Patterns of Cortical Growth as Indicators of Population Health: An Exploratory Analysis of Subadult Remains from the Tell Abraq Site, UAE

Jessica L. Rhodes

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PATTERNS OF CORTICAL GROWTH AS INDICATORS OF POPULATION HEALTH: 
AN EXPLORATORY ANALYSIS OF SUBADULT REMAINS 
FROM THE TELL ABRAQ SITE, UAE

by

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Jessica L. Rhodes
PATTERNS OF CORTICAL GROWTH AS INDICATORS OF POPULATION HEALTH: AN EXPLORATORY ANALYSIS OF SUBADULT REMAINS FROM THE TELL ABRAQ SITE, UAE

Jessica L. Rhodes, M.A.
Western Michigan University, 2005

The analysis of children in archaeological contexts is a relatively new field of study that emerged largely as a result of feminist and gender studies in the social sciences. Thus, methodologies that are typically employed in bioarchaeological analyses of children have yet to be refined and standardized. The commingling of subadult remains in archaeological contexts further confounds this issue by eliminating the ability of the researcher to establish reasonable age-at-death distributions.

This study seeks to explore the utility of analyzing patterns of cortical growth-for-diaphyseal length in commingled subadult remains. Specifically, commingled subadult remains excavated from the Tell Abraq site (UAE, dating to 4600 – 1600 BP) are compared to subadult remains from the Hamman-Todd Osteological Collection (housed at the Cleveland Museum of Natural History). The samples are divided into cohorts based on maximum diaphyseal length and radiographic measures of midshaft femoral cortical thickness are compared for each cohort. Results indicate that the Tell Abraq subadults displayed more robust patterns of cortical growth than the Cleveland children. This corroborates preliminary analyses, which indicated that the children from Tell Abraq were physically healthy as compared to modern standards.
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CHAPTER 1
INTRODUCTION

Archaeologists and biological anthropologists have historically ignored children in prehistory (Johnston 1968; Saunders 1992). Reasons cited for this include the fact that subadult remains are small and fragile, thus easily overlooked and broken during the excavation process (Johnston and Zimmer 1989; Kamp 2001; Saunders 1992; Storey 1986; Sundick 1978). Second, subadults are underrepresented in burial contexts, as differential burial practices (and differential recovery practices) often result in the exclusion of juveniles (Danforth et al. 1994; Saunders 1992; Scrimshaw 1984; Turnbull 1972). Finally, researchers historically did not consider children to be important members of society worthy of study (Bird and Bliege Bird 2000; Kamp and Whittaker 2002; Saunders 1992). Current research, however, challenges many of these notions. Saunders (1992), for example, cites excavator inexperience as the key determinant of nonrecovery of subadult remains. Additionally, feminist and gender studies in archaeology have led to a re-examination of what is deemed “archaeologically significant” (Brumbach and Jarvenpa 1997; Conkey and Gero 1991, 1997; Conkey and Tringham 1996; Gero 1985; Harry et al. 2003; Kamp 2001; Kamp and Whittaker 2002). This re-examination has effectively broadened areas of study to include women and children in interpretations of past societies (Kamp 2001; Kamp and Whittaker 2002; Saunders 1992). Of specific interest in the context of this thesis is the recognition that the analysis of children’s health through the growth process is a sensitive indicator of the relative success of a population at any specific moment in time (Goodman and Armelagos 1999; Saunders 1992; Saunders and Hoppa 1993; Steyn and Henneberg 1996).

Population health is a common jumping-off point for interpretations of past societies. Diachronic comparisons of skeletal indicators of health provide insight into the effects of large-scale societal changes, such as shifts in subsistence strategy or the consequences of colonialism or industrialization (See Cook 1984; Hummert and Van Gerven 1983; Jantz and Owsley 1984; Larsen 1995; Lewis 2002; Mensforth 1985; Stodder 1997). Inter-group comparisons of health can reveal information relevant to ways of life at a specific point in time (Hummert 1983; Hummert and Van Gerven 1983; Wall 1991). Each type of analysis benefits from the examination of growth and development of subadult remains, as interruptions in the growth process are solid indicators of poor health (Himes et al 1975; Hoppa 1992; Johnston 1962; Mays 1999; Merchant and Ubelaker 1977; Saunders and Hoppa 1993; Saunders et al. 1993).

Most studies of skeletal growth and development examine longitudinal growth against chronological age (Hummert 1983; Hummert and Van Gerven 1983; Jantz and Owsley 1984; Johnston 1962; Mays 1999; Mensforth 1985; Saunders et al. 1993; Storey 1986; Wall 1991), while
others examine cortical bone growth (in long bones) against chronological age (Himes et al. 1975; Hummert 1983; Mays 1999). In the absence of reliable age estimators (occurring when remains are commingled), analyses of growth and development are rarely (if ever) attempted. This study seeks to examine skeletal growth and development in a sample for which reliable age indicators are not present. In this study, longitudinal growth is used as a standard by which to judge cortical growth, both within and between populations.

This study examines the growth and development of subadults from a commingled context, excavated from the Tell Abraq site, UAE, dating to 4600 – 1600 BP. Subadult femoral growth is analyzed in terms of cortical thickness-for-bone length and compared to a modern sample with associated health records. This analysis tests the hypothesis that disruptions in growth can be detected through the analysis of a single element. Ultimately, this analysis will add to a growing dialogue of health in Bronze Age Arabia and in archaeological contexts in general.

**Skeletal Growth and Development: Assessing Children Osteologically**

Any analysis of skeletal growth and development in the archaeological record must begin with the assumption that a cross-sectional representation of deceased individuals is analogous to a longitudinal analysis of a living population. This is a potential bias that many researchers (if not all) recognize and even attempt to quantify (Johnston 1968; Saunders and Hoppa 1993). Subadults in the archaeological record are obviously representative of children who die, and therefore factors causing death will be present in higher proportions in these children than in living children (Johnston 1962; Saunders and Hoppa 1993). Despite this, many researchers now agree that frequencies of skeletal lesions are unrelated to cause of death, and thus meaningful interpolations can be made (Mensforth et al. 1978; Stuart-Macadam 1985; Saunders and Hoppa 1993; Wood et al. 1992). This suggests that a skeletal sample of subadults is, in fact, representative of the living population that they were once a part.

Most bioarchaeological studies of growth and development begin with the use of estimators of chronological age. To avoid a kind of "circular reasoning," these estimators need to be independent of the measures of growth under study. As growth is often adversely affected by suboptimal health, analyses will be biased if estimated ages are based on elements that are used to otherwise determine health status (Johnston and Zimmer 1989; Mays 1999; Saunders 1992; Steyn and Henneberg 1996). Collective burials often present fragmented, disassociated remains. In these cases, accurate and independent estimates of chronological age are not readily available. Thus, archaeological growth studies have been typically limited to contexts in which individual burials are present.
Studying Children in the Past and Comparisons with the Present

Although patterns of human growth and development have remained somewhat consistent throughout the window of modern human existence, many researchers have noted a secular increase in both adult stature and timing of growth completion among people in developed countries (Garn 1980; Hoppa 1992; Mays 1999; Tanner 1989). This increase is usually attributed to nutritional improvements. Hoppa (1992) observes that socio-economically advantaged children in modern populations tend to be heavier and taller than their counterparts in impoverished communities. Similarly, modern urban children are heavier and taller than children from rural areas. Clearly, the course of growth and development is influenced by environment.

Ideally, diachronic comparisons of growth and development should utilize appropriate reference standards for both populations as well as accurate estimates of chronological age (Mays 1999; Saunders 1992). In the absence of these standards, growth status can potentially be judged by methods that enable the relative comparison of multiple modes of growth. The ultimate goal of this research is to add to the growing dialogue of juvenile health in prehistoric societies. As the remains from the tomb at Tell Abraq are commingled, and current methods of analysis of commingled remains are limited, the proximate goal of this research is to overcome these problems by testing a method of examining skeletal growth. Specifically, this study analyzes two means of femoral growth by examining a measure of endochondral growth (cortical thickness) in conjunction with a measure of longitudinal growth (diaphyseal length) both within a prehistoric population and collectively to a modern population with associated health records.
CHAPTER 2
BACKGROUND AND LITERATURE REVIEW

The biocultural analysis of juvenile health in prehistory is a relatively new field of inquiry that emerged from a purely critical science approach to examining skeletal remains in the archaeological record (Kamp and Whittaker 2002; Saunders 1992). The initial processual analyses of juvenile health was focused on method over theory and did not often address questions regarding specific ways of life in the past (Hodder 2001; King and Ulijaszek 1999; Saunders 1992). Instead, it sought to establish volumes of data that superficially described various living and archaeological populations. Under the influence of post-processual (including feminist) thought in archaeology, the current dialogue of prehistoric juvenile health recognizes the interplay between biology and culture and subsequently interprets skeletal biology in light of culture (e.g., see Lewis 2002; Sobolik 2002; Stodder 1997). It is believed that this mode of research produces analyses that are not entirely scientifically-driven or biased, and thus more meaningful (Hodder 2001). Many current researchers view children and childhood as concepts that hold significant cultural relevance (Kamp 2001; Kamp and Whittaker 2002; Rothschild 2002). Western societies have historically deemed the role of children insignificant (Bird and Bliege Bird 2000; Rothschild 2002), as it is assumed that children do not contribute directly to economic progress or technological advancement. It is likely that this notion has been the impetus behind the historical dearth of research on children in the archaeological record. Feminist evaluations of the male-dominated research environment have shown that, historically, male researchers have been drawn toward analyses of male-dominated arenas (i.e., economy and technology) (Gero 1985; Harry et al. 2003). While this certainly still occurs today, the increasingly gender-balanced research arena has also helped balance the subjects of study.

