Ancient Health

Skeletal Indicators of Agricultural and Economic Intensification

Edited by Mark Nathan Cohen and Gillian Crane-Kramer

Skeletal Biology of the Central Peruvian Coast

Consequences of Changing Population Density and Progressive Dependence on Maize Agriculture

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On the Peruvian coast, population growth and the rise of social complexity preceded dependence on intensive maize agriculture by some two thousand years. This unique cultural trajectory provides an opportunity to study the consequences of increasing population density for human health independently from the consequences of reliance on maize agriculture. Demographic expansion and large-scale monumental construction began on the central coast sometime between four and five thousand years ago (Moseley 1975; Shady et al. 2001). Maize was apparently first cultivated during the Initial period (1400–900 BC) but had yet to become a staple crop (Pearsall 2003). The large population centers of the Cotton Preceramic period probably thrived on abundant marine resources, augmented with foods produced by means of noncereal agriculture (Moseley 1992a, 1992b; Sandweiss 1996).

The proximity of the steep slopes of the Andes to the narrow coastal expanse of the Sechura desert creates a circumscribed area of remarkable environmental variability in western Peru. In this rugged terrain, microclimates vary within very short distances, and up to twenty different environmental zones can be crossed on foot in a matter of days (Burger 1992: 12). Temperatures and rainfall vary significantly from site to site, along with requisite subsistence practices, pathogens, and parasitic loads.

Prehistoric fishing peoples generally benefited from bountiful marine resources, rich in protein and iron. However, they frequently suffered from intestinal parasites of the genus *Diphyllobothrium,* probably contracted from fish (Reinhard and Urban 2003). *Diphyllobothrium* ova have been documented in Chinchorro mummies (2000–3000 BC) from Chile (Reinhard and Aufderheide 1990), in coprolites from Los Gavilanes (2700–2850 BC) (Patrucco et al. 1983), and in human remains at Chiribaya (AD 600–1476) from southern Peru (Holiday et al. 2003).

With the development of irrigation, people in the lower valleys eventually came to depend more on maize-rich diets, deficient in iron, lysine, and niacin. Heavy parasitic loads in these communities apparently resulted from their freshwater sources being polluted by upstream dwellers (Blom et al. 2005). Intestinal parasites—including pinworm (*Enterobius vermicularis*), giant roundworm (*Ascaris lumbricoides*), and whipworm (*Trichuris trichiura*)—were contracted from conspecifics or hunted animals (Patrucco et al. 1983). High rates of anemia for lowland fishing and farming populations stand in contrast to a virtual lack of this pathology among upland dwellers (Blom et al. 2005; Hrdlička 1914).

Modal subsistence practices changed considerably through prehistoric times on the central coast of Peru. During the Middle Preceramic period (6000–2500 BC) marine resources provided an overwhelming majority of the available calories for coastal villagers (Reitz 1986, 1998, 2001). Trace element and stable isotope analysis of human bones from Paloma indicate probable reliance on fishing to acquire food. The common occurrence of auditory exostoses on Paloma crania suggest that diving and swimming were practiced on a regular basis, especially by males (Benfer 1990).

Although horticulture apparently played a secondary role at Paloma (Weir et al. 1988), Pearsall (2003) has identified eleven cultivated plant taxa from Middle Preceramic sites in the area. The most common was the bottle gourd, valued as a container and later for net floats. Other documented cultigens include four tubers: begonia, *achira,* jicama, and manioc; the cereal quinoa; various cucurbits; peanuts; and *ciruela* (Pearsall 1992, 2003). By the end of the Middle Preceramic, beans had been added to the mix as well. Possibly in response to the introduction of beans, an independent source of protein, the frequency of anemia indicators at Paloma declined steadily through succeeding levels, from 36 percent of crania affected at Level 400 to only 12 percent of crania affected at Level 200, while average individual stature increased (Benfer 1990). Benfer (1984, 1997) has also proposed that cultural adaptations to sedentary life at Paloma developed with time, resulting in a gradual improvement in overall health.

For the subsequent Late (Cotton) Preceramic period (2500–1500 BC), there are clear archaeological indications of increasing population density, the emergence of social hierarchies, and more formalized governance in central Peru (Haas et al. 2004). Faunal analysis (Weir et al. 1988), the stable isotope composition of human bones (Falk et al. 2004; Tykot, Burger, and Van der Merwe 2006), and high frequencies of auditory exostoses (Tattersall 1985) all indicate that heavy reliance on marine resources continued through the Late Preceramic and into the Initial period (1800–850 BC). Nevertheless, the overall subsistence base appears to have become more complex, involving ir-

rigation-based production of some food plants (Pearsall 2003). Both maize and potatoes were added to the list of cultigens during the Initial period, but neither immediately assumed a staple role (Pearsall 2003; Tykot, Burger, and Van der Merwe 2006; Falk et al. 2004).

It remains uncertain when maize finally became a staple on the central coast. In the highlands, there was very little maize in the human diet even during the subsequent Early Horizon (900–200 BC) (Burger and van der Merwe 1990). For the time being, the earliest evidence that maize contributed substantially to the human diet comes from the Villa Salvador and Tablada de Lurín skeletal collections, dating to the Early Intermediate period (Falk et al. 2004).

The Archaeological Setting

Our study is focused on human skeletal collections from archaeological sites located between Río Seco and Río Grande de Asia, an area spanning approximately three hundred kilometers from north to south (Figure 7.1; Table 7.1). These sites are all situated directly on the coast or else in the lower valleys, below where fog oases occur. The nine chronologically sequential skeletal collections utilized in this study span the time frame represented by the Middle Preceramic (4500–3000 BC) through the Middle Horizon (AD 400–1000). These collections vary greatly in size, from only four skeletons from Río Seco and from Chilca 1 to 201 individuals from Paloma. As missing elements result in different sample sizes depending on the indicator being examined, pertinent sample sizes vary from table to table.

Table 7.1. Chronology and Sample Sizes for Skeletal Series Discussed

Site	Period[a]	Dates[a]	Number of Individuals				
			Total	Males	Females	Indt.	Sub.
Paloma	Middle Preceramic	6500–4750 BP	201	44	42	29	86
Chilca One	Middle Preceramic	5150–4750 BP	4	3	1	—	—
Asia Beach	Cotton Preceramic	4350–3000 BP	33	9	11	1	12
Río Seco	Cotton Preceramic	3950–3800 BP	4	2	—	—	2
Cardal	Initial Period	3400–2900 BP	48	16	14	4	14
Tablada de Lurín	Early Intermediate Blanco Sobre Rojo	2200–1900 BP	31	11	16	0	4
Villa Salvador	Early Intermediate Blanco Sobre Rojo	2200–1900 BP	181	64	68	5	44
Huaca Pucllana	Early Intermediate Lima Culture	1800–1300 BP	25	3	22	0	0
Huaca Huallamarca	Middle Horizon– Late Intermediate	1400–1000 BP	78	30	23	2	23

