HEALTH CHANGES ASSOCIATED WITH THE AGRICULTURAL TRANSITION: ANALYSIS OF CORTICAL BONE GROWTH AND MAINTENANCE AND ASSOCIATED NON-SPECIFIC STRESSORS IN SUBADULT SKELETONS FROM WESTERN IRAN

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A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF ARTS

ABSTRACT

Analysis of the skeletal remains of infants and children from the Early Neolithic site of Tepe Ganj Dareh and the later Chalcolithic site of Seh Gabi in western Iran indicates that the Seh Gabi skeletal sample exhibits consistently higher indicators of non-specific stress in comparison to the Ganj Dareh sample. The Seh Gabi infants and children display very poor cortical bone growth and maintenance as measured by analysis of cross sections of bone taken from the femora and tibiae. Analysis also suggests that bone tissue in the Seh Gabi babies was being resorbed from the endosteal surface faster than it was being deposited on the periosteal surface of long bone cortices. This may represent an attempt by the body to maintain linear long bone growth at the expense of cortical thickness. However, the level of stress was such that linear long bone growth may have ceased as well, as the Seh Gabi sample also exhibits possible evidence of growth stunting as measured by lag in skeletal versus dental development. Cursory analysis of the micromorphology of thin sections removed from femorae and tibiae suggests the Seh Gabi babies were experiencing a lower bone turnover rate at the time of death in comparison to the Ganj Dareh sample. The Seh Gabi sample also displays a higher rate of growth arrest episodes as denoted by linear enamel hypoplasias and Harris lines. These combined indicators suggest the general health of the Seh Gabi infants throughout their short lives was extremely poor. Differential diagnosis suggests that at the time of death these children may have been suffering from marasmus, a chronic form of protein-calorie malnutrition.

Further analysis of both samples found relatively low rates of anaemic reactions. Infectious lesions found in the Ganj Dareh sample are for the most part secondary to trauma while those of the Seh Gabi sample may be a result of cultural practices or communicable disease. Both samples exhibit possible evidence of metabolic disturbances, including evidence of infantile scurvy, hypervitaminosis A, and rickets.

The pattern of deteriorating health through time as measured by the comparison of these two samples is in keeping with a similar pattern found in other parts of the world thought to be associated with the transition from a hunting and gathering economy to that of an agriculturally based one. The Ganj Dareh infants and children were quite healthy as their peoples had just begun the transition from a hunting and gathering economy to an agrarian based one. These peoples relied on a diversified subsistence strategy of incipient horticulture, hunting and collecting, and incipient pastoralism in an area of high resource and low population density. In contrast, the Chalcolithic peoples of Seh Gabi relied upon a very narrow spectrum of resources, primarily domesticated plants and animals, within the context of a stressed resource base, a higher population density, and possible climatic flux.

The increased evidence of stress in the Chalcolithic children is attributed to a relatively narrower and poorer maternal diet, higher population density, an increased disease load, the advent of childhood diseases, and a possible shift to an earlier age at weaning in comparison to their earlier Neolithic predecessors.

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I would also like to offer a special thanks to Dr. Mark Skinner of Simon Fraser University for the use of the Forensic Lab facilities at the Department of Archaeology while examining and preparing the Seh Gabi materials, and for initially instilling upon me an intense interest and curosity in the Iranian skeletal materials.

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Like many graduate students, I could not have finished my thesis without the assistance of assorted family members. I owe a great deal to my better half, Catherine Flynn, who heroically endured my rants and tirades about academia and for listening to most of my half baked ideas, and to my son Breandan for reminding me (occassionally unwillingly) that there is far more to life than academia.

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CHAPTER I

INTRODUCTION

Paleopathologists and skeletal biologists have long been interested in identifying the effects of substantial changes in subsistence and technology on human health and disease. Using a variety of techniques a large number of workers have investigated how the transition from semi-nomadic hunting and gathering to a sedentary agricultural lifestyle affected the health of human populations (see Cohen 1989 for a recent summary).

Throughout this thesis I will refer to the shift from semi-nomadic hunting and gathering to sedentary village based agriculture as the "agricultural transition". Until recently this shift has typically been referred to as the "Neolithic Revolution". However, many archaeologists have now come to realise that the shift from hunting and gathering to agriculture was not revolutionary but evolutionary in nature. Reliance on fully domesticated plants and animals and its cultural concomitants (increased sedentarisation, higher population densities, increased birth rates, etc ...) are the end result of hundreds, and in many cases, thousands of years of cultural evolution. Hence, there has been a de-emphasis of what were previously considered revolutionary characteristics (eg. the "sudden" appearance of ceramics and domesticated animals) in favour of viewing the presence of these traits as the product of long term in-situ cultural developments or as a result of diffusion.

Initial investigations into the health effects of the agricultural transition were somewhat wanting for lack of their explanatory power and interpretations. Frequently, authors went to great lengths to collect data, only to provide an analysis totally lacking substantiative conclusions regarding culture change. Others, seeing this, preferred to ascribe causality to a particular variable or phenomenon. Within the last twenty years an increasing number of researchers have begun to apply a more holistic approach which seeks to avoid unicausal explanations or non-explanatory interpretations. Often referred to as archaeobiology, bioarchaeology, biological archaeology, or biocultural anthropology, the biocultural approach (as it will be referred to from here on) provides an interpretive framework within which physical anthropologists can interpret their observations. One of the key goals of the biocultural approach is to place the findings of physical anthropological inquiry into the broader context of diachronic change in culture. As Della Collins Cook, a noted biological anthropologist, observed:

> "The analogy between technological change and biological adaptation has been widely accepted in anthropology. Modification in subsistence technology is often given as an example of such a cultural adaptation. Testing this premise requires that we relate changes in subsistence to changes in the biology of human populations, but rigorous demonstrations of this sort are uncommon in the large body of literature that the culture-as-adaptation question has generated. Such analyses are of critical importance to an integrated study of prehistoric subsistence systems because they provide a direct measure of the biological costs and benefits attached to change in technology or subsistence base (Cook 1980: 219)

Obviously, when one is dealing with archaeologically derived materials, the definition of culture becomes an explicitly material one; as can be seen from Cook's statement, the biocultural approach relies heavily on technological change (particularly as it affects subsistence patterns) at the expense of social and ideological considerations. Reliance on the immediate aspects of material culture has created a bias which consistently permeates this kind of inquiry in that it is based on various forms of technological or demographic determinism, both of which have been recently subject to a certain amount of criticism (Bender 1978).

While some may see this as a major drawback, it is simply one of the limitations of the data at hand. It is a rare instance where one has in hand the necessary information (ethnohistoric, architectural, archaeological) to make inferences regarding social and ideological components of culture. This is unfortunate as cultural idiosyncracies often have tremendous explanatory power with regards to understanding patterns within skeletal data (e.g. differential access to foodstuffs according to age and sex, cultural concomitants of infanticide).

In order to relate technological change to human health and disease, the biocultural anthropologist must synthesise a variety of different types of information from subdisciplines like palynology, limnology, zooarchaeology, archaeology, and paleoclimatology. The goal is to synthesise all existing data sources in an effort to build as complete a picture as possible of prehistoric subsistence, settlement patterns, diet, and how these and other variables change through time. Only after this is done can we give meaning to the data we collect from analysing human skeletons from the past. In many ways this approach is still in its infancy and often subject to considerable unknown error and discrepancy, but nonetheless it has yielded considerable insight into how human beings adapted (or not) in the past to substantial changes in material culture, subsistence, climate, etc... .

In the course of research into the health effects associated with the agricultural transition, many physical anthropologists have found the analysis of subadults provides a wealth of information, in some cases of better acuity than data derived from adults. The basic premise underlying this difference is that infants and children are far more sensitive to changes in subsistence patterns; simply put, evidence of changes in disease ecology, nutritional stress, and subsequent metabolic disturbance show up more readily in subadult skeletons (Goodman and Armelagos 1989; Goodman et al. 1984; Huss Ashmore et al. 1982). The analysis of subadult remains in the context of long term change associated with the agricultural transition has attracted more and more attention within the last two decades. Authors have sought out evidence for change in health status associated with technological and social transitions by looking at long bone growth (Jantz and Owlsey 1984; Hummert and Van Gerven 1983; Merchant and Ubelaker

1977; Owlsey and Jantz 1985), limb proportionality (Mensforth 1985; Owlsey and Jantz 1984), deciduous dentition reduction (Lukacs 1981, 1989), Harris lines (Goodman and Clark 1981), porotic hyperostosis and infection (Lallo et al. 1977; Lallo et al. 1978; Mensforth et al. 1978) linear enamel hypoplasia (Blakey 1981; Goodman 1991; Goodman and Armelagos 1989; Goodman et al. 1984b), and variety of other dental defects, both macroscopic [enamel hypocalcification, localised hypoplasia of the primary canine (LHPC)] and microscopic (Wilson bands, striae of Retzius, contour lines of Owen).

One of the results of such interest has been the search for and application of innovative and sensitive techniques of analysis to detect subadult stress. In particular, the examination of cortical bone growth and maintenance has proven sensitive to growth disturbance resulting from dietary and disease related stress (Hummert 1983; Huss Ashmore 1978, 1981; Keith 1981). However, until recently, research on bone growth and maintenance has focused mainly on adults. Yet, because of their rapid growth rates, subadults are particularly sensitive to environmental insult which is recorded in bone tissue. Analysis of cortical bone growth offers a means of assessing the health of an individual or group at the time of death and can give an idea of whether growth is proceeding normally or if the individual or sample was drawing upon bone tissue reserves at the time of death for nutrients in order to sustain growth and maintenance of other body tissues (Huss Ashmore et al. 1982).

Biocultural anthropologists have focused a great deal of attention on two particular periods in human prehistory; the Upper Paleolithic and the Neolithic (or its equivalent). Both of these periods mark major biological transitions and investigations into both have proven quite successful, likely because of the large amount of pre-existing archaeological research that has been carried out. In the case of the Neolithic, a tremendous amount of effort has been expended by archaeologists on uncovering the origins and spread of agriculture from the Near East and eventually into Europe. Yet, despite all the archaeological research, we still know comparatively little about the skeletal biology and paleopathology of the peoples who were actually involved at the beginning of the agricultural transition. Research on skeletal remains has been sporadic and uneven in the Near East; in areas like the Levant paleopathologists and skeletal biologists are finally beginning to assemble a complete picture of human health and disease in relation to the transition (Smith et al. 1984). In other key areas, such as the Zagros Mountains of western Iran, the picture is incomplete and often muddled despite the ground breaking work of various authors (Agelarakis 1989; Lambert 1980; Meiklejohn et al. 1980; Rathbun 1972, 1980, 1981, 1984).

It is possible to access two skeletal samples from key sites from the Kangavar region of the Zagros Mountains; Tepe Ganj Dareh and Seh Gabi. These two sites represent a substantial part of the continuum in the transition from semi-nomadic hunting and gathering / incipient agriculture to sedentary village agriculture in western Iran during the Neolithic and Chalcolithic ages some 10,000 to 5,000 years B.P.

In light of the potentially valuable source of information subadults constitute, it is of great interest that both of these samples have an unusually large subadult component. In the case of the Seh Gabi sample, all individuals are subadults, the majority infants.

Problem Statement

The purpose of this thesis is to examine cortical bone growth and maintenance and other indicators of health and disease in subadults from Ganj Dareh and Seh Gabi and to relate observed changes in health and disease to the shift from semi-nomadic hunting and gathering / incipient agriculture to sedentary village agriculture during the Neolithic and following Chalcolithic. Based on the analysis of cortical bone growth, it should be possible to relate differences between the two samples to changes in subsistence and technology as reflected in the archaeological record. The data from the cortical bone analysis will also be compared with other existing archaeological samples of subadults as well as existing paleopathological data on the two samples collected by Skinner (1980) and Agelarakis (1989). These data sets will be augmented to enhance compatibility. The results will then be discussed within the context of what is known in general about diachronic change in skeletal health associated with the transition to agriculture.

Thesis Outline

First, the regional setting, physiography and climate history of the study area is described and summarised in chapter II.

Next, in keeping with the biocultural perspective, in order to gain an understanding of changes in subsistence and technology in the region, the archaeological record of the Zagros Mountains of western Iran is reviewed in considerable detail. The purpose of chapter III is to delineate the local prehistoric archaeological sequence as well as major shifts in material culture through time. By looking at the archaeological record, it is possible to detect changes in subsistence patterns, which are reflected in the use of wild and domesticated plants and animals, changes in population and site density, settlement patterns, paleoclimate and seasonality in population distribution and diet. After summarising these observations a series of predictions regarding changes in health and disease in the western Zagros are proposed.

Chapter IV provides a detailed description of the two archaeological sites under consideration as well as the skeletal samples recovered from them. The significance of these two sites and the skeletal samples recovered from them is touched upon. Finally, past research on the Ganj Dareh and Seh Gabi samples and findings of interest are discussed.

Chapter V outlines the underlying concepts of cortical bone growth and maintenance and provides a review of bone growth from infancy to adulthood. It also deals with the techniques to be used in analysing cortical bone parameters in the subadult remains from Seh Gabi and Ganj Dareh. This chapter also touches on the cortical bone growth and maintenance research that has been conducted on archaeological samples to date, as well as reviewing the medico-clinical literature on the subject, particularly as it relates to deficiency diseases. This information is then used as an interpretive base for results derived from the Iranian data generated here.

The relationship between cortical bone behaviour and non-specific indicators of stress, both cumulative and episodic (Harris lines, enamel hypoplasia, long bone growth, anaemia, infection) is explored in chapter VI. Based on this review, a series of predictions is forwarded on the relationship between cortical bone growth and maintenance and non-specific indicators of stress.

The next chapter (VII) discusses methodological considerations involved in employing the various techniques used to derive the cortical measurements, as well as the methods specifically employed in this analysis. This chapter also provides a brief historic overview of measurement techniques.

Chapter VIII outlines the findings of the analysis of cortical bone growth and maintenance and other associated non-specific stressors in the Ganj Dareh and Seh Gabi samples. The results of the analysis are also contrasted with other relevant skeletal samples for which comparative data exist.

Finally, in chapter IX the results of the analysis of cortical bone are contrasted with the archaeological evidence for technological and subsistence change in the Zagros. The cortical data are compared to data on associated non-specific stressors collected by Agelarakis (1989), Meiklejohn (n.d), Skinner (1980) and the author. Lastly, a series of recommendations for future research are forwarded.

CHAPTER II

DEFINITION OF THE STUDY AREA

The Zagros mountain system covers most of western Iran; the region consists of four core areas: the lowland steppe of southwestern Iran (Khuzistan), the Azerbaijan region of northwestern Iran ,the mountain plains of the extreme southeastern Zagros in Fars province, and the central Zagros intermontane valleys and highlands (Hole 1987a). The Khuzistan region is located to the east of the southern Mesopotamia heartland, at the base of the southwestern Zagros mountains and includes the Susiana, Raz Hormuz and Deh Luran plains. The Azerbaijan region encompasses the area around Lake Urmia, including the Solduz Valley. The Fars region encompasses parts of the extreme southern Zagros mountains, including the Marv Dasht plain. However, since we are primarily interested in the central Zagros a more detailed definition of this region is in order.

The Central Zagros

The central Zagros proper is bordered on the northern periphery by the great Khorasan road from Baghdad to Tehran (also known as the High Road or Silk Road). The region encompasses all of the mountain valleys and plains of the central Zagros mountains all the way southwest to the northern margin of the Mesopotamian plains. The central Zagros is bordered on the west by the formidable Kabir Kuh mountain range, and the lower outer fold zone known as the Pish-i Kuh, which runs along the eastern periphery of central Mesopotamia. The central Zagros is bordered on the east by the Kuh-i Alvand range, which in turn borders the western edge of the inland Iranian Plateau. Marginal areas associated with the Zagros include areas of low agricultural potential such as the mountains of Kurdistan, which are sandwiched between the northern periphery of the central Zagros and the Azerbaijan region, and Luristan, which includes the lower mountain ranges and foothills of the central Zagros that meld in with the Khuzistan lowland steppe. The Pish-i Kuh may also be included within Luristan (Henricksen 1985a).

Based on physiography, vegetational zones, and political boundaries the central Zagros region can be broken up in a variety of ways into different areas. This can be particularly confusing at times as authors employ different criteria for defining areas while at the same time using identical names. Thus it would be prudent to define the areas within the central Zagros that are of interest here. For the purposes of this thesis, which partially reflect the nature of archaeological research in the area, the region can be divided into three primary areas; the Kangavar, Khorramabad and Mahidasht areas (figure 1). These designations largely reflect the intensive nature of archaeological reconnaissance and excavation in particular valley systems. In addition to these three core areas, I will also consider peripheral evidence from Kurdistan and Luristan (as defined here). It should be noted, so as to avoid confusion, that the term "Luristan" is occasionally used to refer to the entire central Zagros region (excluding Kurdistan); however, I will adhere to the definition provided here.

The Kangavar area is located in a mountainous region known as the Pish-i Kuh, in the northeastern portion of the central Zagros. It consists of a series of high altitude valleys to the northeast of the Kuh-i Sefid mountain range. The prominent valleys in the Kangavar group include the Kangavar-Asadabad-Sahneh cluster, the Nehavand-Khawa, Harsin, Borujerd and Alishtar valleys (Hole 1987a). The peripheral Malayer and Tuisarkhan valleys may be included as well.

The Khorramabad area, located in a series of folded mountain ranges in the southern central Zagros, encompasses a series of fertile valleys (Tarhan, Rumishgan, Kuh-i Dasht, and Khorramabad, Saimarreh, and Chakalwandi) at an elevation of 700 to 1500 meters above sea level (Goff 1971). The region can be loosely defined as encompassing the drainages of the southern Saimarreh river and the Kashgan river. The Mahidasht area consists of a series of valleys

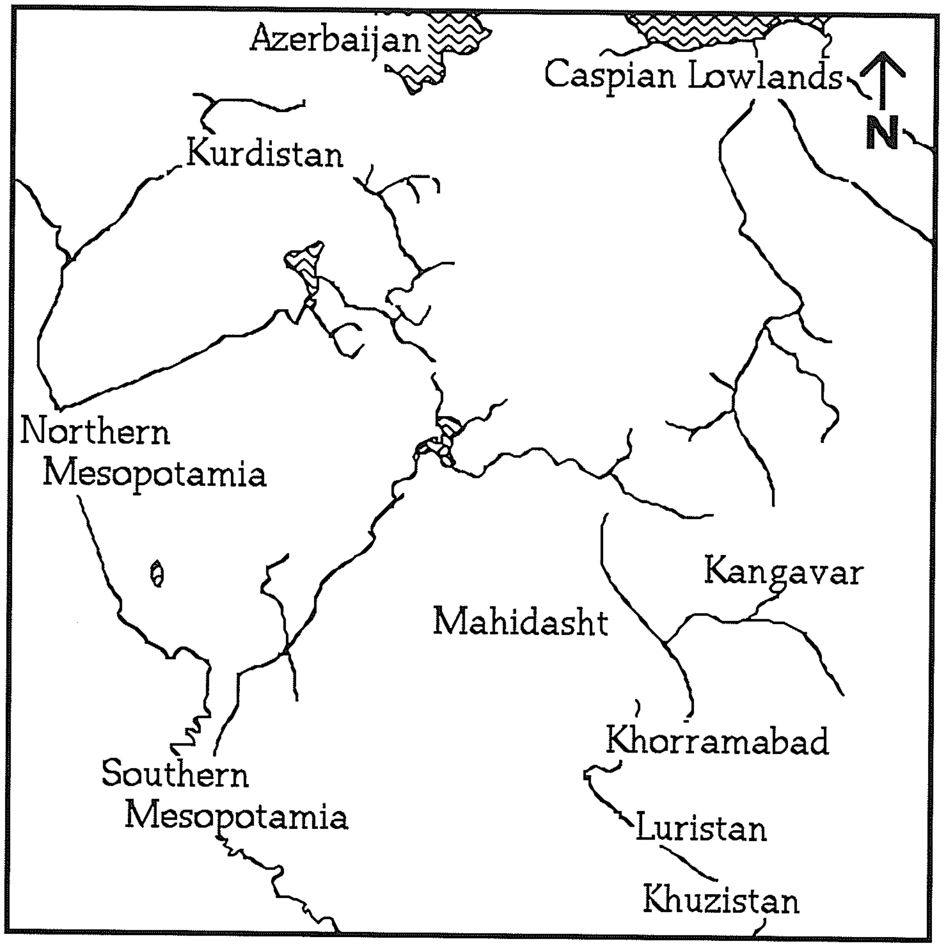


Figure 1. Regions in western Iran and eastern Iraq.

along the western half of the Khorasan road (Shahabad, Zibiri, Mahidasht, Kermanshah, Hulailan, Shian), ranging from 1300 to 900 meters above sea level (Hole 1987a). The area also includes parts of southern Kurdistan and the northern half of the Pusht-i Kuh of Luristan.

Kurdistan proper includes the northern Zagros area north of the Mahidasht region, around the political boundary between northeastern Iraq and northwestern Iran, up to the plains of southern Azerbaijan around Lake Urmia. Some authors occasionally refer to parts of the Mahidasht as Kurdistan (and visa versa).

Luristan, as defined here, encompasses the southern most region of the Zagros mountains from the Khorramabad region to the edge of the lowland plains of southwestern Iran (Khuzistan). Luristan also includes the Pusht-i Kuh mountain range to the extreme west, which borders the northern half of Mesopotamia (Henricksen 1985a,b). Both Luristan and Kurdistan are rugged mountainous areas of low agricultural potential and have traditionally been the home of transhumant pastoralists. These two regions occupy a large portion of the study area.

Physiography

The central Zagros mountains are built up of long parallel ridges oriented in a northwest to southeast fashion. The ridges are separated by deep intermontane valleys; however, the ridges increase in height the further east one progresses. The region is drained by the Khabur, Karkheh, Diz, Kashgan, Diyala, Greater and Lesser Zab rivers (and numerous smaller tributaries) which cut transversely across the ridges to meet up with the Tigris river on the Mesopotamian flood plain (Van Zeist and Bottema 1977).

For the purpose of human occupation, the Zagros region has a rather curious inverted quality (Gilbert 1983). The Zagros is really composed of three geomorphic zones; a lower folded zone, an intervening thrust zone, and a higher fold belt. The lower fold belt, bordered on the west by the Iraqi Zagros piedmont and Mesopotamian lowlands, is rippled and craggy as a result of relatively young ridges. Valleys tend to be difficult to access as they are often quite narrow and confined by the steep ridges; however, the valley floors of the lower folded zone are significantly lower than those to the east. Also, in contrast to the valleys further east, very little alluvium has accumulated (Brookes et al.1982). However, it is the thrust zone and parts of the upper fold belt which furnish some of the best agricultural land in modern Iran. In contrast to the hotter, more humid lower folded zone, the upper fold belt and thrust zone are marked by moderate summer temperatures and a reasonable amount of precipitation, but in turn are characterised by rather severe winters (Gilbert 1983). The higher, older fold belt consists of isolated peaks and broad, interconnected valleys; the bottom of the valleys are typically clogged with alluvial fill.

Climate History

The modern climate of the central Zagros is characterised by great variability in rainfall patterns. Typically, the southwestern valleys are warmer and wetter than the northeastern valley systems; this is largely a function of the west-east track of tropical storms which pass through the region. As the storms track towards the northeast, they are forced to rise continually to make it over the successively higher ridges, thus producing a pronounced rainshadow effect which intensifies towards the northeast. Precipitation averages 400 mm +/year and is usually limited to the winter; summers are typically hot and dry. On a year to year basis, variability in the amount and distribution of precipitation is dangerously high, varying as much as 300 % from one year to the next (Melville 1984).

There exists a fairly extensive body of information on the past climate of the Zagros region in Iran and Iraq. Much of our information is derived from lake sediment cores extracted from the two largest lakes in the region, Lake Zeribar and Lake Mirabad, the former located in the southern reaches of Kurdistan and the latter located in the Saimarreh valley.

In the Lake Zeribar area, trees appear to have been entirely absent from about 22,000 to 14,000 B.P. (corresponding to the Baradostian and Zarzian cultures); the scarcity of trees during the late glacial/early postglacial is often suggested to be a result of much colder, drier environment (Van Zeist 1967). Wright (1983) estimates that snowlines in the Zagros were depressed as much as 1200 to 1800 meters, implying a temperature decrease of 8-12 degrees celsius. The region was characterised by a steppe environment comprised of xeric grasses, tamarisk, poplar, conifers and the occasional rare oak (Van Zeist and Bottema 1977). Analysis of pollen cores from Lake Zeribar (Van Zeist 1967; Van Zeist and Wright 1963) indicates that from approximately 14,000 B.P. (beginning of the Proto-Neolithic) onwards, annual precipitation and temperature increased slowly, allowing for a sparse oak and pistachio forest to become established. By 11,000 to 10,000 years B.P. the cool steppe grasses had disappeared (Van Zeist and Bottema 1977). Between 10,000 and 8,000 years B.P. (Early to Middle Neolithic) the region was still sparsely forested. From approximately. 8,000 to 4,000 years B.P. there was a gradual increase in tree pollen, indicating a slow replacement of a steppe-environment with a more forested one (Van Zeist 1967). The Zagros region is believed to have supported an oak / pistachio / almond savanna, as it was not until modern climatic conditions were established that the savanna could thicken into oak-pistachio woodland. Modern climatic conditions are suggested to have been established by 6500 to 6000 years B.P. (corresponding to the Early Chalcolithic).

During the Late Neolithic to Early Chalcolithic, a growing oak / pistachio / almond savanna appears to have dominated the highland valleys. This vegetation was a result of the progressively warmer and wetter conditions which peaked during the end of the Early Chalcolithic. During the Middle Chalcolithic this trend began to reverse; trees became more common, temperature dropped and precipitation increased. This trend continued past the Middle Chalcolithic as the moist climate cooled, reaching present levels and supporting the present climax oak-pistachio woodlands.

CHAPTER III

ZAGROS CULTURE HISTORY

Even though the current archaeological literature on the Zagros is somewhat confusing and incomplete, it is still possible to make sense of the regional archaeological record. This is enhanced by recent reviews of the archaeological record (e.g. Henricksen 1985b; Hole 1987a,b; P.E.L. Smith 1986; Voight 1987) as well as the skeletal biology of prehistoric populations (Rathbun 1984). However, the purpose of this chapter is not to provide yet another literature review of the region, nor is it to examine the various theories explaining the origins of agriculture, but rather to interpret the local archaeological sequence as it relates to the diet and, ultimately, health of the prehistoric inhabitants of the Zagros highlands. The purpose here is to systematically examine the connection between changes in the archaeological record (as indicated by architecture, artifacts, faunal and floral remains, and the palynological and paleoclimatic record) and compare it to what is known about the skeletal biology and paleopathology of the prehistoric inhabitants. The ultimate goal here is to examine changes in the health of the prehistoric indigenous populations through time and in the context of the shift from hunting and gathering to agriculture.

Chronology

How to examine the archaeological sequence of a particular region is always a problem even at the best of times. However, the problem of chronological terminology has become complicated with the passage of time. Traditionally the transition from simple hunters and gatherers to sedentary agriculturalists runs from the end of the Upper Paleolithic through what is referred to in the Near East as the Epipaleolithic Age (rather than Mesolithic), through the Neolithic, and to the end of the Chalcolithic Age.

However, these terms have been criticised as being far too general and conflate what should be distinct periods within an age (Hole 1987a).

Many authors have proposed a variety of new chronological schemes which reflect, for the most part, their own experiences and research interests (e.g. Voight 1987; Henricksen 1985b; Hole 1987a,b,d). Upon first glance, Hole's (1987a) chronology for the Zagros Mountains would seem acceptable. However, his scheme does not include the Epipaleolithic and Proto-Neolithic ages, and does not articulate very well with the older terminology, and it creates unnecessary chronological divisions where data is too weak to support it locally. Thus, the traditional culture historical sequence (Epipaleolithic, Proto-Neolithic, Neolithic and Chalcolithic) of the western Zagros will be adhered to, with chronological distinctions within these ages employed where supporting evidence is forthcoming.

The Epipaleolithic and the Zarzian Culture

Interest in the Zagros archaeological sequence begins with pre-Neolithic cultures during the terminal Upper Paleolithic or Epipaleolithic. The rationale for selecting this as a starting point lies in the fact that the Zarzian culture, as the Epipaleolithic is known locally, represents the last during which food collecting was the predominant mode of subsistence. The Zarzian culture in the Zagros existed from approximately 15,000 to 12,000 years B.P. (Smith 1986), although the lower end had initially been suggested to extend to perhaps 20,000 B.P. (Hole and Flannery 1967). Uncalibrated radiocarbon dates available from two Zarzian sites, Shanidar Cave (12,000± 400 B.P., W-179) and Palegawra (13,350+460 B.P., UCLA 1714D; 14,400 B.P., UCLA 1703A) confirm the former estimate (Hole 1987d; P.E.L. Smith 1986). Zarzian sites include the type site of Zarzi itself, Hazar Merd, Palegawra Cave, Pa Sangar, Warwasi, and Shanidar Cave (level B2). The above sites and other lesser known Zarzian occupations appear to be located primarily within a narrow band running northwest to southeast in a line with the Zagros from the lower piedmont zone of the Iraqi Zagros into Iranian Kurdistan and the Khorrmambad region of the central Zagros [figure 2 (Henry 1983; P.E.L. Smith 1986)]. The Mahidasht Epipaleolithic is known peripherally through two sites excavated by Peder Mortensen (1974, 1975), although a number of Zarzian sites are known in the area. No Zarzian culture occupations have been identified in the Kangavar area despite intensive survey projects. While a wide variety of Epipaleolithic sites have been discovered in the region as a whole (see P.E.L. Smith 1986), not that many have been reported in detail. Thus, discussion will focus for the most part on the most familiar sites that have been reported.

The Epipaleolithic Lithic Industry

The archaeological assemblages of Zarzian culture sites are typically composed of chipped flint, although some worked bone and polished stone has been recovered. The chipped stone industry, which comprises 75-90% of all Zarzian lithic materials, is typically dominated by scrapers, blades and blade cores, notched blades, as well as the occasional burin and backed blades. Hole and Flannery (1967) suggest that, at least at Pa Sangar, the latter are replaced by backed bladelets. This may represent a trend in later Zarzian sites towards miniaturisation of the tool kit. For example, many later Zarzian sites possess a geometric microlith component consisting primarily of scalene triangles (Braidwood and Howe 1960); lunates and trapezoids, albeit rare, are found occasionally [(e.g. Shanidar Cave B2, Pa Sangar, Palegawra) Solecki and Solecki 1983)]. This microlithic component has been suggested to characterise most later Zarzian occupations (Bar-Yosef 1970 in Solecki and Solecki 1983; Wahida 1981). Worked bone material (awls and points) has been recovered from Zarzi, Palegawra and Shanidar Cave. Some Zarzian sites, like Shanidar Cave, also include a small but significant polished stone component including unshaped sandstone abraders and ochre stained groundstones (Solecki and Solecki 1963, 1970).

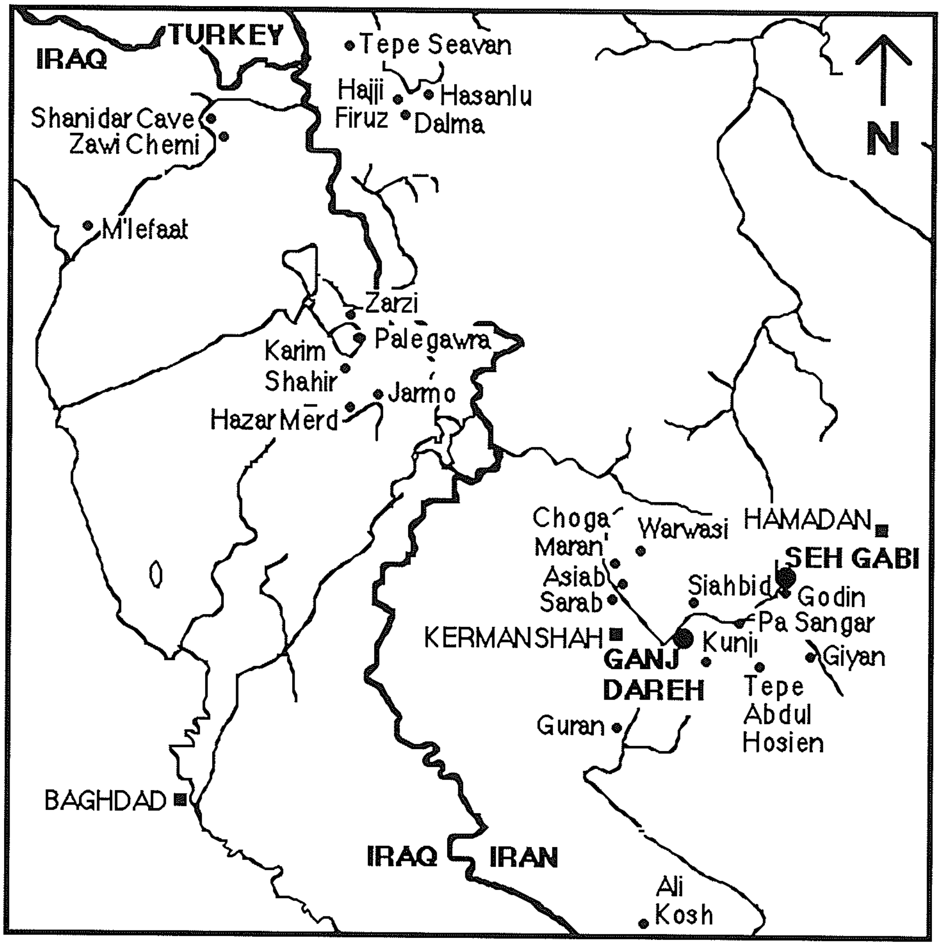


Figure 2. Archaeological sites mentioned in text

Epipaleolithic Subsistence Patterns

The nature of the subsistence base appears to be subject to some argument. Authors such as Flannery (1969 [1971]) have suggested, largely on theoretical grounds, that Epipaleolithic assemblages should present evidence of an increasingly diversified subsistence base (otherwise known as the Broad Spectrum Revolution). There appears to be some support for Flannery's hypothesis; Turnbull and Reed (1974), Hole and Flannery (1967) and Reed and Braidwood (1960) have briefly presented evidence of a diversified subsistence base, as indicated by faunal remains. However, Henry (1983) makes the point that while the range of food remains recovered from Zarzian occupations may be quite diverse, the relative contributions of each species suggests the Zarzian peoples relied primarily on a few species of ungulate. Indeed, Henry appears correct as a closer examination of Turnbull and Reed's (1974) detailed analysis indicates that *Equus*, *Cervus*, *Capra*, *Gazella*, *Sus*, and *Vulpes* dominate all Zagros Epipaleolithic assemblages and account for 92% of the total bone recovered; this would seem to suggest a narrow subsistence base. Other authors have suggested the same (Perkins 1964; P.E.L. Smith 1986). Henry (1983) suggested that most of the smaller fauna, which accounted for much of the apparent diversity, may have been a result of incidental inclusion and taphonomic processes. However, this is difficult to ascertain, and I feel highly unlikely, as fauna like land snails, fresh water crabs, turtles and birds appear consistently in the faunal assemblages of most Zarzian sites, both caves and open air; if the proportion (approximately 10% according to Turnbull and Reed 1974) of miscellaneous faunal remains was utilized, it may have meant the difference between having to periodically move from camp to camp or being able to remain in one place for a longer period of time. This latter point is crucial as Redman (1978) has suggested,

> "Being in one place for a long period enabled them [the Zarzians] to spend time and effort in the development of non-portable equipment, such as heavy ground stone

tools, elaborate dwellings, and a means of storing foods" (Redman 1978: 67).

