbondale Center for Archaeological Investigations Occasional Paper No. 8.

Carson, M. T. 2012. An overview of *latte* period archaeology. *Micronesica* 42(1/2):1–79.

Chatrchaiwiwatana, S. 2006. Dental caries and periodontitis associated with betel quid chewing: Analysis of two data sets. *Journal of the Medical Association of Thailand* 89:1004–1011.

Craib, J. L. 1992. *Data Recovery Project SNM Hotel Area, Rota: End of Field Report.* Report submitted to SNM Corporation, Rota and Commonwealth of the Northern Mariana Islands Historical Preservation Office, Saipan.

Craib, J. L. 1994. Letter to Michael Pietrusewsky dated April 4, 1994, regarding the burials from SNM Hotel, Rota.

Davis, B. 1990. *Research Design and Data Recovery Plan for Archaeological Mitigation at the Leo Palace Hotel Site, Tumon Bay, Guam, Mariana Islands*. Unpublished manuscript. Honolulu: International Archaeological Research Institute, Inc.

Davis, B., M. J. Tomonari-Tuggle, S. Wickler, and C. K. Favreau. 1992. *Archaeological Investigations at the Leo Palace Hotel Site, Naton Beach, Tumon Bay. Volume I: Archaeological Data Recovery, Burial Recovery, and Monitoring.* Honolulu: International Archaeological Research Institute, Inc.

Dias, G. and N. Tayles. 1997. Abscess cavity: A misnomer. *International Journal of Osteoarchaeology* 7:548–554.

Dixon, B., D. J. Welch, and C. M. Magnuson. 2003. *Archaeological Data Recovery of Site TN-1-691, West Tinian Airport Improvement Area, Island of Tinian.* Prepared for Commonwealth Ports Authority, Saipan, CNMI. Honolulu: International Archaeological Research Institute, Inc.

Douglas, M. T. and R. M. Ikehara. 1992. *Archaeological Investigations at the Leo Palace Hotel Site, Naton Beach, Tumon Bay. Volume II: Osteological Study of Prehistoric Chamorro Skeletal Remains.* Honolulu: International Archaeological Research Institute, Inc.

Douglas, M. T., M. Pietrusewsky, and R. M. Ikehara-Quebral. 1997. Skeletal biology of Apurguan: A precontact Chamorro site on Guam. *American Journal of Physical Anthropology* 104:291–314.

Fitzpatrick, S. M., G. C. Nelson, and R. Reeves. 2003. The prehistoric chewing of betel nut (*Areca catechu*) in western Micronesia. *People and Culture in Oceania* 19:55–65.

Goodman, A. H., D. L. Martin, and G. J. Armelagos. 1984. Indications of stress from bones and teeth. In *Paleopathology at the Origins of Agriculture* (M. N. Cohen and G. J. Armelagos, eds.):13–49. Orlando: Academic Press.

Goodman, A. H. and J. C. Rose. 1991. Dental enamel hypoplasias as indicators of nutritional status. In *Advances in Dental Anthropology* (M. A. Kelley and C. S. Larsen, eds.):279–294. New York: Wiley-Liss.

Graves, M. 1986. Organization and differentiation within late prehistoric ranked social units, Mariana Islands, Western Pacific. *Journal of Field Archaeology* 13(2):139–154.

Graves, M. 1991. Architectural and mortuary diversity in late prehistoric settlements at Tumon Bay, Guam. *Micronesica* 242:169–194.

Graves, M. W., T. L. Hunt, and D. R. Moore. 1990. Ceramic production in the Mariana Islands: Explaining change and diversity in prehistoric interaction and exchange. *Asian Perspectives* 29(2):211–233.

Hanson, D. B. 1988. Prehistoric mortuary practices and human biology. In *Archaeological Investigations on the North Coast of Rota, Mariana Islands* (B. M. Butler, ed.):375–435. Micronesian Archaeological Survey Report No. 23. Carbondale: Southern Illinois University at Carbondale Center for Archaeological Investigations Occasional Paper No. 8.