Despite the all-inclusive scope of the current research climate, there is still a dearth of growth research on commingled skeletal remains. Established methodologies of growth research require multiple elements from the same individual in order to create a standard (chronological age) by which individuals and populations can be compared (Mays 1999; Saunders 1992). Commingled burials do not readily provide evidence to associate various skeletal elements. Single-element methodologies that examine one skeletal element per individual would allow research to be conducted on commingled remains. These single-element methodologies could not only provide a means by which many commingled collections can be evaluated, they could also provide a new lens through which prior research can be viewed.

Unlike early growth research (which sought to categorize and enumerate skeletal elements), contemporary growth research seeks to address cultural issues such as the health consequences of large-scale societal change. Bioarchaeological studies conducted in a contemporary research climate
often go beyond methodology and begin to address issues surrounding past lifeways (see Stodder 1997; Sobolik 2002). Specifically, the analysis of human growth provides insight into population health (via the inference of the timing and extent of growth faltering), which can be an indicator of economic/social conditions and/or changes (Hoppe and Fitzgerald 1999; Larsen 1995, 1997).

To place this study in a broader context, this chapter will first provide a background of skeletal biology, including skeletal growth and osteological ageing techniques. It will then review the methodologies that researchers currently utilize in analyzing population health from skeletal remains. Finally, it will review how the use of these methodologies contributes to the current dialogue of human growth and juvenile health in prehistory.

Overview of Skeletal Biology/Histology

Bone is composed of protein (collagen) and mineral (hydroxyapatite) and has two structural components: a dense cortical bone and spongy trabecular (cancellous) bone (Scheuer and Black 2000; Steele and Bramblett 1988; White 2000). Cortical bone is found in the walls of bone shafts and on external bone surfaces. It forms a protective shell around bone, providing strength and resistance against bending and torsion. Haversian systems are the basic structural units of cortical bone. The hollow haversian canal at the center of each haversian system allows blood lymphs and nerve fibers to pass through, nourishing the bone. Trabecular bone is spongy in appearance and therefore more lightweight than cortical bone (Scheuer and Black 2000; Steele and Bramblett 1988; White 2000). It is found in vertebral bodies, in the ends of long bones, in short bones, and within flat bones. Trabecular bone is nourished by diffusion from nearby blood vessels.

Histologically, bone can be classified into two categories: immature and mature (lamellar) (Scheuer and Black 2000; Steele and Bramblett 1988; White 2000). Immature bone develops prenatally and is replaced by mature bone during growth (Scheuer and Black 2000; Steele and Bramblett 1988; White 2000). It also develops at fracture sites during bone repair, and in many bone tumors. Immature bone has a higher proportion of osteocytes (living bone cells) than mature bone. In adults, both cortical and trabecular bone are made of mature bone (Scheuer and Black 2000; Steele and Bramblett 1988; White 2000). This lamellar bone is laid more slowly than immature bone and usually replaces it.

Skeletal Growth & Development

Two types of bone can be distinguished developmentally: intramembranous and endochondral (Scheuer and Black 2000; Steele and Bramblett 1988; White 2000). Intramembranous bone begins within a membrane that becomes bone via mineralization. Endochondral bone begins
as a cartilage matrix that is eventually replaced by trabecular bone (Scheuer and Black 2000). All bones of the limbs and vertebral column (with the exception of the clavicle) are endochondral (Scheuer and Black 2000; Steele and Bramblett 1988; White 2000). In these bones, ossification centers appear as cavities erode in the cartilage and osteoblast (bone forming) activity begins in localized areas. In long bones, primary centers of ossification form the diaphysis, or shaft (Scheuer and Black 2000; Steele and Bramblett 1988; White 2000). Here, osteoblasts deposit cortical bone around the diaphysis, while cartilage in the center is replaced by trabecular bone. Osteoclasts then break down the trabecular bone to form the medullary cavity. Secondary centers of ossification form the epiphyses, or ends of the long bones. During growth, the diaphysis is separated from the epiphysis by a growth plate (epiphyseal cartilage) (Scheuer and Black 2000; Steele and Bramblett 1988; White 2000). As bones increase in length (via endochondral growth), the growth plate shifts toward the epiphysis and is replaced by new bone at the diaphyseal side.

Long bones increase in width due to the apposition of new bone on the cortical walls (termed appositional growth) (Scheuer and Black 2000; Steele and Bramblett 1988; White 2000). Throughout growth, bone is added to the outer surface of the cortex beneath the periosteum. At the endosteal surface, bone undergoes a complex cycle of resorption during early childhood, followed by apposition during puberty, and again resorption during the final stages of growth (Garn 1970). The apposition/resorption of the periosteum and endosteum occurs at varying rates, with an early period of rapid apposition and resorption followed by slowed apposition until the adolescent growth spurt (Garn 1970). The apposition-resorption relationship nets a change in cortical thickness that follows this general schedule: an initial decrease in cortical thickness in early infancy, followed by a rapid increase (during the years of motor development), then a slower increase until the adolescent growth spurt, and then again slowed into adulthood (Garn 1970). After the initial decrease in early infancy, both cortical thickness and total bone thickness increase throughout the growth period. Cortical index (the percent of total bone width that is accounted for by cortical bone) also increases, indicating that cortical thickness increases at a faster rate than total bone thickness. In late adulthood, cortical thickness (and cortical index) begins to decrease. This growth and degeneration is largely controlled by a combination of hormonal control and muscle use. It is also heavily influenced by malnutrition and disease.

Once long bone growth is complete, the epiphysis and diaphysis fuse (Scheuer and Black 2000; Steele and Bramblett 1988; White 2000). Epiphyseal fusion begins occurring at about age twelve and continues into adulthood. The major areas to fuse during adolescence include the bones of the limbs, hands, feet, sternum, scapula, and pelvis. When external stressors have not disrupted growth, the timing of epiphyseal fusion for individual bones is relatively predictable.
Growth Inhibitors and the Marks They Leave

Although skeletal growth and development follow a predictable course, there are factors that influence the timing of the process. These factors are influential in varying degrees, and may include genetics, hormones, psychological stress, nutritional stress, and infectious disease (Larsen 1997). As the relationship between the various factors is dynamic and complex, there is no reliable method of establishing causation in an archaeological context. It is widely accepted, however, that nutritional stress and infectious disease are the most detrimental to the growth process (Larsen 1997). Social factors such as suboptimal socioeconomic conditions can often increase the prevalence of malnutrition and disease (Owsley and Jantz 1985). Regardless of specific causation, the presence or absence of these stressors in archaeological remains can be determined by the skeletal evidence they leave (Buckley 2000; Hoppa 1992; Hummert 1983; Hummert and Van Gerven 1983; Johnston 1968; Keenleyside 1998; Larsen 1997; Mays 1999; Merchant and Ubelaker 1977; Saunders 1992; Saunders et al 1993; Storey 1986; Wall 1991).

Long-term suboptimal nutrition will cause growth to slow and the growth period to be extended (Garn 1970; Hoppa 1992). Researchers have identified a correlation between poor nutrition and smaller-for-average cortical area in both living populations (Frisancho et al. 1970; Garn 1970) and archaeological populations (Cook 1979; Himes et al. 1975; Himes 1978; Hummert 1983; Hummert and Van Gerven 1983; Mays 1995, 1999). This correlation suggests that appositional growth is adversely affected by poor nutrition. These observations indicate that appositional growth may as sensitive to adverse conditions as longitudinal growth.