There is really very little evidence for the wide scale use of plant foods; the ground stone industry is too small and undeveloped in comparison to later periods to offer any suggestion of plant processing. However, Solecki and Solecki (1983) have suggested that pits discovered at Shanidar Cave may have been used for storage. If plants were consumed (as they must have been), it was most likely immediately after collection and on a seasonally available basis.

Epipaleolithic Settlement Patterns

With regards to settlement pattern, Hole and Flannery (1967) suggest that there were three types of sites: seasonal base camps (caves), butchering stations (rockshelters), and transitory stations (rest stops, quarries). It appears that the Zarzian peoples lived in relatively low densities, moving the locations of their camps regularly, their movements probably regulated by localised availability of specific resources (Mortensen 1972, 1983). In this respect, Redman (1978) suggests the location of most Zarzian sites (primarily seasonal base camps at this point) indicates they were located in an optimum environment to take advantage of a vertically oriented economy, the catchment area ("catchment" being used only in a general sense here) of these sites encompassing a wide variety of different ecological zones within a short distance.

The Proto-Neolithic Age

The Proto-Neolithic comprises a distinct archaeological age between the preceding Epipaleolithic and the following Neolithic Age in the Zagros. While Proto-Neolithic cultures appear to represent an increase in technological complexity and change in subsistence in comparison to the Epilaleolithic, material culture similarities suggest strong cultural continuity (Hole and Flannery 1967). Just as in the Zarzian culture, there is a certain amount of debate regarding material culture homogeneity/heterogeneity during this age. For instance, Solecki and Solecki (1983) suggest a single phase in the Proto-Neolithic, while Henry (1983) has suggested that the Proto-Neolithic is comprised of two cultures, the Zawi Chemian and Karim Shahirian. While the idea of intra-age cultural variation is interesting, evidence of a division is rather weak, so, for the sake of simplicity, I will consider the Proto-Neolithic as representing a single undivided cultural pattern. Chronologically, the Proto-Neolithic last from approximately 12,000 B.P. to around 10,000 B.P.

As with the Epipaleolithic, most information regarding the Proto-Neolithic is derived from sites located primarily in the northern reaches of Kurdistan; these include Shanidar Cave B1 (Solecki and Solecki 1983), Zawi Chemi Shanidar (R.L. Solecki 1981), Karim Shahir (Howe 1983), M'lefaat, and Gird Chai (Braidwood and Howe 1960; Braidwood et al. 1983). Proto-Neolithic Mahidasht is known primarily by one site, Asiab (Braidwood, Howe, and Reed 1961), while the best reported evidence in the Kangavar area comes from basal (level E) Tepe Ganj Dareh (P.E.L. Smith 1972c, 1983). The earliest evidence of Proto-Neolithic occupation occurs at Shanidar Cave B1 (10,600 $\pm$ 300 B.P, W-667) and the open air village of Zawi Chemi Shanidar [(10,870 $\pm$ 300 B.P., W-681) Henry and Servello 1974)].

The Proto-Neolithic Lithic Industry

While we see many changes in the Proto-Neolithic, there is still a relatively high degree of cultural continuity to suggest in-situ technological change. Lithic technology during the early Proto-Neolithic is still dominated by a chipped stone industry, but bone and ground stone tools begin to become more common (R.L Solecki 1964, 1981). The chipped flint industry, comprised of backed blades, perforators, side scrapers, choppers, spall tools, celts and chisels, is obviously derived from the Zarzian, but is associated with the development of a complex ground stone industry (Mellart 1975; Singh 1974).

Proto-Neolithic Trade

Evidence of long distance trade appears during the Proto-Neolithic; exotic shell items originating from the Gulf of Arabia has been recovered in Shanidar Cave B1 burials (R.S. Solecki 1969) as well as obsidian blades from Anatolia (Solecki and Solecki 1983).

Proto-Neolithic Subsistence Patterns

The archaeological evidence from Proto-Neolithic sites in the central Zagros and Kurdistan region seems to indicate an increasing reliance on plant food items and a strengthening of the relationship between humans and wild species of ungulates in comparison to the earlier Zarzian. Although it is debatable that sheep were domesticated (Perkins 1964), faunal analysis indicates a profile suggestive of selective culling and cultural control among both goats and sheep (Hesse 1978; Reed 1983). A variety of wild faunal resources have also been recovered, including red deer, wild pig, fallow deer, wolf, marten, beaver, tortoise, clam, and snail (Bökönyi 1977; Reed 1983).

Although direct evidence of plant foods (e.g. seeds and macro-fossils) was not recovered from either Shanidar Cave or Zawi Chemi, the development of an increasingly non-portable ground stone technology consisting of mortars, querns and handstones, hammerstones, rubbers and groovers seems to be associated with the collecting and processing of plants; this would imply an intensive exploitation of plant resources such as wild cereals (emmer and einkorn wheat, hulled barley), legumes, and nuts [(pistachios, acorns, almonds) Henry 1983]. Indeed, floral evidence from basal Ganj Dareh seems to confirm a heavy reliance on barley, pistachios, almonds, and lentils (Van Zeist et al. 1986). The handstones and querns are interpreted as having been used for the processing of wild cereal grains, with the deep trough querns having been used for threshing and the smaller, shallow or flat querns used for grinding grains (R.L. Solecki 1969). Other evidence of plant use includes the recovery of an intact bone sickle from Zawi Chemi Shanidar (Solecki and Solecki 1963) and tentatively identified storage pits at Zawi Chemi Shanidar (R.L. Solecki 1969) and Karim Shahir (Howe 1983). Concensus has it that collecting and processing of plant materials intensified throughout the Proto-Neolithic (Braidwood and Howe 1960; Braidwood et al. 1961; Howe 1983). Stable carbon isotope analysis indicates that the Proto-Neolithic inhabitants of the Zagros relied quite heavily on plant foods (Agelarakis 1989), and in fact, an almost exclusive reliance on plant foods. This runs contrary to the commonly held assumption that pre-argicultural people relied heavily on large mammals.

Proto-Neolithic Settlement Pattern and Architecture

The first substantial evidence of architecture in the Zagros appears at Shanidar Cave; an alignment of stones was excavated, suggesting some form of incipient above ground architecture. Zawi Chemi, M'Lefaat, Asiab and Ganj Dareh (level E) exhibit evidence of semi-subterranean structures seen elsewhere in the Near East (Mureybet, Mallaha, Jericho) typically associated with late hunting and gathering and incipient food production (Flannery 1972). The large semi-subterranean structure seen at Asiab indicates an increasing investment in more permanent forms of architecture and probably increasing sedentism, or at the very least, a change in settlement pattern, from moving periodically to a new location in a cyclic fashion to carrying out subsistence activities from a semi-permanent home base (Mortensen 1972, 1983). Analysis of avifauna and neonate caprovids suggests the inhabitants of Proto-Neolithic Ganj Dareh E resided at the site during the winter, spring, and possibly early summer as well (Hesse 1978). However, as Redman emphasises, in comparison to the peoples of the Levant, the inhabitants of the Zagros were still largely nomadic:

> "That nomadism continued in the Zagros was related to the fact that sites were located in areas that were not so rich environmentally and subject to wider variations in climate than those of the Levant" (Redman 1978: 86).

The Neolithic Age

The Neolithic in the central Zagros lasts from approximately 10,000 B.P. to 7000 B.P. This period is traditionally heralded as the period of sedentary village based agriculture. It is at this point that there is a shift in focus in archaeological activity from the Iraqi Zagros piedmont and the Kurdistan region in general to the central Zagros (Kangavar, Mahidasht, Khorramabad).

The Neolithic can be subdivided in a number of ways. Redman (1978) suggested that it could be partitioned into an "early village" stage lasting from c. 10,000 to 8000 B.P., followed by an "advanced village" stage lasting from 8000 to 7000 B.P. Hole (1987d) has broken Redman's "early village" stage up into an "early aceramic" Neolithic and and "early ceramic" Neolithic; it should be noted that there is considerable overlap between the two stages. The use of such a distinction in the Zagros is problematic as ceramics appear at the very beginning of the Neolithic at some sites (e.g. Ganj Dareh) but do not appear till the end of the Neolithic at other (e.g. Jarmo). Like Redman (1978), Hole (1987d) includes a later phase, in this case the "developed ceramic" Neolithic, which for all purposes is the Late Neolithic. For our purposes I will simply refer to sites as Early, Middle or Late Neolithic.

The Neolithic Age is much better known than the preceding Proto-Neolithic; a few sites have been repeatedly excavated (Tepe Ganj Dareh, Guran, Jarmo, Tepe Abdul Hosein) and intensive surveys throughout the region have identified numerous other Neolithic occupations (Goff and Pullar 1970; Hole and Flannery 1967; Levine and McDonald 1979; Mortensen 1974a, 1975; Smith and Mortensen 1980; Young and Smith 1966). However, reconstruction of subsistence is difficult as many of the type sites, although constantly cited, have only been briefly tested and reported [e.g. Bog-i No in Khorramabad (Hole and Flannery 1967); Sarab (McDonald 1979) and Tepe Siahbid (Braidwood 1960) in the Mahidasht].

The Neolithic Lithic Industry

The Neolithic in the central Zagros is characterised by a few ongoing trends. First, there appears to be substantial cultural continuity between the preceding Proto-Neolithic and the Neolithic (P.E.L. Smith 1975; Mellart 1975; Singh 1974). The chipped flint industry seen in the Proto-Neolithic continues on into the Neolithic, although the frequencies of particular classes of tools changes. The ground stone industry which began to develop in the Proto-Neolithic becomes increasingly important, reflecting a greater reliance on processed plant foods, both wild and eventually domestic. The ground stone industry becomes non-portable as heavy tools like querns, mortars, and pestles appear in large numbers (Mellart 1975).

Neolithic Ceramics

Ceramics appear for the first time in the central Zagros. For the most part the initial ceramics were crude, chaff tempered bowls and pots covered in a variety of fabric impressions, such as those found at Tepe Guran [(e.g. Guran grey-brown ware) Meldgaard, Mortensen, and Thrane 1963; Mortensen 1964] and Ganj Dareh (P.E.L. Smith 1975). During the Middle and Late Neolithic a number of painted and slipped varieties began to appear, like Tadpole ware, Sarab linear and geometric, and White on Black (Levine and McDonald 1977). These latter varieties appear to have been fairly widely distributed throughout the west central Zagros and up into Azerbaijan [(e.g. Hajji Firuz) Voight 1987)] and even into the northern Mesopotamian region [(e.g. basal Hassuna) Redman 1978]. It should be noted that these wares appear to be similar to each other only in a very general sense and and were most likely locally manufactured [for example, as denoted by the presence of kilns at Ganj Dareh (P.E.L. Smith 1983)].

Neolithic Architecture

The Neolithic provides us with a wealth of architectural information; the large semi-subterranean structures seen in the Proto-Neolithic are no longer present. There appear to be at least two architectural styles present in the Early to Middle Neolithic; at Ganj Dareh there is evidence of increasingly sophisticated rectilinear, multi-room buildings constructed from chineh (mud walls) and plano-convex bricks, from level D onwards (P.E.L. Smith 1990). In contrast, early architectural features at other partially contemporaneous sites like Guran (Mortensen 1963, 1964) and Tepe Abdul Hosein (Goff and Pullar 1970) consist of small wooden huts with rectilinear and slightly curved walls. The universal appearance of rectilinear and multi-room structures by the end of the Neolithic throughout the central Zagros (as in other areas of the Near East) is suggested to reflect a change in the division of labour and social organisation. This change is suggested to have been brought about by shift in economy as agriculture and animal husbandry replaced the earlier more mobile hunting and gathering way of life and as community size grew (Flannery 1972).

Neolithic Subsistence Patterns

There is abundant evidence for changes in subsistence in the central Zagros during the Neolithic. It appears that goats and sheep were being domesticated in the Zagros at this time; initial evidence points to culling of local herds of wild goats and sheep, followed by eventual domestication (Hesse 1978). Domestic cattle begin to appear in the Late Neolithic, as do pigs (Flannery 1983). Hunting wild animals still appears to have contributed heavily to the diet during the Neolithic. However, data from Bökönyi (1977) suggests a gradual decrease in the number of wild animals harvested from the Proto-Neolithic (Asiab) to the Neolithic (Sarab), which he suggests may be a result of increasing pressure on local resources as populations increased (see Smith and Young 1983 for a discussion of the latter).

The Neolithic is also characterised by a greater reliance on plants for subsistence purposes. As noted, the increasing elaboration of the ground stone industry points to a greater utilisation of processed plants. Analysis of seeds and plant macrofossils by Van Zeist et al. (1986) suggests that a variety of wild plants including almonds, wild lentils, vetches and pistachios were eaten, the latter quite frequently during the Early Neolithic but not later on. The status of domestic plants is a bit unclear. While there is evidence of very early domestication of barley in the Early Neolithic at Ganj Dareh, other domesticated cereals do not appear to have become relatively important until the Late Neolithic; we do find emmer wheat and lentils at later Neolithic sites in the Khorrmambad (Bog-i No; Hole and Flannery 1967), Kangavar (Tepe Abdul Hosein; Goff and Pullar 1970) and Kurdistan areas (Jarmo; Braidwood and Howe 1960, Braidwood et al. 1983). However, the Neolithic in the former two areas is poorly known.

The actual mode of subsistence in the central Zagros during the Neolithic is open to considerable debate. For the longest time, the temporal and spatial pattern of Neolithic villages was complicated by the assumption that any substantial village must have had an agricultural base (as at Jarmo). We now know that this is clearly not true (see Ames and Marshall 1980-1 on this point). It seems that the developing consensus is swaying in the direction opposite of traditional interpretations that all Neolithic villages were sedentary and based on agriculture and animal husbandry (e.g. Flannery 1969). Initially, Mortensen (1972) suggested settlement in the central Zagros Neolithic was comprised of a number of small villages engaged a mixed strategy of farming <u>and</u> gathering. However, he was not altogether certain that this was the only adaptation present at the time, and suggested that substantial physiographic heterogeneity and a dependence on domestic herd animals would have encouraged a more nomadic mode of existence. The possibility of a concurrent nomadic mode of subsistence existing alongside a Neolithic mixed farming and gathering economy has recently been echoed by Henricksen (1985a) and Pullar (1977). In fact, archaeological evidence from basal Guran (Mortensen 1963, 1964), Sarab (McDonald 1979), and Tepe Abdul Hosein (Goff and Pullar 1970) suggests that some form of transhumant and / or developed pastoralism may have been a predominant mode of subsistence at times throughout the central Zagros.

Smith and Young (1983) have constructed a model which suggests the Early Neolithic inhabitants of the Zagros were pastoralists living in upland valleys, engaged in some form of incipient animal husbandry and later began herding domesticated goats and sheep. These peoples also relied on hunting and collecting for a large portion of their subsistence. As a result of a postulated increase in population coupled with the full domestication of goats and sheep, settlement patterns shifted from the upland valleys to the relatively unoccupied valley floors. A direct result of this shift in settlement pattern was that domesticated plants, obviously quite difficult to grow on rocky upland slopes, could now be readily assimilated into the subsistence pattern (Smith and Young 1983). Thus, during the seventh millennium B.C., agriculture is suggested to have comprised a minor component of the subsistence base of early villages in the Zagros region. The emphasis in the Zagros Early Neolithic appears to have been on animal herding (Redman 1978) .

Thus, one is left with the distinct impression that sedentary village based agriculture has never been a profitable mode of subsistence in the Zagros region. The Zagrosian Neolithic witnessed a considerable delay, in comparison to other areas of the Near East, of the adoption of a sedentary village based adaptation based on a reliance on domesticates. Also, the data from the Late Neolithic is vague to the point that we can not be entirely certain how exclusive the agricultural adaptation was (Pullar 1977). It appears that the central Zagros groups had always relied heavily on an investment in herding, beginning sometime in the Early Neolithic, which they supplemented with hunting and collecting. Farming may have composed a minor component of overall subsistence and appears not to have been fully established until sometime in the Late Neolithic, if at all (Pullar 1977).

The Chalcolithic Age

If archaeological research in the preceding ages seems incomplete, then the data from the Chalcolithic are at best confusing. Initially, the central Zagros Chalcolithic was known primarily from the excavations at Tepe Giyan (Contenau and Ghirshman 1935). However, excavations at the badly disturbed site could best be characterised as a salvage excavation; also, the culture historical sequence present at Giyan is primarily limited to the later Metal ages; thus the Chalcolithic chronology was at best incomplete. In addition, there seems to be a propensity among archaeologists to ignore the central Zagros Chalcolithic altogether, in favor of the developing Ubaid and Uruk urban civilisations of the adjacent Mesopotamian flood plain. When archaeologists do refer to the Zagros highlands, it is often in the context of developments in the southern Mesopotamian region. However, work within the last 15 or so years has served to correct this problem and the Tepe Giyan sequence is now essentially ignored for the purposes of higland Zagros Chalcolithic chronology building.

Chronological distinctions within the Zagros Chalcolithic are based primarily on the distribution of ceramics. It is probably not profitable to engage in a detailed discussion of Chalcolithic ceramic chronology at this point; discussion will be limited primarily to the sparse evidence for subsistence. Henricksen (1985 a,b) has recently constructed a reasonably simple local chronology based of the distribution of ceramic types and uncalibrated radiocarbon dates; for the purposes of this thesis the Chalcolithic can be divided into three phases; Early (7000-6000

B.P.), Middle (6000-5000 B.P.) and Late (5000-4600 B.P.).

The greatest amount of research (which is also the most up-to-date and best published) to be carried out in the central Zagros Chalcolithic has focused on the northeastern portion of the area, in the Kangavar and associated valley systems. This is predominantly the result of the Royal Ontario Museum's ongoing research interests in this particular part of the Zagros. Even so, the Kangavar is still relatively unknown as much of the work has focused on site survey (hence the excellent settlement data for this area) and on the excavation of a few type sites in an effort to expand and refine the local chronology, so long dependent upon the chronology of Tepe Giyan (Contenau and Ghirshman 1935). As a result of the ROM's work, the early Giyan chronology has been effectively replaced.

The Mahidasht and Khorramabad regions are somewhat of a problem as very little recent work has been carried out in the region. One frustrating aspect of these two areas is that many of the often cited village sites (e.g. Choga Maran, Siahbid, Deshavar) are not published, or are referred to only in passing; their primary importance in the available literature lies in their relative positions in the local ceramic chronology. The vague nature of the archaeological record in these two areas during the Chalcolithic may also be a function of past survey activity, which has indicated a relative paucity of agricultural village sites during the Chalcolithic; this may have a reinforcing effect (e.g. the areas are simply not worthy of intensive survey). However, recent synthetic work (Henricksen 1985a,b) has served to clarify the Chalcolithic of the western central Zagros considerably; one byproduct of this research has resulted in considerable insight into the development of alternative subsistence strategies in otherwise marginal areas, in this case, many of the valley systems in the Khorramabad and Mahidasht regions.

The Chalcolithic Lithic Industry

In terms of lithic materials, there appears to be substantial cultural continuity between the Late Neolithic and Early Chalcolithic in all regions (Young and Levine 1974). Lithics include a substantial flint blade industry as well as abundant ground stone implements (e.g. mortars, querns, decorative items).

Chalcolithic Ceramics

The ceramic chronology in the Zagros becomes quite complex as a number of regional ceramic styles begin to evolve during the Early Chalcolithic, and even earlier in the Mahidasht, during the Late Neolithic. The diversity of cermamic styles is to a large extent a reflection of external cultural contacts. Ceramics in the Kangavar regions during the latter portion of the Early Chalcolithic and the Middle Chalcolithic are heavily influenced by the Dalma culture to the north in Azerbaijan (Young 1963); the Kangavar Dalma wares, although nearly identical to to the various forms of Azerbaijan Dalma ceramics, appear to have been locally manufactured (Henricksen and Vitali 1987).

The Early Chalcolithic in the Mahidasht begins with the appearance of 'J' ware, ceramics apparently related to the Eastern Halafian Tradition (Levine and McDonald 1977). The Eastern Halafian Tradition developed out of the northern Mesopotamian Neolithic to the west. Oates (1983) has suggested that the combination of 'J' ware and later Middle Chalcolithic Ubaid and Dalma wares found in the Mahidasht may represent ethnic intermixing, much like the Hassunan / Sammaran / Halafian triad seen in north central Mesopotamia. However, Henricksen (1985a,b) and Henricksen and Vitali (1987) point out that the 'Ubaid' wares in the Mahidasht are not actually Ubaid at all, but local wares reflecting Ubaid influences from the southwest (Henricksen 1985a,b). The Middle Chalcolithic is charactised by an abundance of Ubaid influenced Black-on-Buff 'hard' wares. Some Dalma related wares have been found as well (Levine and McDonald 1977).

Chalcolithic Subsistence Patterns

Very little evidence of subsistence in the Mahidasht has been reported to date; Early to Middle Chalcolithic faunal remains at Siahbid indicate a general reliance on domesticates such as goat, sheep, cattle, and pig. The latter occur in large numbers and are indicative of a sedentary village occupation, as domestic pigs do not take well to being continually moved (Flannery 1983). Most interesting is the fact that the breadth of the dietary contribution of wild animals is halved in comparison to Late Neolithic Sarab (Bökönyi 1977). Analysis of faunal remains from Seh Gabi indicates an increasing reliance of domesticates over wild faunal resources from the Early Chalcolithic onwards (Heathcote cited by Hamlin 1974). Analysis indicated an overwhelming reliance on sheep and goat (60% in Early Chalcolithic deposits, increasing throughout the Chalcolithic), with smaller percentages of cattle and pig [(5% each) Heathcote in Young and Levine 1974]. Middle and Late Chalcolithic inhabitants in the Kangavar region were sedentary agriculturalists engaged in dry land farming supplemented by hunting and fowling.

Evidence suggests some form of sedentary village based subsistence in the Khorramabad and Mahidasht areas during Early Chalcolithic times. Survey data indicates a substantial decrease in village mounds at the end of the Middle Chalcolithic and a concomitant increase in so called 'boulder ruins', herder's camps and pastoralist cemeteries (Henricksen 1985a; Levine and McDonald 1977; Mortensen 1976).

As a result of these new insights one is left with the distinct impression that village based farming was an erratic and unevenly distributed adaptation at best, highly dependent upon local physiography, climate, population density, etc... . In the beginning of the Chalcolithic we see that some sort of limited form of agriculture was practised throughout the region. However, for whatever reason, it appears that this particular adaptation was not stable enough to form the cornerstone of the subsistence base. In the Middle and Late Chalcolithic this mode of subsistence apparently became unprofitable in the western central Zagros, to the point where it appears that people shifted to a more nomadic existence predicated on herding, hunting, and collecting. However, archaeological evidence seems to indicate that the peoples of the more easterly Kangavar area did not participate in this shift in subsistence. The source of this difference may lie in differences in climate between the western and eastern halves of the central Zagros. It has been argued that a shift in subsistence, from agriculture to pastoralism, is exceedingly difficult to achieve (Redman 1978). However, it may be that the agricultural adaptation in the Zagros was of such a nature (unstable and peripheral to primary subsistence strategies) that such a shift could have occurred with relative ease.

Summary of Changes in Subsistence Through Time

Hole and Flannery (1967) see diachronic change in subsistence in Western Iran as comprising three stages. The first stage, largely synonymous with the Epipaleolithic and the Proto-Neolithic, denotes a shift from simple hunting and gathering to utilisation of all available resources; this is appropriately called the Broad Spectrum Revolution. According to Flannery (1971 [1969]) this change in subsistence is suggested to have begun prior to the Zarzian, around 20, 000 B.P., during the preceding Baradostian culture. The author suggests the broad spectrum revolution was in full swing during the first stage and is marked by a greater reliance on a wider diversity of species. Cohen (1989) suggests the process driving the broad spectrum revolution was a result of

> "... diminishing returns probably motivated by growing population, expansion into game poor environments, and the disappearance of large game animals, rather than improving technology" (Cohen 1989: 56).

While the broad spectrum revolution is largely theoretical there appears to be substantial archaeological evidence in the Zagros for its existence, although Henry (1983) suggests much of the perceived diversity in faunal remains may actually be a function of taphonomic processes. Many of the faunal items recovered from archaeological contexts are characterised as 'second choice' food items; a variety of Zarzian and later Proto-Neolithic sites (e.g. Palegawra Cave, Shanidar Cave) reveal a secondary reliance on species such as snails, mussels, small game, crabs, fish, turtles, and seasonal water fowl.

Flannery suggests that the broad spectrum collecting pattern characterised all subsequent cultures up until 8000 B.P. This terminal date appears to be confirmed by Bökönyi's (1977) analysis; he indicates that the diversity of wild resources at sites after this terminal date dropped dramatically, possibly a result of over-exploitation. It is also important to bear in mind that there likely was regional variation in broad spectrum use; for example, Flannery (1971 [1969]) notes that although Palegawra Cave possesses abundant evidence of broad spectrum use, items such as land snails , which are abundant in some Zarzian culture sites, are absent in areas like the Khorramabad Valley (eg, Kunji Caves; Hole and Flannery 1967). Flannery suggests that environmentally marginal sites would likely rely more heavily on smaller resources. Once the pattern of broad spectrum use was established it is suggested to have been taken up in more favourable areas as well.

However, as Henry (1983) notes, most Epipaleolithic sites are also characterised by a heavy reliance on wild ungulates like sheep/goats, gazelle, and onagers; these animals make up a very large percentage of the faunal remains recovered, approximately 90%. Hole (1985) suggests that these large ungulates were beginning to be culled, initiating the process of bringing these animals under domestic control. During the Proto-Neolithic one also sees a heavy reliance on large ungulates, indicating a high protein diet. The major difference appears to be in the nature of the relationship between these resources and humans; during the Proto-Neolithic the beginnings of domestication are found, in the form of culling of local herds.

The major contrast between the two ages has to do with the quality and quantity of the plant component of the diet. In contrast to other areas of the Near East (e.g. Levant), heavy reliance on naturally occurring wild plants in the Middle East (e.g. Zagros) seems not to have occurred as early on or been as important. However, the Zarzian people must have at least relied on seasonally available plants; since there is no evidence of processing and storage facilities it might be that that Zarzian people may have been susceptible to seasonal dietary stress; certain micronutrients and vitamins found in plants may have been scarce on an annual basis. In contrast, there is abundant artifactual evidence for processing and storage (albeit no floral remains) during the succeeding Proto-Neolithic. Processing and to a lesser extent storage would act as a seasonal buffer to reduce dietary stress, particularly in times were access to wild ungulate herds was disrupted. It must also be kept in mind that during the Proto-Neolithic some form of seasonal transhumance appears to have been the rule; the presence of storage and processing facilities need not imply a great degree of sedentism but merely a caching of food resources to be relied upon when the inhabitants return.

As for the significance of the broad spectrum revolution during the Proto-Neolithic, Henry (1983) is quick to point out that although there is some evidence for a diversified resource base, the majority, over 90%, of faunal remains recovered from Zagros sites are dominated by medium to large ungulates. However, one must keep in mind the effects of taphonomic processes which may produce differential preservation of larger elements at the expense of smaller elements; this in effect may cause the contribution of second choice resources to be seriously underestimated. As I noted earlier, these supposedly minor resources could make a world of difference with regards to settlement patterns as they may function as a dietary buffer, allowing people to stay in one place longer than would be otherwise possible.

During Zarzian times, the peoples inhabiting the region were largely semi-nomadic hunter-gatherers. Sites tend to be located in particular environments to take advantage of the "vertical economy", that is, seasonally abundant resources which occurred in various ecological niches restricted to particular elevations on the mountain slopes and alluvial plains (Redman 1978). Population movements were arranged to coincide with the localised occurrence of these specific resources in particular ecological niches. Some form of limited transhumance appears to have been the rule at this time, akin to the seasonal rounds and settlement patterns of some North American ethnographic groups (P.E.L. Smith 1986). While discussing Epipaleolithic settlement patterns in the Zagros, Flannery proposed that:

> "... archaeological settlement patterns suggest that the basic residential unit was a "base camp" composed of several families, which shifted seasonally; from this base, hunting parties made periodic forays to "transitory stations", vantage points from which they stalked and eventually killed game, which was then cut up into portable sections at temporary "butchering stations" (Flannery (1971 [1969]: 55).

During the Proto-Neolithic, settlement patterns also changed. The first evidence of substantial architecture, plant processing equipment and possible means of storage together with the early stages of domestication of goats and sheep appear to signal a shift towards a more sedentary settlement pattern (Mortensen 1972). Base camps are occupied for greater periods of time, as denoted by the increasingly non-portable tool kit and labour investment in shelter. However, subsistence is still likely based on a "seasonal rounds" model where people periodically broke camp and moved on to harvest locally abundant resources in accordance with their seasonal appearance.

The transition in subsistence from the Proto-Neolithic to Neolithic is difficult to delineate as there are no good archaeological sequences which document the transition from Epipaleolithic hunting and collecting to agriculture and animal husbandry. However, the common consensus has it that hunter-gatherers probably existed concurrently alongside early agriculturalists for at least one to two thousand years (Redman 1978).

The Neolithic coincides roughly with what Flannery (1971 [1969]) deemed the second stage, which is suggested to have lasted from approximately 10,000 to 7500 B.P. Flannery (1971 [1969]; after Hole and Flannery 1967) suggests that this stage was characterised by "... early dry-farming and caprine domestication, and it seems to have involved predominantly emmer wheat (Triticum dicoccum), two row hulled barley (Hordeum distichum), goats (Capra hircus), and sheep (Ovis aries)" (Flannery 1971 [1969]:51). He considers permanent villages, early hornless sheep, and transitional domestic grains as hallmarks of this stage. However, the fact that Flannery's work was concentrated in the Khuzistan lowlands deserves serious consideration as the local sequences in the Deh Luran, Susiana, and Ram Hormuz plains differs considerably from the Zagros highland valleys during this stage.

While the Zagros peoples were likely transhumant herders, contemporary peoples in areas like the Taurus mountains of Anatolia were living in large sedentary communities, relying on both domestic plants and animals [(e.g. Can Hassan III, Hacilar, Çayönü) Redman 1978]. To partly account for this apparent discrepancy, Hole (1985) suggests that the domestication of plants and animals followed separate and very different trajectories that eventually met to give the "Neolithic Revolution" its revolutionary characteristics;

> "The picture in the Zagros is somewhat different in that there is no long Epipaleolithic tradition of seed use, and the first domestic cereals occur along with domestic livestock. Although some of the late Paleolithic (in the Zagros) sites contain grinding and pounding stones, these seem to have been used principally for smashing pigments" (Hole 1985: 57).

Indeed, the archaeological evidence from the Zagros seems to indicate that Early Neolithic peoples did not rely on domestic plants to any great degree; while barley has been found in all levels of Ganj Dareh, it does not occur in large quantities and appears to be the only domestic cereal present. On this point it is interesting to note that Flannery (1971 [1969]) suggested that in areas of marginal rainfall, barley appears to have been the main crop, otherwise wheat was preferred. It is only during the Late Neolithic that emmer and einkorn wheat, domesticated lentils and other plants begin to appear. The evidence for such in the central Zagros is vague and has yet to be systematically examined in a regional context, so we do not really know to what degree and how widespread these domesticates were. Indeed, it has been suggested that the adoption of domestic cereals was delayed until a wetter and warmer climatic regime became established towards the end of the Neolithic in the Zagros (Hole 1987a).

In summary, during the Neolithic the established pattern of reliance on ungulates is still apparent, but the relationship between this food source and humans changed when compared to the Epipaleolithic and Proto-Neolithic; domestication ensures reliable access to protein without having to travel to gain access to the same. Constant access to this surplus "on the hoof" would have also functioned as a buffer in times of stress. Domestication of ungulates also has the added affect of creating a new source of food, diary products (although initial yields would have been minimal). Ethnographic evidence suggests that dairy products can also be stored for long periods of time, thus acting as an additional dietary buffer (Watson 1979). Plant domestication is a somewhat contentious issue as there is little evidence of it in the Early Neolithic of the Zagros; also, it is not known to what degree domestic plants were utilized. However, it is known that wild resources were still heavily relied upon; storage of these in combination with incipient utilisation of domestics as well as improved processing and storage technology would act to enhance dietary quality and quantity. At the same time cultural pressure was beginning to take its toll on wild resources, as denoted by a reduction in the number of wild species present at archaeological sites. However, it is not known when this trend became marked enough to have an effect on dietary breadth. As for the relative contributions of plants versus animals we have no idea, but suffice it to say that archaeological and ethnographic evidence has indicated that a reliance on animal protein possesses considerable time depth in the Zagros; the relative contribution of both may not have changed dramatically from the Proto-Neolithic to the Neolithic.

The third stage of Flannery's scheme, roughly co-terminous with the Chalcolithic, has been traditionally ignored by archaeologists working in the Zagros region. As already noted, the focus of interest among archaeologists shifts to the Khuzistan lowlands and to northern and southern Mesopotamia. The Zagros highlands are seen as a cultural backwater during this time of incipient urbanism and city states. Also, in cases where Zagros authors are interested in changes in subsistence, the focus is typically on comparison between the Zarzian / Proto-Neolithic and developed Neolithic; little if any attention is paid to the Chalcolithic. This is unfortunate as there appear to be some interesting trends in subsistence and health extending from the Neolithic to the Chalcolithic.

Technological and social developments in the Zagros continued after the Late Neolithic; by extension so did trends in health and disease. In addition to the previously mentioned cultivars (emmer wheat, two-rowed hulled barley) and goats and sheep, bread wheat (*Triticum aestivum*), 6 rowed barley (*Hordeum vulgare*), lentils, grass peas, linseed, domestic cattle (*Bos taurus*) and pigs (*Sus scrofa*), and domestic dog (*Canis familiaris*) appear in the Late Neolithic and Early Chalcolithic. However, in contrast to the developing urban centres in Susiana and Ubaid Mesopotamia, the settlement pattern in the Zagros remains distinctly rural. In some ways the Zagros Early Chalcolithic can be seen as a period of "settling down", a regularisation of the subsistence patterns established in the Late Neolithic. However, things seem to change dramatically in the Middle and Late Chalcolithic ages.

One of the more interesting trends in settlement pattern distribution in the Zagros is identified by Smith and Young (1983). Based on synthesis of existing survey work and intensive surveying of their own, the authors argue that while site density and total population numbers appeared to be declining in many other regions during the Middle and Late Chalcolithic (e.g. Deh Luran and Susiana plains) the site density in the central Zagros (the Kangavar area in particular, and parts of the Mahidasht) appeared to increase. Archaeological reconnaissance and excavation in the region indicate that with increasing site and population density, people began to inhabit areas that would otherwise be considered marginal under lower population densities. This would in effect put undue stress on local wild resources, ultimately reducing their numbers or causing local extinctions, thus resulting in a reduction of dietary breadth as already noted. Bökönyi (1977) presents evidence that suggests a 50 % + reduction in the number of wild animal species in the Kermanshah area from the Early Neolithic to the Late Chalcolithic. Increased population density would also reduce the area available to forage per village. These variables would have the effect of reducing dietary breadth and forcing an ever increasing reliance on domesticates, leaving the population open to periodic dietary stress as a result of crop failure (Flannery 1969; McDonald 1979; Melville 1984). While one may argue such a scenario is deterministic, it is nonetheless plausible and is supported by the archaeological record.

