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Paleopathological Observations on Human Skeletal Remains from Rota, Mariana Islands: Epidemiological Implications

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Abstract—Recently recovered mortuary data from Rota are examined within the context of existing epidemiological models for island populations. It is suggested that the seasonal availability of potable water from catchments along the island's northern coast was a major epidemiological factor in the morbidity and mortality of late prehistoric and early historic coastal populations on Rota.

Introduction

Sociocultural and biological adaptation to environmental variation in island ecosystems has become a major focus of island archaeology in the past decade (Terrell 1986, Kirch 1986). Primarily because of their bounded, circumscribed nature, island ecosystems are ideally suited to the study of human adaptation. This characteristic of island ecosystems and insular societies allows us to define and quantify, with a reasonable degree of certainty, a set of limiting resources which served as constraints upon the adaptive flexibility of past island populations. The primary environmental fluctuations which alter the distribution of these resources in island ecosystems—tropical storms and drought—occur frequently and often regularly even though the severity and duration of these stresses cannot be anticipated. Nevertheless, our ability to delineate a reasonably well-defined set of environmental constraints operating on the adaptive systems of island populations should facilitate development of predictive models of sociocultural change and biological adaptation and make these models much more amenable to rigorous testing. By evaluating demographic restructuring and changing patterns of community health and disease of island populations, we can begin to assess the relative costs and benefits and perhaps determine the effectiveness of adaptive strategies which seek to reduce or modify the strains associated with competition for and utilization of a very limited set of critical resources.

This paper has two objectives. The first is to report on some recent paleopathological observations on a small sample of human skeletal remains recently recovered from the island of Rota. The second objective is to briefly examine some of the factors which may have influenced health and survival among infants and children in late prehistoric coastal villages of the Marianas archipelago. Although this paper focuses primarily on juvenile remains, the findings have implications for late prehistoric community health in general.

Materials and Methods

Rota Island is located approximately 70 km north of Guam at latitude 14° north and longitude 145° 30′ east and is the fourth largest island in the Marianas archipelago. From

October through December 1984, archaeological investigations were conducted on the northern coast of the island along a 2 km right-of-way for improvement of the road linking Rota Airport with Songsong Village (Butler 1988). During the excavations, 25 burials were encountered representing the partial and complete skeletons of 27 individuals (Hanson 1988).

Seven of these burials were associated with Pre-Latte deposits and 18 with Latte period deposits (Butler 1988). In general, the earliest occupation of the Marianas is dated to ca. 1000 B.C. with the probable occurrence of the Pre-Latte/Latte transition sometime around A.D. 1000. The Latte period continues until the time of regular Spanish contact ca. A.D. 1565 and is primarily characterized by the initial appearance and rapid spread of the distinctive stone-pillared domiciles known as *latte*. Graves (1986) suggested that *latte* structures were constructed by kin-based corporate groups whose members were hierarchically ranked and who exercised varying degrees of control over limited resources.

Thirteen subadults, from both Latte and Pre-Latte contexts, were represented in the mortuary sample (Figure 1). For this study, several stress indicators in the dental and skeletal remains of ten subadults, ranging in age from neonatal (2 individuals) to 48