A phenomenon known as “catch-up growth” regulates growth and development to ensure that growth continues on a regular course after a period of illness or starvation (Prader et al. 1963). After a period of slowed growth (as bodily resources become available again), growth tends to resume at a rate of up to 4 times faster, in order to “catch up” to a normal growth curve. This period of fast growth is often observed skeletally as a rapid increase in longitudinal growth at the expense of endochondral growth. Prader et al. (1963) were among the first to document occurrences of catch-up growth. In the Harpenden Growth Study (1948-1971, Harpenden, England), children were measured every six months for height, weight, and skeletal maturity. Prader and colleagues (1963) illustrate cases of catch-up growth by plotting height and weight for chronological age, height and weight gain per year (for chronological age), and skeletal maturity score and skeletal age (for chronological age). The skeletal score are determined radiographically using the bones of the hand and wrist, as proposed by Tanner and colleagues (1962). The cases illustrated are of individuals who display slowed growth as a result of malnourishment, celiac disease (gluten intolerance), rickets, and hypothyroidism (Prader et al. 1963). During this period of illness or malnutrition, these children show a slowed rate of increasing height, weight loss, a slowed skeletal maturity score, and a skeletal
age that does not keep pace with chronological age. After the period of malnutrition or illness, these individuals exhibit sharply increasing height, weight, skeletal maturity, and skeletal age.

In addition to slowing skeletal growth, malnutrition and disease may leave more specific and permanent skeletal markers. Health indicators that are often examined in subadult samples include the prevalence of porotic hyperostosis and/or cribra orbitalia (Buckley 2000; Keenleyside 1998; Larsen 1997), trauma (Glencross and Stuart-Macadam 2000; Keenleyside 1998), and nonspecific infections (Buckley 2000; Keenleyside 1998).

Porotic hyperostosis refers to the skeletal changes that occur as a direct result of iron deficiency anemia (Larsen 1997). Iron is essential in the transport of oxygen to the body tissues. It is found in a variety of foods, but the body absorbs iron more easily from some foods (such as meats) than from others (such as plants). Iron deficiency can also be caused by a variety of nondietary factors: low birth weight, chronic diarrhea, parasitic infections, scurvy, and hypervitaminosis A (Buckley 2000; Larsen 1997). Porotic hyperostosis manifests as expansion of the cranial diploe, and thinning of the compact cranial bone. Cribra orbitalia is a related disorder that consists of similar lesions on the roof of the eye orbits.

Evidence of childhood trauma is often scarce in skeletal remains, as juvenile bones remodel at a rapid rate as compared to adult bones (Glencross and Stuart-Macadam 2000). Most childhood injuries effectively disappear into adulthood. In subadult remains, injuries are best preserved in an archaeological context when an individual dies shortly after (or as a direct result of) the traumatic event. Where infectious disease and nutritional stress are not a problem, injury is the most common cause of death of living children (Glencross and Stuart-Macadam 2000). Studies of living children indicate that different age groups exhibit different patterns of injury. In children who are not yet walking, injuries to the skull and clavicle are the most common (Tibbs et al. 1998). As children begin to walk, injuries to the tibia and femoral shaft become common. Throughout growth, as cartilage is replaced by bone, the incidence of fractures increases (Glencross and Stuart-Macadam 2000). Because the diaphyses of subadult bones are relatively thin and porous, complete fractures are rare.

There are a variety of infections and disease that can be identified through the evidence they leave in skeletal remains (Buckley 2000; Keenleyside 1998; Larsen 1997). Lesions left by infection range in severity from those that affect the periosteum (periostitis) to those that affect the periosteum, cortical bone, and medullary cavity (osteitis and osteomyelitis.) Periostitis is usually a result of bacterial infection, but has also been attributed to trauma (Larsen 1997). On skeletal remains, it appears as irregular “swelling” of the bone surface. Osteitis and osteomyelitis are caused by infections by microorganisms such as Staphylococcus aureus, Escherichia coli, Salmonella typhi, and Neisseria gonorrhoeae (Larsen 1997). The infected bone appears severely swollen and often has large holes for drainage of pus. Rickets, or osteomalacia, is the condition that arises as a result of vitamin
Vitamin D deficiency in childhood. Bones become softened as the body loses the ability to properly regulate calcium and phosphate. The load-bearing bones (such as the long bones of the legs) become markedly bowed.

**Ageing Techniques**

In the absence of growth-disrupting factors, the predictability of skeletal growth and development allows for reasonably accurate estimations of chronological age at death. Methods of chronological age estimation used in archaeological and forensic contexts include those utilizing dental remains, stages of epiphyseal union, maximum diaphyseal length, and multiregional methods that analyze multiple areas of the skeleton (Bass 1995; Fazekas and Kosá 1978; Flecker 1942; Garn et al. 1967; Greulich and Pyle 1950; Hill 1939; Hoffman 1979; Hoppa and Gruspier 1996; Klepinger 1992; Kósa 1989; Larsen 1997; McKern and Stewart 1957; Olivier and Pineau 1960; Pyle and Hoerr 1955; Saunders 1992; Scheuer 1980; Todd and D’Errico 1928; Ubelaker 1978). If multiple methods can be used concurrently, their reliability greatly increases. Ritz-Timme and colleagues (2000) question the reliability of any method in forensic contexts, as standardization and quality assurance techniques have not yet been developed.

The independent method typically preferred among researchers utilizes dental remains (Bass 1995; Hoffman 1979; Hoppa and Gruspier 1996; Klepinger 1992; Larsen 1997; Saunders 1992; Ubelaker 1978). Dental methods of age estimation have indeed proven to be highly reliable, as dentition is less susceptible than bone to growth inhibition caused by malnutrition or illness. Two of the most widely accepted and utilized dental methods are tooth emergence and dental calcification. The timing of tooth emergence is very predictable, and is thus a potentially reliable measure of physiological maturity (Saunders 1992). Biocultural factors such as tooth extraction or infection can influence the reliability of the method. It is for this reason that dental calcification is the preferred method of age estimation. Tooth formation and mineralization is a distinct and predictable process that is completely independent of skeletal growth (Larsen 1997; Saunders 1992). Radiographic techniques can be employed to measure the stage of dental calcification.

When dental remains are unavailable and ages need to be assessed for young subadults (perinatal – 12 years of age), the only methods available are the appearance of ossification centers (Garn et al. 1967; Greulich and Pyle 1950; Hill 1939), or the measurement of the maximum length of the diaphysis (Fazekas and Kosá 1978; Hoffman 1979; Kósa 1989; Olivier and Pineau 1960; Saunders 1992; Scheuer 1980; Ubelaker 1978). The appearance of ossification centers are either observed in one localized area to determine a minimum age, or collectively to arrive at a more specific age range. This method is limited in value, as much individual variation exists in the appearance of ossification centers. Thus, it is not used often in growth and development studies.
Fetal reference standards for diaphyseal length have been developed by Olivier and Pineau (1960), Fazekas and Kosá (1978), Kosá (1989), and Scheuer (1980). Ubelaker (1978) first established this method by comparing the maximum diaphyseal length of the humerus, radius, ulna, femur, tibia, and fibula with dental age for five North American populations (four Native American and one modern European American). The results are tabulated to provide reference indices. Ubelaker (1978) cautions against using these tables for non-North American (even non-Native American) populations, as population differences in growth patterns will likely affect age estimations. Similar tables have been developed for other populations; researchers are cautioned about using appropriate references.

Sherwood et al. (2000) tested a number of skeletal and non-skeletal methods of fetal age estimation. Skeletal methods, such as the appearance of ossification centers and the maximum length of the diaphysis were found more reliable than soft tissue methods of age estimation. While the skeletal methods were somewhat reliable, the presence of various growth-related pathologies greatly increased the inaccuracy of estimations.

Stages of epiphyseal union can be used to estimate age at death of older juveniles in individual burials that have a high degree of preservation (Saunders 1992). First identified by Stevenson (1924), this method is based on the universal similarity in the timing of epiphyseal union. The order and timing of the union of various epiphyses has been documented by Todd and D’Errico (1928), Flecker (1942), Greulich and Pyle (1950), Pyle and Hoerr (1955), and McKern and Stewart (1957). What many of these references lack is the degree of individual variability of epiphyseal union (Ubelaker 1989). This method is only applicable in “older” juveniles, as epiphyseal union does not begin until about 12 years of age (Ubelaker 1989). Individual burials are necessary, as multiple bones are used to assess the stage of development of the entire skeleton. Epiphyseal union can take several years, so various stages of union are typically assessed.

In the case of commingled remains, the measurement of maximum diaphyseal length is the only available method of age estimation. This method is problematic for any health study, as the age estimates will skew the results toward “normalcy.” In other words, age estimates based on the maximum diaphyseal length could artificially lower the ages of underdeveloped individuals. Likewise, overdeveloped individuals would appear older. Clearly, since independent methods of age estimation cannot be applied in commingled contexts, alternative methods of analysis must be developed.