Note: Indt. = adult, sex indeterminate; Sub. = Subadult.
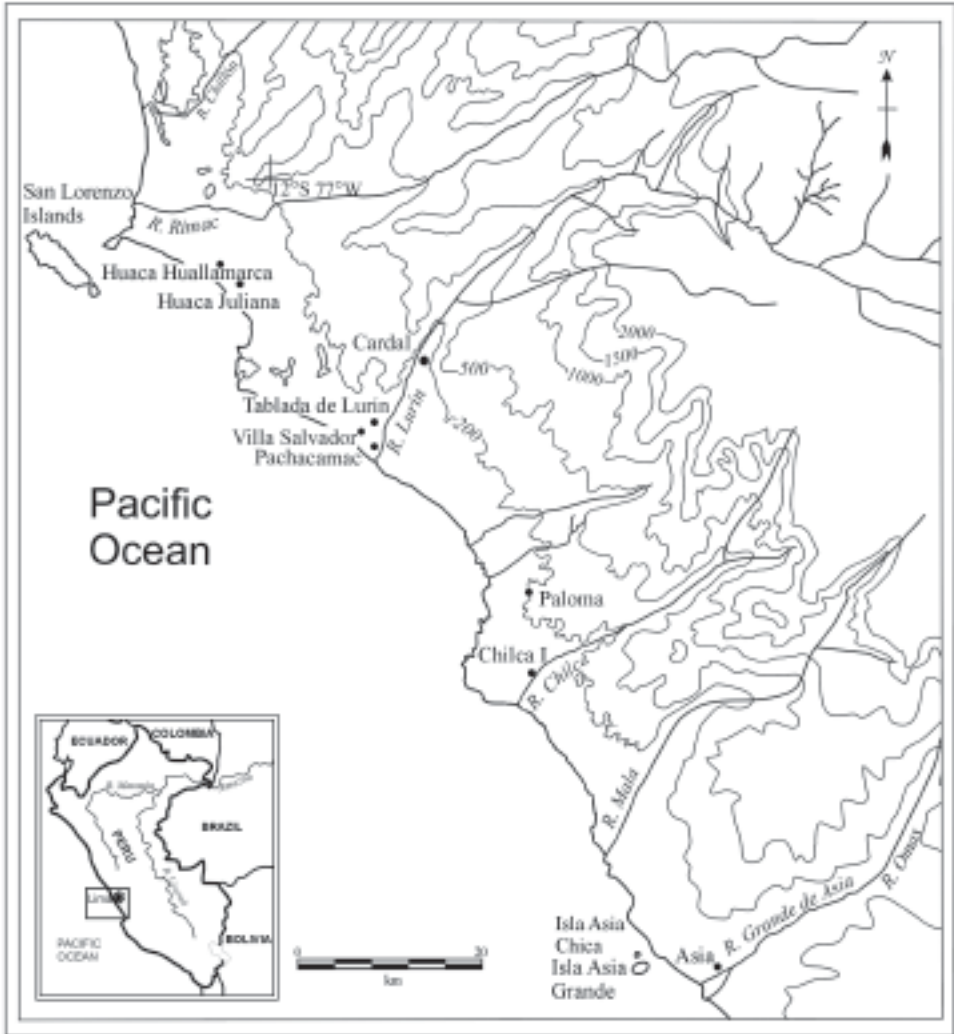[a] Adapted from Benfer 1990, Vradenburg 2001, and Lanning 1967.

Figure 7.1. Map of study area on the Peruvian Central Coast.

Paloma, a Middle Preceramic period village reliant on fishing and foraging, was located on the northern edge of the Chilca Valley, at 12°30' S, 76°40' W, within 7–8 kilometers of the river and lying 3.5 kilometers east of the coast (Engel 1980; Quilter 1989). Situated on a steep slope at between 200 and 220 meters above sea level, the site is just below the fog oasis today. Three excavated occupation levels contained human skeletal remains: Paloma Level 400 (4500–3300 BC), Paloma Level 300 (3300–3100 BC), and Paloma Level 200 (3100–2700 BC).

A total area of 2,860 square meters has been excavated at Paloma, uncovering evidence of fifty-five simple reed huts and deep middens. Human burials were recovered primarily from below or adjacent to house floors. The skeletal remains of a total of 201 individuals from Paloma were analyzed (Benfer 1990). These bodies were typically flexed, wrapped in mats and placed on their sides in straw-lined pits. Sparse grave goods included grinding stones, beads, shells, and stone tools, offering little to suggest social stratification (Quilter 1989). The number of Paloma residents apparently increased considerably between the time period represented by Level 400 and that represented by Level 300, as suggested by comparison of total house floor areas and the demographic profiles of the respective populations, but thereafter declined slightly (Vradenburg et al. 1997).

The Chilca 1 site lies on the banks of the lower Chilca River, which carries water only a few months of the year. Burials and houses recovered at Chilca 1 are very similar to those found at Paloma. It was the first Middle Preceramic (Archaic) site to yield substantial evidence of cultigens in Frederic Engel's excavations (Engel 1970). The common bean was especially important as a plant protein source (Weir et al. 1988).

The Cotton Preceramic is evidenced by skeletal samples from two sites: Asia Beach (Engel 1963) and Río Seco (Wendt 1963). Asia Beach is a group of mounds located south of Lima at 12°46' S, 76°35' W, some 500 meters from the ocean, on the north bank of the Río Omas. Associated radiocarbon dates suggest that the site was in use from approximately 1300 to 1000 BC (Engel 1963; Weir et al. 1988). The site of Río Seco is located at the river mouth, 87 kilometers north of Lima at 11°20' S, 77°24' W. At both of these loci, bodies were bundled in a tightly flexed position into grass mats and textiles, then buried underneath the floors of structures. Grave goods were few, although some of them were quite elaborate.

Skeletal remains dated to the Initial period come from Cardal, a U-shaped civic ceremonial center occupied between 1500 and 800 BC (Burger 1987; Burger and Salazar-Burger 1991). Cardal is located one kilometer south of the Río Lurín, within walking distance of both the littoral and the fog oasis. In total, the remains of at least forty-eight individuals were recovered from three distinct proveniences at Cardal: the central pyramid in Sector IIIA, the general residential Sector IIIB, and an area of apparent public architecture in Sector V. Burial ritual was similar to that of the Cotton Preceramic, although greater social inequality is documented by disparities in funerary offerings (Burger 1992).