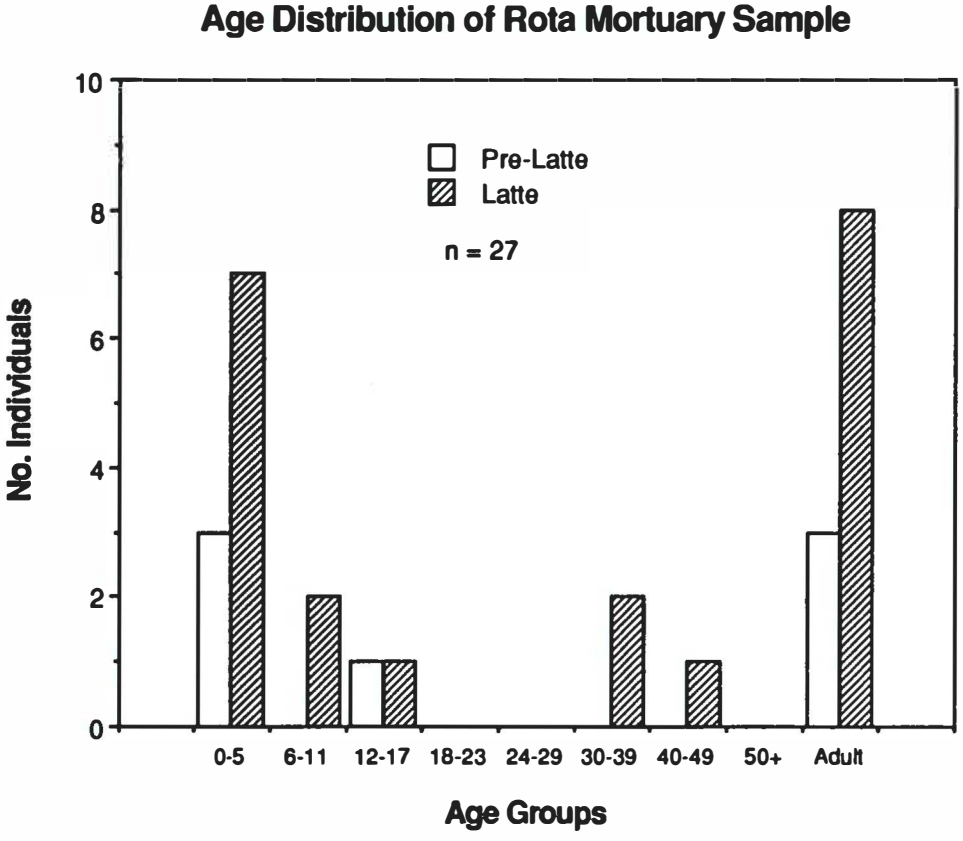

Figure 1. Age distribution of the Rota mortuary sample.

postnatal months (neonate-2; 6–12 mos.-2; 12–24 mos.-1; 42–48 mos.-4) are briefly described and discussed.

Age at death in this sample was determined using dental eruption standards established for Native Americans (Ubelaker 1978, 1989). Given the small sample size involved only the presence or absence of carious lesions and their location were scored for each of the erupted deciduous teeth. Lesion location was scored as either occlusal or crown. Enamel hypoplasias and hypocalcification were noted as present or absent. Enamel hypoplasias are operationally defined as transverse linear grooves or pitting of decreased enamel thickness caused by arrested deposition of calcium during the matrix deposition phase of enamel development (Goodman *et al.* 1980). These defects occur when disease and/or malnutrition interfere with the availability of calcium or the normal functioning of the cells (ameloblasts) responsible for deposition of enamel matrix. Hypocalcification of enamel occurs during the mineralization phase of enamel development and appears as spots or bands of chalky-white or yellow-brown enamel resulting from the incorporation of extrinsic pigments (Nikiforuk *et al.* 1981).

Two types of skeletal lesions were observed in the subadult remains studied: a proliferative bony reaction (periostitis) representing a generalized inflammatory response to infection and a specific cranial lesion referred to as porotic hyperostosis. These lesions when present were defined as either active or inactive (healing or healed) at the time of death based on criteria detailed in Ortner & Putschar (1981, 1985) and Mensforth *et al.* (1978). Active lesions are those which have undergone little or no remodeling while quiescent lesions display remodeled bone surfaces in which much of the porous reactive bone associated with the active lesion has been filled in with new bone.

Results

The frequency of caries in fully erupted deciduous teeth is presented in Figure 2. Only one Pre-Latte juvenile (aged 2.0 yrs) had a set of fully erupted deciduous teeth available for examination. Eleven of the 17 deciduous teeth displayed one or more caries and all but two of these teeth exhibited the yellow-brown discoloration characteristic of enamel hypocalcification. Pitting hypoplasia was observed in one of the deciduous second molars from the maxilla. In this same individual, all of the cusps have been worn flat on upper and lower first molars and faceting was observed on the recently erupted second molars. In addition, active periostitis was noted on the left humerus. In a Pre-Latte infant (aged 6 mos.) from the same burial locus, one of the incisors displayed developmental "fissioning" (Figure 3).