Review of Current Methodologies

In the analysis of prehistoric juvenile health, researchers currently draw on a number of established approaches. The lack of a single, standard methodology precludes comparisons of many
analyses (Saunders et al. 1993). Methodologies employed include macroscopic analyses of skeletal indicators of health (Sobolik 2002; Stodder 1997), analyses of growth based on bone dimensions (Hoppa 1992; Hummert 1983; Hummert and Van Gerven 1983; Jantz and Owsley 1984; Johnston 1962; Mays 1995, 1999; Mensforth 1985; Merchant and Ubelaker 1977; Saunders et al. 1993; Steyn and Henneberg 1996; Storey 1986; Wall 1991), paleodemography (Storey 1986), radiographic analyses (Hummert 1983; Mays 1995, 1999; Sobolik 2002; Stodder 1997; Storey 1986), and even DNA and Immunoglobulin analysis (Ortner et al. 1992). While the most comprehensive analyses utilize multiple methods, factors such as sample size, preservation, and burial type determine which methods, if any, are applicable.

All health research carried out on archaeological populations begins with the assignment of chronological age (or stage of osseous or dental development). Hoppa (1992) cautions against using age estimations to analyze individual health, as the error inherent in these estimations will inevitably confound the results. Instead, analyses utilizing chronological age estimations should look at data in aggregate form only. Population-level comparisons will not suffer from the same source of error, as age estimations will generally be biased in the same direction, thus maintaining accuracy relative to one another.

Once ages have been established for the population, researchers analyze patterns of non-specific indicators of stress and compare them to published data on either prehistoric or modern populations. The type of stress indicator depends on the method of analysis. For example, macroscopic analyses will investigate patterns of porotic hyperostosis, cribra orbitalia, non-specific infections that attack bone, or even trauma. These analyses are usually somewhat subjective. Often, researchers will use an arbitrary scale to assign severity of specific conditions. The lack of standardization with this approach often makes for difficult comparison with similar studies. This type of analysis is often done in conjunction with measurements of bone dimensions, paleodemography, and radiographic analyses.

Measurements of bone dimensions reveal patterns of growth that may or may not indicate the presence of various environmental stressors. Often long bone length-for-chronological age is compared diachronically for the same population, or to a modern reference standard (see Hoppa 1992; Hummert and Van Gerven 1983; Johnston 1962; Mays 1999; Merchant and Ubelaker 1977; Saunders et al. 1993; Steyn and Henneberg 1996; Wall 1991; y'Edynak 1976). If growth appears deficient for chronological age, researchers often attempt to pinpoint the cause of growth disruption. This is usually done by inference based on archaeological or historic evidence.

Paleodemography constructs life tables to analyze mortality and fertility rates (Meindl and Russell 1998). These types of analyses rely primarily on chronological age estimations. Using these,
they construct demographic profiles of past societies. Many paleodemographic analyses are supplemented by macroscopic, radiographic, and dimensional analyses.

Radiographic analyses are often employed to investigate the skeletal manifestations of stress such as Harris lines and cortical bone deficiency (Hoppa and Fitzgerald 1999; Mays 1995, 1999; Saunders 1992). Harris lines form as a result of growth arrest following a period of illness or malnutrition (Park 1964). They are composed of dense, laterally-oriented trabeculae and appear radiographically as transverse lines on the diaphyses of long bones. While many researchers note the appearance of Harris lines as a potential indicator of physical stress during the growth period (see Mays 1995, 1999; Ribot and Roberts 1996) a direct one-to-one correlation between disease and/or malnutrition and line formation has yet to be made (Mays 1999).

Radiographic analyses have also been used to study cortical growth. (See Hummert 1983; Mays 1995, 1999). Typically, a long bone with a symmetrical diaphysis (such as the femur) is chosen for analysis. Cortical thickness is measured on the x-ray at the midshaft point. Cortical index and percent cortical area can be derived from this measure. All measures of cortical growth are generally compared with estimates of chronological age, and sometimes with measures of longitudinal growth. These analyses currently suffer from a lack of reference standards. They can however, prove insightful when compared with a different measure of growth.

Finally, molecular biology has proven useful in the analysis of prehistoric health, familial relationships, and diet (Ortner et al. 1992; Thomas 1993). Of interest in this context, DNA and immunoglobin analyses represent potentially informative methods of analyzing health in prehistoric populations (Thomas 1993). If DNA can be extracted from a skeletal element, it may reveal the presence of genetic disease, such as cystic fibrosis or sickle-cell anemia (Ortner et al. 1992; Thomas 1993). Similarly, immunoglobin analysis can potentially yield information relevant to non-genetic diseases an individual was exposed to during life, such as tuberculosis. These analyses both corroborate visual analyses of health and disease and potentially enhance them by pinpointing specific genetic and non-genetic diseases.

Early growth research (as early as 1800) was characterized by an abundance of physical data (Garn 1980). Researchers measured bone dimensions against chronological age and established many pioneering notions such as the secular trend, the adolescent growth spurt, differences in growth by sex, and population differences in growth. In the 1900's, medical researchers began undertaking growth studies that were longitudinal in nature (Garn 1980). These studies allowed for a more thorough understanding of the growth process in living children. In the 1960's, the knowledge gained from these longitudinal studies began to be applied in archaeological and forensic contexts, allowing researchers to infer growth patterns from the analysis of skeletal remains (see Himes 1978; Himes et al. 1975; Hoffman 1979; Johnston 1962, 1968; Mensforth et al. 1978; Merchant and
Ubelaker 1979; y'Edynak 1976). Most recently, growth research has become increasingly problem-oriented, often seeking to correlate large-scale societal changes with disruptions in growth patterns, while striving to refine and standardize the methods used in the analysis of growth (Garn 1980).

The examination of subadult remains from commingled contexts provides a new source for potentially meaningful information regarding health in prehistory. Before this can be accomplished, current methodologies must be examined and redefined.

Review of Dialogue of Juvenile Health in Prehistory

Despite the increasing interest in the analysis of juvenile health in the archaeological record, most researchers still recognize the problems inherent in any bioarchaeological analysis. There are three main biases that have the potential to skew the results of any analysis. The first is that of biological mortality bias. Johnston (1962) was among the first to recognize biological mortality bias, noting that individuals in a skeletal sample are, by nature, not representative of a living population. This bias has since been defined as "the physiological and morphological difference between those who die and those who survive" (Saunders and Hoppa 1993:129). The second major factor is cultural mortality bias, which can be defined as producing a non-representative sample by means of differential burial practices. This is seen in cultures whose social hierarchy determines differential treatment of the dead. The third limiting factor is termed environmental mortality bias, which refers to the potential for differential preservation of skeletal remains due to soil types or climate.

Saunders et al. (1993) examined growth in a historic context through the analysis of diaphyseal length. The skeletal sample (n=2800) is from a 19th century cemetery in Ontario, Canada and is comprised of individuals determined to be under the age of 15 (via tooth formation). Saunders and colleagues created skeletal growth profiles by plotting diaphyseal length against chronological age. In this way, they were able to compare the skeletal growth among the individuals in this cemetery to that of modern reference standards as well as other archaeological groups (including the medieval Anglo Saxon Raunds from western Europe and the prehistoric Anikara of North America). The results of this study indicate that skeletal growth in the 19th century archaeological population does not differ significantly from that of modern North American reference standards. The authors conclude that biological mortality bias may not be a large determining factor of sample representativeness.

Even so, the potential for bias in bioarchaeological studies makes the analysis of subadult remains quite challenging. Many researchers have effectively avoided dealing with cultural and environmental mortality biases by focusing on patterns of growth as indicators of general population health, rather than attempting to "unravel" the demographics of a particular group (Saunders and
Hoppa 1993). The early studies that utilize skeletal remains of children address childhood health and diseases (Johnston 1962). Many recent studies of children in archaeological contexts have begun to use skeletal remains to address biocultural issues such as the effects that increased population density (Stodder 1997) or the advent of agriculture (Sobolik 2002) had on children’s health in the past.

Johnston (1962) represents an early study that applies contemporary medical knowledge to analyze skeletal growth in the past. The ultimate goal of this project was to begin a database of population-specific measures of skeletal growth could later be used for comparative purposes. In this analysis, Johnston presented data on diaphyseal length of the major long bones of 165 infants and young children (up to 5.5 years of age) from the Indian Knoll site in Kentucky. The individuals represented were aged according to stages of dental and osseous development. The data were tested for significance (using the Student’s t-test) against data from modern Americans. The most significant differences were seen between ages 3 and 5; these differences were attributed to general environmental differences.

Buckley (2000) presents another example of a study that focuses on quantitative methods and results without addressing culturally-specific issues. This is a study of health patterns among subadult remains from prehistoric Polynesia. The subadult remains (n=17) used in her study were excavated from individual burials. Thus, age at death could be determined by as many as four methods per individual: dental calcification, dental eruption, diaphyseal length, and epiphyseal union. Buckley uses macroscopic and radiographic techniques to observe health and disease patterns throughout the population. Results of this study show that the most prominent pathology is subperiosteal new bone deposition and cribra orbitalia. These pathologies are present exclusively in individuals from six months to three years of age. The precise etiology of these conditions can not be determined, and thus it is assumed that multiple causes of pathology existed in the Pacific Islands. While Buckley’s analysis successfully identifies the type and frequency of many subadult diseases in Polynesia, it falls short of identifying potential biocultural factors that contributed to the skeletal pathologies seen in the population.