No skeletal collections dated to the Early Horizon were available for analysis. Therefore, human remains from Villa Salvador (Stothert and Ravines 1977;

Delgado 1992, 1994) and Tablada de Lurín Necropolis (Makowski 1994, 2002), two cemeteries dated to the beginning of the Early Intermediate period, come next in our temporal sequence. Both cemeteries are situated just south of Lima in the arid Tablada de Lurín, which divides the lower Lurín and Rimac valleys. At 12°15' S and 76°56' W, Villa Salvador is four kilometers west and downstream from Tablada de Lurín Necropolis. The majority of individuals in these cemeteries were buried in a seated position facing towards the ocean. Undecorated pots, copper plaques, shell beads, and bone tools were the most common offerings. A few graves contained more elaborate sculpted ceramic vessels or gilded copper objects. Burials at both sites were associated with examples of a local variant of the White-on-Red ceramic tradition (Miramar style) (Patterson 1966; Earle 1972). As interlocking motifs are absent from the decoration of this pottery, Makowski (2002) suggests that all these burials predated the formation of the Lima State at shortly after AD 100.

Huaca Pucllana, also known as Huaca Juliana, became an important administrative and ceremonial center during the florescence of the Lima culture. The site is located in the lower Rimac valley, on what is now General Borgoño Street in the Miraflores district of modern Lima (Flores 1981; Vasquez 1984). Most of the prehistoric structures at the site were built between AD 200 and AD 700, including the main pyramid. We have studied twenty-five skeletons from Huaca Pucllana, most of which are the remains of young females, probably sacrificial victims.

Huaca Huallamarca (12°05' S and 77°02' W), also known as Huaca Pan de Azúcar, is a large pre-Inca pyramid located at Nicolás de Rivera 210 in the San Isidro district of modern Lima. The earliest prehistoric construction at this site, which is only about 100 meters above sea level, was probably contemporaneous with the buildings at Huaca Pucllana, dating to the end of the Early Intermediate period (Ravines 1985: 74). Huaca Huallamarca gained further importance during the Middle Horizon. The majority of burials there are from that later era. Many of the burials were multiple and skeletons were often commingled. Identifiable individuals from Huaca Huallamarca included thirty adult males, twenty-three adult females, two adults of indeterminate sex, and twenty-three subadults.

Diet and Oral Health

The rate of carious infection estimates the dietary importance of starchy carbohydrates and, by extension, the degree of reliance on agriculture, as well as providing evidence as to prevailing methods of food preparation (see for example, C. S. Larsen 1983, 1984; Rose et al. 1984; Turner 1979). Significant

Table 7.2. Frequencies of Carious Lesions and Calculus Accretion

			Teeth with Calculus Accretion			
Site	n^a	Carious Teeth	Absent	Slight/ Moderate	Severe	Lost Antemortem[b]
Paloma[c]	704	0.0043	NA	NA	NA	0.00
Asia Beach						
Total	398	0.0591	0.32	0.61	0.00	0.27
Male	199	0.0312	0.28	0.68	0.00	0.18
Female	110	0.1900	0.40	0.59	0.00	0.34
Cardal						
Total	335	0.0448	0.25	0.31	0.44	0.11
Male	176	0.0398	0.22	0.33	0.44	0.07
Female	153	0.0522	0.29	0.29	0.42	0.17
Tablada de Lurín						
Total	323	0.0588	0.41	0.56	0.01	0.67
Male	156	0.0577	0.27	0.69	0.09	0.64
Female	113	0.0442	0.57	0.43	0.03	0.68
Villa Salvador						
Total	1,184	0.1942	0.15	0.70	0.14	0.25
Male	520	0.1346	0.14	0.71	0.13	0.22
Female	642	0.2688	0.16	0.69	0.15	0.30
Huaca Pucllana						
Total	332	0.0724	0.22	0.76	0.02	0.24

[a] n = number of permanent teeth analyzed.
[b] Frequencies of teeth lost antemortem computed from the number of tooth sockets present.
[c] Paloma frequencies are based on analysis by Edwards (1984), which included only complete dentitions with no teeth lost antemortem or postmortem; data on calculus are not available.

differences among skeletal samples suggest large-scale shifts in the human diet between the Middle and Cotton Preceramic, as well as between the Initial and Early Intermediate periods (Table 7.2).

The frequency of carious teeth in the Paloma collection is below 1 percent (3 carious teeth out of 704 analyzed; Edwards 1984). Moderate frequencies of carious teeth were found in the samples from Asia Beach (5.9 percent), Cardal (4.5 percent), Tablada de Lurín (5.9 percent), and Huaca Pucllana (7.2 percent). All fall within the range typical for populations with a mixed or horticultural subsistence base (Turner 1979).

Significantly higher rates of carious lesions in the Villa Salvador sample probably reflect a greater reliance on starchy carbohydrates than at the sites of earlier time periods. Stable isotope data also suggest a shift in dietary emphasis toward maize (Falk et al. 2004). The remains of both sexes from Villa Salvador exhibit a high frequency of caries (males, 13.5 percent; females, 26.9 percent), and a high percentage of adults had at least one carious lesion (males, 85 percent; females, 94 percent).

The rate of carious lesions in the Tablada de Lurín sample is lower than that for Villa Salvador and similar to those found in chronologically earlier collections. However, the individuals examined from Tablada de Lurín apparently lost an astounding 67 percent of their adult teeth antemortem. This high tooth loss may have resulted in an underestimation of the rate of carious lesions in the collection.

All of the dental samples, except for that from Tablada de Lurín, exhibit somewhat higher caries percentages for females than for males. This difference presumably reflects pregnancy- and lactation-related stress and/or dietary and behavioral differences between the sexes (Lukacs 1996). The inversion of caries percentages for males and females from Tablada de Lurín (5.8 percent for males and 4.4 percent for females) may be related to a higher frequency of tooth loss attributable to caries among females.

Morbidity and Mortality on the Central Peruvian Coast

Differential distribution of pathological lesions and physiological stress indicators among temporally distinct skeletal samples is potentially affected by three factors: by morbidity itself (Bennike et al. 2005); by morbidity-enhanced mortality in certain age groups (Wood et al. 1992; Wright and Chew 1998); and by changes in the specificity and sensitivity of disease indicators (Boldsen 2001). An increased likelihood of death among anemic children might lead to low frequencies of porotic hyperostosis among adults (Wright and Chew 1998). In a similar way, selectively high mortality of frail or undernourished children might lead to paradoxically higher adult stature in a population that is heterogenic for frailty (Saunders and Hoppa 1993; Kemkes-Grottenthaler 2005). Evolutionary changes in pathogenic microorganisms, as well as the introduction of new pathogens, can affect the frequency, topography, or morphology of bone lesions found in skeletal collections, without any change in the frequency of a particular illness. Therefore, in this analysis, particular attention was given to the distribution of pathological lesions among different age groups.