Deciduous teeth were also available for five Latte period subadults with ages at death ranging between 3.0 and 4.0 yrs. Three of these individuals were affiliated with the same latte structure while the other two were isolated burials. Seventy-five fully erupted deciduous teeth were examined. Forty-four precent of these teeth displayed severe carious lesions (Fig. 4) with a mean of 6.6 carious teeth per individual. The lesions frequently occurred as linear bands across the labial and buccal surfaces of the teeth. The maxillary dentition was affected more frequently than the mandibular teeth (25% and 19% respectively), with incisors and canines affected about as frequently as molars. Caries in the maxillary dentition were exclusively crown-associated and did not affect the occlusal sur-

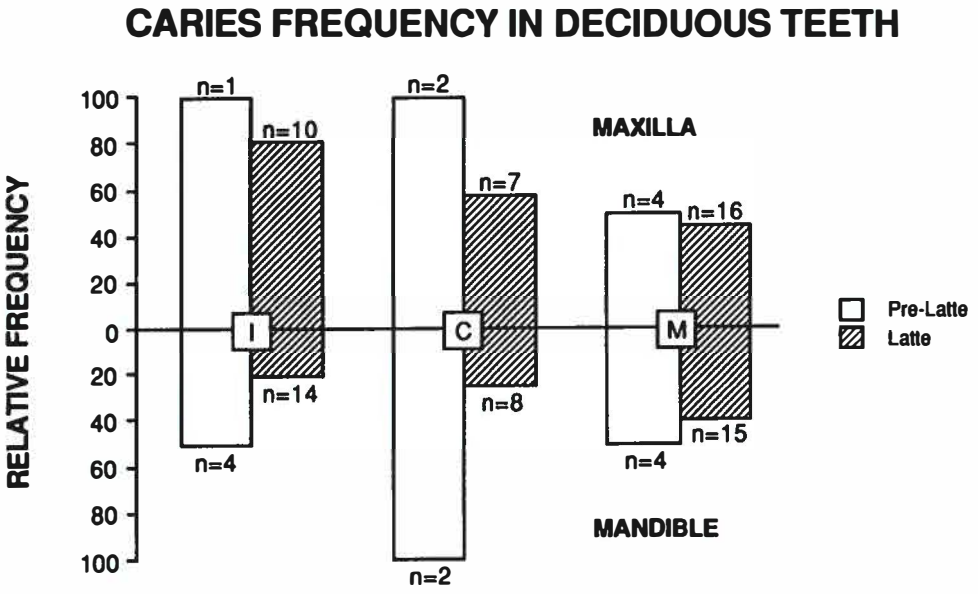

Figure 2. Caries frequency in the deciduous teeth.

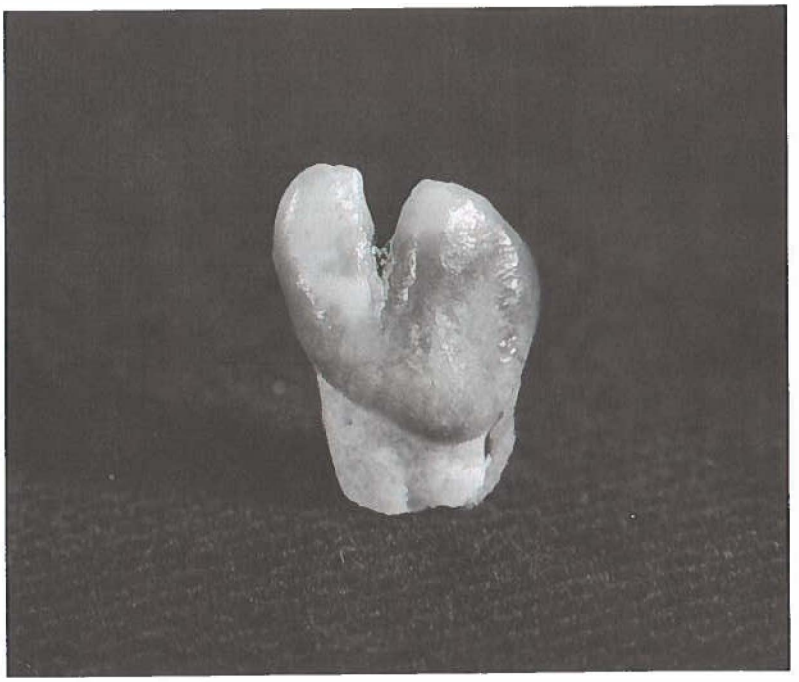

Figure 3. Developmental "fissioning" of unerupted upper central deciduous incisor.