Another trend of some importance has been recently identified by Henricksen (1985a,b). She provides substantial archaeological and ethnographic evidence to suggest that specialised nomadic pastoralism grew rapidly during the Middle and Late Chalcolithic, and came to characterise the subsistence pattern for the western half of the central Zagros. At the same time, she suggests that agricultural site densities in the western central Zagros began to decrease, a pattern she suggests was a result of climatic deterioration. Henricksen (1985a,b) and other authors (e.g. Gilbert 1983) see nomadic pastoralism as being very different from Early Neolithic transhumance. Nomadic pastoralism in the Chalcolithic was and still is characterised by long range return migration between cooler high altitude summer pastures in the eastern central Zagros and lower, warmer pastures in the western central Zagros, whereas seasonal transhumance is seen as a more short range seasonal rounds type of migration involving utilisation of specific resources at various altitudes (vertical economy). This issue of pastoralism in the Late Chalcolithic is of some concern to paleopathological interpretation as it is often difficult to determine if a community is truly sedentary and agriculturally based or possibly transhumant or pastoralist. These three lifestyles entail very different diets and disease ecologies.

The shift from low density semi-nomadic / seasonal transhumance in the Proto-Neolithic to semi-sedentary and sedentary village sites in the Neolithic and Chalcolithic means that people tended to aggregate in larger groups for longer periods of time at some point from the Proto-Neolithic onwards. This trend appears to continue through time, as we have evidence of substantial village sites in the region beginning some 10,000 to 9,000 years B.P., Ganj Dareh being the earliest of these village sites yet discovered in the region. This pattern culminates in sedentary villages in the Late Neolithic and Chalcolithic throughout the Kangavar area and into the Mahidasht and Luristan.

The health implications associated with increasing settlement and population density as well as reduced mobility have been noted by many anthropologists. These include a greater rate of infectious disease as a result of closer and more sustained inter-personal contacts as well as higher population density which permits density dependent diseases to become established (Black 1975). Increased sedentism also has the net effect of increasing potential exposure to parasites due to poor sanitation (thus close proximity to fecal matter) as well as exposure to zoonoses via contact with potential disease reservoirs like domesticated animals. Another consequence of sedentism is the much cited reduction of birth spacing and earlier age at weaning among agriculturalists in comparison to hunter-gatherers (Blurton-Jones et al. 1992; Lee 1972; Sussman 1972). This latter point is of crucial importance in the well being of subadults as a reduction in birth spacing means a lower age at weaning, creating the potential for greater infant weaning stress. A reduction in birth spacing also effectively increases maternal stress as a result of less recovery time between births and the increased physiological demands of having more children.

In terms of mode of subsistence we see a variety of potential trends. Generalisations based on these trends are, however, informed speculation on occasion, as the archaeological record of the region is very vague when it comes to reconstruction of subsistence practices. The general pattern appears to be one of increasing reliance on domesticates through time, from the Early Neolithic onwards. There also appears to be a parallel decrease on reliance on wild fauna which becomes pronounced during the Middle Neolithic and Chalcolithic. This trend in part is probably a result of increasing sedentism and population density throughout the region as increased population density overtaxed wild resources and sedentism effectively reduced the available catchment area per village.

The problem of greater reliance on domesticates is that even though it alleviates the potential problems associated with seasonal scarcity of foods often found among hunter-gatherers it creates the spectre of acute food shortages during periods of crop failure or suboptimal yields.

The dietary shift associated with the agricultural transition also means a qualitative difference in the weaning diet of children; a shift to starchy gruels in combination with a lower weaning age in agricultural populations can be quite devastating as the combination can produce dietary deficiencies and greater chances of infection.

In summary, it becomes increasingly apparent that throughout the various developmental stages of the Zagros, the peoples of the region did not adhere to a uniformly distributed rigid mode of subsistence. Due to considerable geographic heterogeneity, environmental marginality, climatic fluctuation and variability, there was likely a considerable range of variability in the subsistence pattern and dietary composition at any given time.

CHAPTER IV

SITES AND SAMPLES

Rather than include the samples under consideration within the last chapter I decided it would be more appropriate to discuss the sites and skeletal samples separately and in considerably more detail as the following discussion of the skeletal samples themselves would likely be lost within the preceding chapter.

As I mentioned previously in chapter 1, Ganj Dareh and Seh Gabi represent a substantial part of the continuum in the transition from semi-nomadic hunting and gathering to sedentary village agriculture. The importance of both sites is that within the central Zagros region Ganj Dareh and Seh Gabi are the archaeological type sites for the Early Neolithic and Chalcolithic ages. Ganj Dareh is also one of the earliest sites on the planet at which evidence of incipient agriculture is found. For the purposes of physical anthropology, these two sites are of great importance as they have yielded relatively large and complete skeletal series, in comparison to other sites from the region.

The Ganj Dareh Site

Much of what we know of the Zagrosian Neolithic, particularly the Early Neolithic, is derived from site of Tepe Ganj Dareh. Based on a variety of radiocarbon determinations Tepe Ganj Dareh dates from the eleventh to ninth millenia B.P. [figure 3 (Henry and Servello 1974)]. Located approximately 37 kilometres east of Kermanshah at an altitude of 1,400 meters, the site was excavated by P.E.L. Smith during 1967, 1968, 1971 and 1974. Approximately 20% of the mound was excavated, yielding a well stratified deposit comprising of 5 primary occupation levels, labelled A through E. (P.E.L. Smith 1966, 1968, 1970, 1972a,b, 1974, 1975, 1978, 1983) . The first 4 levels (A-D) were the result of occupations most likely dating to the second half of the eighth millennium B.C. Level E, which I already touched upon in chapter 3, is roughly contemporaneous in terms of radiocarbon years; however, there are

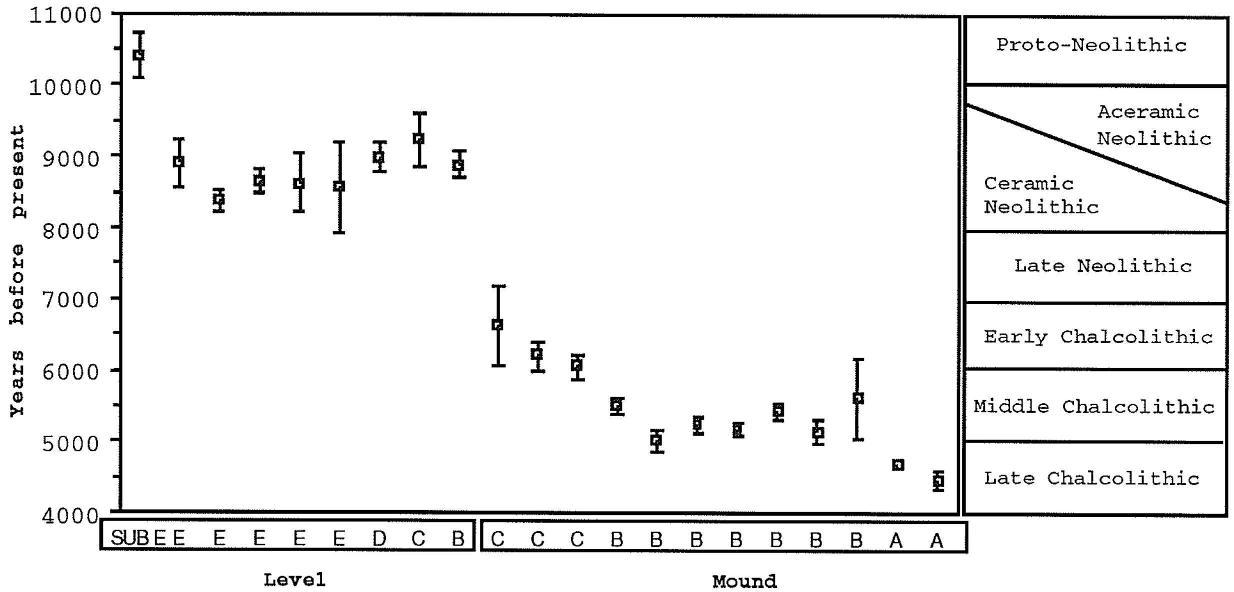


Figure 3. Ganj Dareh and Seh Gabi uncalibrated radiocarbon dates (from Hole 1987)

some problems with the dates from this level.

Basal level D of Ganj Dareh yielded a substantial chipped stone industry similar in many ways to the earlier Proto-Neolithic component found in level E, including a heavy reliance on a blade industry. On the basis of similarity of lithic materials between levels D and E cultural continuity is inferred (P.E.L. Smith 1975). In fact, the lithic tool types display some similarities to those found at earlier sites like Asiab and Karim Shahir, as well as contemporary and later Neolithic sites like Tepe Guran, Sarab, and Jarmo (P.E.L. Smith 1972). No obsidian was recovered. A variety of ground stone tools were also recovered from the Neolithic levels at Ganj Dareh, including mortars, pestles, rubbing stones, and hammer stones.

Level D exhibits some of the earliest ceramics to have been found in the central western Zagros region to date. Some of the ceramics appear similar to the greyish-brown ware found in early Tepe Guran deposits (see Meldgaard, Mortensen and Thrane 1963; Mortensen 1964). Shallow bowls, dishes, small vases, and a number of large storage vessels have been recovered in situ in the rooms they were left in (P.E.L. Smith 1975). A number of kilns have also been identified in post level D deposits, indicating local manufacture of ceramics (P.E.L. Smith 1983). In addition to the lithic and ceramic assemblages, stone and shell beads (the latter from the Persian Gulf), and traces of woven matting were recovered from a number of the burials excavated from the site.

The faunal analysis performed by Brian Hesse (1978) revealed a wide variety of mammals, birds, reptiles, fish and invertebrates. The analysis, however, indicated an overwhelming reliance on goat and sheep; Hesse (1978) further suggested that there was evidence for the controlled harvesting of wild sheep/goats in post E levels, a pattern seen commonly in ethnographic nomadic pastoralists. Goat hoofprints in sun dried bricks are suggested to indicate evidence of cultural control. However, hunting was also important as shown by the presence of auroch, wild pig, red and fallow deer, gazelle and onager (both rare), hare, fox, Chukar partridge, duck and pigeon. Hesse also identified clams and snails in small numbers, in contrast to abundant invertebrate remains from other Neolithic sites like Sarab and Jarmo.

Floral analysis by Van Zeist, Smith, Palfenier-Vegter, Suwijn, and Casparie (1986) found that both domesticated and non-domesticated barley was present in all levels of Ganj Dareh; however, no other cereals were found. The authors also found abundant evidence for utilisation of pistachio nuts; they note that use declined with time, possible as result of a greater reliance on animal sources of fat. Van Zeist et al. (1986) also found evidence for use of wild lentils, almonds, and a wide variety of seasonally available vegetable resources.

Substantial architectural remains have been recovered in post level D deposits; a number of houses were identified, all constructed in a rectilinear fashion (Smith 1990). All levels included mud-walled architecture (chineh); plano-convex sun dried bricks, to which Chineh was applied, were used in level D while in level A rectangular red bricks were used (P.E.L. Smith 1972, 1990). Some of the houses appear to have been two stories; many had small bin-like cubicles built in on the lower floor. Large ceramic storage vessels were found in place inside some of the rooms as well.

Despite all of the evidence at Ganj Dareh, there is still no agreement on the possible mode of subsistence. Agelarakis (1989) contends the inhabitants were more or less sedentary. However, evidence forwarded by a number of authors (Hesse 1979; P.E.L. Smith 1975, 1983; Van Zeist et al. 1986) suggests the inhabitants of Tepe Ganj Dareh may have been semi-nomadic pastoralists and that the site may not have been occupied on a year round basis. Common consensus has it that the site was inhabited in the warmer months and abandoned during the winter.

Ganj Dareh Skeletal Biology and Paleopathology

The excavation of the site uncovered the remains of approximately 49 individuals. Adults were found in tightly flexed positions while young infants were commonly buried in plastered niches under living floors (P.E.L. Smith 1975). This latter mode of interment appears to possess considerable time depth, lasting in one form or another until the late Chalcolithic. Smith also notes that young individuals were often accompanied by burial offerings. Preservation of the skeletons is better than expected, as a result of both sub-floor burial and a fire that swept through the level D occupation; however, the fire also had the effect of causing much of the remains to become heavily calcined.

The Ganj Dareh sample comprises of a minimum of 49 discrete individuals, of which a minimum of 18 are subadults. The completeness and degree of preservation of individuals varies widely. In addition to the 49 individuals identified by Lambert (1980) there are an indeterminate number of individuals represented by isolated skeletal elements, both from the primary excavations into the mound and adjacent smaller excavations around the mound.

Previous study of the skeletal series by Meiklejohn, Lambert, and Byrne (1980), who carried out a comparative paleopathological analysis of the skeletal remains from Ganj Dareh with data from other sites in the immediate region (Qalat Jarmo, Tepe Hissar) and further afield (Israeli Natufian sites, Çatal Hüyük, Nea Nikomedia, Lerna) revealed that earlier Natufian samples' dental dimensions were generally smaller in comparison to those of Ganj Dareh, particularly the maxilla and anterior mandible. Ganj Dareh teeth were also larger than those from the slightly later site of Jarmo. Rates of pathology appear quite low at Ganj Dareh; caries occurs in only 2.6% of individuals, a rate very similar to other early Near Eastern sites (e.g. Çatal Hüyük and Nea Nikomedia). Three individuals display evidence of hypoplastic defects. There were only two cases of long bone fractures, one possible case of osteomyelitis and one case of osteoarthritis or osteophytosis. One individual (adult female) displays sharply circumscribed lesions of the frontal, parietals and occipitals (metastatic carcinoma?). However, five individuals (all adults) displayed evidence of porotic hyperostosis. No younger individuals were affected and there was no evidence of cribra orbitalia. The authors feel that the presence of porotic hyperostosis in the sample may be significant as the absence of the condition in subadults argues against sicklemia or thalassemia and may in fact indicate a post-adolescent dietary shift. A radiographic analysis of the long bones and vertebrae of 26 of the Ganj Dareh individuals indicates a distinct lack of degenerative bone disease (osteoporosis?); only one individual displayed evidence of generalized metabolic bone disease. Five individuals displayed Harris lines (four under ten years of age, one young adult). The authors concluded that pathology at Ganj Dareh was relatively minor in comparison to either Nea Nikomedia (Angel 1973) or Çatal Hüyük (Angel 1971). The pattern of pathology reported was also quite different in comparison to the Chalcolithic site of Seh Gabi (Meiklejohn et al. 1980). On the whole, the population is characterised by low rates of pathology and early age at death;

> "The general impression is, however, that the paradoxical pairings of low longevity with low pathology is encountered much more frequently in gathering and hunting populations than in later urbanised groups. We can therefore briefly conclude that the demographic and health aspects of this early Neolithic population still mirrored earlier patterning" (Meiklejohn et al. 1980: 11).

Agelarakis (1989) reanalysed the Ganj Dareh material as part of a comparative assessment between the Ganj Dareh skeletal sample and remains recovered from the slightly earlier Proto-Neolithic site of Shanidar Cave. Analysis focused on descriptive paleopathology and indicators of stress. Agelarakis found that the Ganj Dareh sample was not nearly as robust as the Shanidar Cave materials, interpreting the Ganj Dareh samples' morphology to be consistent with contemporary humans living in sedentary contexts.

However, Agelarakis found markedly higher rates of particular pathologies in comparison to the earlier study by Meiklejohn et al. (1980). He found that there was a relatively high frequency of dental pathologies in the Ganj Dareh sample. All age groups with the exception of perinates displayed hypoplastic defects which were interpreted as evidence of growth disturbance, childhood diseases, or the result of malnutrition. However, it should be noted that only one perinate was scorable for the defect. Of 10 scorable adults, 7 displayed defects, of 3 juveniles, all displayed defects, and of 9 scorable infants 5 displayed defects. Agelarakis also recorded a relative high frequency of ontal disease in adults (9/11 scorable adults); juveniles displayed a slightly lower frequency (2/3). Tooth wear was characterised as moderate to heavy for the adult component. Evidence of infectious disease seemed to be concentrated mainly among adults (5/10); only one other individual, an infant, displayed evidence of such. In terms of trauma, again, the highest concentration (4/18 scorable individuals) was seen in adults; one juvenile (out of three) displayed evidence of trauma. As with the earlier Shanidar sample, trauma and periosteal reactions displayed a close correlation; 8 out of 19 scorable adults exhibited some evidence of periosteal reaction. Finally, arthritic conditions were limited solely to adults; 6 out of 17 scorable individuals displayed evidence of such.

Agelarakis suggests the observed differences between Shanidar Cave and Ganj Dareh could be accounted for by differences in mode of subsistence, assuming the Proto-Neolithic Shanidar peoples were semi-nomadic hunter-gatherers and the Ganj Dareh peoples were sedentary village agriculturalists. Consequent changes in subsistence and population density/distribution associated with the two different adaptations may have affected and altered the interrelationships between pathogens, vector, and human hosts (Agelarakis 1989).

Schoeninger (1981) analysed the bone strontium content in a number of individuals from Ganj Dareh as part of a larger project looking at diachronic changes in bone strontium throughout prehistoric Iran and Israel. Using bone strontium as a relative indicator of the proportion of vegetable matter to animal protein in the diet, Schoeninger sought to examine strontium levels in light of what we know in terms of changes in diet related to the agricultural transition. Relying on Flannery's (1969) disequilibrium/broad spectrum revolution model, Schoeninger reasoned that actual changes in diet occurred before the development of agriculture and that in dietary terms the evolution of agriculture actually meant a change in economy. "In other words, it involved a change in management or regulation of a previously exploited subsistence system" (Schoeninger 1981: 74). Results from Ganj Dareh (and sixth millennium Hajji Firuz in Azerbaijan) indicated that bone strontium levels were much higher than contemporary samples from the Levant. In fact, both Iranian samples appeared similar to the earlier Israeli Kebara C samples (ca. 15,000 B.P.), indicating a heavy reliance on animal protein. However, both Iranian samples possessed a wide range of variation, suggesting variation in diet within samples. Although the Israeli data conformed to the authors expectations, thus confirming her hypothesis of a subsistence shift prior to the development of agriculture, the Iranian data appeared ambiguous. Both Iranian sites yielded similar but extremely high bone strontium ratios, something that Schoeninger did not expect at all; the author suggested that the similarity of values may reflect the traditional emphasis on goats and sheep found in the Zagros.

The Seh Gabi Site

The entire Chalcolithic Age in the Kangavar area is represented primarily by the culture sequence uncovered at one archaeological site, Seh Gabi (see figure 3). The site is located in an intermontane saddle between the Kangavar and Assadabad valleys at an altitude of 1500 metres and was excavated in 1971 and 1973 as part of the Godin Tepe Project, conducted under the auspices of the Royal Ontario Museum (Young and Levine 1974). The site was excavated to extend and articulate with the lower end of the Godin culture sequence (primarily an Iron age settlement). It is unlike most other sites in the region in that it consists of a series of three low mound groups (C, B, and A,E,F) in close proximity to each other, as opposed to one single large mound formed by successive occupations.

The Early Chalcolithic at Seh Gabi is represented by the Shanabad and Dalma phases. McDonald (1979) investigated the mound C materials, particularly the Shanabad phase (ca. 6450-5950 years B.P.: MacDonald 1979); analysis of artifactual and faunal remains suggests a primary mode of subsistence based on processed plant products (possibly domesticates) and animal husbandry (sheep, goats and domestic pig). Faunal analysis by Isobel Heathcote (in Hamlin 1974) indicates that during the Shanabad phase the inhabitants placed a heavier reliance on a wide variety of small game and maintained relatively few domesticates in comparison to later phases. Still, analysis of the entire site faunal assemblage indicates and overwhelming reliance on sheep and goat (60%); deer comprised 15%, while cattle and pig represented 5% of the assemblage each (Heathcote in Young and Levine 1974).

McDonald (1979) suggests that although substantial rectilinear architectural remains were found in mound C, the remains themselves seem indicate periodic abandonment, something which she suggests may reflect the first unsuccessful efforts to inhabit an otherwise marginal location. This seems to be reflected in the survey data, which indicate Shanabad phase sites in the region are very rare and that settlement was likely sparse (Smith and Young 1983).

The Dalma phase, dating to the first half of the sixth millennium B.P., is represented by mound B. This phase is interesting in that the ceramics, after which the phase is named, are stylistically identical to ceramics found approximately 400 kilometers to the north in Azerbaijan at Dalma Tepe (Hamlin 1975; Voight 1987; Young 1963). Dalman sites are characterised by sub-floor infant burials in ceramic vessels and a distinctive style of impressed ware. These sites often contain only infant skeletal remains; adult remains are entirely absent (Henricksen and Vitali

1987). Although no substantial architectural remains or infant burials were recovered during this phase, the presence of Dalma Impressed and other associated wares demonstrates long range contacts. While no coherent architectural remains were recovered from Dalma levels, cursory analysis of various artifact classes suggests a certain degree of continuity with Shanabad phase mound C (Levine and MacDonald 1977).

The Middle Chalcolithic in the Kangavar areas is represented by the Seh Gabi and Taherabad phases, both of which date to the latter half of the fifth millennium B.P. (Young and Levine 1974). While the Taherabad phase may actually be anomalous, as it is based solely on questionable radiocarbon dates (Hole 1987b) there is abundant archaeological evidence from the Seh Gabi phase component in mound B. Substantial architectural remains in the classic rectilinear fashion were uncovered; analysis of the architecture suggests the settlement underwent a number of rebuilding episodes. A number of sub-floor infant burials were also recovered from Seh Gabi phase contexts (and in later phases as well); many of these were interred in ceramic bowls placed lip to lip or with a bowl placed on top of the burial.

The A,E,F mound group is dated from 5650 to 5050 years B.P., falling within the Godin VII and VI phases (Young and Levine 1974), thus the latter half of the Middle Chalcolithic. Archaeological and faunal evidence from Mound A,E,F suggests that during the Godin VI I and VI phases the inhabitants were sedentary agriculturalists engaged in dry land farming and animal husbandry, supplemented by hunting and fowling (McDonald 1979). Faunal analysis by Isobel Heathcote (in Hamlin 1974) indicates an increasing reliance on domestic pig, sheep, goat, and cattle, although hunting continued to supplement the diet in a continually decreasing fashion.

The Late Chalcolithic in the Kangavar region (Hoseinabad phase) is represented by deposits from mounds A and E at Seh Gabi, and by Godin VIII deposits at Godin. Architectural remains excavated in mound A were remarkably well preserved, consisting of a large building with at least eight rooms, some of which contain cruciform hearths with central holes. Multistoried structures are also indicated. Contemporary mound E displayed a slightly different style of architecture; three unconnected rooms facing into a common court yard, each with its own hearth. The presence of spindle whorls, clay seals and innovative architecture in mounds A and E suggests that Late Chalcolithic Seh Gabi may in fact represent some sort of small workshop site with an elite residence (Young and Levine 1974).

Settlement pattern densities in the Kangavar valley appear rather stable or increase slightly during Middle and Late Chalcolithic times; 20 sites were recorded through survey for the Dalma phase, while 17 were Seh Gabi phase and 23 Hoseinabad phase; there is no evidence of increase in site size for this time (Levine and McDonald 1977).

Seh Gabi Skeletal Biology and Paleopathology

Excavation at Seh Gabi uncovered a total of 33 burials; two of the burials were double burials while another two consisted of faunal remains. One individual consisted of a single clavicle and another was found to be an adolescent of approximately fourteen years of age (Jarvis 1979). The remaining 31 individuals were found to consist entirely of neonates or infants; the mean age at death was approximately 6 months (Skinner 1980). Five of the burials were recovered from mound C, thirteen from mound B and fourteen from mounds A, E, F. Hamlin (1974) indicates that the infants from Seh Gabi and Godin VII contexts (mounds A, B, E) were interred in pots whereas those in the earlier Shanabad phase (mound C) were simple sub-floor inhumations (McDonald 1979). Analysis of the skeletal remains has made it abundantly clear that the infants were developmentally stunted and nutritionally stressed (Jarvis 1979; Skinner 1980). Seventeen of 19 postnatal infants showed evidence of begin physiologically stressed prior to death. Skinner (1980) found that 88% of the infants (14/16) displayed marked bone rarefaction and nearly 90% of post natal infants exhibited Harris lines. Seventy-one percent of post-natal individuals were found to be skeletally stunted, 45% exhibited enamel hypoplasias, 28% possessed orbital lesions and 6% cranial pitting (Skinner 1980). Waddell (1989) has also presented evidence which suggests that some of the infants may have suffered from infantile scurvy.

CHAPTER V

CORTICAL BONE GROWTH AND MAINTENANCE

The examination of cortical bone involves the study of the growth and maintenance of cortical bone tissue. The use of the term 'cortical bone' refers specifically to circumferential lamellar bone tissue distributed along the diaphyses of long bones laid down in the course of normal subperiosteal apposition. It also refers to the dense compact bone comprised of primary osteonal tissue (as in the case of immature individuals) and secondary osteonal tissue created during intracortical modeling and remodeling.

Cortical bone studies are based on the examination of resorption and deposition of cortical bone tissue at the periosteal and endosteal surfaces of long bones (figure 4), and the interaction between these two surfaces as measured by various indices; ultimately one can make inferences pertaining to the relative health of individuals as well as delineate intra and inter-population trends in 'cortical health'. The examination of cortical bone on a sample level of analysis also enables one to make statements about the nutritional and pathological status of archaeological samples, and offers a means of corroborating or disputing other information pertaining to the relative health derived from other paleopathological indicators. The analysis of cortical bone behaviour is of interest to physical anthropologists as: (a) cortical bone growth and maintenance is not a static phenomena and responds in a synergistic manner to a whole series of internal and external variables; (b) the bone dynamic itself changes as humans age, that is, the processes involved are not constant across age classes. Moreover, the study of cortical bone provides a class of information not regularly relied upon by physical anthropologists, although this is changing (see Ruff 1992 for a review).

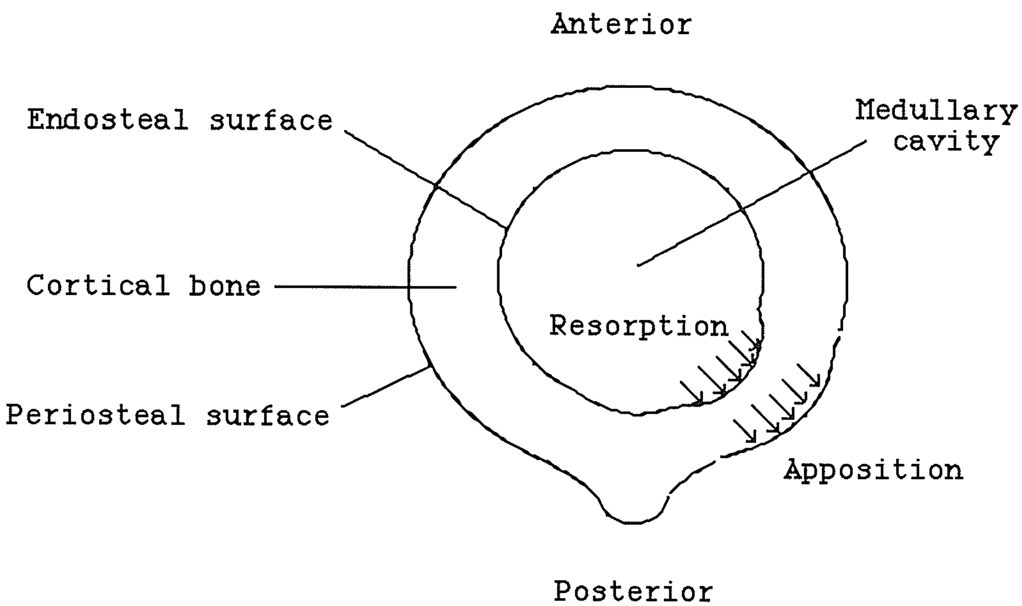


Figure 4. Transverse cross section of midshaft femur

Modeling and Remodeling

Frost (1976) defines a variety of concepts crucial to the study of bone tissue. Of primary importance is the distinction between modeling and remodeling. Modeling "... designates specifically only those cellular based actions which remove and add to skeletal tissues in such a way as to establish and then maintain it's normal architecture" (Frost 1976: 219). Normal architecture is defined as "... outside and marrow cavity bone diameters, and therefore cortical thickness and cross sectional area" (Frost 1985: 213) established by resorption and drift (Enlow 1963). Modeling is associated primarily with the growth process of skeletal development in infancy and childhood and is greatly reduced after the adolescent growth spurt. Note that modeling involves the deposition of bone tissue only; it does not involve the removal of bone. Bone modeling in the immature skeleton can approach rates as high as 200% per year (Frost 1976). The rapid growth of the infant skeleton allows a large number of diseases to leave readily observable features in the bones; it is because of the rapid rate of modeling that many of these diseases are not seen in adults, which have very low turnover rates, or are very difficult to detect. It is for this reason that the study of cortical bone behaviour is so useful and effective in determining infant health and pathological status.

Remodeling "... occurs in anatomically discrete 'packets', a typical average amount of bone is turned over per packet and it occurs throughout the life-span in man, even after skeletal maturity" (Frost 1976: 219). Frost is simply referring to the resorption and replacement of bone tissue by new osteons through the process of resorption and deposition (see Stout 1989, 1992 for review). Remodeling occurs on all bone envelope surfaces; periosteal, Haversian, cortical-endosteal, and trabecular. In the human child modeling and remodeling may occur simultaneously, although modeling accounts for 90% of all activity (Frost 1976).

Cortical Bone Growth

During the last 25 years there has been a great deal of interest in the study of cortical bone growth and maintenance within physical anthropology. Initial interest in bone growth and maintenance was spawned by the problem of adult osteoporosis in western populations; more specifically, the radiological investigation of female age related fracture epidemiology (e.g. Alffram 1964), which led to the realisation that older women suffered from substantial cortical bone loss. The inaccurate nature of subjective assessment of radiographically visible osteoporotic bone led many researchers to attempt to quantify osteoporosis. As research continued into the quantitative assessment of osteoporosis, workers began to realise that that: (a) osteoporosis appeared to be related to resorption of bone on the endosteal surface of long bones or, more specifically, disproportionate resorption in the face of diminished replacement; (b) the incidence of osteoporosis appeared to be age and sex related; (c) osteoporosis was not limited solely to adults, but appeared in children and even infants; (d) there appeared to be significant differences in the amount of resorption and deposition according to age and sex; (e) and cortical bone growth and maintenance followed a fairly predictable pattern in healthy individuals. With this in mind, in order to understand the significance of paleopathological and skeletal biological studies of cortical bone growth and maintenance, the normal course of events related to cortical bone growth has to be delineated.

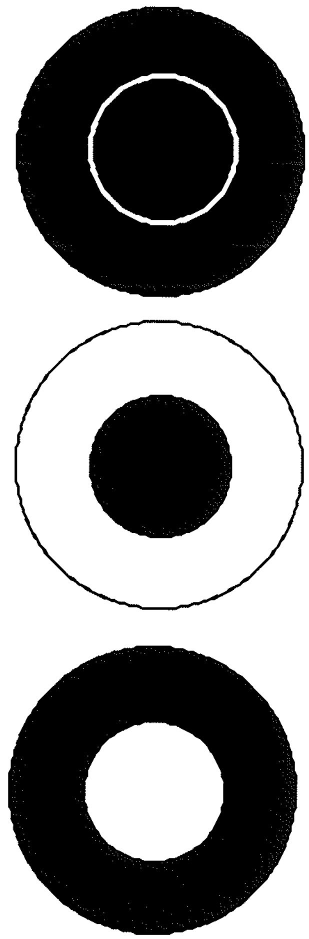
Cortical bone growth and maintenance are governed by two basic mechanisms; apposition and resorption. Apposition of bone occurs primarily on periosteal surface of long bones; however, apposition may also occur endosteally. Resorption, which occurs mostly on the endosteal surface, occasionally occurs on the periosteal surface at the site of entheses or on the metaphyses of rapidly growing bones. These two mechanisms are responsible for the phenomenon known as cortical bone drift, which is the process by which the bone is deposited and resorbed in such a manner that linear growth occurs while it's proper structure and proportion are maintained (Enlow 1963). In normal adult bone growth, deposition of bone occurs primarily on the periosteal surface in a continuous manner. Periosteal apposition results in the creation of concentric layers of lamellar bone. The rate of periosteal apposition changes according to age and sex in a fairly systematic fashion, although differences between populations have been noted. However, measuring just subperiosteal apposition ignores cortical drift (Enlow 1963), as demonstrated by Garn, Silverman, Hertzog, and Rohmann (1968), as well as subadult endosteal apposition (Garn 1970). The changes observed at the endosteal surface are more complex, involving resorption and apposition at various ages. Resorption and apposition occurs at different rates according to sex, and may be surface specific (Carlson et al. 1976; Ruff and Hayes 1981).

As a result, it is appropriate to review here the changes in the cortical bone growth and maintenance according to age and sex. This will enable a fuller understanding of the significance and potential utility of cortical bone studies to skeletal biology and will enable one to interpret data in a meaningful fashion. First, the measurements used here will be outlined.

Measurement

Four measures of cortical growth were calculated from the cross sections (figure 5); the total area of the cross section (TA), the area consisting of the medullary cavity (MA), the area consisting of cortical bone (CA), and the percent of cross sectional area consisting of cortical bone, or percent cortical area (PCA). Percent cortical area was then determined by dividing cortical area by total cross sectional area (x100). See chapter 7 (Methodology) for information of how cross sections were obtained.

In previous studies radiographic assessment of cortical bone measurements was based on three essential measurements; total subperiosteal diameter (T), medullary cavity width (M), and cortical thickness (C) (Garn 1970). These measures are assessed



1 Total Area (TA)

2 Medullary Area (MA)

3 Cortical area (CA)

4 Percent Cortical Area=CA/TA x 100

Figure 5. Area measurements utilised

merely by measuring the value directly from a radiographic plate using a pair of calipers. In the case of direct measurement, the dimensions of C, M, and T can be recorded by employing repeated measurements around the cross section at predetermined equidistant intervals (usually 6-8); the results are then averaged (Carlson et al. 1976). This method possesses the added advantage of being useful in determining surface specific changes in bone thickness as a result of resorption and deposition and between sex and age classes, particularly in investigating continous periosteal apposition in older adults. However, the measurement of simple thickness is of rather limited utility in the study of subadult growth patterns; measurements of area are generally considered superior in assessing growth (Hummert 1983b).

Measurement of area is determined in cut cross section by using a microscopic grid of known size, usually a millimeter grid, and counting the number of grid intersects overlaying total cross section (TA), medullary cavity (MA), or cortical bone (CA). Area equals the number of hits times the grid area divided by the total number of possible hits. Typically, this is repeated three times to ensure accuracy and minimise intraobserver error.

Area measurements yield more information than simple thickness measurments. For example, a one millimeter addition to total thickness and medullary cavity width will cause cortical thickness to remain constant. However, a one millimeter addition will produce a considerable increase in cortical area. Conversely, a small amount of subperiosteal apposition will not demonstrably alter total thickness, but it will cause a considerable increase in total cross sectional area (Garn 1970).