Indicators of Childhood Anemia

In precontact America, hyperostotic lesions of the cranial vault and orbital roof—porotic hyperostosis (PH) and cribra orbitalia (CO)—are commonly linked to acquired anemia (for example, Goodman, Martin, and Armelagos 1984; Steckel 2005; Blom et al. 2005), although other conditions can cause similar pathologies (Ortner et al. 1999; Ortner and Putschar 1985; El-Najjar 1979; Aufderheide and Rodriguez-Martin 1998). Alternatively, artificial cranial deformation has been proposed as a major contributing factor to the high

Table 7.3. Prevalence of Cribra Orbitalia (CO) and Porotic Hyperostosis (PH)

	CO freq. [nᵃ]	PH freq. [n]
Paloma		
Adults	0.30 [69]	0.06 [69]
Subadults	0.18 [44]	0.14 [36]
Subadults adjusted	0.36	0.28
Asia and Río Seco		
Adults	0.57 [9]	0.43 [17]
Subadults	0.80 [5]	0.40 [5]
Cardal		
Adults	0.32 [15]	0.13 [21]
Male	0.38 [8]	0.11 [9]
Female	0.29 [7]	0.08 [12]
Subadults	0.67 [3]	0.22 [9]
Tablada de Lurín		
Adults	0.68 [22]	0.38 [26]
Males	0.50 [12]	0.45 [11]
Females	0.88 [9]	0.50 [10]
Subadults	0.00 [2]	0.00 [2]
Villa Salvador		
Adults	0.46 [60]	0.48 [61]
Males	0.61 [26]	0.58 [30]
Females	0.37 [32]	0.40 [30]
Subadults	0.86 [42]	0.59 [37]
Huaca Pucllana		
Adults	0.67 [18]	0.59 [17]
Huaca Huallamarca		
Adults	0.44 [9]	0.44 [9]
Subadults	1.00 [1]	0.00 [2]

Note: The category "Subadults" refers to skeletal remains with an estimated age at death of less than 20 years.

ᵃ n = the number of individuals that could be evaluated for presence of the respective indicator.

prehistoric frequency of porotic hyperostosis on the Peruvian coast (Aufderheide and Rodriguez-Martin 1998: 349). However, the low frequency of this pathology in the Cardal sample, in which approximately half of the crania were artificially modified, along with its high frequency in the Asia Beach sample, in which only one skull was intentionally deformed, argues to the contrary (Table 7.3).

Overall, Paloma adult crania display significantly lower frequencies of anemia indicators than the remainder of the Peruvian skeletal series examined, with only 30 percent of Paloma adult crania showing evidence of CO. The low frequency of anemia indicators in the Paloma skeletal series might be related to an apparent low parasitic load at the site. Paloma coprolites contain no evidence of intestinal worms. Karl Reinhard (pers. comm.) performed exten-

sive analyses on both coprolites and burial sediments from the site without finding any traces of parasite ova. Overall low human population density and the location of the site could have contributed to this phenomenon. Paloma is seven kilometers from the Río Chilca. Its residents probably depended on wells or moisture-collecting pits for fresh water (Quilter 1989), sources that would have been relatively clean and free of parasites.

The frequency of PH is very low in both the Paloma and Cardal samples, with only 6 percent of Paloma and 13 percent of Cardal adult crania displaying the signs of PH; these frequencies are significantly lower than those found for the same pathology in the other samples analyzed for the purposes of this study, which vary from 38 percent to 59 percent. The Asia Beach, Tablada de Lurín, Villa Salvador, Huaca Pucllana, and Huaca Huallamarca skeletal materials all display high frequencies of anemia indicators (Table 7.3). With the exception of the Asia Beach series, these collections come from contexts postdating the establishment of maize agriculture, a milestone documented to have precipitated an increase in the incidence of anemia elsewhere in the New World (for example, Buikstra and Cook 1980; Buikstra 1984).

The high frequency of PH in the Cotton Preceramic sample from the Asia Beach site can probably be ascribed to dependence on starchy plant foods (other than maize) of low dietary value. The high frequency of carious lesions among Asia dentitions suggests a high proportion of carbohydrates in the human diet there. Seeds of *guayaba,* a sweet fruit with a sticky texture, were common among the plant remains recovered at Asia (Engel 1963). Rich in carbohydrates, guayaba is nearly devoid of proteins and essential minerals. In addition, relatively high population density and the location of Asia on the bank of the Río Omas, close to the coast, would have increased the likelihood of contracting parasites, thus contributing to high rates of anemia, notwithstanding the absence of maize.

Relatively low frequencies of PH in the Initial period sample from the Cardal ceremonial center (PH, 13 percent; CO, 32 percent) are somewhat unexpected. Increased population densities during the Initial period might seem to predict poor hygiene and increased parasitic loads. However, greater population density alone appears not to have led to a marked increase in anemia or growth arrest episodes, and marine resources utilized at Cardal may have provided adequate dietary buffering.

As a rule, hyperostotic lesions are more frequent on subadult skeletal remains because they form during the first few years of life as a result of severe anemia, which increases the likelihood of early death (Steckel 2005). With one exception, the subadult remains examined in our study exhibit higher frequencies of CO than the adult samples (Table 7.3). The difference between adults and subadults is most pronounced in the Villa Salvador sample, in which mac-
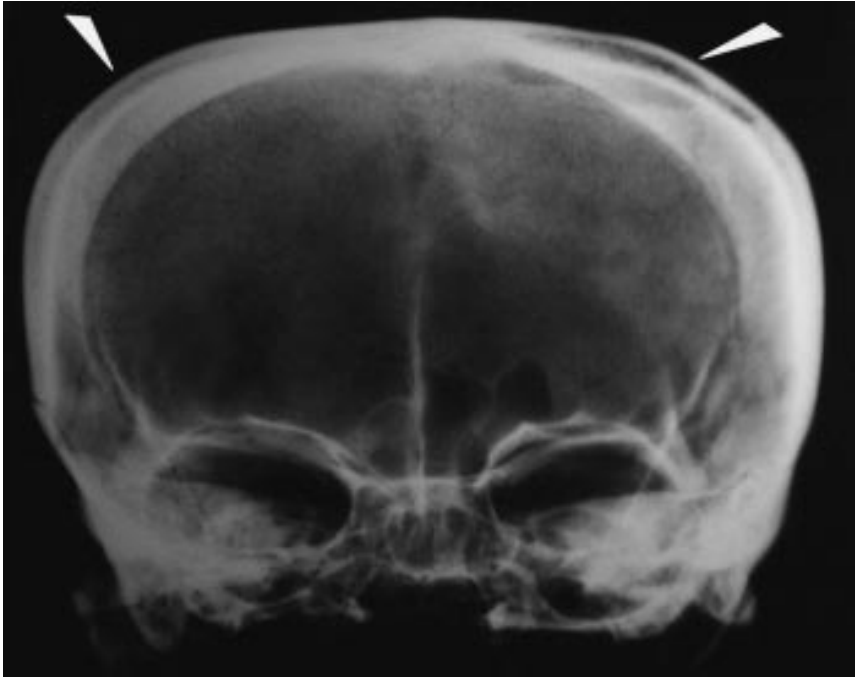
Figure 7.2. Example of expanded diploe from the Peruvian Central Coast.

roporosity of the orbital roof was recorded on 86 percent of subadult crania and on only 46 percent of adult crania. Expansion of the diploe in the cranial vaults of children from this sample was often profound (Figure 7.2). Similarly, in the Cotton Preceramic sample from the Asia Beach and Río Seco sites, 80 percent of subadult and only 57 percent of adult crania exhibited this pathology. Of the collections including a representative number of subadults, the frequency of CO on the crania of children is lower than that of adults only for Paloma.