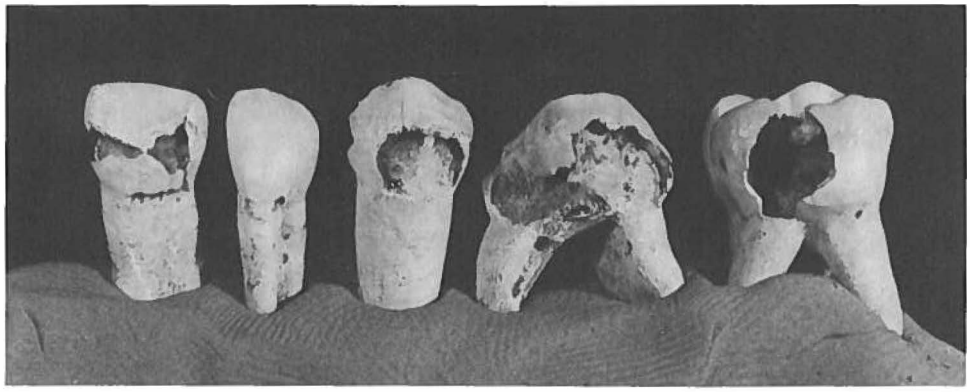

Figure 4. Circular caries in upper right deciduous teeth.

faces. Occlusal surface caries, when they did occur, were restricted to mandibular molars. In nearly all of the deciduous teeth examined, varying degrees of enamel hypocalcification were observed and were characterized primarily by brown pigmentation of the enamel.

The prevalence and intensity of carious lesions in children contrasts very sharply with that observed in adults. The overall frequency of caries in the 253 fully erupted permanent teeth examined was 4.0% (Hanson 1988). In addition, pitting hypoplasia was observed in two molars and two canines from two different adult individuals.

Skeletal preservation of the three juveniles associated with the *latte* structure was sufficient to determine the presence of bony pathology. Diffuse, active periostitis was observed on the lateral surfaces of both tibiae in a child aged between 3.5 and 4.0 yrs and who displayed the most severe caries in the sample (Fig. 4). In this individual, thirteen of the 16 available deciduous teeth were affected by crown and occlusal surface caries. Much of the enamel had been destroyed by the decay process. In addition, several of the loose developing permanent teeth displayed dark brown pigmentation with severe hypoplastic pitting in the gingival third of the developing enamel.

A second child aged 3.0 years (caries: 8/19), displayed no evidence of skeletal pathology while the third child aged 4.0 years (caries: 9/20), exhibited the symmetrical cranial pathology known as porotic hyperostosis which is generally associated with iron deficiency anemia (Stuart-Macadam 1987). The lesion was in a healing phase at the time of death showing evidence of remodeling with bone filling in the peripheral pores. This indicated an earlier episode of anemia. In addition, the developing enamel of the permanent first maxillary molars in these last two children displayed dark, hypocalcified bands.

Discussion

The carious lesions of the dental crown and the associated hypocalcification observed in the deciduous teeth from the Rota sample are very similar in appearance to the lesion morphology described for circular caries in deciduous teeth in both living and skeletal populations (Baume 1969, Baume & Meyer 1966, Cook & Buikstra 1979, Infante &

Gillespie 1974, 1976, 1977, Saul 1972). In both the Pre-Latte and Latte Period deciduous dentitions from Rota, the lesions consist of transverse rings of carious foci on the buccal and mesio-distal surfaces of the anterior and posterior teeth (see Fig. 4). In the more severe cases, the decay process led to considerable destruction of the enamel and involved the dentin and pulp cavity. According to Cook & Buikstra (1979) the development of circumferential lesions such as these is related to perinatal stress which can disturb both the formation and calcification of enamel and make the teeth more susceptible to caries. Some studies (Infante 1974, Infante & Gillespie 1977, Enwonwu 1973) demonstrate a relationship between the appearance of enamel hypoplasias in deciduous teeth complicated by caries and population-level poor nutrition and acute diarrheal disease in the first few weeks of life.