Likewise, Storey (1986) does not attempt to interpret the possible reasons behind a potential disruption in growth. In this study, she analyzed 52 perinatals and 7 infants from the pre-Colombian city of Teotihuacan. Ages were assigned (by means of dental calcification) for nine individuals. The rest were seriated based on size. Life table analysis revealed a high perinatal mortality rate. When compared to perinatal mortality among historic Arikara, the Teotihuacan individuals were determined to be younger at death. Further, four of the individuals had bone lengths that were small-for-age. Storey concluded that individuals at Teotihuacan were not growing in the last month in utero. The author is careful not to identify this as a growth defect; she states that it is possible that normal perinatal size in this population is just smaller as compared to modern standards.
Wall (1991) analyzed human growth by means of long bone length and estimated growth velocity analyses in an attempt to isolate environmental influences on growth. The methodology was designed to minimize potential error introduced by unknown age & sex, population differences in adult stature, small sample sizes, and differential preservation of poor growth performers. Dental estimates of age are compared to long bone length.

Hummert (1983) analyzed total subperiosteal area, cortical area, medullary area, and percent cortical area at the midshaft of 174 subadult tibia from two temporally distinct populations from Sudanese Nubia (early and late Christian populations). Skeletal ages were assigned based on standards of dental formation. Cortical growth and longitudinal growth were found to be normal for age, but percent cortical area reflected excessive endosteal resorption in both populations. Despite the steady increase in overall bone growth, cortical resorption on the endosteal surface occurred at a higher than average rate, indicating the presence of stress. Hummert attributes this to malnourishment, which was more severe in the early Christian population.

In another analysis of the same populations, Hummert and Van Gerven (1983) analyzed long bone growth as compared to growth data from another local population (Wadi Halfa in Lower Nubia). For this study, Hummert and Van Gerven analyzed 180 subadults that were disinterred from two cemeteries in Kulurbnarti. Again, standards of dental formation were used to assess skeletal age. Long bone growth was analyzed via mean diaphyseal length per age category of five long bones: the femur, tibia, humerus, ulna, and radius. Growth was shown to be slower in the Sudanese Nubia populations, possibly as a result of malnutrition.

Mays (1999) analyzes a population from Medieval England for disruptions in growth as evidenced by bone dimensions. He compared measures of longitudinal growth (diaphyseal length) and appositional growth (cortical thickness and cortical index) to estimates of dental age. Results were compared with a modern population. The Medieval group exhibited a greater deficiency in cortical bone growth than in diaphyseal length growth. As compared to the modern population, growth deficiencies in the Medieval population appeared greater. Mays concludes that “The value of measures of cortical bone as stress indicators in immature individuals needs to be more widely appreciated” (Mays 1999:309).

Despite potential biases involved in growth research and the complex interactions between environmental/physiological stressors, many researchers attempt to infer specific causations for growth faltering. Often the cause is directly related to a major societal change. In a study that compared Native American growth patterns during three time periods, Cook (1984) found that growth faltering and a high incidence of skeletal lesions (porotic hyperostosis and cribra orbitalia) occurred coincidentally with the introduction of a maize diet. Similarly, Mensforth (1985) suggests a relationship between poor juvenile health and high levels of infectious disease among a Late...
Woodland sample from Ohio. In this study, Mensforth examined tibia length of subadults (aged birth – 10 years) from two populations: Libben and Bt-5. Growth faltering only occurred in the Libben group. Here, it occurred at an early age, likely around the time of weaning. Mensforth concludes that high levels of infectious disease caused the growth faltering in this population, and this may be a direct result of increased population density and the sedentary effects of increased agriculture.

Jantz and Owsley (1984) attribute growth faltering to disease and undernutrition in an Arikara population from South Dakota. They compared growth among 10 Arikara skeletal samples that span three time periods: prehistoric, protohistoric, and historic. Using regression analysis to predict bone length (given dental age), Jantz and Owsley found differences in growth in each of the three time periods. It is inferred that these differences are a result of differences in health and nutritional status. Jantz and Owsley conclude that, while Arikara in each of the three time periods experienced poor health, causative factors differ through time. The prehistoric Arikara likely suffered undernutrition as a result of poor climatic conditions. The protohistoric groups probably benefited somewhat from improved climatic conditions, and the historic samples fared poorly due to the introduction of epidemic diseases and depopulation that were a result of European contact.

An example of a more comprehensive analysis of health and disease in the past is Stodder’s 1997 study of subadult health among Late period populations of Guam. The materials available for this study include 293 subadults that were buried individually. The majority of these remains are fragmentary, and thus Stodder focused on dental analyses exclusively to estimate chronological age as well as to analyze periods of physiological stress. Periods of physiological stress often result in a disruption of enamel growth which causes pits or depressions on teeth known as linear enamel hypoplasias (LEH) (Mays 1995; Stodder 1997). Stodder (1997) measured the height and frequency of all linear enamel hypoplasias to determine a relationship between childhood stress and life expectancy. To supplement the dental evidence, general macroscopic indicators of health and disease were employed on the skeletal material. These include observing the presence/absence, relative severity, and age distribution of periostitis and cribra orbitalia. The results of Stodder’s study indicate a relationship between linear enamel hypoplasias and reduced life expectancy, as well as a positive correlation between skeletal indicators of disease and linear enamel hypoplasias. These results are interpreted within the context of social change in the late prehistoric period of Guam. Stodder (1997) argues that increasing population density among coastal areas had a negative effect on the health and life expectancy of children.

Another study on the effects of population density on health was done by Sobolik (2002). She reviewed skeletal data on 9,703 individual burials from sites in the American southwest for evidence of childhood disease. Health indicators include childhood mortality rates, adult stature,
evidence of porotic hyperostosis, cribra orbitalia, linear enamel hypoplasias, Harris lines, and periostitis. Sobolik analyzed the health data by site size, time period, cultural affiliation, and location, arguing that canyon regions show higher frequencies of anemia (as evidenced by porotic hyperostosis and cribra orbitalia), due to the higher population density that results from an increased reliance on agriculture. Smaller populations on the sage plains relied on hunting to a greater extent, and therefore there are fewer indicators of anemia there. This supports ideas that overall, the level of childhood mortality seen in the prehistoric southwest would indicate severe malnutrition and physiological stress in a modern population (Sobolik 2002).

Anthropologists have been interested in analyzing skeletal growth and development for years. Boas and Hrdlicka were pioneers in this field of inquiry (Garn 1980). Their early research was primarily concerned with measuring growth rates in order to establish similarities and differences in both modern and prehistoric populations. Over time, interests in the analysis of skeletal growth moved toward understanding the dynamics between various environmental factors and skeletal growth (see Sobolik 2002; Stodder 1997). Currently, researchers are still examining these relationships, and attempting to establish causation.

Many current researchers of subadult health and disease attempt to synthesize quantitative skeletal data with cultural and archaeological evidence (See Sobolik 2002; Stodder 1997). This allows for a more comprehensive examination of past lifeways that can place juvenile health and disease in a broad biocultural context. For relatively unknown societies represented by skeletal samples like those from Tell Abraq, patterns of juvenile health can lead to interpretations about population dynamics, as well as the social and economic roles of children.
In Arabian prehistory, the Umm an-Nar period represents the time from ca 4600 – 4000 BP (Potts 1990). Named after the site where the diagnostic archaeological assemblage was first found (the island of Umm an-Nar), this time period is characterized by the appearance of large, circular communal tombs. Excavations of the Umm an-Nar period on the Oman peninsula began in 1958 (Blau 1995; Potts 1990). From that time, teams of archaeologists from Denmark, France, Iraq, Great Britain, America, Italy, Germany, Australia, and the United Arab Emirates (UAE) have worked there. The area has proven to be a rich source of archaeological material for this time period.

During the Umm an-Nar period, two distinct geographic regions are noted in Arabia (Potts 1993a). The first, called Dimun, is comprised of the area between modern Kuwait and Qatar. The second, Magan, consists of areas on the Oman peninsula (from the UAE to the Sultanate of Oman).
While originally defined in literary sources, an analysis of material culture in the regions (such as tombs, ceramics, and metals) corroborates the distinction.

The Oman peninsula has numerous copper deposits, and during the Umm an-Nar period, copper metallurgy became an important part of the production of everyday tools (Potts 1990). Pins, knives, fish hooks, and awls were often made of copper. Evidence of small-scale smelting operations (i.e., kilns, slag, and molds) is quite common throughout the peninsula. Larger-scale operations, probably for the purpose of copper export have also been found at Umm an-Nar period sites.