Comparison of CO and PH frequencies among samples with different demographic profiles may be misleading because the frequencies of these pathologies vary tremendously between age groups (Figure 7.3). For instance, in the Paloma sample, close to 40 percent of subadults were infants, having estimated ages at death of less than one year (shown as a gray bar with dotted border in Figure 7.3). For this age group, recorded frequencies of CO and PH are zero, perhaps because the individuals died before hyperostosis was sufficiently advanced to be detectable by macroscopic examination.

Unlike at Paloma, infants under one year of age are not represented in the Villa Salvador sample. Furthermore, a steep decline in CO frequencies for age groups older than five years old is noticeable in both samples. Consequently,
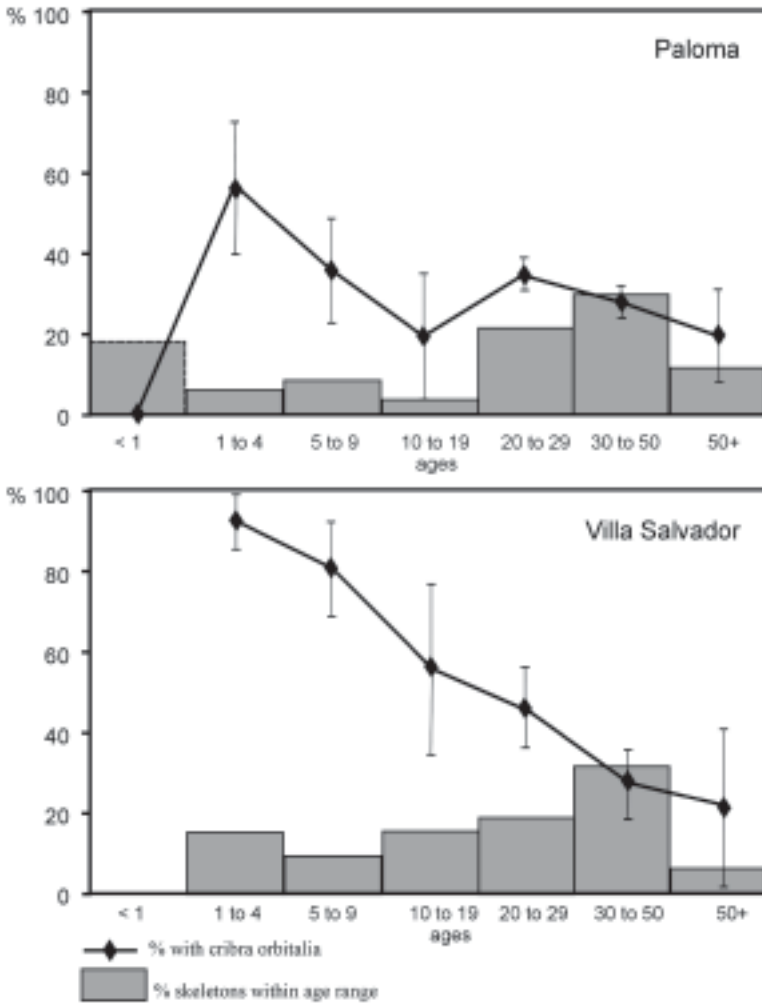
Figure 7.3. Frequency of cribra orbitalia from sites on the Peruvian Central Coast.

when pooled across age groups, the frequencies of CO and PH in subadult samples will vary in accordance with the proportion of infants in each age group. Removal of the skeletal remains of infants with an estimated age of less than one year from consideration in the Paloma sample increases the proportion of skulls with CO and PH to 36 percent and 28 percent, respectively.

The preponderance of PH and CO at Villa Salvador and the way in which the frequencies of those pathologies are distributed across the site's age groups suggest not only that anemia rates were higher in this chronologically later sample but also that anemia-related mortality among Villa Salvador subadults
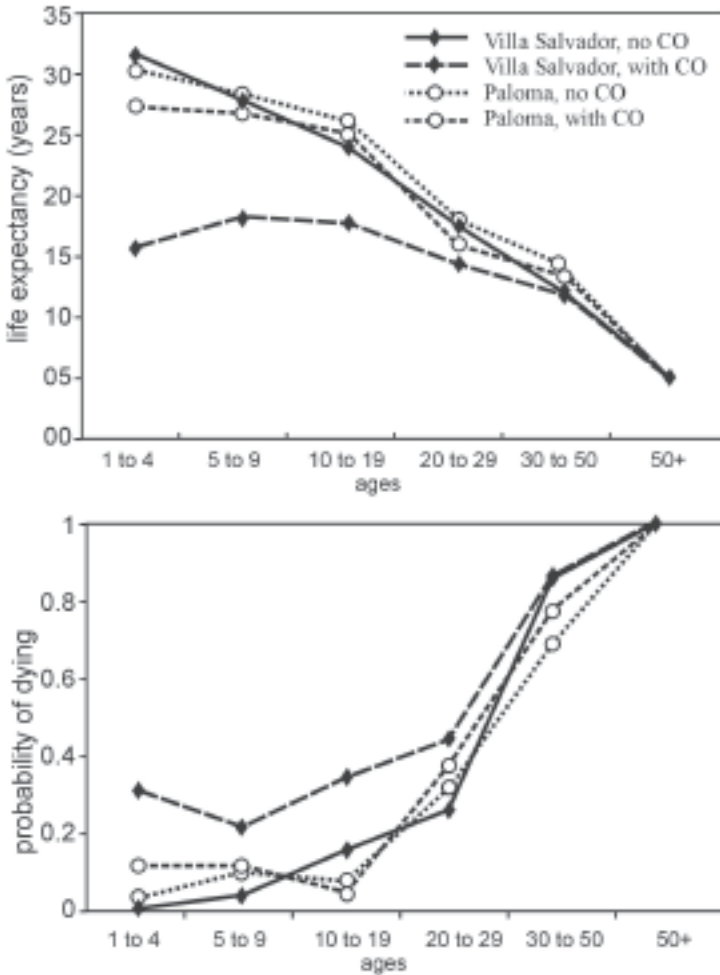
Figure 7.4. Life expectancy and probability of dying at sites on the Peruvian Central Coast.

was greater than at Paloma (Figure 7.4). For children with CO at Villa Salvador, the probability of dying at between one and four years of age was 31 percent, considerably higher than for children with no CO (0.7 percent). Affected individuals continued to experience increased mortality until the age of thirty. For the Paloma sample, the probability of death for children with CO was higher only between ages one and four (12 percent versus 0.4 percent). For older children, mortality was more or less random with respect to the presence or absence of anemia.