Hanson, D. B. and B. M. Butler. 1997. A biocultural perspective on Marianas prehistory: Recent trends in bioarchaeological research. *American Journal of Physical Anthropology* 104:271–290.

Hasebe, K. 1938. *The Natives of the South Sea Archipelago*. Jinruigaku Senshigaku Koza (Lectures on Anthropology and Prehistory) 1:1–35 (in Japanese).

Hildebolt, C. F. and S. Molnar. 1991. Measurement and description of periodontal disease in anthropological studies. In *Advances in Dental Anthropology* (M. A. Kelley and C. S. Larsen, eds.):225–240. New York: Wiley Liss.

Hillson, S. W. 1996. *Dental Anthropology*. Cambridge: Cambridge University Press.

Hillson, S. W. 2008. Dental pathology. In *Biological Anthropology of the Human Skeleton,* 2nd ed. (M. A. Katzenberg and S. R. Saunders, eds.):301–340. New York: Wiley-Liss.

Hocart, C. H. and B. Fankhauser. 1996. Betel nut residues in archaeological samples of human teeth from the Mariana Islands. *Experientia Basel* 52(3):281–285.

Houghton, P., B. F. Leach, and D. G. Sutton. 1975. The estimation of stature of prehistoric Polynesians in New Zealand. *Journal of the Polynesian Society* 84:325–336.

Howden, G. F. 1984. The cariostatic effect of betel nut chewing. *Papua New Guinea Medical Journal* 27(3-4):123–131.

Hung, H.-c., M. T. Carson, P. Bellwood, F. Z. Campos, P. J. Piper, E. Dizon, M. J. L. A. Bolunia, M. Oxenham, and Z. Chi. 2011. The first settlement of Remote Oceania: The Philippines to the Marianas. *Antiquity* 85:909–926.

Hunt, E. E., Jr. 1950. A view of somatology and serology in Micronesia. *American Journal of Physical Anthropology* 8:157–184.

Hunter-Anderson, R. L. 2010. Cultural responses to a Late Holocene climatic oscillation in the Mariana Islands, Micronesia: Lessons from the past. *Human Ecology Review* 17(2):148–159.

Hunter-Anderson, R. L. 2012. Running to stay in place: An adaptive escalation model for the *latte* period. *Micronesica* 42(1/2):148–182.

Hunter-Anderson, R. L. and B. M. Butler. 1995. *An Overview of Northern Marianas Prehistory*. Micronesian Archaeology Survey Report Number 31. Saipan: The Micronesian Archaeological Survey, Division of Historic Preservation, Department of Community and Cultural Affairs.

Ikehara, R. M. and M. T. Douglas. 1995. *Skeletal and Dental Remains from the Academy of Our Lady of Guam Gymnasium Site, Agana, Guam*. Honolulu: International Archaeological Research Institute, Inc.

International Agency for Research on Cancer (IARC). 2004. *Betel-quid and Areca-nut Chewing and Some Areca-nut-derived Nitrosamines, Volume 85.* Lyon, France: Monographs on the Evaluation of Carcinogenic Risks to Humans.

Keel, T. M., J. E. Mylroie, and J. W. Jenson. 2005. *The Caves and Karst of Rota Island, Commonwealth of the Northern Mariana Islands*. Technical Report No. 107. Mangilao, Guam: Water and Environmental Research Institute of the Western Pacific, University of Guam.

Kirch, P. V. 2000. *On the Road of the Winds*. Berkeley: University of California Press.

Kumar, S., G. Pamar, and H. N. Saiyed. 2004. Nut and tobacco chewing. *British Dental Journal* 197:292.

Leigh, R. W. 1929. Dental morphology and pathology of prehistoric Guam. *Bernice P. Bishop Museum Memoirs* 11(3):258–273 and plates IV–VI.