During the Umm an-Nar period, Tell Abraq was a coastal community. It is currently located approximately 7 kilometers from the gulf coast (Potts 1993a). Habitation at Tell Abraq began in the Umm an-Nar period, about 4600 B.P. and continued to about 1600 BP (Potts 1990). This time period marks a transition from late Bronze Age to early Iron Age and late pre-Islamic societies. This 3000-year period is among the longest known continuous habitation periods in the area. The deep stratification provides great potential for analyzing longitudinal society-level changes. Excavations at Tell Abraq began in 1989. A team led by D.T. Potts (University of Sydney) and funded through the Australian Research Council, the Office of the Emirate of Umm al-Qaiwain, and General Motors (Dubai) excavated the site over numerous field seasons from 1989 through 1998.

Archaeological evidence suggests that Tell Abraq was a major trade center (Potts 1993). Many of the artifacts from Tell Abraq are made of materials that originated a great distance from the site. Copper pieces found at Tell Abraq probably of Dilmun origin. Likewise, some polished flint likely came from the Indus Valley. It is hypothesized that the Barbar red-ridged pottery found at Tell Abraq originated on Bahrain. Other types of pottery are similar in form to pottery from Mesopotamia. Nonskeletal material from the tomb at Tell Abraq has stylistic attributes similar to that seen at sites in northern Afghanistan. Also imported to the area was tin (or tin-bronze), probably from the east.

The structures of Tell Abraq were of varied design and materials. A structure unique to Tell Abraq is a large round building, made of mudbrick and white stone. Although similar in design to others in the area, the building at Tell Abraq is much larger, measuring 40 meters in diameter and over 8 meters tall (Potts 1993a). The presence of this fortress-like building indicates that Tell Abraq may have also been an important political center – perhaps even the major political center of ancient Magan (Potts 1990). Residents of Tell Abraq built houses of local stone, often massive and unworked. These houses had walls that were composed of parallel rows of stone filled with gravel, and mudbrick roofs. The presence of hundreds of post holes surrounding the fortress indicates that smaller, less permanent structures were built there. These structures were likely homes made of palm fronds and mats that were lashed to poles (Potts 1990).
The subsistence strategy at Tell Abraq is likewise varied. The people of Tell Abraq probably enjoyed a varied diet that may have had a high nutritive value. Faunal remains from the site (such as fish bones and shellfish) indicate a reliance on marine foods (Potts 1993). Numerous burnt date stones suggest the presence of date gardens. These gardens would have provided ample shade to cultivate wheat, barley, and vegetables. Moreover, the presence of grinding stones further suggests the importance of cereals as a dietary source.

Umm an-Nar Tombs

Perhaps the best-preserved remains of life during the Umm an-Nar period are the tombs. Umm an-Nar-period graves have been found by the thousands on the Oman peninsula (Potts 1990). These tombs are circular, varying in diameter from five to 13 meters. They are made of unworked stone and faced with a single wall. Some larger tombs are faced with masoned limestone. Entranceways to the tombs are often trapezoidal. Internal divisions are variable, ranging from two to ten rooms, and many have more than one interior level. Most Umm an-Nar-period tombs are collective burials that were used over the course of hundreds of years. But little is known about the cultural practices surrounding interment, beyond the fact that many of the remains from Umm an-Nar-period sites were cremated. Artifacts of material culture found in the tombs tend to be finer and likely more culturally valued than those found outside the tombs (Potts 1990). This may indicate that the tombs contain the remains of an elite class of citizens and may also indicate that these people performed burial practices that necessitated the sacrifice of valuable items.

Although Umm an-Nar-period tombs represent defining archaeological features, the human skeletal remains found inside have been studied by only a handful of scholars (see Blau 2001; El-Najjar 1985; Hojgaard 1980; Kunter 1991). This relative lack of scholarship has been attributed to the disarticulated and fragmentary nature of most of the remains (Blau 2001). The human skeletal remains from the tombs from the island of Umm an-Nar, al-Sufuh, al-Mowaihat, Unar 2, Hili, Maysar, and Tell Abraq have been studied the most.

Of 108 individuals interred in three tombs on the island of Umm an-Nar, only 15 are subadults under the age of twelve (Potts 1990). Of these, 13 are under the age of seven. The subadult mortality rates inferred from these Umm an-Nar period burials (approximately 13%) is much lower than that of other ancient populations (Potts 1990). Kunter (1991) analyzed the human skeletal remains from four tombs on the island of Umm an-Nar. He estimates that 18% of the recovered individuals are subadults. This subadult mortality, although higher than Potts (1990) estimate, is still considerably low for ancient populations. Further, Kunter (1991) suggests that the adult remains appear gracile, with long, slender long bones. Analysis of dental wear by Hojgaard
(1980) suggests that they relied heavily on marine foods, and less on agriculture, which may help explain why those buried at Umm an-Nar are not as robust as those individual engaged in the heavy stresses of agriculture. This dental analysis also suggests that individuals in the tombs at Umm an-Nar may have been closely related, as 21 of them exhibit an absence of the lower third molar.

Blau (2001) analyzed the skeletal remains from 3 Umm an-Nar-period sites (al-Sufuh, al-Mowaihat, and Unar 2), as well as two Wadi Suq-period sites (Sh. 602 and Sharm). Most of the remains from each site are disarticulated, fragmentary, and exhibit evidence of cremation. Because of this, the analysis did not rely on the determination of age or sex. Instead, Blau analyzed the remains for skeletal alterations that indicate trauma, congenital disease, joint disease, infectious disease, metabolic disease, and neoplastic disease. Results of the analysis indicate a relatively low incidence of all skeletal alterations among the Umm an-Nar-period remains. Trends in the incidence of trauma and metabolic disease between Umm an-Nar and Wadi Suq-period tombs were noted, however. Although small, the incidence of trauma is greater than that recorded for remains from the Wadi Suq period. Blau suggests that this difference could be a direct result of the construction of large structures during the Umm an-Nar period. Similarly, the incidence of cribra orbitalia is higher for Umm an-Nar-period remains. Blau suggests that this may be a result of a dietary shift from an exclusively marine-based diet to the more varied, agricultural diet of the Umm an-Nar period.

At Hili, at least 188 individuals were excavated from the tombs (El-Najjar 1985; Potts 1990). Of these, less than 28 are subadults. Many of the remains are fragmented and burned (El-Najjar 1985). The skeletal remains of the adult population indicate few occurrences of disease (only a few cases of osteoarthritis); they are also quite tall and robust relative to modern standards. Moreover, there is little evidence of skeletal infection. El-Najjar (1985) suggests that many of these adults met a violent death, as the proportion of bone fractures is quite high.

At Maysar, 21 Umm an-Nar-period individuals were recovered (Potts 1990). The skulls are robust with large muscle attachments. In contrast to the remains from Hili, the skeletal remains from Maysar are markedly sexually dimorphic. The Umm an-Nar period remains show no evidence of dental caries.

The Tomb at Tell Abraq

While Tell Abraq was inhabited for nearly 3000 years, the tomb at Tell Abraq was likely used for a 300-year period during the end of the Umm an-Nar period (ca. 4300 – 4000 BP). This tomb contained the remains of both adults and subadults across all age categories. The MNI for the entire tomb is 250. Unlike other Umm an-Nar-period tombs, almost half of the remains are subadults (MNI = 115). Also contrary to other Umm an-Nar tombs, the remains show little (if any) evidence
of cremation. Preliminary analysis of the subadult remains indicated a relatively low prevalence of porotic hyperostosis and cribra orbitalia. This suggests that the subadults in the tomb at Tell Abraq may not have suffered from high incidences of infection or malnourishment.

As tombs of this type, size, and preservation are rare in the area, Tell Abraq offers a unique opportunity to study both the adults and children who lived in a little-known community. This opportunity can add to a growing dialogue of life in prehistoric Arabia. Specifically, insights into the health status of the children at Tell Abraq can provide insights into total population health. This picture of health in prehistoric Arabia can either corroborate or challenge evidence that Tell Abraq was a thriving community.
CHAPTER 4
METHODOLOGY

Research Problem

The Umm an-Nar-period tomb at Tell Abraq offers a potentially rich source of information regarding life in prehistoric Arabia from ca. 4300 – 4000 BP. A cursory observation suggests that the relative proportion of subadults recovered from the tomb is high. This can be indicative of a number of things. The mere presence of subadults suggests that Tell Abraq was a continual habitation center, and not simply a stop along a trade route. In contrast, the remains from island of Umm an-Nar may be comprised largely of sailors and craftsmen (as indicated by the high male:female ratio, and the relative lack of subadults) Kunter (1991). The high subadult-adult ratio at Tell Abraq may also be an indicator of poor health conditions. Perhaps the children of Tell Abraq suffered from unusually high rates of chronic illness, and thus did not survive into adulthood.