Contemporary epidemiological studies of caries prevalence and intensity in the deciduous teeth of children from Pacific islands reveal a consistent co-occurrence of enamel hypoplasias and dental caries (Barmes 1965, 1967, Baume 1969, Baume & Meyer 1966, Davies 1956, 1965). According to Baume (1969) this condition, known as "odontoclasia", is more likely to occur in areas of the Pacific where traditional foods, as opposed to packaged foods, still make up the bulk of the diet. Among several islands of French Polynesia, the prevalence and intensity of caries was very similar (85% of children 4 years of age had an average of 6 decayed teeth per child), but "among the small children of isolated islands . . . there was a high incidence of linear hypoplasia affecting particularly the upper primary anterior teeth." (Baume 1969: 184) In his study of 1,976 Manus Islanders of New Guinea, Kirkpatrick (1935) noted that 22% of the children under 6 years of age had odontoclasia with an average of 7 affected teeth per individual.

In an investigation of dental health on a coral atoll in Polynesia (PukaPuka) (total population 661), Davies (1956, 1965) reported a caries prevalence of 50% (i.e. one or more decayed teeth) in the 500 adults and children examined. Twenty-eight percent of the deciduous teeth were carious compared with 9% of the permanent teeth. According to Davies, susceptibility to caries was largely determined by the presence of hypoplastic defects in the enamel. Thirty-seven percent of the subjects he examined had enamel defects and deciduous teeth were more prone to defects than permanent teeth. In deciduous dentitions, 30% of the teeth displayed enamel defects while only 4% of the teeth in permanent dentitions were defective. Furthermore, 32% of the hypoplastic deciduous teeth displayed carious lesions compared with 12% of the deciduous teeth without hypoplasias. Davies (1956) attributed the defective enamel in the deciduous teeth to nutritionally inadequate maternal diets during pregnancy and lactation which were very low in protein but high in unrefined carbohydrates. Subsequent development of caries in these teeth as well as primary teeth without defective enamel was associated with the practice of infants and young children drinking coconut milk which had a glucose content exceeding 10%.

The enamel defects and severe caries observed in the deciduous teeth of the Rota sample and their co-occurrence with skeletal pathologies suggest a combination of factors which might have influenced the morbidity and mortality experienced by weanling age children living in pre-contact villages along Rota's north coast. First, the fluoride content in the food and drinking water of maternal and infant diets may have been high enough to interfere with the normal development and mineralization of enamel making the primary teeth more susceptible to decay. Second, limited water resources combined with the introduction of solid foods to the infant diet would have increased the risk of food and water

contamination by enteric bacteria and helminthic parasites thus increasing the probability of developing weanling diarrhea and sustaining blood loss. Finally, weaning foods prepared with coconut milk and consisting primarily of starches softened through boiling or mashing are highly cariogenic and may have been nutritionally inadequate.

There are few perennial sources of water on Rota and these are restricted primarily to small springs in the water caves located in the volcanic area on the south side of the island. Villages on Rota's northern coast probably had to rely almost exclusively on rainwater trapped in catchments—usually coastal wells or ceramic vessels (Butler 1988b). There was very little to buffer against seasonal shortfalls in rain or periodic droughts. In addition, seasonal storms probably affected the quality of the available water supply. Seepage of marine salt-water into coastal wells is very common in Micronesia, particularly during the heavy wave activity associated with storms (Sutton 1979). Coastal wells on Rota have been historically described as very shallow and located close to the beach (Arago 1823 cited in Butler 1988a), which would have made them particularly susceptible to sea-water contamination. In fact, drinking water on Rota was often described as brackish by early European observers (Marche 1982).