While measurement of estimated areas is useful, the calculation of relative cortical area as a proportion of total cross sectional area is far more useful in comparing cortical health within and between samples. Percent cortical area (PCA) is a relative expression of the relationship between TA, MA and CA. For example, percent cortical area, which may increase in the early stages of endosteal resorption as total area outpaces medullary area, may drop precipitously in later stages of endosteal bone loss when the medullary area increases far more rapidly than total area (Garn 1970). Percent cortical area ... "simply describes the proportion of the total subperiosteal envelope that is composed of cortical bone and is therefore a measure of relative bone density ... (Garn 1970: 65). Moreover, PCA is a <u>relative</u> measurement, taking into consideration differences in proportional cross sectional size.

Percent cortical area is computed by dividing the cortical area squared by the area of the total cross section squared and then multiplying by 100. Hummert notes;

> "Because resorption at the endosteal surface is a normal part of the growth process, it is important to assess the degree to which this was taking place. The rate of endosteal resorption relative to the rate of subperiosteal apposition gauges the actual percentage of the total area which is cortical bone" (Hummert 1983: 171).

Thus, PCA is seen as a preferable measurement for comparative purposes. Changes in PCA delineate the balance of activity at the periosteal and endosteal surfaces and calibrate the amount of endosteal resorption versus subperiosteal apposition. By measuring the rate of both mechanisms and their interaction within populations and between age classes one can gain a fairly good idea of the relative health and pathological status of a sample.

Bone Growth and Maintenance

Cortical bone growth occurs in a regular fashion with very little variation between healthy populations. The interaction of bone areas however, changes quite often according to age and sex, but does follow a distinct developmental pattern.

The pattern of cortical bone growth seen in subadults follows a very distinct pattern. For example, subperiosteal apposition behaves more or less like the sexual growth curve. First there is a rapid postnatal phase of apposition at the periosteal surface, which is then followed by a second phase of more moderate apposition which continues from late infancy until just prior to the adolescent growth spurt; the adolescent growth spurt is characterised by a period of rapid apposition (Garn 1970).

Cortical bone growth during the perinatal and infancy period follows a very distinctive pattern. Perinates are typically born with a relative small medullary cavity and very thick cortices, a condition Caffey (1978) calls infantile osteosclerosis; percent cortical area values at birth typically range between 75 to 90 percent, usually upwards of 80%. Almost immediately after birth PCA values begin to drop even though the total area of the cross section is increasing. This drop in PCA is a result of greater endosteal resorption of bone (thus larger MA values) while periosteal apposition occurs at a slower pace. The pattern of diminished PCA growth has been identified by Garn (1970) as transient loss phenomenon and by Bernard et al. (1964) as physiological loss phenomenon. The loss in PCA appears to be normal, as it has been found in all contemporary populations and archaeological samples to date. In contemporary populations there appears to be an initial period of rapid periosteal apposition in the first three months of life, followed by loss in PCA during the second half of the first year of life [figure 6 (Garn 1970)]. Appositional growth resumes, albeit slowly, in the second year of life (Garn 1970). Hummert (1983a,b), Keith (1981), and Huss-Ashmore (1981) found a broadly similar pattern in percent cortical area from birth to two years, although in all three archaeological samples there was no initial increase in PCA in the first three months after birth or in the 9 to 12 month age group. A transient loss pattern similar to that found by Hummert (1983a,b) is also detected by Cook (1979). Hummert suggests the absence of a growth spurt in the 0 to 3 month and 9 to 12 month age groups may be a result of "populational variation in growth, sampling error, or perhaps real stress at these ages" (Hummert 1983b: 173). Similarly, Garn (1970) notes minor population differences according to health status and delays in ossification. One must

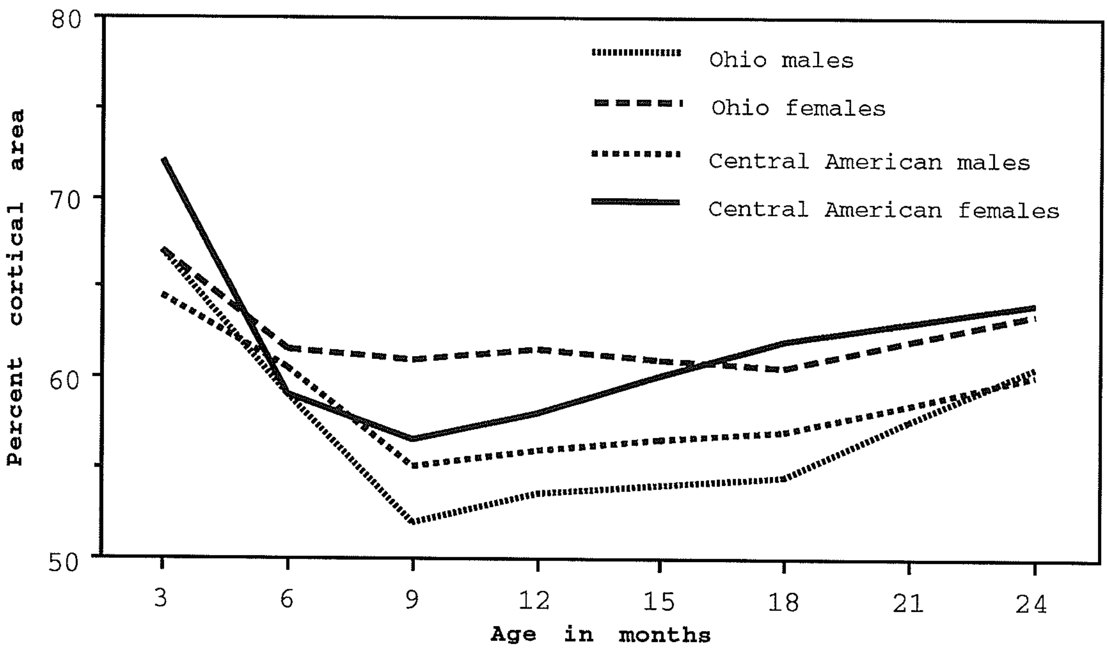


Figure 6. Transient loss in percent cortical area (from Garn 1970)

also consider the fact that different elements and techniques were used to assess the transient loss; Hummert (1983b) and Cook (1979) utilised tibiae and femorae respectively while Garn (1970) used metacarpals. Garn and Cook employed radiographic assessment techniques whereas Hummert used cut cross-sections. However, even when one takes into consideration these sources of error it appears that perinatal transient loss is a real phenomena. It appears that archaeological samples may not display the same exact pattern as Garn (1970) has found in contemporary healthy populations.

While this loss in PCA is occurring, the bone areas are still growing; total cross sectional area continues to proceed steadily as does medullary cavity area and cortical bone area. However, in contrast to contemporary populations, in archaeological samples it seems that cortical bone area may lag consistently behind total area and medullary cavity growth, in some cases well into childhood.

During the childhood phase cortical bone is simultaneously deposited at the periosteal surface and lost at the endosteal surface. Data generated from metacarpal measurements indicates the expansion in width and cross sectional (total) area is a result of greater subperiosteal apposition in comparison to endosteal resorption (Garn, Rohmann, and Nolan 1963; Garn and Poznanski 1969; Garn 1970; Smithgall et al. 1966; Johnston and Malina 1966; Bonnard 1968). The timing of the childhood phase of subperiosteal apposition appears to vary according to maturational status and socioeconomic status between populations.

The pattern of PCA during childhood appears relatively simple; after the reduction in PCA during the perinatal period of the first year as a result of transient loss (Garn 1970), percent cortical area rises from a low of ca. 50 to 55% to a level of ca. 70%; keep in mind that these percentages were derived from radiographic assessment and may not correspond exactly with direct assessments. The timing of the increase varies in accordance with relative health and ossification status. Data from Cook (1979) and Hummert (1983b) suggest the increase in PCA may vary substantially, beginning anywhere from two years of age to between four to six years of age, depending on the sample in question. After the initial rebound, PCA appears to remain relatively stable until the adolescent growth spurt, reflecting the net balance between endosteal resorption and periosteal apposition.

However, data from archaeological samples seems to contradict the clinical literature regarding endosteal resorption versus subperiosteal apposition in childhood; while cortical area growth continues it does so a a much slower pace. Cortical area grows so slowly that apparently 'normal' increases in medullary and total area prevent PCA from reaching values higher than 65 to 70% (figure 7). Decreased cortical thickness in stressed subadults has been suggested by Huss-Ashmore (1978, 1981) to be the result of increased endosteal resorption. Increases in medullary cavity area are suggested to represent cortical dumping of bone tissue, the endosteal surface functioning as a labile store of nutrients which can be drawn upon in times of stress to maintain normal linear growth.

Because the skeleton is undergoing a process of 'biological sculpting', in order to attain adult-like dimensions, endosteal resorption continues steadily throughout infancy and childhood until the adolescent growth spurt. As already noted, during the perinatal phase the medullary cavity enlarges proportionally at a rapid pace; however, this does not reflect increased endosteal resorption but a reduction of subperiosteal apposition while normal endosteal resorption continues. During childhood there appears to be a constant rate of endosteal resorption as reflected by a fairly stable increase in medullary cavity width. Thus, the rate of resorption appears to be relatively stable and continues until the adolescent growth spurt where bone tissue begins to be deposited on the endosteal surface of the entire medullary cavity. There appears to be a sex differential in the timing of the termination of the childhood or juvenile resorptive phase. Also, the duration differs between sex, lasting longer in males than in females.

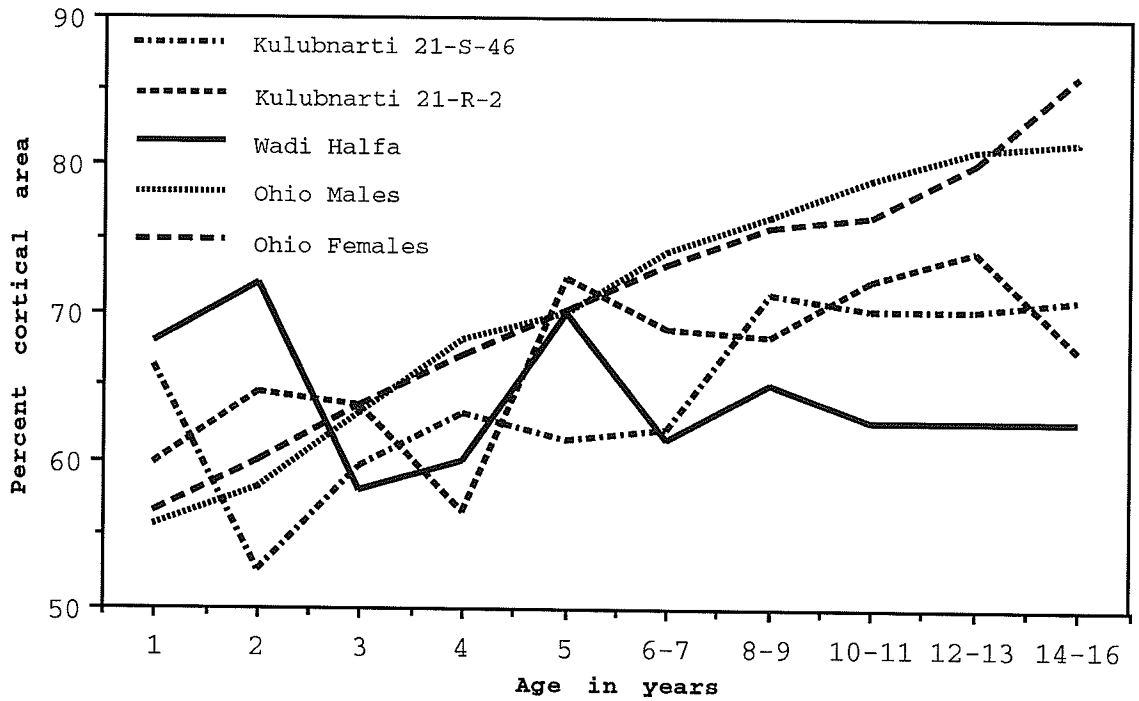


Figure 7. PCA growth patterns: archaeological samples vs. Ohio children

Cortical bone growth during the adolescent growth spurt is often complex. It is at this time that sexual dimorphism, as expressed in cortical bone growth, greatly increases, from approximately 4 % in childhood to about 15% (Garn 1970). The timing of the adolescent growth spurt varies widely, both within and between populations and according to sex (Harrison 1988; Tanner 1978). As touched on in the previous section, there is a shift from endosteal resorption to endosteal apposition (Garn 1970; Frisancho et al. 1970a; Johnston and Malina 1966).Thus, the area of the medullary cavity increases in size until adolescence and then, with the onset of endosteal apposition, begins to shrink; this reduction in medullary cavity diameter continues until the fourth decade of life (Frisancho et al. 1970a). Thus, the endosteal surface in adulthood comprises new bone laid down during adolescence. There also appears to be a sex difference in the timing of apposition; the onset and duration of endosteal apposition is earlier by about two to three years and of relatively greater duration in females (Frisancho et al. 1970a).

Data from Garn (1970) indicates that, for Caucasian American children from Ohio, females undergo the growth spurt at about 10-12 years of age, which is completed by 14. Boys on the other hand start at 12 to 14 years of age and continue to about 16 years. Frisancho et al. (1970a) produced very similar results. Garn (1970) notes that males consistently exceed females in the relative amount of bone deposited. However, Frisancho et al. (1970a) found a surface specific sex differential; more bone is laid down endosteally in females than males (36 versus 23% respectively). Periosteal apposition appear to be a different matter however; the authors observed that females gain relatively less bone at the periosteal surface than males, [(64 vs. 77%) Frisancho et al. 1970a].

In terms of the onset of endosteal apposition, Frisancho et al. have suggested there are no observable differences between populations:

> "Despite differences in gross size, level of nutrition, activity level, and disease experience, the age of onset

> of adolescent endosteal apposition is comparable in the USA and Central American samples. This finding would suggest that the hormonal factors responsible for the onset of adolescent endosteal apposition overcome many environmental influences" (Frisancho et al. 1970a: 658).

This would seem to conflict with the timing of the adolescent growth spurt. Data from Central American populations (Garn 1970; Frisancho et al. 1970a) indicates that the growth spurt was delayed and that the cumulative increase was relatively less in comparison to the American populations.

In terms of cortical area, Frisancho et al. (1970a) found that for US boys, overall cortical area was greater than girls. Conversely, in Central American samples there was no difference; in fact, in some cases girls had larger cortical areas. With the advent of the growth spurt sexual dimorphism became apparent in the Central American samples.

In terms of percent cortical area (PCA), Frisancho et al. (1970a) found PCA to be similar in preadolescent males and females, but with the growth spurt it rose to 85% in males, 90% in females. Conversely, PCA in a Central American sample was higher in all preadolescent age groups in girls, but with the adolescent growth spurt produced the same values as those for USA children. The variation in timing in cortical bone growth during the adolescent growth spurt has obvious implications for archaeological samples.

Frost (1966) notes that by as early as 20 years of age, the dramatic increase in bone mass that began during the adolescent growth spurt begins to slow down. Cortical bone thickness will continue to increase, albeit slowly, until about the fourth decade, when endosteal resorption resumes and begins to exceed periosteal apposition (Ekper and Frost 1965; Garn et al. 1967); this is reflected in percent cortical area values. After the fourth decade, a well established pattern of age and sex related bone loss ensues, which has been demonstrated clinically and in archaeological samples (e.g. Nordin 1962; Frost 1966; Garn et al. 1967; Garn 1970, 1973; Van Gerven 1973; Van Gerven et al. 1969;

Dewey et al. 1969).

Subperiosteal apposition does not cease after the adolescent growth spurt but continues on at a much slower pace (e.g. 2% from age 30-80: Garn 1970; Frisancho et al. 1970a). This process consists solely of the bone remodelling described by Frost (1966), which has more recently come to be known as continuing periosteal apposition or CPA (Lazenby 1990a,b). Garn (1970) notes that the total subperiosteal width (of metacarpals in this case) is consistently larger in the later decades of life than in the third decade; the trend is small but consistent, and relatively larger in females than males (Garn, Rohmann, Wagner, and Ascoli 1967; Garn, Wagner, Rohmann, and Ascoli 1968). This small but continuous apposition has been the source of some contention amongst authors for quite some time. On the basis of comparison of metacarpal versus femoral apposition rates, Garn (1970) suggested that since the increase in total subperiosteal diameter was linear, it was unlikely that "... the late growth of T (total subperiosteal diameter) is a compensatory response to adult endosteal resorption, which begins at the end of the fourth decade and which peaks into the sixth decade" (Garn 1970: 18). It is now agreed upon (see Lazenby 1990a) that

> " Differences in remodelling rates undoubtably come about to some degree due to variation in mechanical stimuli, producing variation in age-related endosteal resorption and subperiosteal apposition between different bones and even within the same bone. Age related bone remodeling is also affected by hormonal differences, perhaps leading to sex differences in osteoporosis" (Carlson et al. 1976: 297).

Subadult Cortical Bone Studies in Anthropology

As physical anthropologists become increasingly interested in examining the relationship between diet, health, stress, and disease in prehistory, many have come to realise that subadult remains can provide a tremendous amount of information on the subject. As Buikstra and Cook have suggested, "Although the investigation of adult dimensions can be informative, by far the most stimulating studies involve juvenile remains" (Buikstra and Cook 1980: 449-450). However, as Johnston (1962, 1969), a pioneer in the analysis of subadult remains from archaeological contexts, has noted, juvenile remains have been sadly neglected by both paleopathologists and archaeologists. This sentiment has been echoed by other authors interested in subadult growth studies (e.g. Wall 1991; Owlsey and Jantz 1985) and cortical bone growth (Cook 1979; Hummert 1983; Van Gerven et al. 1985). The apparent reluctance of physical anthropologists to accord more importance to subadult remains, even in the face of pleas to do so, seems based on a number of presumptions. Many physical anthropologists view immature remains as a liability and a nuisance; this is probably a result of the utter unfamiliarity most physical anthropologists have with subadult remains. Also, the overwhelming majority of the literature has dealt with adult remains. As such, if one were to engage in studies of subadults, they would be forced to resort to more clinically based literature, something which many physical anthropologists are still reluctant to do. Finally, if one is to become familiar with subadult remains it becomes necessary to become immersed in the burgeoning literature on growth and development.

Buikstra and Cook (1980) have observed that the utility of bone growth studies in paleopathology depends upon the well documented fact that the skeleton responds to stress more readily than does the dentition; also, subadults possess a more dynamic skeletal structure than adults due to greater growth velocity. In light of this fact, the study of cortical bone is particularly useful in determining the relative health and pathological status of subadults, as subadult skeletal remains exhibit a bone dynamic very different from that of adult remains. In examining subadult bone growth and maintenance, it is useful to distinguish between the remains of infants, children, and adolescents as it has been demonstrated that bone growth in each of these age groups is different.

The infant skeleton grows at a tremendous rate from birth to approximately 4 years and then slows its growth trajectory somewhat. This slowed growth continues until the steroid mediated adolescent growth spurt. During the first few years of growth cellular bone turnover can approach 200% per year (Frost 1966). Because of this rapid growth rate, any disturbance in infant skeletal homeostasis will be amply reflected in bone tissue, more so than in adulthood as by age 30 skeletal turnover is only approximately 2.5 % per year (Frost 1966); some argue even less (e.g. Lazenby 1990a,b).

As such, the study of cortical bone in infants and children can be of immeasurable use in determining the relative health, nutritional and pathological status of skeletal samples. In particular, the paleopathological application of cortical bone analysis in subadults can not only provide one with a powerful tool to enhance differential diagnosis in a clinical mode of analysis but also provide greater acuity as a general indicator of stress in the population as a whole, not just in a subsample of infants, as evidence of stress in infants also provides clues to the relative health of mothers from the population in question.

Subadults in the Anthropological Literature

Very little skeletal biological work has been carried in the realm of subadult cortical bone studies as most of the literature pertaining to subadults is medico-clinically based and examines (radiologically) cortical bone growth in metacarpals of subadults suffering from specific disease states like protein calorie malnutrition and kwashiorkor. Conversely, anthropologists have for the most part limited their studies to adults. Much of the anthropological research has focused on examining cross populational age related decreases in cortical bone (Carlson et al. 1976; Dewey et al. 1969; Ericksen 1976; Martin and Armelagos 1979; Van Gerven 1973; Van Gerven et al. 1969), overall nutritional and pathological status of populations (Palmer 1987; Tiffany et al. 1988; Van Gerven et al. 1985) or population health status with reference to substantial diachronic changes in technology and mode of subsistence (Cook 1976, 1979; Martin et al.

1987; Owsley 1985; Ruff 1992; Ruff and Hayes 1983a,b; Ruff et al. 1984).

There are to date half a dozen articles which deal specifically with the analysis of subadults from archaeological samples in a comprehensive manner (Cook 1979; Keith 1983; Hummert 1983a,b; Huss-Ashmore 1981; Ruff, n.d.; Sumner 1984; Van Gerven et al. 1985, 1993). A few authors have measured the thickness of cortices in conjunction with other indicators of stress (e.g. Hatch et al. 1983; Mays 1985).

Cook's (1979) study was the first to examine cortical bone growth from an anthropological perspective. More specifically, she employed a biocultural approach to assess the effects of subsistence base changes on skeletal health. Looking at sample composition, evidence of growth retardation, growth arrest markers, nutrition, dental health and cortical bone behaviour, the author, making use of a population pressure model (Cohen 1975 in Cook 1979), examined the decline in health status relative to increasing population density, reliance on plant domesticates and exploitation/occupation of marginal resources and environments respectively in two Illinois samples from the Middle Woodland Gibson mound group and early Late Woodland Ledders mound group. In terms of cortical bone growth Cook only examined infant cortical behaviour using the radiographic equivalent of percent cortical area, Nordin's index, thus the study was of limited utility. The author found radiographic evidence of marked cortical thinning in the femorae of the Ledders terminal Late Woodland series during the age at which weaning occurred. She suggested there was a relationship between growth retardation and cortical bone loss, as well as bone loss and Harris line frequency, and suggested protein-calorie malnutrition in infancy would best explain the pattern of pathology in the later agrarian based Ledders sample. However, Cook neglected to consider the "early transient loss" phenomena of Garn (1970) in her assessment of early infant cortical bone fitness.

Keith (1981) examined cortical bone behaviour of the midshaft of femorae in individuals aged 0-15 years in two sequential samples, one hunter-gatherer (n=56) and the other corn horticulturalist (n=33), from the Dickson Mounds site in eastern North America, dating from A.D. 950 to 1300. Although the author employed direct measurement techiques, only midshaft width, cortical thickness (not area) and PCA were reported. When midshaft width was plotted against cortical thickness in both groups cortical thickness failed to keep pace with midshaft width. However, Keith failed to find any significant difference in cortical thickness between the two groups although PCA values in the later Middle Mississippian sample were somewhat lower. Keith also (erroneously) compared her femoral data to Garn's (1970) metacarpal data, arguing that both groups displayed a deficiency of cortical bone in comparison to contemporary populations, particularly the Middle Mississippian sample.

Huss-Ashmore (1981) examined an agricultural Nubian subadult sample (0-14 yrs; n=75) from Wadi Halfa dating from A.D. 350 to 1300. In this case the midshaft diameter, cortical thickness and PCA of femorae were calculated from cut sections. Of great interest was the finding that total cortical thickness actually decreased after the age of 10 with the onset of accelerated long bone growth and concomitant endosteal resorption. Huss-Ashmore also found that PCA values remained depressed throughout childhood, interpreting this as indicating that overall bone growth was being maintained at the expense of an increase in cortical thickness.

Hummert's (1983a,b) analysis of subadults from Sudansese Nubia was the first to systematically examine all aspects of cortical bone behaviour in a subadult sample and is far more comprehensive in it's dealing with cortical bone behaviour than Cook (1979), Keith (1981), or Huss-Ashmore's (1981) studies. The author notes that cortical bone studies of archaeological populations up to that point had focused largely on adults, but made the timely observation that bone rarefaction was not restricted to adults. Citing contemporary clinical studies (e.g. Garn 1970; Frisancho et al. 1970 a, b; Garn et al. 1964, 1969; Himes 1978; Himes et al. 1975, 1978), the author examined the cortical bone growth of 174 children, ages 1 to 16 years, from two Medieval Christian cemeteries from Kulubnarti, Sudanese Nubia (550-1450 A.D.). Examining total, cortical, and medullary area, as well as PCA, Hummert found that total and cortical areas as well as length were fairly well maintained in the samples, but that percent cortical area (PCA) revealed "unusual growth patterns which reflect excessive endosteal resorption". Compared to contemporary malnourished children, the Kulubnarti sample was suggested to be nutritionally stressed but the two samples did not present any evidence of diachronic dietary change.

Sumner (1984), employing a more biomechanically oriented approach, analysed a Southwestern Amerindian juvenile sample from Grasshopper Pueblo in New Mexico employing both direct measurement techniques and photon absorptiometry and found that anteroposterior to mediolateral bending strength increased with age in the mid and distal femur. The AP/ML ratio indicated an increase in bending rigidity during growth and development as the bone became less circular. Yet, despite this change in bending rigidity the orientation of the bending rigidity remained quite similar, implying that while types of forces governing the structure of the bones did not change all that much, intensity of activity increased with age.

Van Gerven et al. (1984) rigorously examined the relationship between PCA, bone mineral content, and cross sectional moments of inertia in the Medieval Nubian material investigated by Hummert (1983a,b). The authors found that a reduction in PCA in juveniles corresponded to a dramatic increase in bending strength of the bone measured by anterior-posterior cross-sectional moment of inertia. It was argued that, despite what PCA had to say about the general health of the individual, cross sectional moment of inertia suggested the structural quality of the bone was maintained.

Van Gerven et al. (1985) take their cue from Ruff et al. (1984) and Ruff and Hayes (1983a,b) work on the geometric properties of bone in relation to age and subsistence: " Research on subadults has not... taken the next logical step suggested by

Ruff and Hayes' analysis of the adult femur and tibia, that is, to ask how changes in the geometric properties of growing bone affect bone strength during periods of bone loss and gain" (1985: 276-277), acknowledging that "... few studies have documented subadult patterns of cortical bone maintenance in archaeological populations and none have incorporated the relationship between patterns of cortical bone loss and gain and the changing geometric properties of growing bone"(Van Gerven et al. 1985: 275). The authors examined the relationship between percent cortical area (PCA), bone mineral content and cross-sectional moments of area (or inertia) in the Medieval Nubian material previously examined by Hummert (1983a,b). Analysis revealed a substantial loss in PCA during early and late childhood; the later PCA reduction corresponded with an increase in subperiosteal expansion and an increase in cross-sectional moment of inertia (bending strength). While Van Gerven et.al. (1985) could not discern whether the reduction in PCA was a part of normal growth and development or stress related, they felt that a decrease in bending strength could be used as a relative indication of pathological stress. An increase in bending strength seen after 12 years in the Medieval material was suggested to be consistent with " the increased mechanical demands of advancing age and physical activity". Van Gerven and co-workers also found that anteroposterior to mediolateral bending strength of the midshaft tibia increased throughout childhood and adolescence; the bone became less circular through time. Lastly, it was argued that even in the face of a reduction in PCA at 12 years, tissue quality is not compromised.

Lastly, Ruff (n.d. in Ruff 1992) has begun initial investigations into the subadult skeletal material from Pecos Pueblo in New Mexico. In this case the author is interested in examining how early in development the pattern of sexual dimorphism in cross sectional shape (and inferred behaviour) as seen in adults becomes established in different populations. Initial results indicate that the sex difference in bone shape around the knee is already present in middle to late adolescence in this sample.

Subadults in the Medico-Clinical Literature

There exists a large body of medical literature on the interrelationship between nutritional deficiency and skeletal maturation; a significant component of this is devoted to the examination of cortical bone growth and loss during nutritional stress, no doubt because of the readily apparent manifestations of nutritional deficiencies in the immature skeleton. However, the focus of this research has centred on a few specific metabolic disturbances such as protein calorie malnutrition and allied conditions (Adams and Berridge 1969; Barr et al. 1972; El Nawaby et al. 1962; Garn, Behar, Rohmann, Viteri, and Wilson 1964; Garn, Rohmann, Behar, Viteri and Guzman 1964; Garn, Guzman, and Wagner 1969; Garn 1969; Himes et al. 1975; Platt and Stewart 1962; Platt et al. 1963; Prader et al. 1963; Reichman and Stein 1968). While it is well known that mineral deficiencies and hypovitaminoses will alter cortical bone growth, it appears that very little in the way of quantification of cortical thinning, growth cessation and associated features has been carried out.

Clinical subadult cortical bone growth and maintenance studies have concentrated primarily on metabolic disturbances, particularly protein-calorie malnutrition. Protein-calorie malnutrition is an all inclusive designation which encompasses mild to severe nutritional deprivation of carbohydrates (measured as calories in the diet) and protein or essential amino acids (Alleyne et al. 1977; Van Itallie 1974). Three clinical types of severe malnutrition are commonly recognised; kwashiorkor, marasmus, and marasmatic kwashiorkor. This does not include the gamut of mild to moderate nutritional deficiencies often encountered in a clinical setting. The three severe forms of protein calorie malnutrtion are by no means mutually exclusive and should probably be considered clinically convenient labels for a continuum of features that severe malnutrtion presents. In general, kwashiorkor is the result of a high calorie, low protein diet, while marasmus, or severe semi starvation is a result of very low intake in all nutrients and protein and is often associated with vitamin deficiencies as well (Alleyne et al. 1977). Marasmatic kwashiorkor is a label used to describe a range of conditions between the two extremes of kwashiorkor and marasmus (Van Itallie 1974). Clinical diagnosis of protein calorie malnutrtion and allied conditions is usually based on percentage standard body weight, the presence or absence of oedema, anthropometric measurement, hair and skin changes, and changes in internal organs (Alleyne et al. 1977). The attention devoted to PCM is understandable as it is the most prevalent nutritional disease found among children today in developing nations (World Health Organisation 1972).

Protein-Calorie Malnutrition: Bone Growth and Maintenance in Experimentally Deprived Laboratory Animals

Alteration of cortical parameters has been observed by a number of authors in experimental situations in laboratory animals. A number of studies carried out by McCance and co-workers (Dickerson and McCance 1961; McCance 1960; McCance et al. 1962; McCance et al. 1961; Pratt and McCance 1958, 1960, 1964a,b; Widdowson and McCance 1962) on experimentally deprived pigs and other animals has shown that the earlier a nutritional deficiency is introduced, the more pronounced and irreversible growth stunting was. In terms of caloric deficiency, Dickerson and McCance (1961) found that, in comparison to controls, severely undernourished piglet and chicken humeri were shorter and had thinner cortices. Most importantly though, the ratio of length to transverse diameter remained constant in both groups. McCance et al. (1961) found that mandible growth was affected during severe undernutrition, associated with crowding of teeth and impaction of unerupted teeth within the bone. They did find, however, that abnormal bone growth was reversed during proper realimentation. Widdowson and McCance (1962) observed a variety of skeletal changes associated with generalised starvation in rats. In addition to dramatically decreased long bone growth in linear and transverse dimensions, the authors found that growth plate osteoblast activity was greatly reduced. As a result, the capacity to lay down new bone was exceeded by continuing osteoclastic activity, resulting in cortical thinning and enlarged medullary cavities.

Many authors have focused on the role of protein deficiency in alteration of bone growth and maintenance. Frandsen et al. (1954) found that rats fed high calorie/low protein diets displayed skeletal features similar to simple malnutrition, but more pronounced. They found severely retarded linear growth, narrow epiphysial growth plates and little osteoblastic activity. On a protein free diet, bone growth in the rats ceased all together.

The research of Stewart and Platt (Stewart and Platt 1958; Platt 1961; Platt and Stewart 1962) confirmed Frandsen et al.'s (1954) findings. They found that pigs fed a protein restricted diet displayed generalised osteoporosis, severely thinned cortices, Harris lines, rarified trabeculae and distorted and/or anomalous epiphyses.

Fleagle et al. (1975) investigated the affects of both calorie and protein deprived diets on Cebus monkey long bones. They found that although growth in length was depressed in both caloric and protein reduced diets, long bone elongation continued at a reduced rate. While femoral diameters were depressed (presumably proportionally to depressed linear growth) in both diets, diameter was depressed more so in the protein deficient diet, suggesting protein deficient diets resulted in greater growth retardation and smaller cortical dimensions than caloric deprived diets.

In general, protein-calorie malnutrition in lab animals has been associated not only with thinned cortices and overall growth retardation, but medullary expansion, osteoporosis, coarse trabeculation (as a result of resorption on transverse trabeculae), Harris lines and deformed or anomalous epiphyses. Taken together, these studies indicate that protein-calorie deficit causes decreased bone formation as a result of lack of essential proteins, amino acids, and calories and increased bone resorption as the body attempts to draw nutrients essential to maintain growth from already existing bone tissue. It appears that this cellular activity represents a response by the body to suboptimal levels of exogenous materials necessary to maintain growth. Cortical bone tissue appears to represent a labile store of endogenous materials from which the body can draw upon in times of pronounced nutritional stress to maintain growth. When dietary deficiencies become too severe, growth simply ceases.

Protein-Calorie Malnutrition: Subadult Bone Growth and Maintenance During Nutritional Deprivation

A number of authors have conducted field research with human children which confirms experimental data on laboratory animals. Depressed growth in the diameter and cortical thickness of various tubular bones has been repeatedly demonstrated in malnourished children (Adams and Berridge 1969; Barr et al. 1972; Behar et al. 1964; El Nawaby et al. 1962; Garn 1966; Garn et al. 1964; Garn et al. 1969; Garn and Rohman 1964, 1966; McFie and Wellbourn 1962; Himes et al. 1975).

In their analysis of malnourished Ugandan children, McFie and Wellbourn (1962) found that while there was no appreciable reduction in bone length for age, bone density and transverse width were decreased in children who were below weight for age. El Nawaby et al. (1962) conducted a detailed study of Egyptian children suffering specifically from kwashiorkor and found evidence of delayed ossification, generalised osteoporosis, coarse trabeculation and the presence of Harris lines.

However, it is the work of Stanley Garn and collegues that has given us the most complete understanding of nutritional stress and cortical bone growth and maintenance. Garn et al. (1964a) found deficient compact bone formation in the form of thinned cortices of the second metacarpals of 71 children suffering from kwashiorkor. In addition to finding evidence of catch-up growth after realimentation, the authors also found evidence of delayed skeletal maturation. Similarly, Garn et al. (1964b) and Garn and Rohmann (1964) found that cortical thickness was greatly reduced in children with PCM, in all three clinically defined subgroups (kwashiorkor, kwashiorkor-marasmus, marasmus). Also, the authors suggested that the more marasmatic a child, the greater the degree of compact bone deficiency. This finding is of particular interest in light of the fact that marasmus is thought to be a result of long standing malnutrition, in contrast to the rather acute nature of kwashiorkor. They also suggested that cortical loss was not the result of growth stunting, but was a real phenomenon.

Behar et al. (1964) reported similar findings in children with kwashiorkor; the children displayed evidence of cortical thinning, delayed skeletal maturation and catch up growth following recovery. The authors noted that in many cases there was no reduction in midshaft circumference in children followed through the development and recovery from kwashiorkor; they suggested that kwashiorkor was an acute process (which it is) superimposed upon an already existing chronic protein-calorie malnutrition afflicting the majority of children in rural Central America.