This study attempts to explore some parameters of childhood at Tell Abraq by addressing issues relating to subadult growth. If growth faltering did occur at Tell Abraq, it is suggestive of the presence of malnutrition and/or illness. If, however, growth proceeded normally or at rate superior to that of modern, unhealthy children, it is likely that the children buried in the tomb at Tell Abraq did not suffer from malnutrition and/or illness in rates similar to modern children in underserved populations. Ideally, the subadult remains from Tell Abraq would be compared to a temporally and geographically similar population or to a healthy modern population. Due to various constraints, neither scenario is plausible.

As all established methodologies of growth analysis require an independent and accurate estimate of chronological age, the subadult remains from Tell Abraq represent an opportunity to explore alternative approaches to the study of prehistoric health. Such approaches attempt to make individual and population-level comparisons of health through the analysis of one skeletal element per individual. This study first tests the null hypothesis that we cannot determine if growth faltering occurred by analyzing one skeletal element exclusively. If we can disprove the null hypothesis, then we may be able to determine if growth faltering actually occurred at Tell Abraq.

The approach used in this analysis measures two types of growth that growth-inhibiting factors may differentially affect (longitudinal growth, as measured by maximum diaphyseal length, and endochondral growth, as measured by midshaft cortical thickness). If a constant pattern between these types of growth emerges across populations, and that relationship is distorted in the subadult remains from Tell Abraq, it may be indicative of the presence of malnutrition and/or illness.

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If the null hypothesis is rejected and growth faltering did occur at Tell Abraq, we can conclude that growth-inhibiting factors were present. Although pinpointing the exact nature and severity of these growth-inhibiting factors may be outside the scope of this analysis, it certainly represents fertile ground for future research.

Sample

The MNI of the subadults from Tell Abraq (n = 115) was established using the proximal right femur. As all of the subadult remains from the tomb at Tell Abraq are disarticulated, only one element was chosen for analysis. This ensures that each bone represents a unique individual. The sample includes all complete left femora, as well as those fragmentary femora whose diaphyseal mid-shaft point exists (as determined by regression analysis). Although the right femur was counted to establish the MNI, the left femur was chosen for analysis. This is because there are more complete left femora than there are right femora. Selecting this bone reduces error by increasing the reliability of the regression formula used to predict bone length and reducing the number of bones for which length is estimated.

Preliminary macroscopic analysis of the remains reveals some evidence of non-specific (periosteal) infection. This infection appears at higher frequencies in smaller (i.e., younger) individuals. There is little evidence of porotic hyperostosis or cribra orbitalia. The relative absence of these conditions suggests a diet rich in absorbable iron, as well as a general lack of parasitic infections, chronic diarrhea, scurvy, low birth weight, and hypervitaminosis A (Buckley 2000; Larsen 1997). Conclusions from preliminary analyses (Stone et al. 2001) indicate that the subadults from Tell Abraq appear healthier than would be expected for young individuals in a prehistoric population.

Comparison Sample

The Hamann-Todd osteological collection housed at the Cleveland Museum of Natural History consists of the skeletal remains of 3100 modern humans and over 900 non-human primates. It is the largest and most widely researched and published collection of its kind in the world. The human remains are representative of all age categories and each has associated vital records. Many of these records detail height, weight, chronological age, skeletal age, sex, race, and cause of death. The collection consists of both unclaimed bodies, as well as those individuals who willfully donated their bodies to the collection (Usher 2002). For this reason, it is fair to assume that the human remains in the collection are from varied socioeconomic backgrounds. Nevertheless, many of the subadults in the collection died from “wasting” diseases that often adversely affected growth. For the purposes
of this study, this comparative collection represents a low baseline of health to which population health at Tell Abraq is compared.

The comparison sample was initially divided into two subsamples based on developmental status. The first subsample (HTH underdeveloped or HTHu) represents individuals whose chronological age is greater than their skeletal age-at-death, as noted in the coroner’s report. The well-developed HTH (HTHw) subsample is composed of individuals whose skeletal age is at or higher than their actual chronological age at death. As not all vital records indicated skeletal age, there are individuals who are not classified into either subsample. An independent samples t-test was conducted to evaluate the hypothesis that mean femoral length is longer in the well-developed HTH subsample. The test was significant, \( t(20.227) = -2.730, p = .013 \). Upon closer examination it becomes clear that the HTHw subsample is biased in favor of older individuals (table 1). It is for this reason that the HTH sample is not subdivided in this analysis.

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Table 1. HTH Subsamples

Methods

Data recorded for this study include femoral diaphyseal lengths, proximal and distal mediolateral transverse shaft breadths, vertical diameter of the femoral head, midshaft femoral thickness (measured both on the bone and x-ray to minimize enlargement error), and midshaft medullary thickness in the anterior-posterior plane. All diaphyseal lengths were measured on a standard osteometric board to the nearest millimeter, as outlined by Bass (1995). All other measurements were taken with digital calipers and rounded to one-tenth of a millimeter.

As many of the subadult skeletal elements from the tomb at Tell Abraq are fragmentary, the initial stage of this research sought to predict maximum diaphyseal length and midshaft points for the broken femora. To do this, regression analysis was employed to identify correlations between
various measurements of the proximal subadult femur and maximum diaphyseal length among the complete femora. This is based on the work by Hoppa and Gruspier (1996), who established through regression analysis that many of these correlations do exist in the subadult skeleton. Initially, complete femora were measured to establish the formula that would predict the lengths of fragmentary femora. Maximum diaphyseal length (y) and various measures of the proximal and distal ends (x) were tested in Minitab for correlations via least squares regression analysis. The measurement that best predicts diaphyseal length ($R^2 = 99.6\%$) is the maximum transverse diameter of the proximal end (figure 2).

The maximum transverse diameter of the proximal end was measured for each fragmented (proximal) left femur. Maximum diaphyseal length was estimated using the regression formula generated from the complete femora ($L = 22.34 + 2.38(D) + 0.04(D)^2$, where $L =$ maximum diaphyseal length and $D =$ maximum transverse diameter of the proximal end). The midshaft distance was calculated using the formula $MS = \frac{1}{2} L$ (where $MS =$ midshaft distance). This distance was measured from the proximal end of each broken femur to find the midshaft point. All broken femora that retain their midshaft point were included in analysis. All midshaft points of broken and complete femora were marked directly on the bone with a small pencil mark. By predicting the length and midshaft points of broken femora, this regression analysis effectively increased the sample size from 29 to 56.

Radiographic Techniques

The Tell Abraq subadults were radiographed at Borgess Medical Center (Kalamazoo, Michigan) using a Picker MTX X-Ray machine with tube height set at 32.5 inches. The film was read with an FCR 5000 film reader. A total of 56 individuals from Tell Abraq were radiographed. The Hamann-Todd subadults were radiographed at the Cleveland Museum of Natural History with a portable x-ray machine. 53 subadults from the Hamman-Todd collection were radiographed.

For each sample, each femur was set up in an anterior-posterior position on the x-ray film. In instances where bones did not lie naturally in the a-p plane, they were propped up with a modeling compound that would not damage the bone. The midshaft point of each femur was aligned on the film, and a metallic marker was set up to record the line. Each film was set up with two controls for enlargement. Two standard paper clips were set at the height of the shortest and tallest bone. For all films, the difference in size of the paper clips was negligible.
Figure 2. Measures of the Femur: Maximum Diameter of the Proximal End (D) and Maximum Diaphyseal Length (L).

Data Analysis

As independent estimators of age are not available for the Tell Abraq sample, data are analyzed in aggregate by grouping measurements into arbitrary cohorts based on diaphyseal length. For consistency, the same cohorts are used for each population. Although arbitrary, this grouping allows for comparisons at various developmental stages.

Cortical thickness (C) is calculated by subtracting medullary thickness (M) from total midshaft thickness, T, \( C = T - M \); figure 3) (Mays 1995, 1999). Cortical thickness is plotted against
diaphyseal length for the Tell Abraq subadults, as well as the Hamann-Todd subadults. Mean cortical thickness for each length cohort is compared across samples using an independent samples t-test. Percent change between cohorts (increase or decrease) is measured and compared between samples as well.

Figure 3. Midshaft Femoral Measurements: Medullary Thickness (M) and Total Midshaft Thickness (T).

The cortical index is a number that represents the percent of total bone width that is taken up by cortical bone, standardized for bone size (Mays 1995, 1999). This is calculated as follows:
CI = \frac{C_x}{T} \times 100

This index allows for a comparison of endochondral growth in bones of various sizes. The mean cortical index for arbitrary cohorts of each sample can be compared directly using an independent sample t test. Percent change in cortical index between cohorts is also compared.
CHAPTER 5
RESULTS

Entire Sample

For all samples, mean cortical thickness increases with mean diaphyseal length (figure 4). The rate of this increase varies by sample and cohort. When compared with the Hamman-Todd sample, the subadults from Tell Abraq have thicker cortical areas in 3 of 4 cohorts. Only one of these (cohort one) is significant at the p=.05 level.