Lévesque, R. 1997. *Translation of Berman Jesuit Documents*. Prepared for the Commonwealth Council for the Humanities. Manuscript on file with the Division of Historic Preservation, Saipan.

Lieverse, A. R. 1999. Diet and the aetiology of dental calculus. *International Journal of Osteoarchaeology* 9:219–232.

Lieverse, A. R., D. W. Link, V. I. Bazaliiskly, O. I. Goriunova, and A. W. Weber. 2007. Dental health indicators of hunter-gatherer adaptation and cultural change in Siberia's Cis-Baikal. *American Journal of Physical Anthropology* 134:323–339.

Lovell, N. C. 2008. Analysis and interpretation of skeletal trauma. In *Biological Anthropology of the Human Skeleton,* 2nd ed. (M. A. Katzenberg and S. R. Saunders, eds.):341–386. New York: Wiley-Liss.

McManamon, F. P. (ed.). 1989. *The Archaeology of Songsong Village, Rota, Northern Mariana Islands*. Unpublished manuscript.

Merbs, C. 1996. Spondylolysis and spondylolisthesis: A cost of being an erect biped or a clever adaptation? *Yearbook of Physical Anthropology* 39:201–228.

Möller, I. J., J. J. Dborg, and I. Effendi. 2009. The relation between betel chewing and dental caries. *European Journal of Oral Science* 85:64–70.

Moore, D. R. 1983. *Measuring Change in Marianas Pottery: The Sequence of Pottery at Tarague, Guam*. Master's Thesis. Mangilao: University of Guam.

Moore, D. R. 1988. Description and analysis of Songsong pottery. In *The Archaeology of Songsong Village, Rota, Northern Mariana Islands* (F. P. McManamon, ed.). Report prepared for the Division of Historic Preservation, Commonwealth of the Northern Mariana Islands, Saipan.

Ortner, D. J. 2003. *Identification of Pathological Conditions in Human Skeletal Remains,* 2nd ed. New York: Academic Press.

Oxenham, M. F. and I. Cavill. 2010. Porotic hyperostosis and cribra orbitalia: The erythropoietic response to iron-deficiency anemia. *Anthropological Science* 118(3):199–200.

Pietrusewsky, M. 1986a. *A Study of Human Skeletal Remains from Three Sites in the Northern Mariana Islands*. A Report to the Historic Preservation Office, Saipan, CNMI. Honolulu: Department of Anthropology, University of Hawai'i at Manoa.

Pietrusewsky, M. 1986b. *Report on the Human Skeletal and Dental Remains Excavated During the San Vitores Road Project, Tumon Bay, Guam, Mariana Islands*. Prepared for Maeda Pacific Corporation and Maeda Road Construction Company, Ltd., A Joint Venture.

Pietrusewsky, M. 1988. *Human Remains from Songsong Village, Rota, Commonwealth of the Northern Mariana Islands.* Honolulu: Department of Anthropology, University of Hawai'i at Manoa.

Pietrusewsky, M. 1994. *Human Skeletal Remains from the SNM Hotel, Rota, Northern Mariana Islands.* Report prepared for Bonhomme, Craib and Associates, Australia.

Pietrusewsky, M. 2006. *The Osteology of the Human Skeletal Remains from the Beach Road Sewer System Upgrade, Phase II (BRSS) Project, Saipan, Commonwealth of the Northern Mariana Islands*. Final Report Prepared for Swift and Harper Archaeological Resource Consulting, Saipan, MP 96950 and the Division of Historic Preservation, Saipan, MP.

Pietrusewsky, M. and C. Batista. 1980. *Human Skeletal and Dental Remains from Four Sites on Tinian and Saipan, Commonwealth of the Northern Mariana Islands*. Final report to the Northern Marianas Archaeological Society, Inc.