Garn (1966) compared tibial and metacarpal cortical measurements of frankly malnourished Jamaican children with kwashiorkor with those of well nourished Ohio children of comparable tibial length and found that the malnourished children had greatly reduced cortical thickness, cortical area and percent cortical area compared to the well nourished children. Garn and Rohmann (1966), in a comparison of boys hospitalised with kwashiorkor and a group of controls, found that while there was a marked reduction in cortical thickness (30% less), there was no systematic reduction of transverse width. In fact, transverse bone width were found to be slightly larger in the boys with kwashiorkor. On this basis they concluded that bone loss in protein-calorie malnutrition was surface specific (endosteal).

Garn, Rohmann, and Blumenthal (1966), in a follow-up study of children recovering from kwashiorkor, found that boys recovering from protein deficiency continued to lose bone endosteally during catch-up growth as measured by increases in metacarpal length. Similarly, other authors such as Garn et al. (1969) and Adams and Berridge (1969) found that metacarpal diameters of children suffering from kwashiorkor were larger compared to a control samples of children suffering from mild to moderate PCM. Garn et al. (1969) found that PCM bone loss was as great as 30-40% of total bone mass as a result of excessive endosteal resorption.

In addition to differences in metacarpal diameters, Adams and Berridge (1969) found the cortices of Ugandan children suffering from kwashiorkor were thinned and there was significantly less trabecular bone and a concomitant delay in skeletal maturation in comparison to controls. The authors also examined the incidence of Harris lines; however, they did not find any difference in the incidence of Harris lines between the controls and children suffering from kwashiorkor.

Himes et al. (1975) conducted a systematic investigation of metacarpal cortical dimensions of 710 Guatemalan children suffering from mild to moderate protein-calorie malnutrition. In comparison to well nourished children of the same age and sex, the Guatemalan children with PCM displayed severely retarded metacarpal measures of thickness and area. The authors found area diameters consistently lagged behind comparative controls, with the exception of medullary area, which was slightly larger as a result of greater endosteal resorption. Overall, the Guatemalan children with PCM possessed relatively larger medullary cavities and less cortical bone, thus diminished percent cortical area (PCA) values. It was suggested that chronic protein-calorie malnutrition (e.g. marasmus) retarded total area (transverse circumference at the midshaft), while acute bouts of kwashiorkor did not, as suggested earlier by Garn et al. (1964b) and Garn and Rohmann (1964). Most importantly, the authors concluded that the lower metacarpal cortical bone values seen in the the moderately malnourished children was not simply a reflection of smaller body size as a result of growth stunting, but the result of a differential response to nutritional stress.

While the greater proportion of research on cortical bone dimensions has concentrated on PCM and related conditions, cortical loss also occurs in a wide variety of other conditions, including celiac disease (Barr et al. 1972), intestinal bypass, partial gastrectomy (Morgan et al. 1966), Down's syndrome, Turner's syndrome, trisomy G, congenital heart disease, (Garn and Poznanski 1970), alkaline phosphatase deficiency (Garn and Wagner 1969), Addison's disease, osteogenesis imperfecta, partial hypopituitarism, hypophosphatasia, congenital hypothyroidism, Holt-Oran syndrome, and Paget's disease (Garn 1970). However, in most cases these conditions are relatively rare and are usually identifiable by other skeletal features.

In summary, children fed protein and/or calorically deprived diets display a number of skeletal manifestations. These include coarsened or rarefied trabeculae, Harris lines, cortical thinning and concomitant enlargement of medullary cavities, delayed appareance of ossification centres, alteration of ossification sequence and multiple or deformed centres of ossification. While not discussed here, it should be noted that children suffering from protein calorie malnutrition also display high rates of enamel hypoplasias (Goodman et al. 1987; Sweeney et al. 1971). Chronic protein-calorie malnutrition can also lead to supression of transverse growth, whereas acute PCM does not affect transverse growth.

Vitamin Deficiency and Bone Growth and Maintenance

The following discussion concentrates primarily on the effects of deficiency diseases upon long bone cortical growth; for the sake of brevity other skeletal features considered pathognomic of specific deficiencies are not discussed in detail. Readers are directed to Caffey (1978) and Jaffe 1972) for detailed information.

For the purposes of skeletal biology, the attention given to protein-calorie malnutrition and allied conditions is problematic as a wide variety of specific nutritional deficiencies leave their mark on bone tissue as well. Deficiencies involving vitamins A, B complex, C, D, E, as well as calcium, phosphorus, zinc, and iron have been known for quite some time to produce skeletal alterations which must be considered in any investigation of cortical bone growth and maintenance.

Vitamin A is necessary for the maintenance of normal growth and in particular the development and maintenance of normal color vision. The question of bone involvement in hypovitaminosis A bone is open to debate; Huss-Ashmore et al. (1982) maintain that bone involvement in hypovitaminosis A is exceedingly rare as even poor diets often contain a dietary surplus. However, Van Itallie and Follis (1974) have indicated that vitamin A deficiency may often accompany diarrhea and various malabsorption syndromes which may act in concert with already existing protein deficiencies (as vitamin A is transported by protein). Vitamin A deficiency is an endemic public health problem in developing nations (Van Itallie and Follis 1974; Robson 1972) and is often a complication of PCM (Alleyne et al. 1977; Martorell 1980).

In some cases, chronic vitamin A excess may be a problem in diet. Excess vitamin A is toxic; only 10 times the recommended daily allowance is considered toxic. Chronic hypervitaminosis A in children may cause hypertrophic periosteal bone formation, particularly along the long bone shafts of the metatarsals, tibiae, and ulnae (Caffey 1950). However, the mosy common feature of hypervitaminosis A is cortical bone loss (Jowsey and Riggs 1968).

Vitamin C is necessary for the synthesis of collagen; deficiency of vitamin C leads to the formation of deficient osteoid, the organic matrix of bone. During vitamin C deficiency (scurvy) bone cortices become thinned and radiolucent as a result of the reduced formation of calcifiable bone matrix. Osteoblast activity drops off markedly and osteclastic activity continues on unabated. Metaphyses take on a "ground glass" appearance and metaphyseal fractures may occur. Massive subperiosteal hemorrhages may develop, which during healing may calcify. Radiopaque zones of mineralisation may appear at the ends of long bones (Albanese 1977).

Of all the vitamins, vitamin D is perhaps the most studied in terms of mediation of bone growth. Vitamin D is vital in bone growth as it controls the absorption and transport of calcium and phosphorus from the intestine (Albanese 1977). Lack of vitamin D, either as a result of lack of exposure to ultraviolet radiation or dietary deficiency, can affect the growth of long bones quite drastically, as growing cartilage fails to mineralise. When the body is lacking vitamin D, osteoclastic activity increases to free up calcium and phosphorus in existing bone cells. While this is occurring, osteoid and cartilage tissue production increases, leading to excessive unmineralised cartilage, which deforms easily, leading to characteristically trumpet shaped metaphyses.

There are two types of rickets, depending on nutritional status; generally malnourished children display an atrophic form by which bones are thin and porotic, with large medullary cavities and thin, sparse trabeculae (Jaffe 1972). Well nourished children display a hypertrophic form where cortices are porous but thick as a result of excessive deposition of osteoid. Marrow spaces become narrowed as a result of abundant spongy osteoid trabeculae (Jaffe 1972).

General feature of rickets include rarefaction as well as twisting or bowing of long bones. Other features include blurred trabecular patterns, irregular calcification of the growth plate, disturbed metaphyseal remodelling, deeply cupped articular surfaces and rachitic rosary. It should be noted, however, that the development of bowing and metaphyseal cupping occur mainly in infants with good muscle tone and that are active; these features may not be apparent in inactive children, such as those suffering from generalised malnutrition. Vitamin D deficiency can also produce cortical lamellations or an envelope of periosteal bone, similar to that found in congenital syphilis or infantile cortical hyperostosis (Caffey 1978).

Mineral Deficiency and Bone Growth and Maintenance

There is considerable debate over the appearance of phosphorus, zinc, magnesium and calcium deficiencies in prehistoric populations. It has been occasionally suggested that diets high in phytic acid may have caused mineral deficiencies in prehistoric populations (e.g. Angel 1984), as phytates are known to bind with phosphorus and inhibit the absorption of calcium, iron, zinc, and magnesium. It is also known that elements like calcium, phosphorus and sodium can interact with already existing dietary deficiencies to produce osteoporosis and cortical thinning.

Next to phosphorus, calcium is the most important mineral necessary for normal bone growth and maintenance. Calcium is stored in bones so that the body may draw upon internal reserves during times of rapid growth or stress (Ortner and Putschar 1985). Calcium deficiency may result in florid rickets and juvenile osteoporosis or osteomalacia in adults (Robson 1972). Deficiency may result from malabsorption or dietary insufficiency; in such cases the body draws upon labile stores of the mineral stored in bone cortices. Calcium deficiency can be exacerbated by a number of concurrent conditions including protein-calorie malnutrition, vitamin D deficiency, high concentrations of dietary phytates or by altering the calcium-phosphorus ratio by restricting phosphorus. Conversely, excessive calcium intake can also affect available phosphorus as calcium readily binds with it. The result is excessive osteoid formation and poor mineralisation.

Dietary deficiency of calcium is uncommon and when it does occur it is usually associated with malabsorption states or in conjunction with vitamin D deficiency (Adair 1987). Calcium deficiency is occasionally found in some areas of Asia where low maternal calcium intake combined with high parity produces hypocalcemia and rickets in infants (Krisnamachari and Iyengar 1975). Foods rich in phytic acid (cereals) may also induce rickets via inhibition of absorption of calcium. Calcium loss may also occur as a result of high protein intake producing an acid imbalance. Increased osteoclastic activity coupled with diminished osteoblastic activity resulting in osteoporosis, slowing or cessation of growth and increased intracortical resorption spaces have been reported for animals raised on low calcium diets (El-Maraghi et al. 1965; Parson and Hampton 1969) and in humans (Berlyne et al. 1973).

Zinc deficiency merits special mention as it has been shown to produce pronounced skeletal manifestations, including delay of the adolescent growth spurt, anddelayed skeletal maturation in general. Zinc deficiency has been noted in many parts of the world, notably Iran, and has been shown to be the byproduct of the use of unleavened breads; grains and legumes are high in phytates, which bind readily with minerals like zinc (Reinhold and Kamal 1972; Sandstead 1974; Ter-Sarkissian et al. 1974). High consumption of these breads will eventually cause zinc deficiency; the problem is particularly bad in cases where unleavened breads are consumed as yeast found in leaven breads produces phytase enzymes which break down phytates (Reinhold and Kamal 1972). For example, in areas of the Middle East zinc dwarfism syndrome has been reported (Halsted et al. 1972; Prasad et al. 1961; Ronaghy and Halsted 1975). Growing children, adolescents and pregnant women are most likely to be affected (Sandstead 1974). Zinc absorption is also impaired in malabsorption syndromes.

Copper deficiency is very rare but may occur in infants recovering from severe protein-calorie malnutriton (Sandstead 1974). In some cases copper deficiency may accompany anemia as copper is required for the proper transport and utilisation of iron (Prasad 1985). In addition to developing anemia bone cortices may be thinned and pathological fractures may occur (Sandstead 1974).

It should be noted that other deficiencies may cause alterations of bone dimensions by extension of their general involvement of the body. B12 deficiency has been associated with miscarriages and possibly chronic tropical sprue (Adair 1987); since tropical sprue causes a long term malabsorption of nutrients it could concievably cause cortical bone loss in chronic cases. In mountainous areas, endemic goiter (iodine deficiency) may affect growth, resulting in cretinism (Greene 1980), thus presumably altered cortical dimesions.

Subadult Cortical Bone Loss and the Problem of Differential Diagnosis

It is apparent that despite the overwhelming focus on protein-calorie malnutrition and allied conditions, single vitamin and mineral deficiencies, and synergystic reactions between multiple deficiencies are capable of causing alterations of cortical dimensions. Huss-Ashmore et al. (1982) argue, as do I, that the definitive diagnosis of a single dietary deficiency in a skeletal population is at best a hazardous undertaking. Single nutrient deficiencies are rarely encountered outside a laboratory setting and are rare in human populations (Adair 1987; Scrimshaw 1964, 1966).

> "Even in clear-cut cases of deficiency disease, however, it is doubtful that only a single nutrient is lacking. An actual diet so restricted as to cause frank vitamin deficiency may be limited in protein, energy, or minerals as well. As in animal studies, the degree of interaction of multiple nutritional factors is difficult to assess" (Huss-Ashmore et al. 1982: 400).

While some paleopathologists have ascribed skeletal lesions in subadults to specific nutritional deficiencies like protein-calorie malnutrition and encompassed conditions (Cook 1979; Huss-Ashmore 1981; Keith 1981), vitamin C deficiency (Ortner 1984; Roberts 1987; Rose 1985; Waddell 1989), and vitamin D deficiency (Angel et al. 1985; Manchester 1983; Ortner and Putschar 1985) there are a number of problems associated with the diagnosis of specific conditions.

In the case of pure vitamin deficiencies, these are exceedingly rare in non-industrialised populations. Many deficiencies may have arisen relatively lately, within the past 500 years or so, as a result of industrialisation and serious cultural disruption as a result of traumatic contact situations. Stuart-Macadam (1989) has suggested that, based on the observed frequency of lesions attributable to vitamin D deficiency in European skeletal samples, rickets appears to have increased gradually since the Middle Ages, particularly in cities. Infantile scurvy, while it may have occurred periodically throughout prehistory, became well known in the late 19th and early twentieth century as a result of the popularity of infant formula feeding and the fact that most of these formulas were entirely devoid of vitamin C (Waddell 1989).

The point is, pure vitamin and mineral deficiencies are likely to have been exceedingly rare and distributed in a sporadic fashion throughout prehistory. This is not to say that one should not look for specific features (most of which are largely radiological) associated with single deficiency diseases, but that it would be highly unlikely to find them in archaeological populations as single deficiency conditions are extremely rare in prehistory and no one has yet to systematically hunt for evidence for skeletal manifestations of multiple nutrient deficiencies. If anything, the distribution of 'pure' deficiency diseases is usually the result of cultural variables (like dietary prohibtions, clothing preferences, culturally controlled access to foods by age and sex) and natural and cultural disasters like wars, seiges, and long distance travel (Stuart-Macadam 1989).

While the skeletal features associated with PCM are well known, it appears that there is some overlap in the skeletal features associated with specific vitamin and mineral deficiency states. One must also keep in mind that in a nutritionally stressed individual, multiple deficiencies may exist in a complex synergystic state whereby an increase or decrease in one deficiency may affect another accordingly (for example, the relationship between vitamin D and calcium). As such, the skeletal picture is likely to become rather complicated; it appears that most dietary deficiencies have a number of features in common, all generally related to the cessation of osteoblast activity and continuance of normal osteclastic resorption, or in some cases, increased resorption. This likely is a result of the role protein and carbohydrates play in the formation of skeletal tissues (as the raw materials) and the regulatory or mediative roles of the vitamins and minerals discussed here.

In summary, the cessation of osteoblast activity may occur for a number of reasons; a net deficit of calories and or protein, a lack of vitamin C, D, an excess of vitamin A, a lack of zinc, copper, calcium, or phosphorus, either as a result of dietary factors or simply as a result of malabsorption due to an already existing deficiency. When apposition of bone tissue has ceased, normal osteoclastic resorption proceeds, eventually resulting in a variety of features commonly noted in deficiency diseases. These may include thinned cortices (by far the most commonly recorded feature), coarsened trabeculae (as a result of resorption of trabeculae surfaces in general and transverse trabeculae in particular), and 'ground glass' osteoporosis of the metaphyses (likely the result of a disproportionate amount of intracortical resorption of osteonal spaces in the metaphyseal region). If the deficiency continues for an extended period of time growth stunting may occur. While other specific features are often found in each of the deficiency conditions, the general underlying basis of cortical alteration is similar.

As I have already noted, there is almost no information dealing with skeletal manifestations of multiple deficiency conditions. For the purposes of paleopathology, it would be far easier to simply admit that the diagnosis of single nutrient deficiencies in subadults from prehistoric archaeological contexts in most cases is not a realistic goal and to consider all possible variations of nutritional deficiencies as part of a generalised syndrome affecting infants and children (in conjunction with the concomitants of weanling stress, reduced immunocompetence and infection, etc... .). It stands to reason that any infant or child displaying symptoms of growth stunting, thinned cortices, coarsened trabeculae and generalised osteoporosis is likely to have been suffering from severe nutritional stress at the time of death. In severe cases of malnutrition, fat, muscle and epithelial cells lining the gut are used to maintain growth relatively early on. It is relatively late in cases of malnutrition that skeletal features become apparent (Huss-Ashmore et al. 1982). In non-industrialised and prehistoric populations severe nutritional stress was rarely the result of a specific deficiency but likely part of a generalised deficiency of protein, carbohydrates, and assorted micronutrients, all occurring is various combinations. It is also well documented that dietary deficiencies are often associated with health complications, particularly diarrhea as a result of comprimised nutritional status (Scrimshaw 1964). Diseases otherwise non-threatening in healthy children can become lethal during stress, exacerbating any existing deficiency (Martorell 1980). What one arrives at is a very complicated pattern of nutritional deficiency in terms of skeletal pathology, which makes differential diagnosis an almost impossible proposition. Instead, I propose that skeletal evidence of childhood nutritional stress might be more aptly dealt with if one were to consider all potential multiple deficiency states as part of one broad spectrum, continous condition with potential skeletal manifestations.

CHAPTER VI

CORTICAL BONE AND NON-SPECIFIC INDICATORS OF STRESS

While cortical bone growth and maintenance can be examined in isolation, it has more meaning if related to what Buikstra and Cook (1980) have called "non-specific indicators of stress", a term which encompasses relative growth performance, Harris lines, enamel defects, infectious lesions and anaemic reactions. Non-specific indicators of stress are of tremendous use in assessing the health status of a skeletal sample; however, these techniques are of little importance in particularistic descriptive studies (Buikstra and Cook 1980) and their utility is best realised within the more productive biocultural approach. Goodman and Armelagos (1989) and Goodman et. al. (1984) note that there are qualitative differences in non-specific stressors; stressors can be divided up into cumulative, periodic and specific indicators. Cumulative indicators, which include long bone growth and cortical bone growth and maintenance, provide a summary of the amount of stress experienced over long periods of time, while periodic indicators like Harris lines and enamel hypoplasias, are more precise and confined to the time at which a particular stress event occurred (Goodman and Armelagos 1989). Specific stressors include anaemic reactions and lesions attributed to infection.

The purpose of this chapter is to examine the question, "what is the correlation of cortical bone growth and maintenance to other non-specific indicators of stress"? This question has yet to be examined in any detail or in a systematic fashion with all commonly cited non-specific indicators of stress although some authors have periodically suggested there may be a relationship between cortical bone growth and maintenance and particular stressors. For example, Cook (1979) has hinted there may be a correlation between cortical bone growth and maintenance, linear growth, and Harris lines. Hummert (1983a,b) statistically tested the correlation between long bone growth and cortical area parameters and found a statistically significant correlation in certain age classes. As a result it seems reasonable to suggest there may be a correlation between cortical bone growth and maintenance and non-specific indicators of stress.

Cortical Bone Growth and Linear Bone Growth

Analysis of growth in subadults is usually based on long bone growth, which in turn is often plotted against dental development to gain an idea of relative growth performance (as dental development is far less affected by stress than skeletal growth). Wall (1991), in an analysis of long bone growth in Californian Amerindian subadults, notes the potential relationship between linear bone growth and cortical bone growth, and suggests that a combination of the two may be useful in enhancing understanding of the growth process.

The clinical literature suggests there should be a correlation between linear bone growth and cortical bone growth in disease and health. Linear long bone growth has been shown to be depressed in cases of prolonged fasting or starvation (Carlson and Hoelzel 1947; Quimby et. al. 1951), caloric deficiency (McCay et. al. 1935, 1939; Adams 1969; Kerr et. al. 1973; Fleagle et. al. 1975) and protein deficiency (Frandsen et. al. 1954; Heard et. al. 1958; Fleagle et. al. 1975) and chronic protein and calorie deficiency (Dickerson and McCance 1961; Himes 1978). However, the question of the relationship between cortical bone development and linear long bone growth in health and disease is problematic as there are virtually no studies which have considered both at the same time. There is some evidence that protein deficient diets result in greater growth retardation and smaller cortical dimensions than caloric deprived diets in Cebus monkeys (Fleagle et. al. 1975). Fleagle et. al. (1975), found that although growth in length was depressed in both caloric and protein deprived diets, long bone elongation continued at a reduced rate in both. Femoral diameters were found to be depressed in both diets, but more so in the protein deficient diet. This would seem to suggest that periosteal apposition slows or ceases during nutritional stress and endosteal resorption begins to affect cortical thickness, but before growth in length ceases. Research by Huss-Ashmore (1978, 1981) suggests that in times of stress cortical bone growth will cease while long bone growth may continue. In cases of severe stress where long bone growth ceases, cortical thinning will be quite pronounced.

Hummert (1983a) examined linear bone growth and cortical parameters in two samples of Sudanese Nubian children and found that tibia length was most strongly correlated with total area in all age classes (thus affirming Himes [1978] assertion that length-width proportions remain relatively unaltered even during periods of stress). Cortical area was found to be less strongly correlated with linear growth, the lowest correlation within the newborn to one year age class (.588) and in the 4 year age class (.546). Medullary area on the other hand is quite another story; the correlation between medullary area begins very high at birth but drops precipitously in the two, three, and four year age classes (.151, .294, .175. respectively). The high correlation between linear long bone growth and total area is understandable as total area is not often affected by stress. The exception to this rule would be chronic nutritional deprivation which would cause the cessation of subperiosteal apposition, thus increase in total area. The low correlations of cortical area and linear growth in the one and four year age classes in Kulubnarti are explainable as well; the drop in the newborn to 1 year age class is the result of transient loss phenomenon. The lower correlation in the four year age class is likely related to cortical loss as a result of weaning stress. The low correlation in the medullary values between ages two and four is also likely related to this phenomenon.

Based on Hummert's findings and the general relationship found by many others between disease states, slowed long bone growth, and depressed cortical parameters, it is likely that there will be a strong relationship between linear long bone growth and total area, particularly in cases of chronic growth disturbance. Cortical area and medullary area should display a strong relationship with linear growth during periods of uninterrupted growth; physiological loss during the first year and weaning stress will reduce the strength of the relationship.

Cortical Bone Growth and Harris Lines

Harris lines, or lines of resumed growth, are radiopaque lines oriented transversely to the shaft of long bones. In cases where long bone growth ceases lengthwise, cartilage cells at the epiphyseal endplate become sparse and the endplate thins. Osteoblasts (bone forming cells), which normally penetrate the epiphyseal cartilage, are unable to do so and instead produce a thin layer of bone just below the endplate called the primary stratum (Steinbock 1976). When growth resumes, osteoblasts begin laying down more bone; the bone tissue consists of a layer of horizontally oriented trabeculae, which appears as a radiopaque transverse line radiographically (Park 1964).

Harris lines are often cited as sequelae to various childhood diseases and nutritional deficiencies, but may also form as a result of psychological stress (Tanner 1978). At the present time there is a weak correlation between Harris lines and illness (Garn, Silvermann, Hertzog, and Rohmann 1968) as well as other non-specific stressors (Goodman and Clark 1981). This is particularly true of adults as Harris lines are removed throughout life as a result of normal growth processes (Garn and Schwager 1969; Gindhart 1970).

The relationship between Harris lines and suboptimal cortical dimensions is open to question. Many authors have noted the appearance of Harris lines in children with illnesses known to reduce cortical thickness (Garn et. al. 1968; Gindhart 1969; Himes et. al. 1975; Jones and Dean 1959; Marshall 1968) but others (e.g. Adams and Berridge 1969) suggest there is no correlation. To date, only two studies (Mays 1985; Pfeiffer et. al. 1986) have systematically examined the relationship between cortical bone and Harris lines. Mays (1985) examined the relationship between Harris line formation, linear bone growth, dental age and cortical bone thickness (but not area) in a sample of subadults (n=54) from the Romano-British site of Poundbury in England. The author found that there was no correlation between the presence/absence of Harris lines and femoral length, cortical index (cortical thickness /total thickness in a radiograph) and total cortical thickness, although a correlation between all three measures and dental age in both individuals with Harris lines and those without was found. In contrast, Pfeiffer et. al. (1986), examining the relationship between percent cortical area (as measured from radiographs) and Harris lines in subadult tibiae (n=66) from the Uxbridge ossuary in southern Ontario, found that individuals with Harris lines displayed lower percent cortical area values than those without.

In cases of a poor but sustaining level of nutrition there may be a strong relationship between Harris lines and cortical bone dimensions as Harris lines would have abundant opportunity to form. Conversely, one could possibly expect a negative relationship between Harris line frequency and cortical dimensions in severely stressed populations since a recovery phase is necessary for transverse lines to form and chronic stress has been suggested to suppress line formation (Buikstra and Cook 1980). In severely stressed samples Harris lines might also be resorbed along with endosteal bone, further complicating matters. The best candidates for the formation of Harris lines would be populations suffering from periodic or cyclic stress where there is an opportunity for resumption of growth (e.g. McHenry 1968); however, in such cases realimentation following periodic deprivation may be sufficient to allow cortical dimensions to return to normal.

Cortical Bone Growth and Dental Defects

Enamel hypoplasia is a deficiency in enamel thickness as a result of disturbance in amelogenesis (formation of tooth matrix). Enamel hypoplasias are lines, bands, or pits of decreased enamel thickness occurring on the tooth crowns (Goodman et. al. 1980). Enamel is formed by ameloblasts depositing tooth matrix along a co-ordinated front; when ameloblasts are disturbed less enamel matrix is formed along this front (Goodman et. al. 1984). Since tooth enamel is not resorbed, evidence of disturbance in amelogenesis is recorded permanently.

Hypoplasias have been associated with a variety of diseases and nutritional deficiencies (Rose et. al. 1984) and have also been associated with greater mortality in comparison with individuals without hypoplasias. Deciduous enamel hypoplasias provide a good record of life stresses of the last five months of pregnancy to the end of the first year and the distribution of defects can be used to reconstruct a chronology of stress episodes.

While examining the frequency of enamel defects in infant samples used by Cook (1979), Cook and Buikstra (1979) found a significant relationship between cribra orbitalia and enamel defects, Harris lines and enamel defects, and endocranial periostitis and enamel defects; by extension of the postulated relationship between Harris lines, anaemic reactions, and cortical bone health suggested by Cook (1979) there is likely some sort of a substantiative relationship.

Since enamel hypoplasias have been repeatedly shown to be associated with increased mortality, it stands to reason that poor cortical bone values, shown to be associated with various dietary deficiencies and disease states, would be correlated with enamel hypoplasias.

Another form of hypoplasia which has received some attention lately is localised hypoplasia of the primary canine (LHPC). LHPC is a small pit defect found on the labial surface of deciduous canine crowns occurring most commonly on the cervical half of the crown. The defect can range in size from a pin-prick to a pit several millimetres in diameter (Skinner and Hung 1986). In it most pronounced form, the pit can cover nearly all of the lingual surface of the crown. The pit defect is a result of disturbance of ameologenesis during crown formation, but unlike linear enamel hypoplasia, LHPC appears to be caused by minor physical trauma to the developing canine crown as a result of deficient cortical bone formation of the labial crypt wall (Skinner and Hung 1989).

Thinner than average crypt wall cortical bone is suggested to permit mechanical forces to be efficiently transmitted to the crown surface, disturbing amelogenesis (Skinner 1986; Skinner and Hung 1986). It has been suggested that during the first year of life, when infants begin to hold and mouth objects, immature motor co-ordination causes unintentional trauma to the mandibular and maxillary areas (e.g. the infants hits itself with a toy or other object around the mouth while trying to mouth it), disturbing amelogenesis and producing the defects.

LHPC occurs twice as often in the maxillary canines in comparison to mandibular canines (Skinner 1986); the average age of formation is approximately six months (Skinner and Hung 1989). There appears to be some evidence that ethnicity and socio-economic status may affect the expression and frequency of LHPC (Skinner 1986; Skinner and Hung 1989).

Causative mechanisms accounting for the underlying etiology of thinned cortical bone (and thus increased chances for presence of the defect) have been forwarded by Skinner and Hung (1986, 1989). Skinner (1986) and Skinner and Hung (1989) have suggested that LHPC may arise as a result of a calcium deficient diet via milk avoidance or suboptimal breast feeding, thus suboptimal vitamin D bioavailability. Dr. Mark Skinner has recently suggested that the frequency of LHPC may also be a result of hypervitaminosis A (C. Meiklejohn, pers comm. 1993).

The relationship between LHPC and cortical bone growth is uncertain. Skinner and Hung (1989: 169-170) suggest that cortical bone loss in the region of the canine crypt is crucial in the formation of LHPC. They infer that there may be a relationship between reduction of the canine crypt wall cortex and loss of cortical bone thickness postcranially in early infancy. As Dr. Skinner has recently indicated that there may be an age effect involved in the formation of LHPC and it is well known that infants undergo systemic physiological loss of bone tissue during the first year of life, it is conceivable there may be a relationship between the intensity and duration of physiological or transient loss of bone in the first year of life and the presence of conditions permitting the development of LHPC.

Cortical Bone Growth and Anaemia/Infection

The relationship between anaemia and cortical bone growth and maintenance is difficult to ascertain, partially because anaemic reactions can stem from a bewildering array of causes. One might expect deficient cortices in nutritional anaemias, as, for example, iron deficiency anaemia is usually a concomitant of malnutrition or disease (particularly parasitic infestation). As a result, there may be some overlap in the etiology between the causation of iron deficiency anaemia and loss of cortical bone. At any rate, deficient cortices have been found in individuals displaying evidence of porotic hyperostosis attributed to iron deficiency anaemia (Ortner and Putschar 1985: 262). In cases of genetically based anaemias, the problem is more complex, depending upon the expression of skeletal manifestations of the disease in question. In some cases there may be cortical thinning while in other cortical hypertrophy may be the rule.

In the case of infection, the situation is at least as complex as that of anaemia. In obvious cases of infection, cortical parameters are altered as a result of apposition due to bone inflammation and concomitant periosteal proliferation or haematogenous osteomyelitis, which often produces an involucrum. The end result is an expansion in cortical area and a relative of absolute reduction in medullary cavity area, particularly in cases of haematogenous osteomyelitis where there is occlusion of the medullary cavity as a result of considerable formation of dense trabecular tissue. However, care must be taken to note the distribution of elements affected as infection may be highly localised or systemic and a result of acute or chronic diseases.

Cortical Bone Growth and Non-Specific Indicators of Stress: Some Predictions

Based on the brief examination of the relationship between cortical bone growth and maintenance and non specific indicators of stress it is possible to make a series of predictions based on the literature.

Cortical bone growth and maintenance

In terms of bone growth in general, both samples should display the 'transient loss' phenomenon in the perinatal period as seen in other archaeological and contemporary samples. It is likely that neither the Seh Gabi or Ganj Dareh samples will exhibit the 0-3 month and 9-12 month brief growth phases discussed by Garn (1970) as these phases were not found in Hummert's (1983) or Cook's (1979) samples. It may be that one may not expect growth of this type in a sample of infants who died prematurely. Conversely, the absence of an early recovery of growth may reflect a difference in health between modern and prehistoric populations.

Linear long bone growth

It will be very interesting to examine the relationship of cortical bone to other indicators of non-specific stress. Based on the author's familiarity of both the Seh Gabi and Ganj Dareh samples and already existing analyses of non-specific indicators of stress (Agelarakis 1989; Skinner 1980), linear growth and skeletal maturation will likely be shown to be delayed more in the Seh Gabi sample than the Ganj Dareh sample. If this proves to be the case, there will be a strong relationship between the lag in skeletal development and depressed cortical dimensions. In infants and children displaying little skeletal lag, cortical parameters will be not as depressed as those infants who display evidence of skeletal lag. The comparison of cortical bone growth and maintenance to linear growth should prove the strongest relationship as both are a measure of an organism's growth performance up until death.

Linear enamel hypoplasia and LHPC

There should also be a correlation between linear enamel hypoplasia and disturbed bone dimensions. As both cortical bone growth and formation of hypoplastic defects have been shown to be influenced by dietary stress and disease. there should be a strong relationship between the two. However, since the two indicators are of different types (one cumulative, the other periodic), the correlation between the two would likely be strongest in those age classes at which hypoplasias typically form (1-4 years). Since cortical bone homeostasis has been shown to be affected by these variables it would seem safe to tentatively suggest that there would be at least a moderate, if not strong correlation between the two.

The relationship between LHPC and cortical bone performance is difficult to assess. Skinner (1986) and Skinner and Hung (1989) imply there might be a relationship between the expression of Skinner's pits and cortical bone loss within the first year of life. It is conceivable that there might be a relationship between the degree of transient loss, which is more pronounced in archaeological samples than contemporary ones, and the sample frequency of LHPC, which is dependent in part on the thinning of bone overlying the primary canine tooth crypt.

Harris lines

The relationship between Harris lines and cortical bone growth is problematic because of the uncertainty of the etiology of Harris line formation, and because the relationship between the two could function in a number of ways. For example, it is accepted by most authors that Harris lines represent lines of resumed growth following cessation of growth. If this is true, a chronically undernourished population, while suffering nutritional stress, which will be reflected in cortical bone growth and linear growth, may not display any Harris lines as they have not had the opportunity to form (Buikstra and Cook 1980). It seems that the best candidate for the formation of Harris lines would be populations suffering from periodic stress, where there is an opportunity for resumption of growth (e.g. McHenry 1968). Based on the observations of various authors of the association of Harris lines in children with depressed cortical dimensions, it seems reasonable to postulate that there will be at best a moderate correlation between Harris lines and cortical measurements. However, the relationship may be poor as Harris lines typically display poor correlations with other non specific stressors (Goodman et. al. 1984).

Anaemia and Infection

The relationship between cortical bone growth and anaemia and infection is a difficult one to assess. In the case of anaemia, some relationships are (hopefully) relatively clear cut. In the case of iron deficiency anaemia, Ortner and Putschar (1985) present evidence suggesting thinned cortices are a concomitant of the conditions, although they caution that problems of conflicting findings and differential diagnosis warrant further investigation into the relationship. As for congenital anaemias, the rule seems to be an increase in the total area of a cross section. However, in such cases, pronounced intracortical porosity and cortical lamellations would make it difficult to assess medullary and cortical areas.

As for infections, most are site specific and highly localised. Infectious diseases which leave traces on bone tissue like tuberculosis and treponemal infection (yaws, endemic treponematosis, venereal/congenital syphilis) would have to be considered. For example, all three of the above treponemal infections can produce widespread cortical hyperostosis in both adults and chidlren (and in the case of venereal/congenital syphilis, infants). While the main change in tuberculosis is bone lysis, mycotic infections may actually cause partial or complete paralysis of limbs, thus altering cortical parameters (Ortner and Putschar 1985). For example, if active tuberculosis was to afflict a child during a rapid phase of growth, diminished total area and an unusually large medullary cavity (as well as lower CA and PCA through disuse) would result. In dealing with subadult cortical parameters the proliferative expansile lesions of smallpox induced osteomyelitis would also have to be considered. However, in this particular case, it is highly unlikely that smallpox would even be a consideration as the disease had probably not evolved yet.

Given the antiquity of the remains examined here it is unlikely that any of these diseases are of any consideration, with the exception of tuberculosis, which is endemic in many mammal populations globally and is likely of considerable antiquity. The infectious agents of primary concern would be those known to cause the majority of non-specific infections globally; streptococcus and staphylococcus, which together account for approximately 90% of all bone infections (Ortner and Putschar 1985), and others like E. coli. These organisms are responsible for most trauma related infections and haematogenous disseminated infections.