The pattern of mean cortical index by length cohort is much more complex (figure 5). The mean cortical index is higher for the entire Tell Abraq sample (mean CI = 51.66) than HTH (mean CI = 42.54), indicating that, on average, a larger proportion of bone width is taken up by cortical area in the Tell Abraq subadults. As the Tell Abraq sample is comprised largely of shorter femora, this result may reflect selection bias. The shortest bones may have the highest cortical indices, as they represent individuals in early developmental stages that typically have higher-than-average cortical indices.

In the Tell Abraq sample, the mean CI is highest in the first cohort (CI = 58.05). CI decreases rapidly between the first and second cohorts (to 40.43), then gradually increases through the third (50.90) and fourth (51.62).

The Hamman-Todd subadults exhibit the same general trend in cortical index that is seen in the TA subadults (decrease then increase). In the HTH sample, however, the initial decrease is gradual and occurs between the first and third cohorts (46.27; 42.67; 38.10). This is followed by a gradual increase into the fourth (43.07) and fifth (46.28) cohorts.

Cohort 1

In the Tell Abraq sample (n=32), mean cortical thickness (3.82 mm) is significantly greater (at the .05 level) than the HTH sample (n=9, CT=2.94 mm). Mean cortical index in the Tell Abraq sample is also greater than that in the HTH sample, although not at a statistically significant level.
Figure 4. Mean Cortical Thickness (in mm) of the Tell Abraq and Hamman-Todd Subadults.

Figure 5. Mean Cortical Index of the Tell Abraq and Hamman-Todd Subadults.
Total cortical thickness increases from cohort one to cohort two for both samples. The increase is most notable among the HTH subadults (67% increase from cohort one), with TA increasing by 24% over cohort 1. In this cohort, mean cortical thickness is slightly greater in HTH (although not significantly so). Also in cohort two, mean cortical index decreases for both samples from cohort one. The most drastic decrease is in the TA sample (by 30%), with HTH decreased 7% over cohort one. This indicates that, for both samples, midshaft cortical growth does not keep pace with growth in total bone thickness in cohort 2.

This cohort does not exhibit any between-sample statistically significant differences for cortical thickness or cortical index.

Cohort 3

In the third cohort, cortical thickness increases for both samples from cohort two. The greatest percent increase occurs in the TA sample, at 69%, with HTH increasing by 28%. At Tell Abraq, cortical index also increases from cohort 2 (by 26%). In the HTH sample, cortical index decreases by 11%.

Mean cortical index for TA is statistically greater than that for HTH.
Cohort 4

Cortical thickness increases from cohort 3 in both samples. At TA, the increase is 34%, while the HTH sample increases by 42%. Cortical index increases in both samples over cohort 3 (1% at TA and 13% at HTH).

Cohort 5

TA does not have any individuals in this cohort. In the HTH subadults, cortical thickness increases by 18% to 10.62 mm. Cortical index increases 7% in the HTH sample, to 46.28.
CHAPTER 6
DISCUSSION AND CONCLUSIONS

The cortical index represents the percent of total bone width that cortical bone accounts for. This index shows the net effects of the cortical apposition-resorption relationship. In healthy children, the cortical index will decrease in infancy, increase rapidly through the period of motor development, then increase at a slowed rate until the adolescent growth spurt. The cortical index will continue to increase at a slowed rate into adulthood.

For the Tell Abraq sample, mean cortical index is highest in the shortest femora, and lowest in the second cohort. It can be inferred that the first two cohorts (1-100 mm and 101-200 mm) represent the period of early infancy. It follows, then that the second into the third cohort may represent a period of rapid motor development.

The trend lines for cortical index among the HTH subadults show the same general shape (a decrease followed by an increase). The initial decrease in this sample is more gradual and continues into the third cohort. The subsequent increase in cortical index is not as drastic among the HTH subadults (CI increases by 13% from cohort 3 to cohort 4 at HTH, while the corresponding increase at TA (from cohort 2 to cohort 3) is 26%). This may be an indicator of poor health status during the years of motor development.

One possible interpretation of these results is that the steeper and earlier increase in cortical index among the Tell Abraq subadults reflects a healthier growth pattern than is seen in the Hamman-Todd sample. It appears that cortical bone was growing faster and larger at Tell Abraq. It may also be inferred that motor development occurred in individuals with shorter diaphyseal lengths at Tell Abraq. This may be an indicator of the presence of growth-disrupting factors among the Hamman-Todd children. These results support the notion that the children at Tell Abraq were relatively healthy by modern standards (at least relative to unhealthy modern children).

In a broader sense, this analysis contributes to the growing dialogue of juvenile health in archaeological populations by proposing that meaningful analyses of commingled remains can be carried out. As more and more researchers begin to focus on issues surrounding subadults in the archaeological record, it becomes increasingly important to adapt current methodologies to the challenges inherent in studying subadult human remains.

Future analyses might address this further by analyzing cortical growth patterns as a factor of diaphyseal length in more subadult populations, thus adding to a comparative dialogue. Another avenue of future research may be to analyze a larger sample of subadults from the Hamman-Todd collection for cortical growth in under- vs. well-developed children.
BIBLIOGRAPHY

Bass, W.H.

Bird, D.W. and R.Blige Bird

Blau, S.

Brumbach, H.J. and R. Jarvenpa

Buckley, H.R.

Conkey, M.W. and J.M. Gero
1997 Programme to Practice: Gender and Feminism in Archaeology. Annual Reviews of Anthropology 26:411-437.

Conkey, M.W. and R.E. Tringham

Cook, D.

El-Najjar, M.Y.

Fazekas, I.G. and F. Kosá

Flecker, H.
1942 Time of appearance and fusion of ossification centers as observed by roentgenographic methods. American Journal of Roentgenology 47:97-159.

Frisancho, A.R., S.M. Garn, and W. Ascoli

Garn, S.M.

Garn, S.M., C.G. Rohmann, B. Wagner, and W. Ascoli

Gero, J.M.

Glencross, B. and P. Stuart-Macadam

Goodman, A.H. and G.J. Armelagos

Greulich, W.W. and S.L. Pyle

Harry, K.G., J. Dalton, and M.C. Slaughter

Himes, J.H.

Hodder, I.

Hoffman, J.M.
1979 Age Estimations from Diaphyseal Lengths: Two Months to Twelve Years. Journal of Forensic Sciences 24:2.

Hoppa, R.D.

Hoppa, R.D. and C.M. Fitzgerald

Hoppa, R.D. and K.L. Gruspier

Hummert, J.R.

Hummert, J.R. and D.P. Van Gerven

Jantz, R., and D. Owsley

Johnston, F.E.

Johnston

Johnston and Zimmer

Kamp, K.A.

Kamp, K.A. and J.C. Whittaker

Keenleyside, A.

King, S.E., and S.J. Ulijaszek

Klepinger, Linda L.

Kósa, F.

Kunter, M.

Larsen, C.S.


Lewis, M.E.

McKern, T.W. and T.D. Stewart

Mays, S.


Meindl, R.S. and K.F. Russell

Mensforth, R.


Merchant, V.I. and D.H. Ubelaker

Ortner, D.J., N. Tuross, and A.I. Stix

Owsley, D. and R. Jantz

Park, E.A.

Potts, D.T.

1993a The Late Prehistoric, Protohistoric, and Early Historic Periods in Eastern Arabia (ca. 5000-1200 B.C.) Journal of World Prehistory 7:2(121-162).


Prader, A., J.M. Tanner, G.A. von Harnack
1963


Pyle, S.I. and N.L. Hoerr

1955


2000


Rothschild, N.A.

2002


Saunders, S.R. and R.D. Hoppa

1993


Saunders, S., R. Hoppa, and R. Southern

1993


Saunders, S.R.

1992


Scheuer, L. and S. Black

2000


Scrimshaw, S.C.M.

1984


Sherwood, R.J., R.S. Meindl, H.B. Robinson, and R.L. May

2000


Sobolik, Kristin D.

2002


Steele, D.G. and C.A. Bramblett

1988

Stevenson, P.H. 

Steyn, M. and M. Henneberg 

Stodder, A.L.W. 

Stone, P.K., J. Rhodes, D. Martin, D. Potts 


Storey, R. 

Stuart-Macadam, P. 

Sundick, R.I. 

Tanner, J.M., R.H. Whitehouse, and M.J.R. Healy 

Thomas, K.D. 

Tibbs, Jr., R.E., D.E. Haines, A.D. Parent 

Todd, T.W. and J. Di’Errico 

Turnbull, C.M. 
Ubelaker, D.H.  

Usher, B.M.  

Wall, C.E.  

y'Edynak, G.  