Systemic Infection

Most discussions of systemic infection among South American precontact populations are centered on the origin and spread of two pathogenic genera: *Mycobacterium,* the infectious agent responsible for tuberculosis, and *Treponema,* which is responsible for yaws, pinta, and venereal syphilis. On the basis of macroscopic, histological, and radiographic analyses of mummified and skeletonized human remains, numerous cases of pre-Columbian tuberculosis have been documented for populations from the Peruvian and Chilean coast (Allison et al. 1973, 1981; Buikstra and Williams 1991; Salo et al. 1994; Arriaza et al. 1995). *Mycobacterium* DNA has been isolated in several instances, making those diagnoses unequivocal (Arriaza et al. 1995; Salo et al. 1994). The earliest documented case of tuberculosis in Peru comes from the Chongos site, on the southern coast, which dates to circa AD 160 (Allison et al. 1981).

In our analysis, no clearly diagnostic cases of tuberculosis were found. One male skeleton from Villa Salvador had widespread periosteal bone formation on the long bones and thoracic vertebrae, as well as the visceral and lateral rib surfaces, which could suggest tuberculosis, but is more consistent with treponemal infection. Large resorptive lesions surrounded by oppositional bone (a pattern of lesions sometimes resulting from tuberculosis) were present on the anterior portions of the eighth and ninth thoracic vertebrae of a male skeleton from Huaca Huallamarca.

Periosteal lesions were most common on tibias and distal femurs, a pattern also suggestive of treponemal infection (Figure 7.5). Both the Paloma and Cardal collections exhibit relatively high frequencies of bilateral periosteal lesions among subadults, suggesting nonvenereal, probably yawslike, treponematosis (Table 7.4). For Paloma subadults, periosteal lesions were more common in children five to nine years old than in younger children (Figure 7.6).

A shift in the epidemiology of treponematosis could have occurred sometime between the Initial period and the Early Intermediate period. At Villa Salvador, systemic infection became common in adults, particularly males, whereas subadults appear to have been practically unaffected (Table 7.4). Among adults, the frequency of systemic infection declined slightly in individuals aged 50+, while the degree of both severity and healing increased. Adult mean ages at death for affected individuals (males, 34.0; females, 36.7) are similar to those of unaffected individuals (males, 35.3; females, 35.5), suggesting that chronic treponematosis did not increase the likelihood of death during adulthood.

Generalized periosteal lesions were practically absent from the Huaca Pucllana and Huaca Huallamarca skeletal collections. Analysis of the relatively
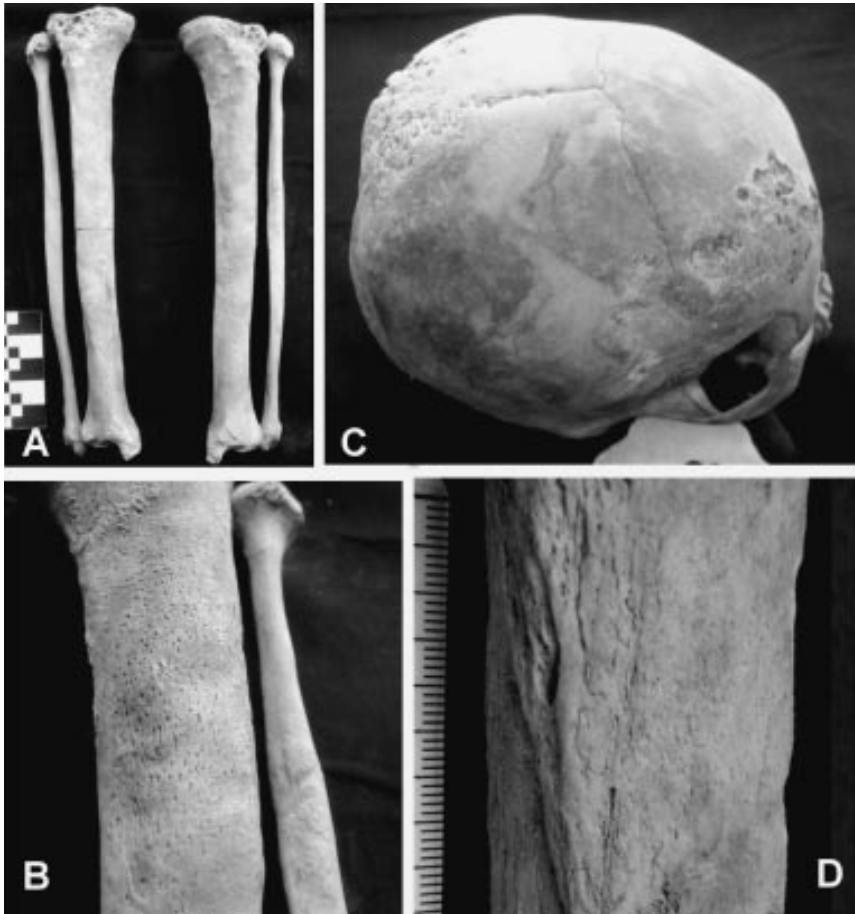
Figure 7.5. Examples of treponemal infection on the Peruvian Central Coast.

small Huaca Pucllana sample, which is heavily weighted toward young females, may suffer from the effects of sampling error. However, the relatively large sample from Huaca Huallamarca displayed almost no generalized periostosis on the diaphyses of long bones, suggesting either that treponematosis had declined significantly by the later part of the Early Intermediate period or that its pathogenesis had changed.

The distribution of periosteal and hyperostotic lesions among the age groups for Paloma subadults suggests that the likelihood of anemia- and systemic infection–related death varied with age (compare Figure 7.3 and Figure 7.6). Hyperostotic lesions were found predominantly on the remains of infants who died between ages one and four, while periosteal lesions were more common in the older age groups. Only one subadult skeleton displayed both

Table 7.4. Frequency of Individuals with Skeletal Lesions Suggestive of Systemic Infection

| Site | Individuals with Generalized Periosteal Lesions | | | |
	Total Adults freq. [n[b]]	Males freq. [n]	Females freq. [n]	Subadults[a] freq [n]
Paloma	0.22 [87]	0.28 [40]	0.18 [40]	0.11 [57]
Chilca One	0.25 [4]	0.33 [3]	0.00 [1]	—
Asia Beach	0.30 [10]	0.20 [5]	0.40 [5]	0.00 [2]
Río Seco	0.50 [2]	0.50 [2]	—	0.00 [2]
Cardal	0.50 [16]	0.28 [7]	0.62 [8]	0.75 [12]
Tablada de Lurín	0.51 [35]	—	—	0.00 [4]
Villa Salvador	0.23 [82]	0.53 [36]	0.11 [46]	0.00 [38]
Huaca Pucllana	0.04 [24]	0.50 [2]	0.00 [22]	—
Huaca Huallamarca	0.03 [34]	0.05 [20]	0.00 [14]	0.00 [18]