In terms of differences between the two samples, based on the knowledge of a concomitant decrease in overall well being of individuals with the development of agriculture and the reliance on domesticates, it is postulated that the Seh Gabi infants will be less healthy in terms of cortical bone growth and maintenance and other non-specific stressors in comparison to the Ganj Dareh sample. However, this is based on the simplistic assumption that Ganj Dareh and Seh Gabi represent a continuum of the increasing sedentarisation and reliance on agricultural products and domesticates that supposedly accompanies the development of agriculture. This may not be the case as there is some confusion as to whether the Ganj Dareh site represents a sedentary agricultural based settlement, a transhumant pastoralist occupation, or a combination of both.

In addition to the problem orientation discussed above, it will be interesting to see how cortical bone behaves at such an early age in two archaeological samples as there is very little information available on archaeological infant and child cortical bone dynamics. I suggest that both the Ganj Dareh and Seh Gabi samples values will be well below the Kulubnarti values (Hummert 1983), particularly the Seh Gabi sample, in light of it's 'wildly' pathological condition.

CHAPTER VII

METHODOLOGY

The assessment of cortical bone growth and maintenance is predicated on the measurement of various dimensions and the calculation of indices. Because the study of cortical bone growth was originally conceived in the clinical study of osteoporosis, the focus was often on radiographic analysis. Initially, osteopenia, the loss or absence of bone substance, was diagnosed by increased radiolucency. But as Himes (1978) noted, "... visual assessment of bone rarefaction from radiographs ... has been shown to be unreliable as at least 25-30% of the calcium normally present in the bone tissue must be lost to be visually detectable on radiographs" (Himes 1978: 152-153). This problem with purely visual assessment eventually prompted researchers to quantify radiographically apparent bone loss.

Radiographic assessment of cortical parameters is a simple process; long bones are radiographed medio-laterally or antero-posteriorally. The dimensions of the bone are then measured from the radiograph with a calliper. Increasing sophistication in radiographic assessment of bone loss also led to the parallel development of other techniques designed to measure bone loss; these include densiometric trace analysis, photon absorptiometry, and others. However, for the most part, clinical studies have measured bone dimensions by means of simple radiographic assessment. Most physical anthropological studies, on the other hand, have until recently had the benefit of using dry bone specimens which can be cut and examined macroscopically, or, as is now common in the United States, examined non-destructively using Computerised Axial Tomography (CAT).

The use of dry bone cross sections eventually led to the realisation that radiographic assessment of cortical parameters was subject to a considerable degree of error

(Bartley and Arnold 1965; Dewey et al. 1968; Van Gerven 1973; Van Gerven et al. 1969). Even trying to compensate by employing two beams oriented perpendicularly to each other to enhance resolution of a cross section is subject to error. For example, Van Gerven et al. (1969) found that the radiographic technique could not distinguish between compact and porous bone (up to 11.7 % error) and surface specific changes because of the two dimensional nature of x-ray images, which accounted for up to 26.6% error in comparison to cut cross sections. Another major source of error in the radiographic technique was found to be the assumption that the cortical bone in question would be circular in cross-section. This in fact is often not the case, even in a relatively circular bone such as the femur, and tended to result in serious errors in the calculation of cross sectional thickness and area. The midshaft of the tibia is especially problematic because of its triangular or rhomboidal shape so that medio-lateral measurements do not accurately represent the complex geometry of the bone (Hummert 1983b: 169). This is also the case for other presumably cylindrical bones like the humerus.

Radiographic measurements differ qualitatively from direct measurement techniques as well; the former are essentially unidimensional whereas the latter are of a two dimensional nature. One can estimate two dimensional measurements from radiographs but these require some assumptions of shape which as already noted have been proven to be error prone and unreliable by various authors.

However, despite obvious drawbacks, physical anthropologists have persisted in employing radiographic assessment techniques (e.g. Ericksen 1976; Buikstra and Cook 1983; Cook 1979; Owsley 1985; Tiffany et al. 1988). It may be that reliance on error prone methods of assessment may stem from a prohibition against destructive techniques as a result of agreements with Native groups or a reluctance in general to engage in destructive testing.

Recently, a number of authors (Ben-Itzhak et al. 1988; Demes and Jungers 1989; Demes et al. 1991; Fresia et al. 1990) have attempted to create simplified geometric models which allow one to take into consideration the shape of the element in question, but these are still subject to an unknown degree of error. However, Runestad et al. (1993) recently compared cross sectional properties for midshaft femorae and humeri calculated from radiographs using geometric models to those properties derived from CAT and direct measurement and found an r^2 of .99 or better. It should be noted however that the authors felt that this kind of correlation would be found only at these two sites.

Computerised axial tomography would obviously be the most favourable alternative as various authors have indicated that information derived from CAT and direct measurement are 100 % compatible (Jungers and Minns 1979; Ruff and Leo 1986). However, there are some logistical problems associated with using CAT. First, using CAT assumes that the researcher actually has access to one; in the case of Manitoba there approximately 6 CAT devices on line; of these 3 are in continual use 24 hours a day and the other three operate in a limited capacity due to provincial government funding restrictions. Secondly, the cost of utilising such technologies in Manitoba is at this time prohibitive. It should be obvious that application of this technique would add up rapidly on a sample level of analysis. The technology involved simply has not become common and easily accessible as it has in other areas of Canada and in the United States. Finally, it has been suggested that using CAT to obtain a single mid-diaphysial cross-section per individual is a dramatic underutilisation of the technology.

Runestad et al. (1993) have also indicated there are some problems with the resolution of very small objects using CAT; they found that significant error began to creep in when analysing cortices less than two or three millimetres thick. The obvious solution to the problem would be to use a micro

CAT. However, such high resolution equipment is difficult to access even in the United States.

In light of the error associated with radiographic assessment and logistical considerations associated with CAT, analysis of cortical bone dimensions by means of bone sectioning was carried out. While a persuasive argument could be made against the use of destructive techniques, particularly on specimens so rare and old, the removal of a cross section of bone mid-diaphysis does not require that the entire element be sacrificed as only a relatively small portion of bone (c. 1-2 mm in width) is removed. Thus, the elements will still be useful for paleopathological analyses and the like and can be reconstructed easily if needed.

Before the samples were sectioned they were both aged skeletally and dentally. The Ganj Dareh sample had previously been aged by various workers (Pinch, n.d.; Lambert, 1980; Carmichael, n.d; Agelarakis, 1989). However, aging had concentrated mainly on adults and some of the subadult ageing estimates were inconsistent. Also, in the process of examining the remains a number of additional dental and skeletal elements were recovered from unprocessed materials, thus occasionally improving the accuracy of aging estimates. In the case of individuals where age estimates were consistent between observers re-aging was not carried out. In cases where there was some discrepancy, age reassessment was accomplished using dental calcification and eruption standards provided by Ubelaker (1978; based on modifications to Schour and Massler 1964). Dental aging for individuals younger than 1 year was accomplished using Deutsch et al. (1984, 1985). The Seh Gabi material was aged by Dr. Mark Skinner of Simon Fraser University using a variety of commonly employed dental calcification standards. Skeletal aging of Ganj Dareh infants less than term was based on Fazekas and Kosa (1978). Skeletal aging of infants older than term was based on a variety of anthropological standards (Jantz and Owsley 1984a; Johnston 1962; Merchant and Ubelaker 1977; Owsley and Jantz 1985; Sundick 1978; Wall 1991).

Before sectioning, long bone maximum length was measured for all femorae and tibiae. Measurements of femoral and tibial length were taken using a pair of Helios sliding callipers. All elements to be sectioned were then photographed in both antero-posterior and medio-lateral aspect. Right femorae and tibiae were sectioned at the midshaft using a Buhler Isomet low speed diamond saw. Right side elements were selected as they were more commonly available than left side elements. Left elements were substituted where right ones were not available. It should be noted that for the purposes of examining cortical bone dimensions, left side elements are preferred as they consistently display less variability in comparison to right elements (Ruff and Jones 1981). However, this is based on adult cortical bone data; infants and children are not likely to exhibit significant asymmetry, which in the post-cranial skeleton is suggested to arise from activity patterns associated with adulthood and sexual division of labour.

The element to be sectioned was marked at the midshaft using an indelible marker and then mounted in the bone chuck of the adjustable pivot arm of the Isomet. After adjustment of the chuck to allowed for proper orientation of the element, in this case perpendicular to the cutting blade, the cutting blade and midshaft mark were lined up using the micrometer adjustment on the Isomet. The Isomet was turned on and the pivot arm was gently lowered until contact was made between the bone and the cutting blade.

It was initially feared that in some cases a number of specimens may have had to have been consolidated before being cross sectioned, as a number of the Ganj Dareh and Seh Gabi individuals are in a very poor state of preservation to the point where repeated handling of the specimens is not recommended. In some cases the bone is so badly degraded that it has a talc-like consistency and rubs off the periosteal surface easily. In other cases, as a result of the post level D fire at Ganj Dareh, the specimens have been fired in such a manner that they have taken on a porcelain like consistency and may in fact shatter if placed under too great a stress. It may have been necessary to stabilise the specimens using either Methyl Methacrylate or Glycol Methacrylate polymer embedding compounds (Anderson 1982). However, the use of such plastic compounds is quite time consumptive as the curing time may reach one to two weeks. It was also not clear if entire elements could be embedded as the compounds are designed for use on much smaller surgical specimens. It was suggested that embedding in a simple Paraffin bath may lend enough structural support to allow for trouble free sectioning without having the entire element shatter or crumble. However, as it turns out, sectioning of even the most fragile unembedded specimens was not difficult as the cutting blade was fast and smooth enough to avoid chatter. In cases where the element was extremely fragile the speed of the cutting blade was slowed and the counterbalance weight of the pivot arm was lightened. The only cases where sectioning was a problem was when the element had been reconstructed using white glue. In this case, because the cutting blade is partially immersed in a water bath to cool it, the water soluble white glue would occasionally dissolve. In such cases the solution was to simply make another cut at a higher speed in an effort to cut the bone before the glue dissolved. The section removed were on average 0.7 mm thick; in cases where the bone was more fragile a slightly thicker section (1 mm) was taken.

To increase sample size, the midshaft of incomplete long bones was estimated by comparison with complete long bones from other individuals of the same age class and by measuring diaphysial diameters to determine the approximate location of the midshaft. Only incomplete long bones with an intact diaphysis and at least one complete epiphysial surface were used. In cases where the long bone was incomplete a second cross section was taken 0.5 to 1 cm distal or proximal of the estimated midshaft and the results were averaged. Sections were rinsed in a water bath of distilled water and allowed to air dry. The cross sections were not ground before being mounted on microscope slides as cutting blade chatter was minimal and grinding may have destroyed the fragile specimen. Once dried the cross sections were mounted on glass slides using Permount® mounting medium. The mounting medium was only applied to the side adhering to the slide so that the sections could be stained and ground thinner if microscopic work is carried out on the material in the future. Care was taken to ensure the proper orientation of the cross sections; sections were mounted distal surface down with the anterior surface facing forward.

After sectioning and mounting the specimens were analysed under low power magnification using a binocular dissecting microscope (x10) and a grid of known size was constructed using the MacIntosh graphics program Illustrator 3.0. A 400 millimetre square grid was created, divided into 1 x 1 millimetre squares (figure 8). The grid was laser printed on a transparency. The grid was checked manually to ensure it was accurate and that there was no distortion during printing.

The areas of a bone cross section were calculated as follows; the transparent grid was placed on top of the cross section. The number of grid line intersects overlying the area to calculated was counted. This was done three times to minimise intra-observer error. Hits over areas of pronounced porosity, trabeculae and those at the edge of the cross section were counted as 1/2 of a hit. This procedure was used to calculate total, meduallry and cortical area.

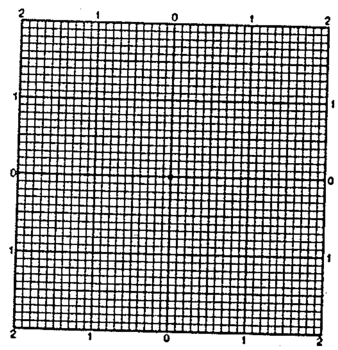


Figure 8. Grid used for calculation of area measurements

CHAPTER VIII

ANALYSIS

Because of skewing in the Seh Gabi sample, the most appropriate comparison between Seh Gabi and Ganj Dareh was within the newborn to 2 year age groups. Most of the individuals with intact tibiae and femorae in both samples are concentrated in the preterm to one year age groups (figure 9). All age classes after one year are limited to single individuals. There are no Seh Gabi individuals older than four years. A broader comparison was possible between the Ganj Dareh sample and other archaeological samples from outside the region as the Ganj Dareh sample contains individuals in age groups up to 10-11 years.

After calculation of cross sectional areas, individuals in each sample were divided up into the following 6 age classes: (1) preterm to newborn, (2) 0-6 months posterm, (3) 6-9 months, (4) 9-12 months, (5) 12-18 months, and (6) 18-24 months. The use of dental calcification standards and anterior dental measurements allowed for individuals to be allotted to well defined age classes. Dental age estimates were confirmed by examining osseous indicators of age such as long bone growth, development of epiphyses, ossification of the tympanic ring and mandibular symphysis, neural arch fusion, etc... . The age classes used here were also employed to ensure compatibility with other existing comparative samples.

Cortical Bone Growth and Maintenance

Comparison of the Seh Gabi and Ganj Dareh preterm to two year olds indicates that there is relatively little difference between the two samples in total area across all age classes (figure 10). The variation present in total area may be the result of sampling bias and/or normal variation in total area. However, it appears that the growth pattern in the Ganj Dareh sample is much smoother

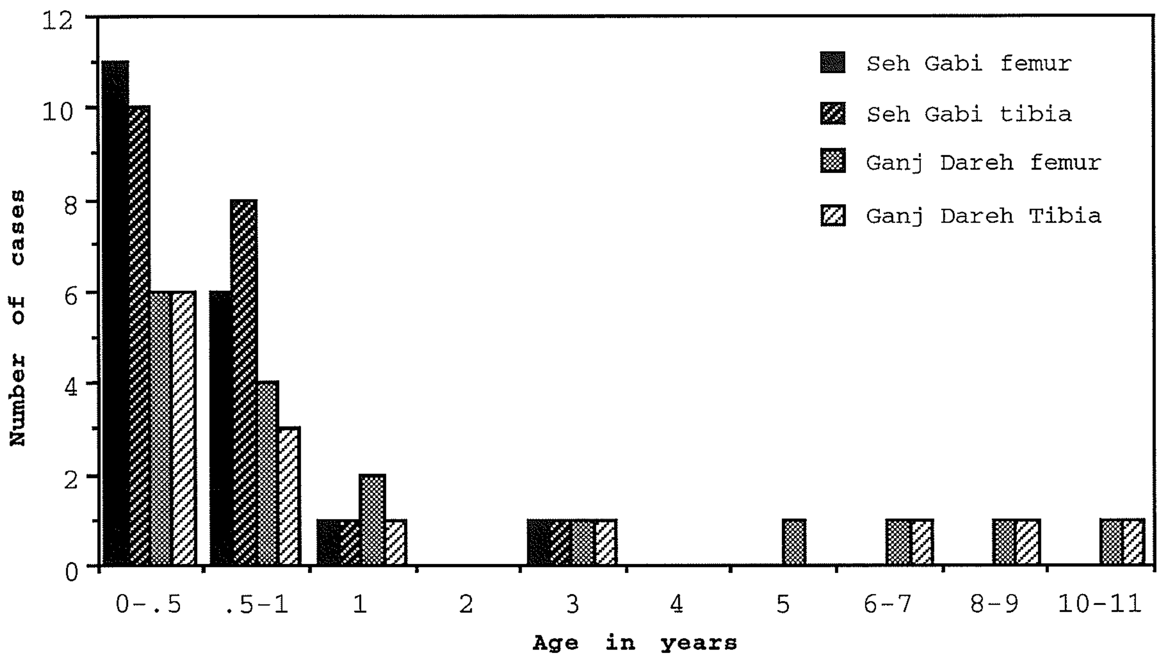


Figure 9. Sample sizes for femur and tibia: Seh Gabi and Ganj Dareh

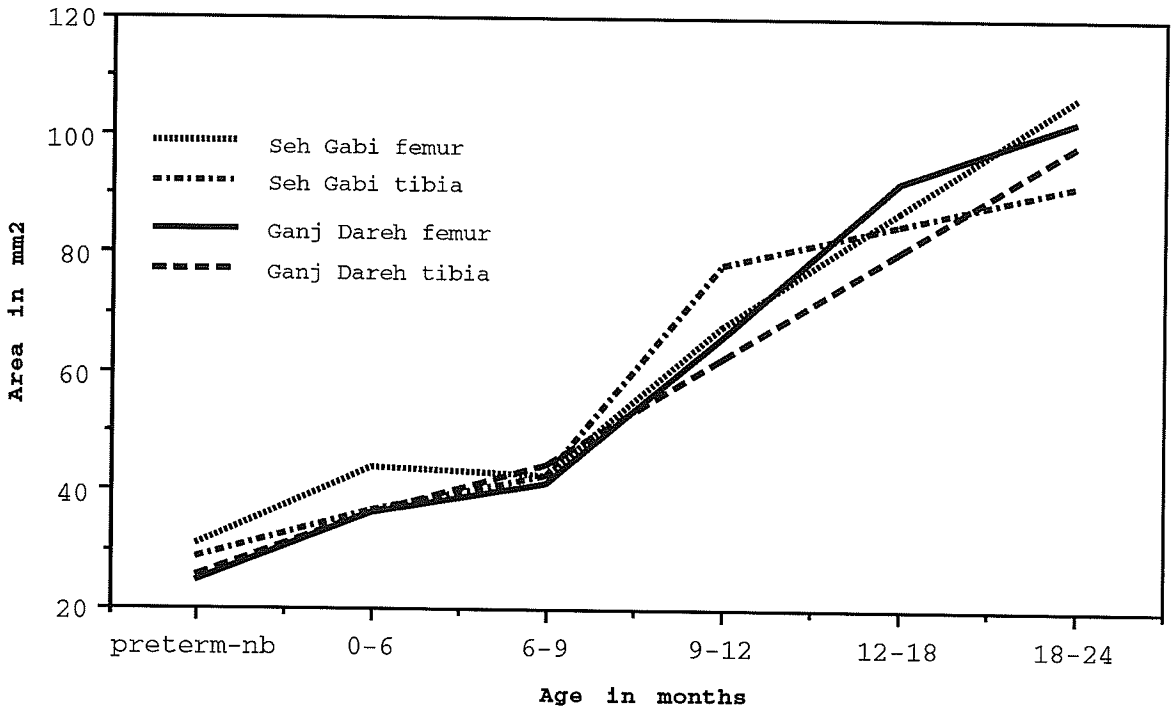


Figure 10. Infant femur and tibia total area: Seh Gabi and Ganj Dareh

than the Seh Gabi sample; both the Seh Gabi tibiae and femorae are punctuated by periods of pronounced cessation in total area growth. It is interesting to note, despite major differences in cross sectional shape and long bone structure, that the femorae and tibiae display nearly identical total cross sectional areas. In fact, for all measurements used, absolute femoral and tibial values closely mirror each other.

The brief period of slowed growth in femur and tibia total area between 0-6 and 6-9 months may be related to transient or physiological loss (Bernard et al. 1964; Garn 1970). This phenomenon occurs immediately after birth and is found in all populations and archaeological samples. Transient loss appears to be related to rapid post natal growth, coupled with a shift from a reliance on in-utero maternal sources of nutrition to endogenous stores of minerals and nutrients. the net result is infants have to rely more on their own body tissues to maintain the tremendous rate growth experienced during the first year of life (Bernard et al. 1964). However, while physiological loss normally causes a drop in the amount of cortical bone in cross section, it does not usually involve a marked slowing of total area. Data from Garn (1970) indicate constant growth in total area from birth to two years. The slowed growth at 0-6 to 6-9 months, particularly in the Seh Gabi sample, may be related to postpartum infant stress as the infants adjust to the external environment.

Figure 11 shows infant medullary area for Seh Gabi and Ganj Dareh. Both samples begin with a normal increase in medullary cavity area until 6-9 months, at which time the Seh Gabi medullary area in both the femorae and tibiae increases dramatically. While it could be argued that the increase in medullary area simply reflects rapid growth related modeling of the long bones, comparison of cortical area clearly demonstrates this is not the case (figure 12). The increase in Seh Gabi medullary area is the result of excessive endosteal resorption. While the total area values suggest that normal periosteal apposition is continuing, Seh Gabi medullary cavity values after 6-9 months are consistently

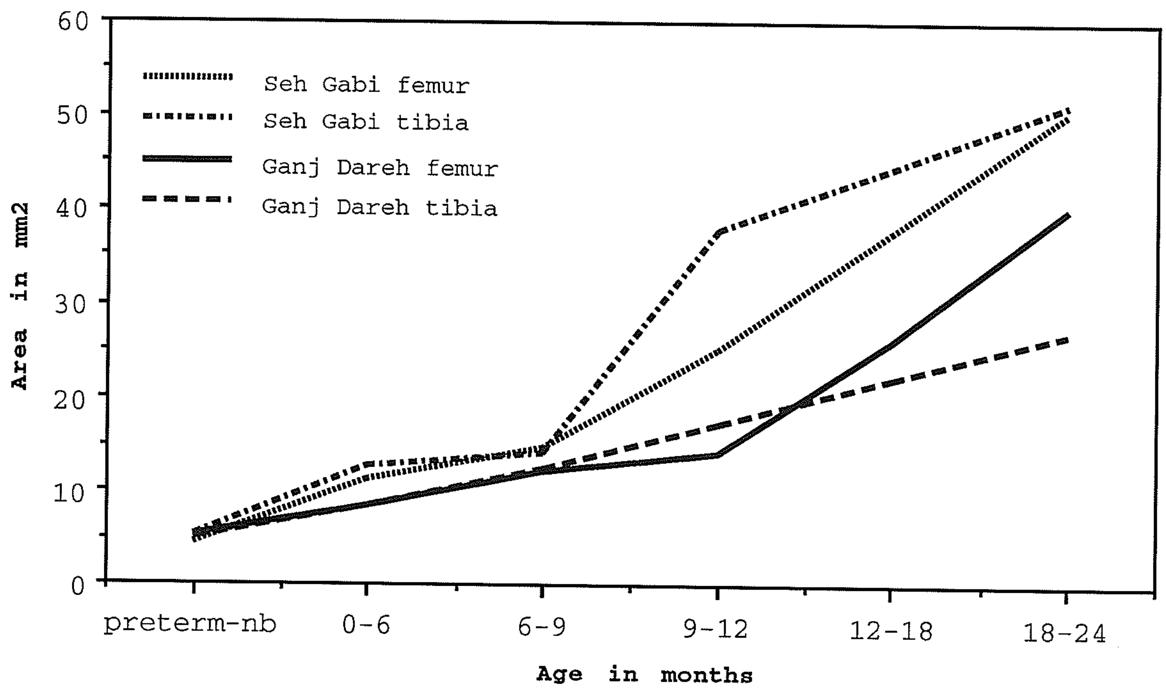


Figure 11. Infant femur and tibia medullary area: Ganj Dareh and Seh Gab:

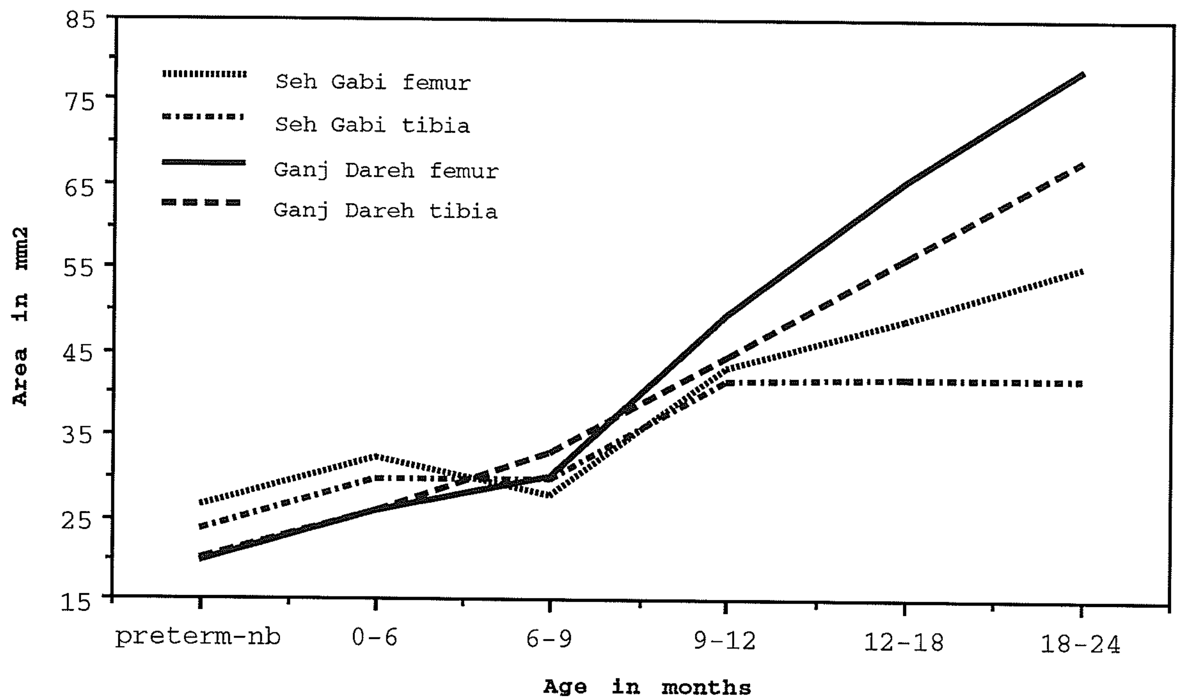


Figure 12. Infant femur and tibial cortical area: Ganj Dareh and Seh Gabi

higher, indicating an increase in the rate of osteoclasia at the endosteal surface.

The pattern of increased endosteal resorption in the Seh Gabi sample is reflected in cortical area (figure 12). Initially, Seh Gabi cortical area is slightly higher than Ganj Dareh, but growth slows between 0-6 and 6-9 months. While growth in both samples continues after 6-9 months, Ganj Dareh cortical area values are consistently higher than Seh Gabi values.

Analysis of percent cortical area (PCA) provides a relative assessment of the amount of cortical bone present and offers a means of assessing the interaction between medullary and cortical area (Garn 1970). At birth, both samples display PCA values of 75 to 90%, (figure 13) indicating the cortices are very thick and medullary cavities are almost non existent. Initially, Seh Gabi percent cortical area is higher than that of Ganj Dareh, reflecting higher TA and CA values in the preterm-n.b to 0-6 month age groups. However, Seh Gabi PCA decreases much faster than Ganj Dareh, dropping to below 65% by 9-12 months. This pattern indicates that resorption is consistently exceeding apposition.

The Ganj Dareh sample still continues to loose bone, but only about 5% from 6-9 to 18-24 months. The intensity and degree of bone loss in the Seh Gabi sample suggests that these individuals were under enormous postnatal stress; this is reflected in Skinner's (1980) analysis in which he recorded a high frequency of Harris lines, hypoplastic defects and post-natal skeletal stunting.

To enhance comparison between Ganj Dareh and Seh Gabi newborn to 2 year olds, other examples using the same elements were sought out. Unfortunately there are no clinical comparative samples available to contrast with the anthropological data as the clinical studies focus on metacarpal cortical growth, not limb bone growth. Although some authors (Huss-Ashmore 1981; Keith 1981) have compared archaeological samples with metacarpal standards (e.g. Garn 1970), metacarpal cortical growth clearly follows a different growth pattern because it is regulated by different

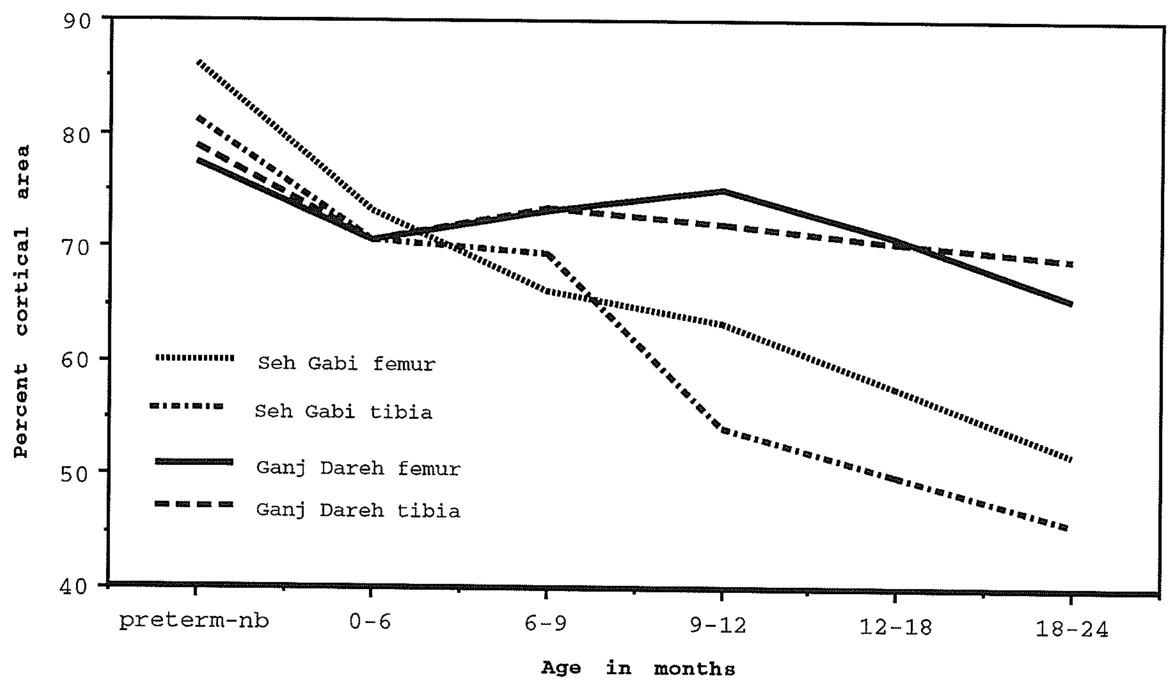


Figure 13. Infant femur and tibia percent cortical area: Ganj Dareh and Seh Gabi

mechanical stresses than limb bones (see figure 7). There are a number of archaeological samples available, although only three are directly compatible. Hummert (1983 a,b) analysed two samples of subadult tibiae from the Mediaeval Nubian site of Kulubnarti. Huss-Ashmore (1978, 1981) analysed the femorae of subadults from the Sudanese Nubian site of Wadi Halfa and Keith (1981) analysed the femorae of subadults from the Late Woodland/Middle Mississippian samples from Dickson Mounds in eastern North America. The Kulubnarti and Dickson Mounds samples contain detailed data for 0-2 years.

A comparison of Ganj Dareh and Seh Gabi with the Kulubnarti sample indicates the Kulubnarti sample follows the early infant physiological loss pattern as found in contemporary populations, more closely than either Seh Gabi or Ganj Dareh (figure 14). The complete lack of PCA recovery in the Seh Gabi material lends strength to Garn's (1970) suggestion that recovery from transient loss occurs earlier in healthier populations. I would argue that, based on what is known of the health costs associated with the agricultural transition, recovery from infant physiological loss occurs earlier in hunter-gatherers than it does in subsequent agricultural populations. The higher PCA values of the Ganj Dareh sample in comparison to both Seh Gabi or Kulubnarti supports the assertion that hunter-gatherers are often healthier than agriculturalists.

Femoral PCA values were also compared to the Dickson Mounds Late Woodland sample from Eastern North America (figure 15). Interestingly, the Dickson Mounds sample displays relatively poor PCA values at 12-18 months, a pattern unexpected from a hunter-gatherer sample. However, the Dickson Mounds sample begins to recover at 18 months while the Seh Gabi sample PCA continues to drop. Again, we see recovery of the Ganj Dareh sample PCA while the Seh Gabi values continue to plummet.