Pietrusewsky, M. and M. T. Douglas. 1989. *Human Remains from Oleai, Saipan, Commonwealth of the Northern Mariana Islands*. Honolulu: Department of Anthropology, University of Hawai'i at Manoa.

Pietrusewsky, M. and M. T. Douglas. 1994. An osteological assessment of health and disease in precontact and historic (1778) Hawai'i. In *In the*

Wake of Contact: Biological Responses to Conquest (C. S. Larsen and G. R. Milner, eds.):179–196. New York: Wiley-Liss.

Pietrusewsky, M. and M. T. Douglas. 2001a. *The Osteology of the Human Skeletal Remains from the Tinian Water Line Improvements Project, Tinian, Northern Mariana Islands, CNMI*. Report Prepared for Swift and Harper Archaeological Resource Consulting, Saipan, MP 96950.

Pietrusewsky, M. and M. T. Douglas. 2001b. *The Osteology of the Human Skeletal Remains from the Chalan Monsignor Guerrero Road Improvements Project, Phase III, Saipan, Northern Mariana Islands, CNMI*. Report Prepared for Swift and Harper Archaeological Resource Consulting, Saipan, MP 96950.

Pietrusewsky, M. and M. T. Douglas. 2002. *Ban Chiang, a Prehistoric Village Site in Northeast Thailand I. The Human Skeletal Remains.* Philadelphia: The University of Pennsylvania Museum of Archaeology and Anthropology.

Pietrusewsky, M. and M. T. Douglas. 2010. *The Osteology of the Human Skeletons from the Reconstruction of Route 202 with Drainage Improvements Project, Tinian, Commonwealth of the Northern Mariana Islands.* Final Report Prepared for Swift and Harper Archaeological Resource Consulting, Saipan.

Pietrusewsky, M., M. T. Douglas, and R. M. Ikehara. 1992. *Prehistoric Chamorro Remains from the Apurguan Site, Tamuning District, Guam: An Osteological Investigation and Comparisons with other Micronesian Series*. Honolulu: Department of Anthropology, University of Hawai'i at Manoa.

Pietrusewsky, M., M. T. Douglas, and R. M. Ikehara. 1997. An assessment of health and disease in the prehistoric inhabitants of the Mariana Islands. *American Journal of Physical Anthropology* 104:315–342.

Pietrusewsky M., M. T. Douglas, M. Swift, R. Harper, and M. A. Fleming. 2010. An assessment of health and lifestyle among pre-1521 Chamorro from Saipan, Commonwealth of Northern Mariana Islands. *American Journal of Physical Anthropology* S50:189.

Pietrusewsky M., M. T. Douglas, M. Swift, R. Harper, and M. A. Fleming. 2011. An assessment of health and lifestyle among prehistoric Chamorro from Tinian Island in the Northern Mariana Islands. *American Journal of Physical Anthropology* S52:238–239.

Pietrusewsky, M. and R. Ikehara-Quebral. 1995. Human Skeletal Remains found during Monitoring Activities at the SNM Hotel, Rota, Northern Mariana Islands. Unpublished manuscript.

Rothschild, B. M. and G. M. Heathcote. 1993. Characterization of the skeletal manifestations of treponemal disease yaws as a population phenomenon. *Clinical Infectious Disease* 17:198–203.

Roy K. J. 1989. *A Study of Early Marianas Islanders, the Skeletons Under their Skins*. Master's Thesis. Otago: University of Otago.

Russell, S. 1978. Letter to Dr. Michael Pietrusewsky dated December 12, 1978, from Scott Russell, Acting Historic Preservation Officer of Saipan.

Russell, S. 1998. *Tiempon I Manmofo'na: Ancient Chamorro Culture and History of the Northern Mariana Islands*. Micronesian Archaeological Survey Report 32. Saipan, CNMI: Division of Historic Preservation, Commonwealth of the Northern Mariana Islands.