The optimal fluoride concentration for mineralization of developing enamel ranges from 1–2 ppm. The fluoride concentration in a liter of sea-water is approximately 1.3 ppm (Riley 1983) and may be somewhat higher in lagoons. Fluoride concentrations in drinking water may have far exceeded optimum levels due to the regular influx of marine salt-water into coastal wells and the accumulation of precipitates with evaporation. Since the developing enamel of primary teeth are particularly sensitive to excessive intake of fluoride during pregnancy and lactation (Driscoll & Horowitz 1983), the fluoride content of drinking water and marine and terrestrial foods in the maternal diet may have been sufficient to produce hypoplasia and hypomineralization of the enamel and result in clinically significant dental fluorosis in developing teeth of infants and weanling age children.

Sutton (1979) has noted the regular occurrence of dental fluorosis in the developing teeth of some island populations in Micronesia and Polynesia which he attributes to the consumption of water contaminated by sea-water. According to Sutton, the eruption of permanent teeth with brown-pigmented enamel in children accounts for the unusually high frequency of labial abrasion observed in the anterior teeth of these islanders. Apparently labial abrasion represents an attempt to remove the cosmetically disfiguring stain from the teeth with abrasives or an abrading tool. Although various forms of abrasion have been noted in the permanent teeth of prehistoric Chamorro remains (Birkby 1977, Pietrusewsky & Batista 1980, Hanson 1988), it is infrequent and not necessarily associated with poor calcification of dental enamel.

Discoloration of the enamel related to hypomineralization of enamel matrix has been observed in the permanent teeth of several contemporary Polynesian groups (Baume & Meyer 1966, Baume & Vulliemoz 1970, 1972, Smillie *et al.* 1986) and is usually associated with very high caries susceptibility (Baume & Meyer 1966, Smillie *et al.* 1986). The "yellow-brown" teeth observed in the Maori is thought to be a variant form of amelogenesis imperfecta—a hereditary defect of the enamel (Rodda & Smillie 1984, Smillie *et al.* 1986), while the "yellow" teeth prevalent in Tahitians is ascribed to nutritional factors affecting mineralization during enamel development (Baume & Meyer 1966, Baume & Vulliemoz 1972).

The lack of alternative water resources on the north coast of Rota and heavy use of

the available sources of water by large aggregates of people living in villages could have created a potential sanitation problem and contributed to the additional risk of food and water contamination by enteric bacteria. Children are particularly susceptible to contraction of diarrheal infection when weaned from sterile milk to food and water contaminated with microorganisms (Keusch & Katz 1979, Mata *et al.* 1980). Walker (1986) has argued that due to limited water resources on islands off the coast of California, water pollution and diarrheal disease contributed to a heightened prevalence and severity of cribra orbitalia and porotic hyperostosis in island populations (relative to mainland groups) whose diets appear to have been nutritionally adequate. With the high nutrient losses associated with weanling diarrhea, children can become anemic and susceptible to further infection even on a diet that would otherwise contain more than enough iron and other essential nutrients.

Relatively little ethnohistoric information is available regarding traditional weaning practices of the Chamorro. Studies of other Pacific societies (see papers in Marshall 1985) indicate that infants are generally breast-fed until the next pregnancy, ranging from 2–4 years, but they are often started on specially prepared liquids and softened/or premasticated foods as early as one month after birth. While prolonged lactation can reduce fertility (Anderson 1983), it also results in a marked decline in the content of iron and other nutrients in breast milk (Filer 1977, Siimes *et al.* 1979) and even with supplementation can often lead to iron deficiency anemia in children (Pijoan & Elkin 1944). This frequently accounts for malnourishment in children between the ages of one and three despite an abundance of food resources (Lepowsky 1985).

In his recent analysis of Pre-Latte and Latte period skeletal remains from Guam, Pietrusewsky (1986) noted a somewhat greater frequency of cribra orbitalia and porotic hyperostosis in pre-Latte adult crania. Although it is not indicated whether the lesions observed are remodeled or not, it is probable that these represent childhood episodes of iron-deficiency anemia (Stuart-Macadam 1985, Walker 1986) suggesting greater survival among those individuals who contracted anemia as a child. The available data, however, do not yet allow us to determine whether iron-deficiency anemia was more prevalent among Pre-Latte or Latte Period children.