[a] Estimated age at death of less than 20 years.
[b] n = the number of individuals that could be evaluated for presence of the respective indicator.
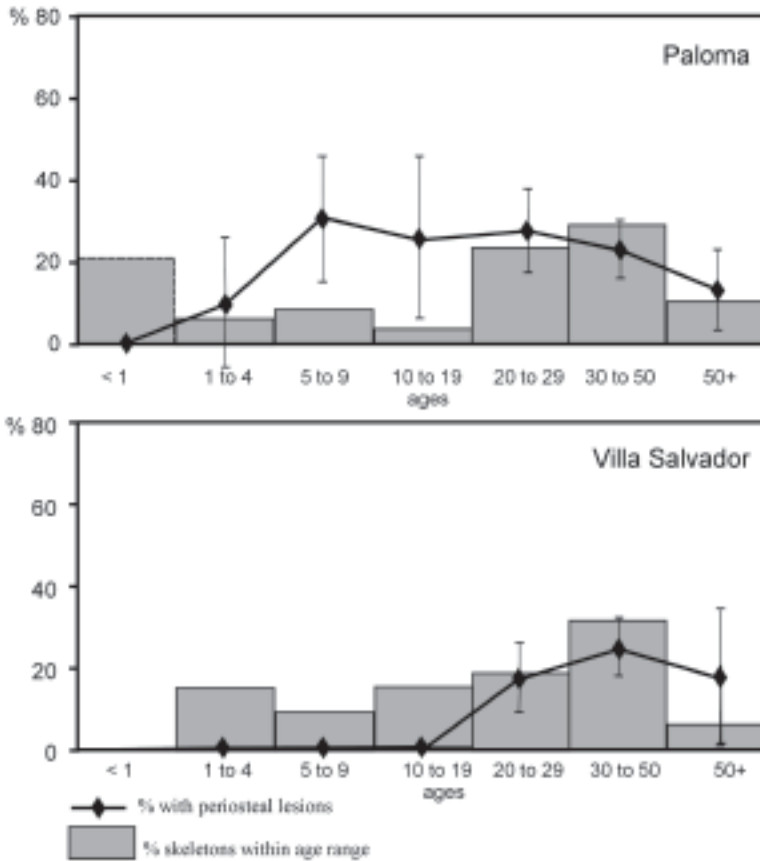

Figure 7.6. Frequency of periosteal lesions at sites on the Peruvian Central Coast.

types of lesions. Slightly more children with CO seem to have survived into adulthood than died before reaching sexual maturity, tentatively supporting a protective role for anemia in increasing resistance to infection (P. Stuart-Mac-adam 1992).

Achieved Adult Stature

Changes through time in adult stature among the sampled populations are remarkable. The average adult stature of the Paloma fishers was significantly higher than that for subsequent populations from the central Peruvian coast (Table 7.5). Pairwise comparisons of Paloma long bone lengths with those from other representative samples result in high *t*-statistic values with a probability below 0.001.

Table 7.5. Long Bone Measurements and Stature Estimates

	Measurement				
Site	Humerus Max Length (mm)[*n*]	Humerus Head (mm)[*n*]	Femur Max Length (mm)[*n*]	Femur Head (mm)[*n*]	Stature[a] (cm)
Paloma					
Males	309.8±10.4[17]	43.7±2.1[33]	436.2±18.9[18]	45.3±2.1[24]	165.1
Females	284.8±10.8[24]	37.4±7.0[29]	395.8±18.3[16]	39.9±2.1[29]	155.2
Río Seco					
Males	299.5±4.9[2]	43.5±0.7[2]	415.5±17.7[2]	43.5±2.12[2]	160.1
Females	—	—	——	—	
Asia Beach					
Males	287.0±9.5[9]	42.4±1.7[9]	415.4±12.5[12]	42.6±2.0[12]	160.0
Females	264.2±31.8[7]	37.8±2.8[6]	389.5±16.2[6]	38.9±2.1[6]	153.7
Cardal					
Males	262.7±18.8[5]	39.5±2.9[3]	376.8±23.4[5]	—	150.6
Females	236.5±16.2[7]	34.5±1.5[6]	344.2±20.2[7]	—	142.7
Villa Salvador					
Males	302.1±14.9[27]	42.2±2.1[29]	412.2±20.6[25]	43.8±2.1[28]	159.2
Females	275.3±13.4[29]	36.6±2.6[28]	385.2±16.4[31]	39.7±2.1[36]	152.7
Tablada de Lurín					
Males	306.0±8.3[6]	—	414.0±10.8[9]	—	159.7
Females	296.2±4.2[2]	—	389.5±7.8[2]	—	153.7
Huaca Pucllana					
Males	311.5±57.3[2]	43.7±3.8[3]	396.0±5.7[2]	47.0±9.9[2]	155.3
Females	273.3±19.7[10]	35.8±1.6[7]	368.0±16.8[15]	37.9±2.6[7]	148.5
Huaca Huallamarca					
Males	300.0±8.7[12]	43.2±2.4[12]	412.1±13.4[20]	45.0±2.4[21]	159.2
Females	279.8±13.2[12]	37.6±1.2[11]	385.7±14.2[14]	41.1±2.3[15]	152.8

Note: Max Length = calculated maximum length of available bones; Head = circumference; *n* = number of observable bone elements.

[a] Stature estimates are based on Mexican male formula for the femur from Trotter 1970.

Table 7.6. Femur Length versus Age at Death in Children Six Years of Age and Younger

Dental Age (months)	Paloma (mm)[n]	Asia Beach (mm)[n]	Villa Salvador (mm)[n]	Huaca Huallamarca (mm)[n]
0–11	78.0 [4]	—	64.0 [1]	62.0 [4]
12–23	130.0 [3]	128.0 [1]	115.0 [3]	118.0 [1]
24–35	150.0 [2]	—	140.0 [3]	—
36–47	179.0 [3]	—	173.3 [6]	177.0 [1]
48–71	247.2 [5]	—	210.0 [4]	213.0 [1]

Note: *n* = number of observable elements.

Among the adult skeletal samples examined, two stand out as comprising remarkably short individuals. These include the remains from the ceremonial centers at Cardal (Initial period) and Huaca Pucllana (Early Intermediate period). Some individuals buried in ceremonial centers might not have been representative members of their local communities. Some burials at these centers might have been those of captives or low-status individuals who did not get adequate alimentation during childhood. At Huaca Pucllana, young females were overrepresented. Two from multiple interments had perimortem stab wounds in the arches of their cervical vertebrae; two skeletons from the same site each lacked a cranium. It seems likely that all these burials were ceremonial. Immigration from high altitudes, population replacement, or increased physiological stress in the context of rapid population growth are other factors that could have contributed to shorter adult stature at Cardal and Huaca Pucllana.