Examination of the area growth patterns in the entire Ganj Dareh subadult sample demonstrates what could be characterised as a 'robust' growth pattern (figure 16). Growth in total, medullary,

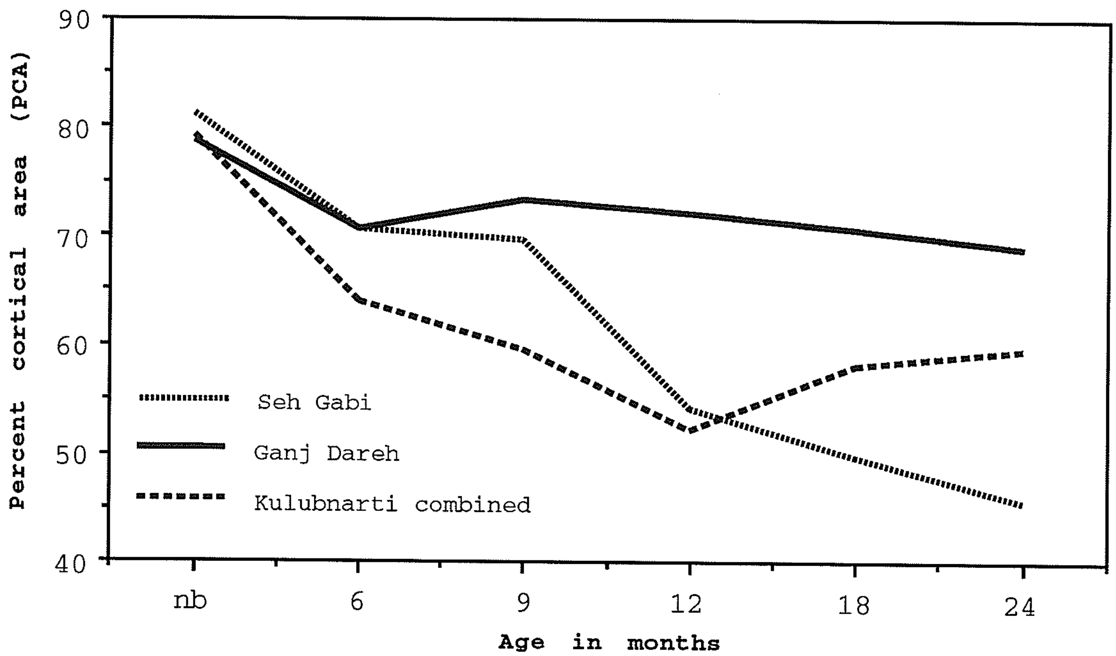


Figure 14. Infant tibial PCA: Ganj Dareh, Seh Gabi and Kulubnarti

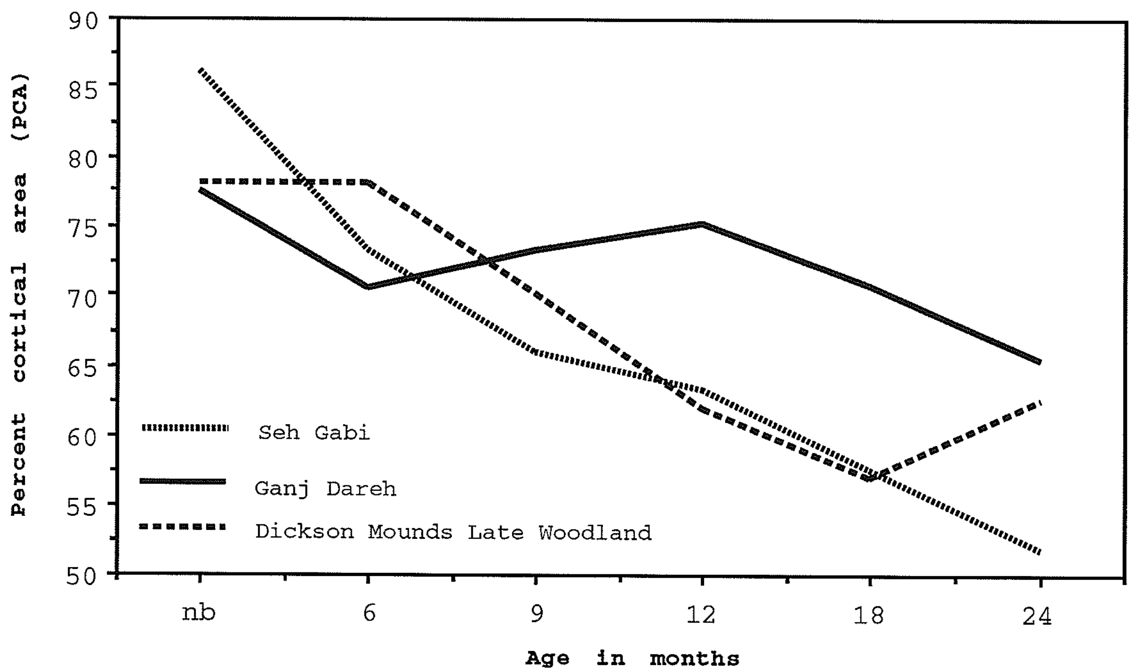


Figure 15. Infant femoral PCA: Ganj Dareh, Seh Gabi and Dickson Mounds

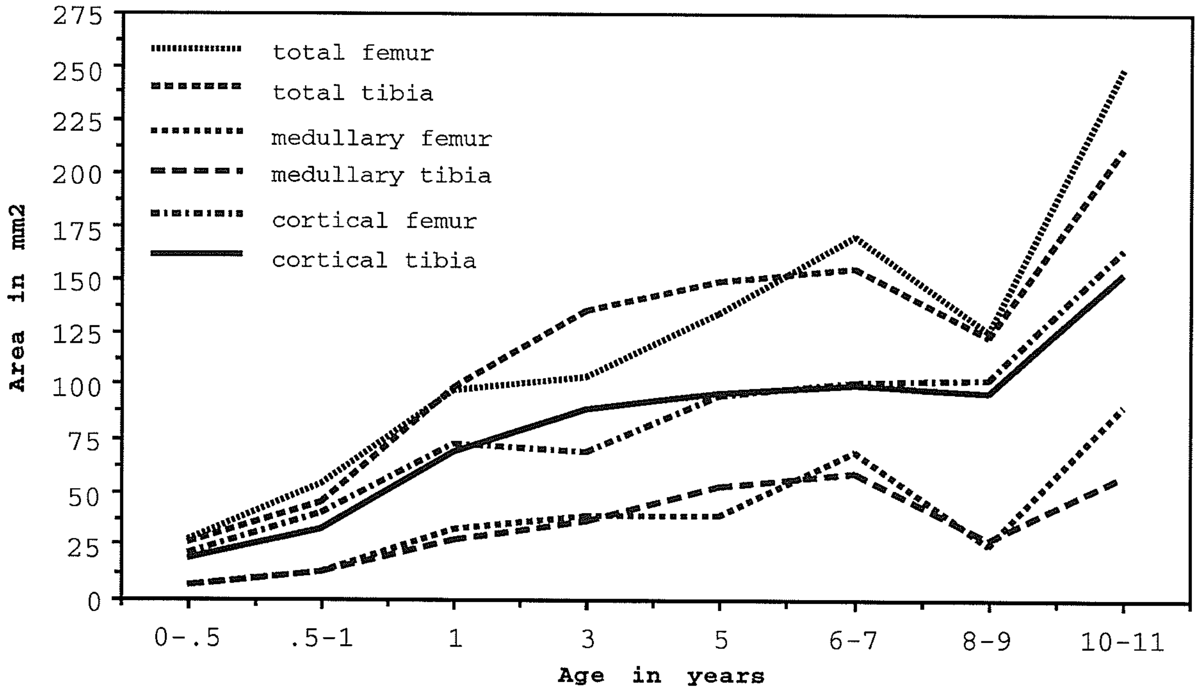


Figure 16. Ganj Dareh femur and tibia: total, medullary and cortical area

and cortical areas are rapid from 0 to 3 years of age. The growth pattern then levels off, remaining more or less constant, from 3 to 6-7 years of age. The drop in total area and medullary area at 8-9 years is anomalous as the single individual in this category appears to display medullary stenosis (Garn et al. 1968), although the total cross sectional area is quite low for dental age. Cortical areas in the 10-11 years age class are similar to those found in contemporary healthy populations. The pattern of growth in Ganj Dareh total, medullary, and cortical areas depicts a healthy skeletal sample characterised by little evidence of stress throughout the weaning years, and very little evidence of childhood stress. The pattern is typical of the sigma curve that characterises normal somatic growth (Tanner 1978).

Ganj Dareh PCA displays a typical drop within the first year as a result of infant physiological loss (figure 17). PCA values from 1 to 6-7 years remain more or less constant, although femoral values tend to fluctuate somewhat. The extraordinarily high PCA values of 75-80% at 8-9 years are a result of the case of medullary stenosis mentioned above. Subadults in contemporary populations do not approach these values till well into the adolescent growth spurt (Frisancho et al. 1970a). The PCA values at 10-11 years are typical of a juvenile. Ganj Dareh PCA values do not indicate the presence of weaning stress or childhood illness.

Since the Seh Gabi sample included infants only, the complete subadult sample from Ganj Dareh was compared to the Kulubnarti samples analysed by Hummert (1983 a,b). The Kulubnarti data is the most complete available as it includes data for all four measures, whereas the only useful data from the Wadi Halfa and Dickson Mounds samples was percent cortical area. When Kulubnarti total area is compared to Ganj Dareh it is apparent that there is a discrepancy between the two growth curves (figure 18). While the slope of the Kulubnarti growth curves after 3 years is similar to the Ganj Dareh sample, Ganj Dareh total area grows much faster in the first three years. This may indicate a marked lag in cortical growth among the Kulubnarti individuals, which continues until

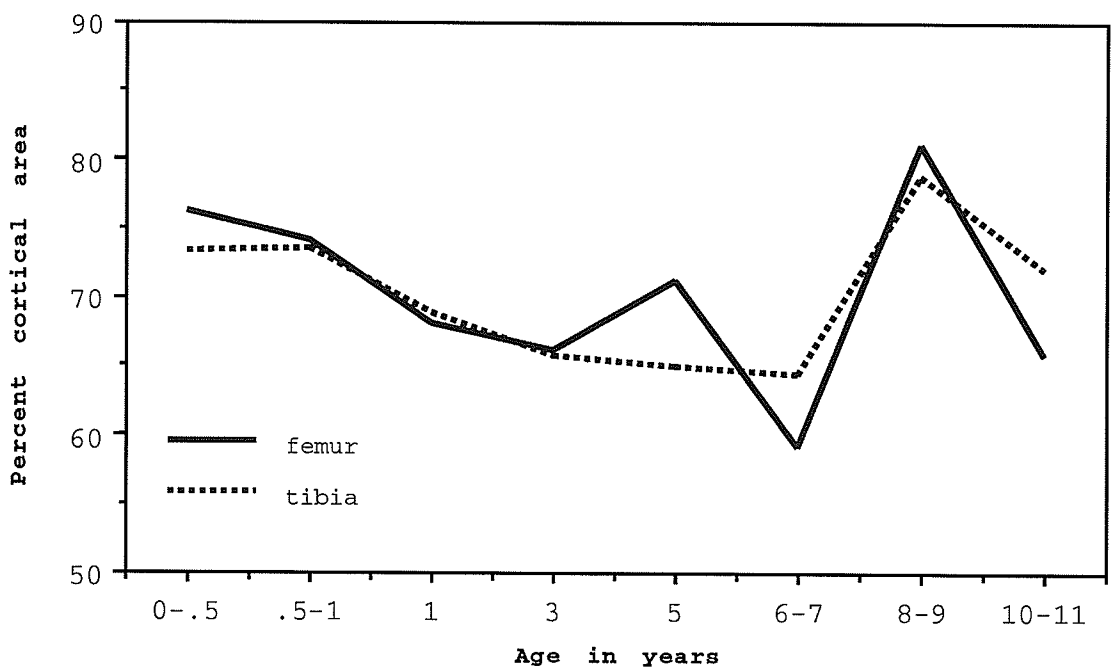


Figure 17. Ganj Dareh femur and tibia, 0-11 years: PCA

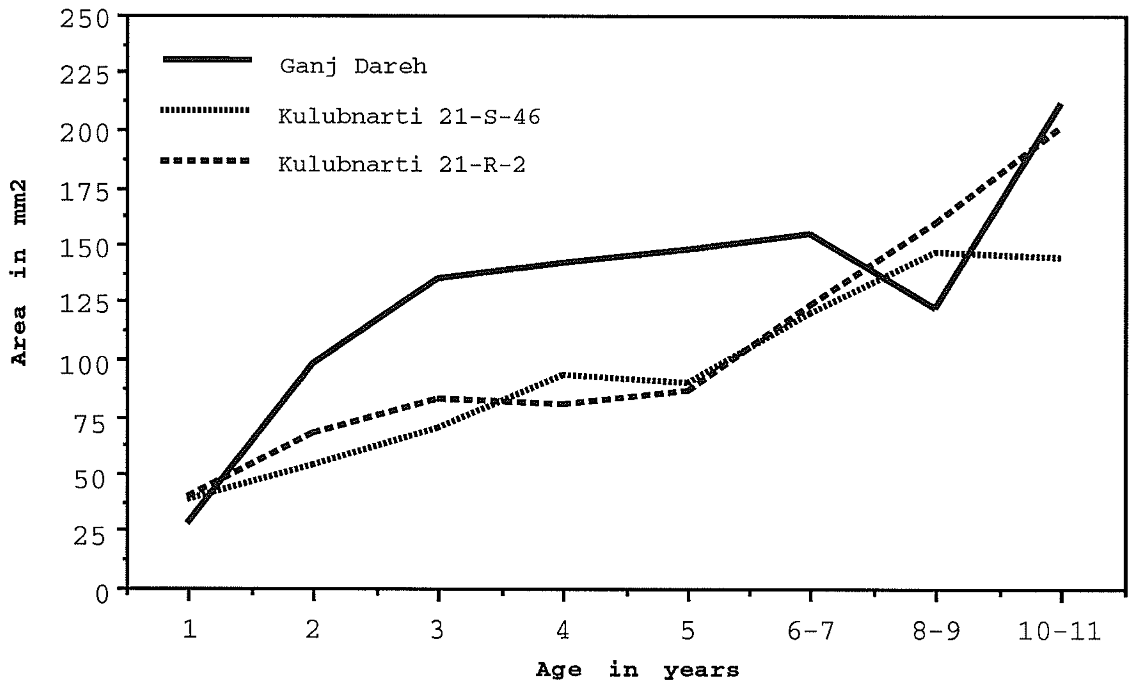


Figure 18. Ganj Dareh and Kulubnarti tibial total area

approximately 5 years of age. After this growth begins to catch up and finally rivals that of Ganj Dareh. The lag in total area growth may be related to the lags in long bone growth velocity detected in the Kulubnarti sample by Hummert and Van Gerven (1983).

In terms of medullary area, the pattern is quite similar to total area; the Ganj Dareh sample displays marked growth of the medullary cavity in all ages in comparison to the Kulubnarti samples (figure 19).

In terms of cortical area, the Ganj Dareh sample displays the same pattern as total area and medullary area with the exception that the Ganj Dareh cortical area growth curve levels off to only maintain cortical area after 3 years, until 10-11 years (figure 20). Contrast this with the Kulubnarti samples, both of which display slow but steady growth in cortical area from 1 till about 4 years, after which cortical area values begin to take off and more closely approximate Ganj Dareh values.

All these areal patterns are reflected in the percent cortical area values; Ganj Dareh drops steeply and levels off at 3 years as rapid transverse growth is experienced and subperiosteal apposition can not keep pace with endosteal resorption (figure 21). This first part of the curve is normal; however, the Ganj Dareh individuals do not experience continuous cortical growth like the Kulubnarti samples. In fact, apposition from 3 years to 6-7 years is not enough to compensate for resorption. It is only in later childhood that Ganj Dareh values finally rise again. The Kulubnarti samples on the other hand begin with much lower values. 21-S-46 values drop precipitously and remain consistently low, rebounding slightly at 2-4 years but nonetheless remain low till 6-7 years. Kulubnarti 21-R-2 values, although not as low as 21-S-46, remain lower than the Ganj Dareh sample till 5 years, at which time they rebound and approximate Ganj Dareh values. Final PCA values for all three samples are similar and quite normal.

There are three comparative samples for the femur with data

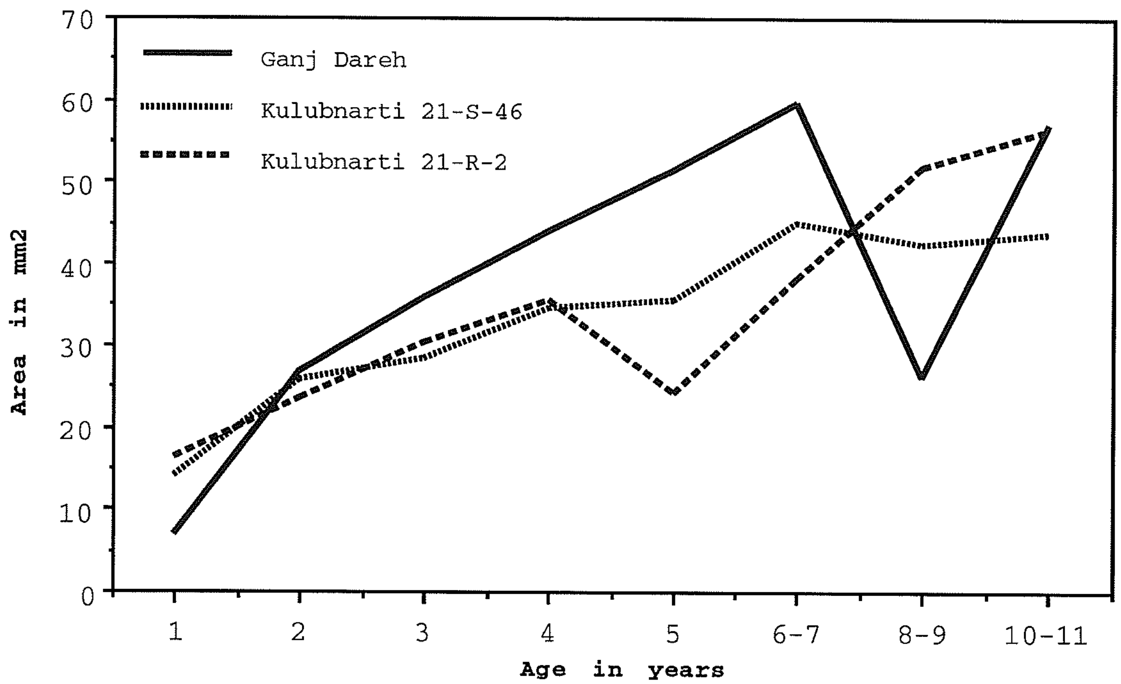


Figure 19. Ganj Dareh and Kulubnarti tibial medullary area

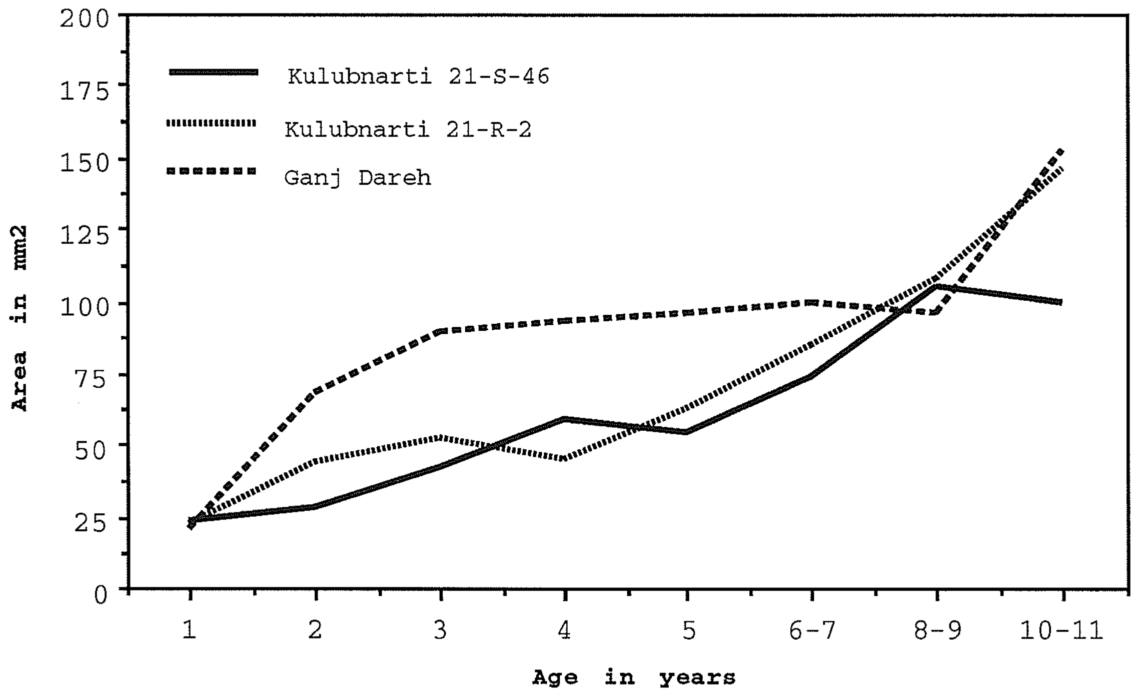


Figure 20. Ganj Dareh and Kulubnarti tibial cortical area

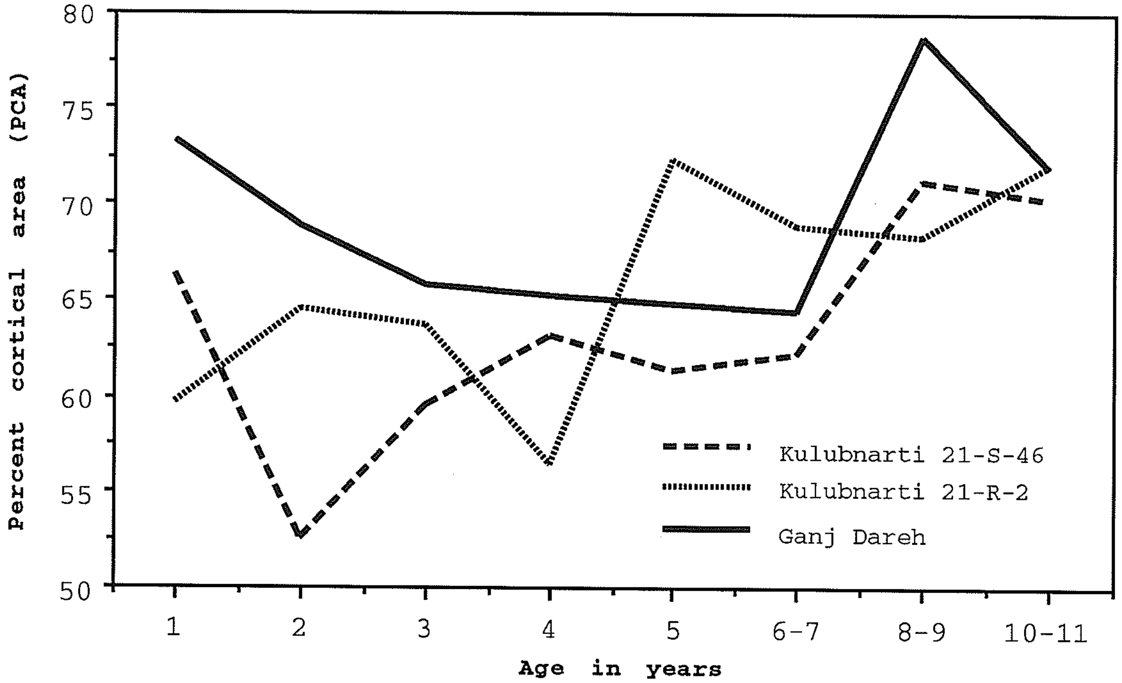


Figure 21. Ganj Dareh and Kulubnarti tibial PCA

for percent cortical area. These include a Mediaeval Nubian sample from Wadi Halfa (Huss-Ashmore 1981), and two samples from Dickson Mounds, one a transitional hunter-gatherer / incipient horticulturalist group and the other a fully horticultural group (Keith 1981). Figure 22 shows percent cortical area values for all three samples. Note that the Ganj Dareh values are consistently higher than the other three. Although the Wadi Halfa agriculturalist sample presents PCA values consistently lower than Ganj Dareh, it does not present the same pattern of initial growth lag and catch up growth as seen in the Kulubnarti data. If anything, the Dickson Mound samples present a pattern more similar to Kulubnarti than to Ganj Dareh. Initially low PCA values characterise both Dickson Mound samples which exhibit consistently slow cortical growth till 5 to 7 years, at which time catch-up growth rivals and eventually surpasses Ganj Dareh. It would seem that all of the comparative samples display evidence of disturbances in infant and childhood growth in PCA, from approximately 2 to 6-7 years of age. Disturbances in growth or evidence of elevated stress levels during this time have traditionally been interpreted as evidence of either weaning stress, particularly between the ages of 1 to 4 years, or, if slightly later, evidence of childhood illnesses. If comparative PCA values are reflecting these sources of stress, then it would appear that the Ganj Dareh sample was relatively healthy and did not experience infant and childhood stress to the same degree as the comparative samples discussed here.

Analysis of Other Non-Specific Stressors

The analysis of cortical bone growth and maintenance can be greatly enhanced by including already existing data of other non-specific stressors collected for the Ganj Dareh and Seh Gabi samples. Data on Harris lines, linear enamel hypoplasia, dental and skeletal age estimates, growth stunting, and notable pathological conditions was collected by Skinner (1980) for the

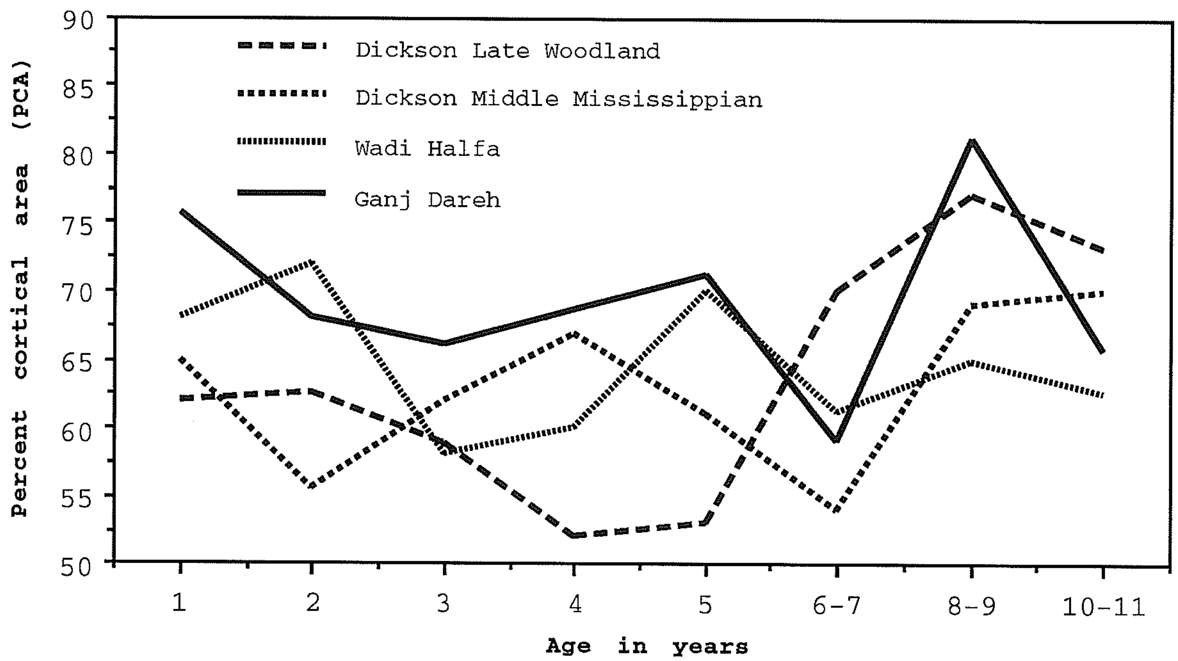


Figure 22. Ganj Dareh vs. comparative samples femoral PCA

Seh Gabi sample. Skinner (1986) also provided detailed data on localised hypoplasia of the primary canine (LHPC) for the Seh Gabi sample. Qualitative observations on the orbital lesions noted in Skinner (1980) are found in Waddell (1989).

Data on the Ganj Dareh subadults come from a variety of sources. A number of authors have calculated dental and skeletal age estimates for the subadults (Agelarakis 1989; Carmichael, n.d.; Lambert, n.d.; Pinch, n.d.; Meiklejohn, n.d.). To date the most comprehensive analysis of the Ganj Dareh subadult material has been that of Agelarakis (1989). The author collected data on aging and standard categories of non specific stressors like linear enamel hypoplasias, LHPC, anaemia (generalised periosteal reactions, cribra orbitalia, porotic hyperostosis), and periosteal reactions (infection). Agelarakis also incorporated specific classes of bony responses (osteolysis, hypervascularity) and grouped observations into generalised classes of response (systemic conditions, inflammatory responses, infection). In order to synchronise Agelarakis's observations with those of Skinner's, reference will be made only to standard non-specific stressors commonly examined in subadult studies. Agelarakis was not looking specifically at the subadults, but the entire sample, thus all observations collected by Agelarakis (1989) on subadults were rechecked to ensure accuracy.

The Ganj Dareh subadult data set extracted from Agelarakis (1989) was also modified to take advantage of new advances in paleopathology; the data on anaemia was re-examined in light of recent advances in the understanding of normal infant skeletal variability (Mann and Murphy 1990; Waddell, n.d.). Agelarakis's data on LHPC was not used; instead, a more detailed data set recently collected for purposes of publication was used (Meiklejohn, n.d.). Since Agelarakis (1989) did not collect data on the presence and absence of Harris lines, radiographs of the Ganj Dareh subadult long bones were examined for the presence or absence of transverse radiopaque lines in the diaphyses and metaphyses of all long bones.

Long Bone Growth

Skinner (1980) suggested that most of the post term infants and children from Seh Gabi displayed evidence of growth stunting (12/14) as measured by dental development plotted against skeletal maturation. The assessment of growth stunting is predicated on the accurate assessment of the dental and skeletal age of an individual. Skinner (1980) found that none of the preterm to newborn individuals displayed evidence of growth stunting; this is probably a result of the buffering effect of the maternal environment which protects the developing fetus even in times of severe stress. However, growth stunting in post-term individuals was found to be quite common. Ten of 12 (83.3%) individuals scored displayed evidence of growth stunting; 8 of 12 (66.7%) were stunted by 0.2 years or less (about 2 1/2 months) and only two individuals greater than 0.3 years (see Appendix, Table 5). While the high rates of pathology among the Seh Gabi infants would likely result in small for age babies who were skeletally stunted, the accuracy necessary to assess growth stunting is arguably not possible.

While dental calcification standards are usually considered quite accurate (although there are some problems with selected standards like Moorees et al. 1963; see Merchant and Ubelaker 1977; Saunders and Melbye 1990 for opinion) the problem lies with selecting the anthropological limb bone growth standards which most accurately reflect the growth pattern and growth velocity of the sample in question. Limb bone growth patterns and velocity seem to be quite variable and can be quite sample specific (Ubelaker 1989). A comparison of Walls (1991) growth standards with those of Armelagos et al. (1972), Fazeka and Kosa (1978), Jantz and Owsley (1984b), Merchant and Ubelaker (1977), or Sundick (1978) clearly demonstrates that substantial disparities in growth patterning exists between archaeological samples. As such, aging using long bone length age estimates is hazardous as there is enough variation between standards to allow individuals to be put into different age categories, depending on which standards are used (Ubelaker 1989). The range of age estimates is also known to increase as the size of the bone increases. Saunders (1992) has suggested that error could be minimised by selecting growth standards based on populations or samples most closely related to the samples under observation. To this author's knowledge, at the present time there exist no comparative growth standards based on Mediterranean or Near Eastern skeletal samples which might be used for aging the Ganj Dareh and Seh Gabi remains.

A number of authors have sought to circumvent this problem by assessing intra-series changes in long bone growth through time (Jantz and Owsley 1984b; Owsley and Jantz 1985; Mensforth 1985) . However, the samples used are quite large in absolute size and number of individuals per age category. However, the Seh Gabi and Ganj Dareh samples are simply too small to permit comprehensive growth standards to be constructed, thus, while Skinner's assertion that most of the Seh Gabi sample displays growth stunting is likely correct, the stunting estimates on an individual by individual basis are too small to be reliable.

A better measure of growth disturbance not dependent upon accurately matching skeletal age to known standards may be to examine upper versus lower limb bone allometry as Jantz and Owsley (1984a) have done. However, while the Seh Gabi sample is relatively complete and intact, the Ganj Dareh subadults are often only represented by one or two long bones, thus such a technique is not applicable here.

Comparison of Ganj Dareh femoral length growth patterns indicates that the Ganj Dareh growth pattern compares favourably with archaeological samples from Dickson Mounds (Keith 1981), Indian Knoll, Altenerding (Sundick 1978) and central California (Wall 1991). Ganj Dareh long bone length are initially quite short in comparison to other growth standards; this may be in part a result of inclusion of early posterm and term individuals within the 0-1 year category. This may also be reflected in the tremendous growth depicted from 1-2 years. In comparison to

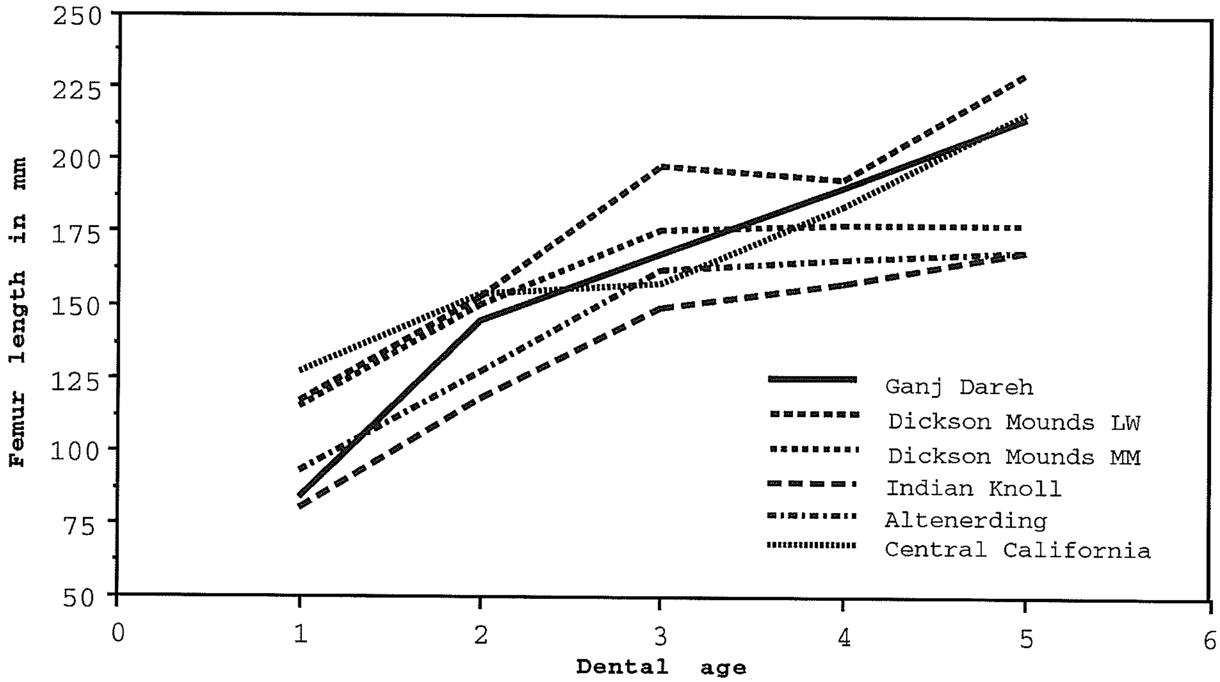


Figure 23. Maximum femur length: Ganj Dareh vs. comparative samples.

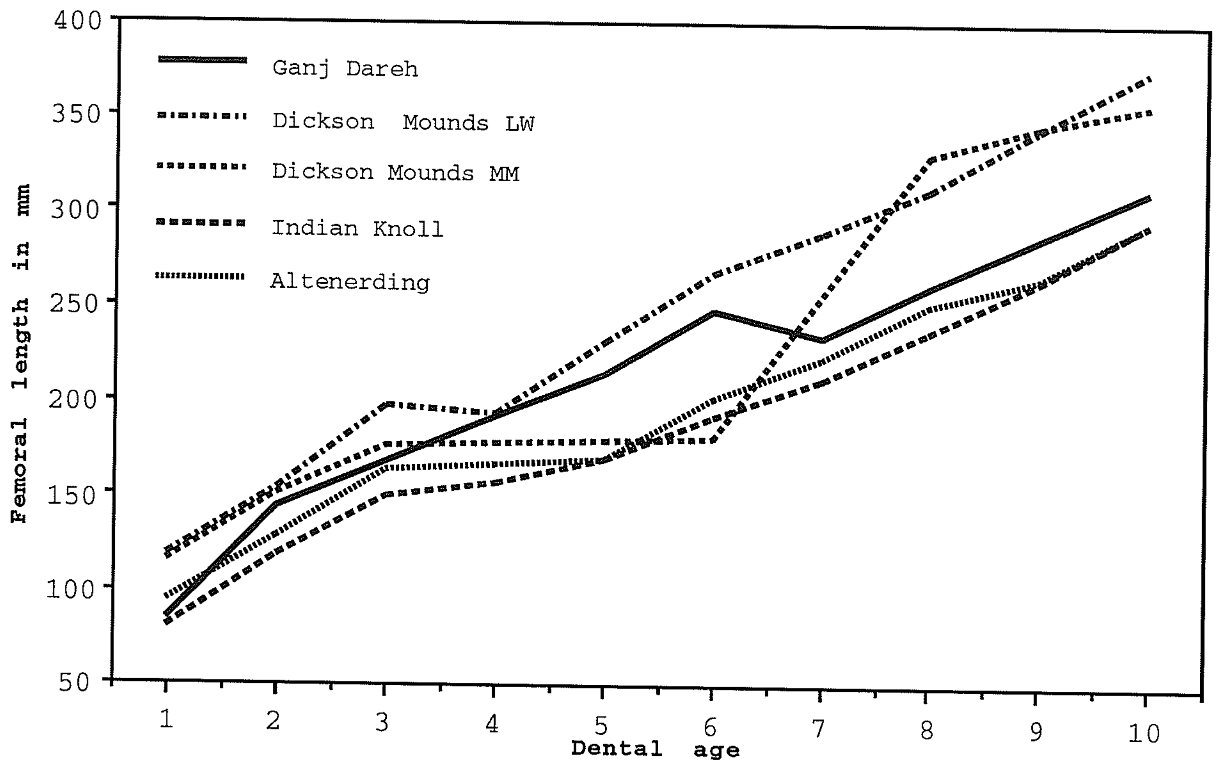


Figure 24. Maximum femur length: Ganj Dareh vs. comparative samples

children aged 1 to 5 years of age, the Ganj Dareh sample displays a constant uninterrupted pattern of growth (figure 23). All of the comparative samples exhibit periods of slowed linear growth, which Wall (1991) has attributed to weaning stress. There does not appear to much in the way of growth disturbance from 5 to 10 years in the Ganj Dareh sample either (figure 24). It should be noted that the sample values from Indian Knoll and the German site of Altenerding may, in reality, be higher, as the aging techniques used by Sundick (1978) consistently overestimated dental age (Merchant and Ubelaker 1977; Saunders 1992).