There is some indication in the Rota sample that solid foods may have been introduced earlier among Pre-Latte than in Latte period infants. This is suggested by the marked attrition observed in the deciduous teeth of the pre-Latte 2.0 year-old noted earlier. Aside from some very minor faceting, significant attrition was not observed in Latte Period deciduous teeth. Alternatively, the differences in attrition may be related to the preparation of softer weaning foods by boiling in Latte Period times. This interpretation is supported in part by functional changes observed in the ceramic assemblages on Rota which indicate a shift from shallow bowls and pans to large vessels capable of sustaining the thermal stresses associated with boiling and simmering (Sant & Lebetski 1988).

If weaning foods were introduced as early as 1.5–2.0 years to pre-Latte infants and possibly later in Latte Period infants, then the nutritional adequacy of the diet at this age would have been of considerable importance to health and survival. In some Pacific island populations special preparations of coconut juice may be introduced several months after birth (Marshall 1985). But, experimental investigations (e.g., Than *et al.* 1975) demonstrate that coconut milk inhibits the intestinal absorption of several essential nutrients,

particularly iron, making these nutrients metabolically unavailable. In addition, the starchy roots, tubers and fruits which provide the bulk of calories in Pacific island diets lack sufficient protein, considerably less than cereal-based diets (WHO 1969, Pollock 1986b). Although protein from fish supplemented the staple adult diet of breadfruit, taro, and yams (Pollock 1986a), it is unlikely that fish played a significant role in weaning diets.

Proscriptions against feeding children fish are common in Oceania (Marshall 1985, WHO 1969) primarily because many species are recognized to be heavily infested by helminths or other parasites. For similar reasons, pregnant and lactating females also experience restricted access to fish. Thus, in those groups with the greatest risk of developing a protein deficiency, dietary protein is limited. However, on islands like Rota where periodic disruptions in the productivity of first-line terrestrial resources occur as a result of storms or drought, coastal villagers may have been almost entirely dependent on marine resources as well as the more storm- and drought-resistant terrestrial species such as cycad seeds (*Cycas circinalis*) and arrowroot (*Tacca leontopetaloides*) (Pollock 1986a). With a scarcity of terrestrial food resources, proscriptions against fish consumption may have been deferred. Although fish-derived protein would have become less limiting in maternal and infant diets, regular consumption of fish would have increased the risk of pregnant females and children contracting marine-derived parasitic infections. Furthermore, the use of toxic plant species as alternate food resources during times of scarcity (Pollock 1986a) probably influenced the incidence of spontaneous abortions and congenital defects, as well as infant mortality and acute illness in weanlings.

It is not known to what extent indigenous toxic plants served as a food resource during shortages, let alone whether they were used in weaning diets. However, during the first international conference on the Identification of Toxic Elements in Cycads held at NIH in 1962, Marjorie Whiting, an anthropologist conducting research on Chamorro diets at the time, made reference to the dependence on cycad starch during World War II and its use by children: "during the process of beating off the husks [of the cycad seed] some persons became dizzy and have to leave their work for a time to recover. Children are not allowed to participate in this stage of the processing. Only small amounts are given to children because many became ill when they first eat a dish made with cycad starch." (cited in Spencer 1987: 351).

Analysis of the subsistence remains from the recent excavations on Rota suggest a temporal change in patterns of marine-derived protein consumption (Butler 1988a). In one site locality where both pre-Latte and Latte period fish and shell-fish assemblages could be compared, there is an apparent decline in the quantity of both fishbone (Davidson & Leach 1988) and shellfish (Carucci 1988) with a shift from utilization of large pelagic fish to the consumption of smaller reef fish. It is not clear whether this variation is due to the changes in settlement organization and resulting patterns of disposal (Butler 1988b) or to subsistence change related either to overexploitation or an alteration in the productivity of marine resources.