Sava, V. 1999. Appendix E. An osteological study of prehistoric human skeletal remains recovered during waterline construction in Songsong Village, Rota, Commonwealth of the Northern Mariana Islands. In *Archaeological Data Recovery Songsong Water System Improvement Project, Island of Rota, CMNI* (Henry, J. D., A. E. Huan, A. M. Kirkendall, and M. A. DeFante, eds.):E1–E51 and Appendices A–D. Hilo: Paul H. Rosendahl, Ph.D., Inc.

Schamschula, R. G., B. L. Adkins, D. E. Barmes, and G. Charlton. 2010. Betel chewing and caries experience in New Guinea. *Community Dentistry and Oral Epidemiology* 5:284–286.

Steckel, R. H. and J. C. Rose (eds.). 2002. *The Backbone of History: Health and Nutrition in the Western Hemisphere*. Cambridge: Cambridge University Press.

Stewart, T. D. and A. Spoehr. 1952. Evidence on the paleopathology of yaws. *Bulletin of the History of Medicine* 26:538–553.

Stich, H. F., M. P. Rosin, and K. D. Brunnemann. 1986. Oral lesions, genotoxicity and nitrosamines in betel quid chewers with no obvious increase in oral cancer risk. *Cancer Letters* 31:15–25.

Stodder, A. L. W. 1997 Subadult stress, morbidity, and longevity in Latte Period populations on Guam, Mariana Islands. *American Journal of Physical Anthropology* 104:363–380.

Stuart-Macadam, P. 1989. Nutritional deficiency diseases: A survey of scurvy, rickets, and iron-deficiency anemia. In *Reconstruction of Life from the Skeleton* (M. Y. İşcan and K. A. R. Kennedy, eds.):201–222. New York: Alan R. Liss.

Stuart-Macadam, P. 1991. Porotic hyperostosis: Changing interpretations. In *Human*

Paleopathology: Current Syntheses and Future Options (D. J. Ortner and A. C. Aufderheide, eds.):36–39. Washington, DC: Smithsonian Institution Press.

Thomas, D. H. 1986. *Refiguring Anthropology: First Principles of Probability and Statistics*. Prospect Heights: Waveland Press.

Trivedy, C. R., G. Craig, and S. Warnakulasuriya. 2002. The oral health consequences of chewing areca nut. *Addiction Biology* 7(1):115–125.

Vilar, M. G., C. W. Chan, D. R. Santos, D. Lynch, R. Spathis, R. M. Garruto, and J. K. Lum. 2013. The origins and genetic distinctiveness of the Chamorros of the Marianas Islands: An mtDNA perspective. *American Journal of Human Biology* 25(1):116–22. Article first published online, Nov. 24, 2012, doi:10.1002/ajhb.22349.

Walker, P. L. 1989. Cranial injuries as evidence of violence in prehistoric southern California Indians. *American Journal of Physical Anthropology* 80:313–323.

Walker, P. L., R. R. Bathurst, R. Richman, T. Gjerdrum, and V. A. Andrushko. 2009. The causes of porotic hyperostosis and cribra orbitalia: A reappraisal of the iron-deficiency-anemia hypothesis. *American Journal of Physical Anthropology* 139:109–125.

Ward, G. and M. Pickering. 1985. *The Japanese Bone Collecting Expedition on Tinian, March 1985: Its Impact Upon Historic Resources*. Manuscript prepared for the Historic Preservation Co-ordinator, Tinian, and the Historic Preservation Office, Commonwealth of the Northern Mariana Islands.

Welch, D. 1991. *Historic Preservation Mitigation Plan, Academy of Our Lady of Guam Gymnasium Project*. Honolulu: International Archaeological Research Institute Inc.

White, D. J. 1997. Dental calculus: Recent insights into occurrence, formation, prevention, removal and oral health effects of supragingival and subgingival deposits. *European Journal of Oral Sciences* 105:508–522.