A higher mortality rate for short, frail children (as opposed to differing growth trajectories for subadults) is another possible explanation for the differences in adult stature among the samples. Only the Paloma and Villa Salvador collections have a sufficient number of subadult postcrania to permit a meaningful comparison of long bone length between the corresponding age cohorts (Table 7.6). In every age group, Paloma children were taller than children from Villa Salvador. When the effect of age was adjusted for by regression and the residuals of femur lengths were compared between the Paloma and Villa Salvador samples, Paloma children were found to be significantly taller than those from Villa Salvador (t=2.45, 20 df, p<0.02). Consequently, the observed difference between adult statures in the Villa Salvador and Paloma samples cannot be explained by higher frailty-related mortality in either group. Taller Paloma children simply grew into taller adults.

Growth Arrest Episodes

Growth arrest lines on teeth are interpreted as resulting primarily, but not exclusively, from periods of systemic physiological stress (Goodman, Armelagos, and Rose 1984; Goodman and Rose 1991; Fitzgerald and Rose 2000). A negative correlation between achieved adult stature and the number of growth arrest episodes is expected. However, no direct correspondence was observed between average adult stature and the frequency of growth arrest lines on permanent anterior teeth (Table 7.7). Although the lowest frequency of hypoplasias was found in the Paloma sample (6 percent), which also had the greatest average adult stature, it was closely followed in that respect by the Cardal sample (16 percent), which had the shortest average adult stature. The highest frequency of hypoplastic teeth was observed for the Huaca Pucllana females (86 percent of anterior teeth), a sample with the second-shortest average adult stature for our total data set.

With the exception of the Cardal sample, male dentitions showed higher frequencies of hypoplastic teeth than female dentitions did, suggesting that males either experienced greater early childhood stress than females or had higher recovery rates. However, these differences are slight.

The age at which a growth arrest episode occurred can be evaluated from linear enamel hypoplasias and measured on the permanent anterior dentition by the half year from birth to 6.5 years of age (Goodman, Lallo et al. 1984; Massler et al. 1941; Moorrees et al. 1963a). The distribution of hypoplasias by age was similar in all samples, with the majority of growth arrest episodes occurring between 2.5 and 4.4 years of age and the peak of hypoplasia formation at between 3 and 4 years of age. This peak is best defined for the Cardal and Asia Beach dental sets, in which 43 percent and 40 percent of the respective growth arrest episodes occurred between ages three and four. For the Paloma sample, this peak is less clearly defined and occurred somewhat later. Only 15 percent of the hypoplasias recorded for Paloma teeth occurred between ages 3 and 3.4, 20 percent between 3.5 and 3.9, and another 15 percent between the ages of 4 and 4.4 years. Similarly, in the Cardal sample, 21 percent of growth arrest episodes occurred between the ages of 3.5 and 3.9; in other dental samples examined, this frequency did not exceed 16 percent. The delayed age of hypoplasia formation among individuals from the Paloma and Cardal samples might be related to a delayed introduction of solid foods or to a different dynamic for parasite contraction among those populations.

The patterns of hypoplasia formation determined for the Villa Salvador and Tablada de Lurín samples are very similar. Both exhibit a relatively even distribution of hypoplasias by age, especially between the ages of 2 and 4: 15 percent of growth arrest lines formed between ages 2.5 and 2.9, 18–19 percent formed

Table 7.7. Frequencies of Enamel Hypoplasias by Sex and Age of Formation

| Site | n[b] | % Teeth with Enamel Hypoplasia[a] | | | % Hypoplasia Formed by Age Group | | | | | |
		Adults[c]	Males	Females	2–2.4	2.5–2.9	3–3.4	3.5–3.9	4–4.4	4.5–4.9
Paloma	260	6	—	—	7	10	15	20	15	8
Asia Beach	143	36	33	65	8	12	24	16	8	12
Cardal	100	16	8	37	6	12	22	21	12	8
Tablada de Lurín	119	47	57	42	10	15	18	14	15	5
Villa El Salvador	331	42	44	66	7	15	19	16	12	10
Huaca Pucllana	123	86	—	86	—	—	—	—	—	—

[a] Frequency of enamel hypoplasia is estimated based on anterior teeth only.
[b] n = number of permanent anterior teeth analyzed.
[c] including males, females, and sex-indeterminate individuals.

between ages 3 and 3.4, and 14–16 percent formed between ages 3.5 and 3.9. This correspondence in the distribution of evidence for growth arrest episodes preserved on anterior teeth suggests a similar incidence of acute illness among children and/or starvation periods at both sites, notwithstanding the location of the Tablada de Lurín Necropolis somewhat upstream from Villa Salvador.

Discussion and Conclusions

Based on the analysis of human skeletal remains presented here, several prehistoric trends in community health on the central Peruvian coast can be tentatively outlined. The Middle Preceramic sample (Paloma) exhibits the lowest rates of all indicators of physiological stress, the lowest rate of caries, and the tallest adult stature for both sexes. A significant deterioration of health during the subsequent periods is suggested by the majority of skeletal indicators. The only exception to this pattern is the frequency of systemic infection, which appears to have already been relatively high at Paloma.

Oral health, as reflected by the incidence of caries, declined significantly during the Cotton Preceramic and remained about equally depressed through the Initial period. This early increase in caries formation was probably caused by a growing reliance on starchy cultivated plant foods, as well as increased population density. The later transition to maize agriculture led to a further increase in the rates of caries formation and antemortem tooth loss.

The Cotton Preceramic and Initial periods also seem to have witnessed an overall increase in the frequency of physiological stress indicators, including cribra orbitalia, porotic hyperostosis, and the formation of enamel hypoplasias, although the Cardal skeletal sample (Initial period) resembles Paloma in its relatively low frequencies of porotic hyperostosis and enamel hypoplasias. Chronic anemia became a strong contributing factor to subadult mortality

during the Cotton Preceramic and in subsequent time periods. However, there does not seem to have been a clear trend toward any further increase in sub-adult physiological stress with the adoption of maize agriculture. The Early Intermediate period Villa Salvador and Tablada de Lurín skeletal collections exhibit frequencies of anemia indicators and evidence of growth arrest episodes similar to those of the Cotton Preceramic Asia Beach sample.

Achieved adult stature for individuals from Paloma was the highest observed. This growth was likely supported by an adequate protein intake and low parasitic loads. For skeletal samples from the subsequent time periods, stature shows large-scale oscillations that might be better explained by population relocation than by changes in either health or diet.

Two shifts in the epidemiology of treponematosis can be tentatively proposed based on the study reported here. Systemic infection commonly affected subadults at both Paloma and Cardal but was virtually absent among children from later populations. Therefore, a change in the mode of transmission of treponematosis from contact to venereal during the Early Horizon or the first half of the Early Intermediate period can be proposed. A second shift probably took place during the Middle Horizon, as the frequency of lesions suggestive of infectious disease on human remains from that time period is relatively low.

We conclude that increased population density, accompanied by a decline in the effectiveness of communal sanitary practices, led to increased physiological stress and parasitic loads among human populations on the Peruvian coast. The eventual transition to intensive maize agriculture resulted in a significant deterioration of oral health, but its effect on other stress and health indicators was not as dramatic.

Acknowledgments