If there was a decline in the per capita availability of marine-derived protein, differential access to marine resources on the basis of age, sex, and /or status during Latte Period times would be one expected sociocultural response. During this period, protein may have been a severely limiting nutrient in the diets of pregnant and lactating females, weanlings, and growing children—those individuals with the greatest physiological re-

quirement for protein. Increased reliance on the highly cariogenic starchy roots and tubers as well as toxic plant species would have further undermined the nutritional status and general health of these high risk groups and would have been a potent factor in differential perinatal survival.

Summary and Conclusions

Examination of a limited series of skeletons from both Pre-Latte and Latte deposits on the north cost of Rota has revealed evidence of stress experienced by subadults, ranging in age from birth to 48 months. Dental caries in deciduous dentitions averaged 6.6 affected teeth per individual and was associated with hypoplasia and/or hypomineralization of the enamel. Several of these individuals also displayed skeletal evidence of infectious disease and iron deficiency anemia. Some of the available evidence suggests that Latte Period subadults may have been exposed to greater levels of stress with an enhanced risk of dying as an infant than in Pre-Latte times. The evidence is not conclusive and in fact, contradicts the results of Pietrusewsky's (1986) preliminary findings on remains recovered from Tumon Bay on Guam. Pietrusewsky finds that infant mortality may have been somewhat higher during Pre-Latte times.

It is suggested that the morbidity and mortality experienced by infants and weaning age children on Rota is related to several epidemiological factors. First, perhaps excessive fluoride intake from food and water sources by pregnant and lactating females interfered with the normal formation and mineralization of enamel in the developing deciduous teeth, making them susceptible to caries when weaning foods were introduced. Second, the transition to a highly cariogenic starch diet with weaning may have not only resulted in caries formation (thus lowering resistance to disease), but secondarily served to introduce disease organisms through contaminated food and water. Finally, maternal and infant diets may have been deficient in several essential nutrients which would have further influenced the synergy between nutrition and disease.

It is hoped that ongoing investigations with this small sample will shed some more light on the problems presented here. Included in these investigations is a more detailed examination of defective enamel formation which will involve histologic and trace element analysis of the deciduous and permanent teeth of this island group. Data from these analyses combined with more thorough morphologic evaluation should help provide us with a much better understanding of the factors responsible for caries resistance and susceptibility in these islanders.

The epidemiological emphasis on water quality and diet presented here also leads us to elemental analyses of bone. One problem currently under investigation is the possible relationship between the high incidence of amyotrophic lateral sclerosis in the Mariana Islands and exposure to toxic levels of trace metals in water used for drinking and cooking (Gajdusek 1984, Yase 1972). Early church records from Guam allude to a symptomology that is characteristic of ALS (Gajdusek, personal communication) indicating the possibility of some antiquity for ALS. Examination of trace element profiles from skeletal remains controlled for ion exchange with the burial matrix may present a means of isolating unusually high peaks or marked depletion of elements implicated in the pathogenesis of ALS.

Gradual accumulation of a neurotoxin found in cycad flour has also been implicated in the pathogenesis of ALS (Spencer *et al.* 1987). More recently, it was suggested the cycad seeds may also contain a compound that has a direct effect on bone collagen synthesis and/or maturation similar to the effects observed for the lathrogenic compound β-aminoproprionitrile (Spencer 1987).

β-aminoproprionitrile (BAPN) is the naturally occurring toxic principle of the pea species, *Lathyrus odoratus*. BAPN does not affect the central nervous system, but is known to cause experimental disorders of skin, bone and blood vessels by inhibiting production of the lysyl oxidase required for the inter-molecular cross-linking of collagen. The characteristic experimental bone disease (osteolathyrism) results from the defective cross-linking of bone collagen and it is possible that a lathrogen-like compound similar to BAPN and which could have effects on bone, may be contained in the cycad seed (see Spencer 1987).

If infants and young children were fed foods prepared with cycad flour, then the cumulative effects of the compound may appear macroscopically as bony defects or as a specific defect in collagen formation that can be observed with appropriate analysis of collagen extracts from buried bone.

It is hoped that the preliminary findings presented here will provide a framework for more rigorous analyses of biological responses to environmental stress and sociocultural change in Micronesia.

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