Harris Lines

Skinner (1980) provided data on the presence or absence of Harris lines in the metaphyses and diaphyses of the long bones of the Seh Gabi infants. Two of 9 (22%) preterm to newborn individuals displayed Harris lines in the diaphyses of the long bones while 4/11 (36%) displayed metaphyseal Harris lines (figure 25). The two individuals displaying diaphyseal Harris lines also displayed metaphyseal bone scars; both of these individuals were assessed as 40+ weeks intrauterine skeletally and 36 weeks dentally (Skinner 1980). The pattern of Harris line distribution is radically different in the post-term individuals; 13/16 (81%) display diaphyseal Harris lines while 12/14 (86%) display evidence of metaphyseal lines. The low values in the preterm to newborns are a result of in vivo maternal buffering, which serves to alleviate the effects of both stressors external to the mother as well as internal stresses. In fact, it is surprising to find any evidence at all of repeated growth arrest and resumption in preterm to newborn children at all; this might suggest that maternal stress levels were quite high. The high frequencies of diaphyseal and metaphyseal Harris lines in Seh Gabi post term infants and children has been interpreted by Skinner (1980) as evidence for chronic malnutrition.

One of the Seh Gabi individuals (burial 29) was suggested by

Skinner (1980) to be severely stunted; there was a 1.6 year discrepancy between dental (3.3 years) and skeletal assessments. Interestingly, while the individual displays diaphyseal lines, there are no metaphyseal lines, suggesting the individual was so severely stressed at the time of death that they did not experience growth resumption prior to death (thus no opportunity for metaphyseal line formation). This would seem to lend support to Buikstra and Cook's (1980) suggestion that chronic stress may supress line formation. The same individual displayed linear and circular hypoplastic defects as well as extremely low cortical areas and PCA for both the femur and tibia. A similar pattern is found in burial 4, which is second highest for growth stunting and displays even lower cortical bone values than #29.

The Ganj Dareh sample displays a consistently lower rate of Harris lines; thirty three percent (2/6) preterm individuals displayed metaphyseal lines, but in contrast to Seh Gabi, none displayed diaphyseal lines (figure 25). In terms of post- natal individuals up to 3 years, 57.1% (4/7) displayed metaphyseal lines but only 14.3% (1/7) displayed diaphyseal lines. Individuals older than 3 years were removed to facilitate a more accurate comparison with the Seh Gabi sample. Almost all Ganj Dareh individuals over three years (4/5, 80%) displayed metaphyseal lines while only one individual displayed diaphyseal lines. Even when the 3 years and older individuals are combined with posterm to 3 year olds the frequency of Harris lines remains lower for the metaphyseal region (8/12, 66.7%) and the diaphyseal region (2/12, 16.7%). Numbers of Harris lines per individual ages 3-10 for the proximal tibia ranged from 6 to 19 Harris lines; the average for all four was 14.

The lower frequency of diaphyseal transverse radiopaque lines may mean two things; that the Ganj Dareh subadults did not endure chronic stresses resulting in repeated growth cessation and resumption, as the Seh Gabi babies appear to have, or, the diaphyseal lines in the Ganj Dareh subadults were removed as a result of remodeling via normal cortical drift. While the first

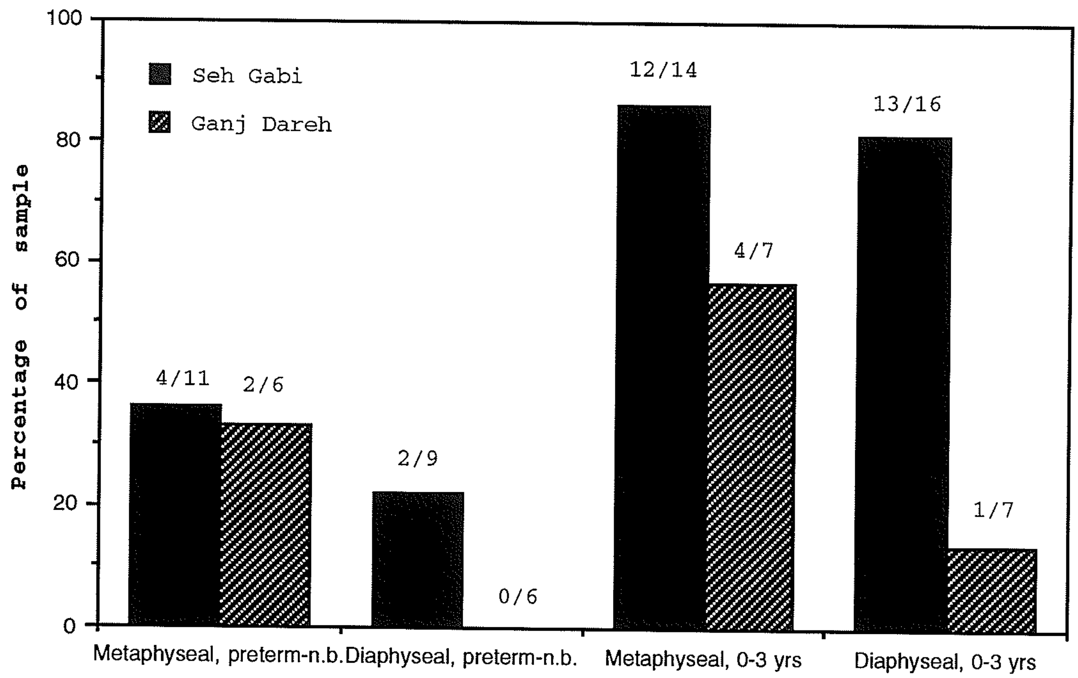


Figure 25. Distribution of Harris lines: Seh Gabi and Ganj Dareh

explanation is most likely the case, the latter cannot be discounted; figures 16 and 17 depict a very 'robust" pattern of cortical growth (thus uninterrupted cortical drift) in contrast to the comparative Nubian samples. As Enlow (1963) has demonstrated, growth of bone cortices is achieved via constant apposition and resorption of bone which continually alters the architecture and internal/external dimensions of bones. As a result, one would expect a greater number of Harris lines to be remodelled out as a result of cortical bone drift and V-principle long bone elongation.

While a number of authors have warned against placing too much faith in Harris line data, they may be used as a corroborative indicator of health in conjunction with other non-specific stressors. The lower frequency of Harris lines in the Ganj Dareh sample corresponds well with the cortical bone data gathered here, which indicates the Seh Gabi infants display greater evidence of growth disturbance than the Ganj Dareh sample.

Enamel Hypoplasias

Data for enamel hypoplasias have already been gathered by Skinner (1980) and Agelarakis (1989). Twenty three and a half percent (4/17) of the Seh Gabi babies possess linear hypoplastic defects (Skinner 1980) while the Ganj Dareh sample exhibits a rate of 30.8% [(4/13) Agelarakis 1989]. However, the reading of the hypoplasia data is not as easy as reading the simple frequencies as one has to take into consideration the age effects associated with hypoplasia data. In light of the considerable evidence of stress found in the Seh Gabi babies a rate of 23.5% is very low. Modern epidemiological studies have demonstrated a consistent relationship between enamel hypoplasia and malnutrition (Goodman 1992; Skinner and Goodman 1992; Sweeney et al. 1971). In rural Mexico, for example, 47% of children suffering from mild to moderate malnutrition displayed hypoplastic defects (Skinner and Goodman 1992). In the Mexican sample, the peak occurrence was between 18 to 36 months, much older than the mean age of the Seh Gabi sample (6 months). Thus, the hypoplasia rate, while probably high for individuals 0-18 months of age, is not truly representative of the population the Seh Gabi infants originated from. The real rate of hypoplasia would likely have been much higher in older age classes. Conversely, the Ganj Dareh rate of linear hypoplasias is not directly comparable with that of Seh Gabi as Ganj Dareh individuals older than 18 months consistently display evidence of multiple linear hypoplastic defects. After removing these individuals to facilitate comparison with the Seh Gabi sample, no individuals between post-term to 18 months (0/6) in the Ganj Dareh sample displayed linear hypoplasias, while 3/16 (18.8%) Seh Gabi individuals 0-18 months possessed linear hypoplasias (one Seh Gabi individual over 18 months with linear hypoplasia was removed). Four of 7 Ganj Dareh individuals older than 18 months had linear hypoplasias; all were between the ages of 2 and 8-11 years. Thus, based on the distribution of enamel hypoplasias, it appears that, again, the Ganj Dareh sample exhibits less evidence of stress than the Seh Gabi sample, at least within the first years of life.

The Seh Gabi sample displays a 53.8% rate of localised hypoplasia of the primary canine [(LHPC) Skinner 1986] while nearly all of the individuals examined in the Ganj Dareh sample (8/9; 88.9%) exhibit evidence of LHPC (Meiklejohn, n.d.). The Ganj Dareh sample also displays the highest rate of all four canines involved in any sample to date (C. Meiklejohn, personal communication). These figures pertain solely to post term individuals as the deciduous crowns of preterm and newborn individuals are not calcified enough to permit formation of these defects.

The difference between the two samples is immediately apparent; while the Ganj Dareh rate of linear hypoplasia is lower that of the Seh Gabi sample, the inverse is true of LHPC. The inverse relationship between the two indicators is not a source of confusion as there does not appear to be a correlation between

LHPC and linear hypoplasia (Meiklejohn et al. 1993), although it is interesting to note all of the Ganj Dareh subadults displaying linear hypoplasias also possessed Skinner's pits. However, this may simply be related to the overall high frequency of LHPC in the sample, although the meaning of the very high LHPC rate in the Ganj Dareh sample is unclear.

Based on detailed analysis of dietary recalls, Skinner (1986) and Skinner and Hung (1986, 1989) have suggested that there is no relationship between LHPC and malnutrition. They do suggest, however, that there may be a relationship between vitamin D deficiency and LHPC, arguing there is a relationship between low maternal vitamin D intake/endogenous production, calcium malabsorption, and thinning of the primary canine tooth crypt. As a result of vitamin D deficiency, bone overlying the crypt is thinned; by extension, as Skinner (1986) implies, long bone cortices should be thinned. Analysis presented here suggests this is clearly not the case. In fact, Seh Gabi displays much lower cortical areas and PCA, thus there should be a higher frequency of LHPC in the Seh Gabi sample. However, Dr. Skinner has suggested there may be an age effect in operation regarding the distribution of LHPC (C. Meiklejohn, pers comm. 1993), thus it may be a sampling error problem; the Seh Gabi sample mean age at death is simply lower than the peak age at formation of LHPC. An alternative explanation could be that the infant and childhood life experience in the Zagros was somehow profoundly different in the transitional Ganj Dareh population than it was in the later sedentary agricultural Seh Gabi population (e.g. greater chances or opportunity to traumatise the developing tooth related to childhood activity patterns). However, the most likely explanation is that the differences are a result of the age effect Dr. Skinner has recently detected in the age distribution of LHPC ((Meiklejohn, per comm. 1993. 1993), and/or sampling error.

Anaemia

The comparison of anaemic conditions between the two samples is difficult for a number of reasons. Data gathered by Agelarakis (1989) on subadult evidence for anaemia overestimated the number of very young individuals less than 1 year of age exhibiting or possibly displaying (as indicated by the designation 'indeterminate') evidence of anaemia. Mann and Murphy (1990) have noted that skeletal features found in very young infants may often be mistaken for signs of anaemia, particularly cranial pitting and striae. These features in fact are related to vascular structures and thin external cortices infants posses at birth. Other features often mistaken for anaemia at birth include 'porotic' basicranial elements and zones of hyperporosity found on the metaphyses of long bones in individuals less than 1 year old. These are, in fact, 'cutback zones' related to long bone elongation and cortical drift (Enlow 1963); the 'hyperporosity' is actually internal cancellous tissue that has been exposed in the course of resorption of metaphyseal periosteal cortex (Waddell n.d.). The Ganj Dareh subadults were re-examined for anaemic conditions; individuals under one year displaying the characteristic pattern of pitting and radiating striae of the frontal and parietals, metaphyseal cutback zones on the long bones, but displaying none of the standard diagnostic criteria of porotic hyperostosis or cribra orbitalia, were not considered anaemic.

The re-analysis of the Ganj Dareh subadults indicates that 5/20 (25%) individuals displayed evidence of anaemic conditions; 3/20 (15%) displayed evidence of cribra orbitalia while 4/20 (20%) displayed evidence of porotic hyperostosis (figure 26). It is interesting to note that individuals are all between the ages of 6 months to 2-3 years of age; none of the older individuals displayed evidence of cribra orbitalia or porotic hyperostosis. In all five cases the cranial and orbital lesions were slight to mild. It should be noted that most of the Ganj Dareh material is highly fragmented; in many cases the only area of the orbital

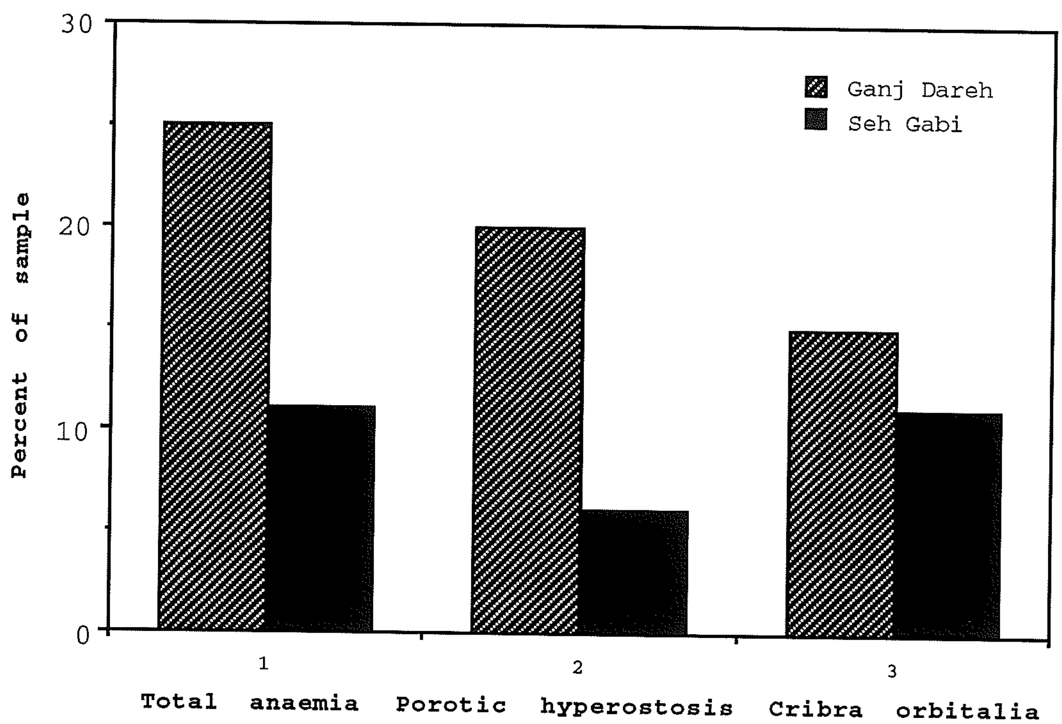


Figure 26. Distribution of anaemia: Ganj Dareh and Seh Gabi

region surviving was the anterior portion along the superior and lateral rim. Thus the rate of cribra orbitalia may be underestimated, although the rates calculated here are similar; Stuart-Macadam (1989) has noted that the frequency of cribra orbitalia is usually quite close to that of porotic hyperostosis.

The Seh Gabi sample, in contrast, displayed lower rates of anaemia as indicated by porotic hyperostosis and cribra orbitalia. Only 1/18 (5.6%) of postnatal individuals displayed evidence of cranial osteoporosis (Skinner 1980 in Rathbun 1984) while 5/18 postnatal individuals displayed evidence of cribra orbitalia (Skinner 1980). All of the individuals are 6 months or age or younger. However, Skinner (1980) noted some problems with the differential diagnosis of the Seh Gabi orbital lesions and Waddell (1989) has described the orbital lesions in detail. Of the five, only two are definitely of the cribriotic type; the other three lesions are nothing like cribra orbitalia, and in fact appear to be some sort of initially lytic or resorptive lesion of the orbital wall. In all cases the lesions are circumscribed by a layer of shell of reactive bone tissue, either overlying the orbital wall, or in some cases projecting slightly outwards to form a sharp ridge. Whatever the case, the lesions are clearly related to some sort of severe ocular infection and warrant further investigation. The presence of these lesions in three individuals, when ocular lesions of this type are generally a rarity in skeletal samples, suggests they may be of infectious origin. Excluding these the three cases of osteolytic/blastic lesions, cribra type lesions occur in only 2/18 (11%) postnatal individuals from the Seh Gabi sample.

While the cranial remains of the subadults were not radiographed to conclusively demonstrate the presence or absence of anaemia, the age distribution of the anaemias seems to suggest some form of late infancy /early childhood anaemia. A differential diagnosis is difficult due to the fragmentary remains and overlapping skeletal features of most anaemias, but conditions like iron deficiency anaemia, congenital anaemias (e.g.

thalassemia) and "milk anaemia of infancy" would have to be considered.

Infection

Skinner (1980) did not report on the incidence of lesions attributable to infection in the Seh Gabi sample, other than to report on the problems of differential diagnosis of the orbital lesions touched on above. However, a number of Seh Gabi infants (n=?) displayed 'double walling' of the diaphyses of long bones. At the present time, to the author's knowledge, Skinner has not conducted a differential diagnosis of these cortical hyperostotic lesions but infection must be considered along with congenital anaemias, rickets, infantile scurvy, infantile cortical hyperostosis, hypervitaminosis A, and a number of other conditions.

A number of Ganj Dareh infants and children displayed bony lesions possibly related to infection. Three individuals (# 1a, 14, 39) displayed slight to mild periosteal lesions which may be attributed to infection (Goodman et al. 1984). However, it should be noted that there are no criteria for distinguishing mild infectious lesions in children from normal episodes of rapid periosteal apposition associated with cortical drift (long bone modeling). Four individuals (#12, 14, 36, 38) exhibited possible involvement of the medullary cavity, mainly cancellous tissue in the midshaft or layers of sclerotic trabeculae lining the endosteal surface. At least one of these individuals (#14) displays definite evidence of osteomyelitis; the right tibia displays a relatively large puncture on the lateral surface surrounded internally by a rim of sclerotic tissue. Another individual (#25) displays a systemic condition affecting all limb bones. All long bones display a pronounced hyperporosity of bone cortices and concentric layers of bone tissue overlying each other. However, at this time it is not clear whether the condition represents chronic infection, congenital anaemia, or a metabolic disturbance. One individual (16) displays a layer of new bone formation on the floor of the maxillary sinuses characteristic of chronic sinusitis.

Micromorphology

A natural extension and companion to the research on cortical bone area would be to examine the microstructural features of the two samples. D. L. Martin and colleagues have investigated the interaction between cortical maintenance and microstructure in adults (Martin and Armelagos 1979; Martin et al. 1987), yielding some interesting evidence of a possible relationship between cortical bone health as measured by area parameters and osteonal resorption/formation rates. However, there appears to be a general reluctance to engage in microscopic analysis of immature bone due to its rather complex histological nature (Stout 1989, 1992). At this time there have been few attempts to analyse subadult micromorphology. Saunders and DeVito (1990) examined the micromorphological structure of subadult femorae (0-15 years; n=47) from the Raymond Dart skeletal collection.While the study was not necessarily of a biocultural bent, they did find some interesting patterns; most of the individuals displayed a large number of resorption spaces and 'wandering osteons', which they suggested was related to normal bone modeling.They also found that secondary osteons size was similar to that of adults. There also appeared to be consistent sex differences in the number of primary longitudinal canals, primary osteons, resorption spaces, secondary osteons and secondary canals, which largely reflected greater female bone turnover. In a more biocultural bent, Huss-Ashmore (1978, 1981) compared osteonal formation and resorption rates in healthy (those individuals within 1 S.D. of mean) and stressed (those outside 1 S.D. of the mean) individuals within the Wadi Halfa sample from Sudanese Nubia. The most obvious feature was the presence of large, active resorption spaces, especially near the endosteal surface of the cortex. While apposition of circumferential lamellae was more or less maintained it was often the only cortical bone present, as compact cancellous and lamellar bone of endosteal origin was completely resorbed (Huss-Ashmore et al. 1982). The ratio of formation to resorption spaces was determined in a small subsample of each group. For those near the mean, the amount of formation spaces exceeded resorption bays by a ratio of 3:2, whereas for those below the mean, resorption exceeded formation by a ratio of 5:2 (Huss-Ashmore 1981). While the quantification of osteoblastic versus osteoclastic activity may provide a potential means for distinguishing normal from pathological development, there may be some difficulty replicating and generating consistent results. Saunders (1985) has noted occasional difficulty in distinguishing between resorptive and forming bone surfaces under normal light microscopy, particularly in cases where the surfaces are not active (i.e. resting).

While no quantitative analysis of the Ganj Dareh and Seh Gabi cross sections was conducted, they were cursorily examined under a low power binocular microscope and a high power stage microscope under polarised light. The preterm individuals from both sites exhibited dense cortices of woven fibre bone peppered with the occasional short row of primary osteons, almost no resorption spaces, and a discontinuous, thin layer of circumferential lamellae. Both samples before the age of six months display the characteristic histological structure of healthy infants.

All of the post natal Seh Gabi infants older than 6 months displayed pronounced areas of intracortical porosity under low magnification. In some cases the porosity was distributed in a non-random fashion while in other cases the porosity was evenly distributed about the cross section. The porosity appeared to have been concentrated in a zone adjacent to the endosteal surface, extending from 1/4 to, in some cases, 2/3 the thickness of the cortex. Upon closer examination under higher magnification, these areas of porosity were clearly large resorptive bays. The resorptive bays often were interconnected and in most cases joined up with the medullary cavity. The largest resorptive bays were often contiguous with the surface of the medullary cavity and are obviously responsible for medullary cavity enlargement. These resorptive bays are not to be confused with regular histological features like primary, Non Haversian canals, Volkmann's canals, primary osteons and the like. Only two individuals displayed secondary osteons near the endosteal border.

Interestingly enough, a few of the Seh Gabi individuals appear to have lost all tissues of endosteal origin through resorption, leaving just a thin layer of circumferential lamellar bone. These individuals are identical to the severely osteoporotic individuals described by Huss-Ashmore (1978, 1981). In many cases the Seh Gabi post natal infants displayed extensive intracortical porosity, which under higher magnification were identified as resorption bays. This intracortical porosity is clearly not related to normal cortical drift or biomechanical factors as it encircles the endosteal surface and often permeates the majority of the cortex. The placement and pronounced nature of the porosity indicates endosteal and peri-endosteal resorption of bone tissue in response to stress.

In comparison to the Ganj Dareh post natal infants, the Seh Gabi infants also displayed very little active bone formation (as denoted by circumferential lamellar bone growth and obvious episodes of cortical drift). The Ganj Dareh infants by contrast display abundant evidence of active and well demarcated cortical drift, meaning the individuals were growing quite normally until the time of death. The Ganj Dareh post term infants and children display a typical pattern of small and sparsely distributed resorption spaces near the endosteal surface, with multiple intertwined layers of primary osteons in the middle third to half of the cortex, permeated by primary vascular canals. In individuals older than three years, secondary osteonal tissue has begun to replace primary osteonal tissue adjacent to the medullary cavity in a centripidal fashion. The periosteal surface is often undulated in appearance as a result of periosteal vessels gradually being converted into new osteonal tissue. In conclusion, the basic findings of this cursory microscopic analysis suggests the Seh Gabi sample was experiencing interrupted bone modeling and in some cases substantial bone loss.

CHAPTER IX

DISCUSSION AND CONCLUSIONS

The analysis of cortical bone growth and maintenance in the Early Neolithic Ganj Dareh and Chalcolithic Seh Gabi skeletal samples indicates that the Ganj Dareh subadults displayed a 'healthier' pattern of growth in comparison to the Seh Gabi sample. It was found that the total area of the cross sections between the two samples did not differ dramatically with the exception that Seh Gabi tibia total area growth slowed markedly after 9-12 months of age. Both samples exhibited a period of slowed growth in total area at 0-6 to 6-9 months of age, although growth was more diminished in the Seh Gabi sample.

The samples initially displayed similar medullary area growth patterns until 6-9 months, at which time Seh Gabi sample medullary area dramatically increases. This indicates a pronounced increase in endosteal resorption of bone tissue; the resorption of bone tissue in the Seh Gabi infants is greater in intensity and duration than one would expect in a normal physiological loss and likely represents an effort to maintain normal linear growth and maintenance of soft tissues by drawing upon endogenous stores of nutrients in the face of dietary deficiency. Postnatal stress due to illness may also have contributed to medullary cavity enlargement by enhancing any nutritional deficiency via malabsorption. A similar albeit less intense pattern of endosteal resorption has been identified by Huss-Ashmore (1978, 1981), Keith (1981) and Hummert (1983b).

The pattern of endosteal tissue loss is clearly reflected in the comparison of cortical area between the two samples. While both samples exhibit a drop of cessation of cortical area growth at 0-6 to 6-9 months related to normal physiological loss, after 6-9 months Ganj Dareh cortical area growth and maintenance consistently exceeds Seh Gabi cortical growth. Thus, while both samples exhibit similar total areas across all age classes after 6-9 months, the Ganj Dareh sample consistently contains more cortical bone, whereas the Seh Gabi cross sections have much larger medullary cavities. This pattern is also clearly reflected in PCA values; although both samples display an initial drop in PCA related to physiological loss, Seh Gabi PCA values after 0-6 to 6-9 months drop precipitously while Ganj Dareh values remain more or less constant.

The Seh Gabi PCA values indicate a seriously stressed infant segment of the parent population. PCA values do not display a recovery phase after 9 months, as is found in healthy populations (Garn 1970), or as demonstrated by the Kulubnarti sample (Hummert 1983b). In fact, the Seh Gabi pattern of PCA mirrors that of the Late Woodland Dickson Mounds sample examined by Keith (1981), with the exception that the PCA values for the Late Woodland Dickson Mounds sample eventually begin to recover after 18 months. Keith (1981) suggested the pattern of bone loss could best be explained as a result of childhood protein-calorie malnutrition.

The Ganj Dareh sample is more widely distributed across age classes than the Seh Gabi sample, thus it was possible to conduct a broader analysis. The Ganj Dareh sample displays a consistent, uninterrupted pattern of growth in all area measurements, although growth slows somewhat by 3 years and then resumes by 8-9 years of age. This 'plateau' pattern of maintenance without dramatic gains in growth during childhood is a reflection of the normal somatic growth pattern. The period of initial rapid growth followed by maintenance of area till late childhood reflects a healthy subadult segment of the total sample. Contrast this with Hummert's (1983) analysis of the Kulubnarti samples. Kulubnarti growth in total and cortical areas remains consistently low till 5 to 6-7 years, at which time growth accelerates. This reflects a pattern of infant and early to middle childhood stress with eventual catch-up growth.

The drop in Ganj Dareh PCA values from 1-3 years appears normal. PCA values remain more or less consistent until 6-7 years, at which time they begin to rise. Note that during this time Ganj Dareh PCA values are consistently higher than the Kulubnarti and other comparative sample values. In sum, analysis of cortical bone indicates that the Neolithic Ganj Dareh subadults display far less evidence of stress in early life in comparison to the sample from Seh Gabi. The Ganj Dareh sample exhibited healthy, thick cortices in all age categories and a 'robust' growth profile. The Ganj Dareh sample cortical data displays little evidence of growth disturbance attributable to weaning stress and childhood illnesses, although reduction in the pace of growth during childhood may indicate an increase in stress via weaning or childhood illness. While the Chalcolithic Seh Gabi infants were initially born with healthy, thick cortices, cortical area was rapidly reduced from birth onwards. Towards the middle of the latter half of the first year of life the Seh Gabi babies began to loose bone tissue rapidly, likely the result of increased exposure to potential pathogens coupled with a poor maternal diet and compromised immune system, all functioning in a synergistic manner to contribute to growth disturbance and illness.

While data on long bone growth was compiled for both samples, only the Ganj Dareh sample included individuals over 3 years. Comparison of long bone growth patterns is meaningful only if the sample contains individuals from all childhood age classes. It is apparent that the Ganj Dareh growth pattern is constant, not punctuated by periods of slowed growth during childhood as comparative samples depict. In fact the Ganj Dareh sample displays a relative high rate of growth from birth to 2 years, higher than all other comparative samples. While the Ganj Dareh sample does not display the longest lengths per age class in comparison to other samples, the growth pattern is that of a healthy subadult sample characterised by relatively little infant or early childhood stress. The uninterrupted nature of the rate of growth suggests an absence of any substantial chronic stress; that is, if individuals were chronically stressed in any fashion, one would expect suboptimal growth in long bone length over more than one age class. The periods of postnatal (0-12 months) and weaning stress (1-4 years) are ubiquitous to most archaeological samples and are often detected in linear growth patterns as a pronounced slowing or even cessation of growth. In the case of weaning stress, suboptimal nutrition in combination with diseases of childhood can delay linear growth up to the age of 6 or 7, as is the case with the Kulubnarti sample.

It has been often argued that Harris line data should be used with caution and only as a corroborative indicator in conjunction with other indicators of stress. The Harris line data presented here indicates that the Ganj Dareh sample did not experience repeated episodes of growth arrest nearly as commonly as the infants in the Seh Gabi sample did. The dramatically lower frequency of diaphyseal Harris lines in the Ganj Dareh sample suggests that the Seh Gabi sample experienced stress of a more chronic nature.

Distribution of enamel hypoplasias from 0-18 months of age seems to indicate that the Seh Gabi sample also experienced elevated levels of acute stress in comparison to the Ganj Dareh 0-18 month infants in which linear hypoplasias are non-existent. The difference between the two samples might represent a shift in the weaning pattern from the Neolithic to the Chalcolithic. The presence of hypoplasias in the 0-18 month old Seh Gabi infants (18.8%), in combination with a higher frequency of Harris lines may indicate an earlier age of commencement of weaning practices in comparison to the Ganj Dareh sample, which displayed no linear hypoplasias and fewer individuals with Harris lines at this age. Smith and Peretz (1986) found a similar pattern in a comparison of the primary and deciduous dentitions of Natufian hunter-gatherers and Early Arab subsistence farmers. The Natufian sample displays minimal hypoplasias of the primary dentition while the Early Arab sample exhibited a rate of 31% for the first primary molars. The authors suggested that the age of formation of the hypoplasias in the Arab sample (within the first year of life) denoted the presence of chronic stress, possibly malnutrition, arguing that "... health status in the Early Arab population was poor throughout life, affecting pregnant mothers, their foetuses, young infants and children" (Smith and Peretz 1986: 535).

Thus, the pattern of linear hypoplasias and Harris lines may be partially explained by an increase in disease load through time, either as a result of poorer nutrition or perhaps earlier supplementation of maternal milk supplies with traditional weaning food (which act as disease vectors and are often poor in vitamins and trace elements). The net result of any of these factors is an increase in frequency and duration of illness (Martorell 1980). Thus, there appears to be an increase in chronic stress (with possible overlying episodes of acute stress) reflected in the Seh Gabi infants, which in part may be due to a shift in age at which supplementation of maternal milk supplies with weaning foods commenced, hence earlier onset of the weaning process, or as a result of increased disease load and generalised malnutrition.

The infants and children in the Ganj Dareh sample appear to have endured less in the way of chronic stress, particularly during infancy. However, the distribution of linear enamel hypoplasias and Harris lines in individuals older than three years suggests a familiar pattern of childhood stress found in many archaeological samples. Fifty seven percent of Ganj Dareh children between 2 to 10 years displayed multiple linear hypoplasias and 80% displayed metaphyseal Harris lines. All individuals exhibited multiple Harris lines, on average 14. However, even though the Ganj Dareh children displayed abundant evidence of stress, it appeared to have not had a pronounced or chronic effect on somatic growth, as demonstrated by linear long bone growth and cortical bone growth and maintenance, although cortical area and PCA from ages 3 to 6-7 years do not grow appreciably. The pattern of linear hypoplasias and Harris lines, both of which are periodic indicators of stress (Goodman et al. 1984), in the Ganj Dareh children aged 2-10 years suggests the presence of weaning stress in combination with normal childhood illnesses and possibly seasonally related dietary stress. But long bone growth and to a lesser extent cortical bone growth and maintenance, both cumulative indicators of stress (Goodman et al. 1984), indicate that these individuals were able to rally effectively from periodic insults in such a way that somatic growth was relatively unaffected, unlike the Seh Gabi sample. The observed differences may be in part attributable to unhindered access to a seasonal abundance of foodstuffs during the early Neolithic, which allowed for catch up growth and obliterated any evidence of growth retardation, with the exception of periodic stress markers. Unhindered somatic growth was also likely enhanced by a lighter disease load than that experienced by the Chalcolithic Seh Gabi infants. While it would have been interesting to obtain an estimate of linear hypoplasia rates for the Shanidar subadults, even though Agelarakis (1989) collected data on hypoplasias, the sample was too incomplete to derive any meaningful figures. Only one of three scorable subadults displayed defects; interestingly, the individual was less than one year old.

The concomitant of increased disease load associated with increasing population density, predicted earlier age at weaning, and greater exposure to disease vectors in the Chalcolithic is difficult to assess. While Agelarakis (1989) included data on bony lesions attributable to infection, Skinner's (1980) analysis did not in a systematic fashion. The Ganj Dareh subadult lesions attributed to infection are difficult to interpret. While two of the individuals display indisputable evidence of infection, others display features which may be of non-infectious origin, an indirect result of trauma (burial 14), a result of cortical drift (1a, 14, 39), or the result of other unknown systemic conditions (25). With the exception of burials 14 and 25, all of the suspected infectious lesions are mild in nature. This pattern of low frequency and mild appearance of lesions is characteristic of low density, semi-sedentary hunter-gatherer populations with unhindered access to resources. While Skinner did not systematically collect data on infection, he did find three post-natal individuals who exhibited osteolytic/blastic lesions of the orbital floor that are clearly the result of some form of (endemic?) ocular infection. A few individuals also displayed 'double walling' of the long bone diaphyses. However, it is not clear whether these lesions are truly a result of infection (Goodman et al. 1984), congenital anaemias like thalassemia and sicklemia (Angel 1966, 1971), benign cortical hyperostosis (Caffey 1978), or metabolic disturbance (Caffey 1950).

As I have noted previously, malnutrition and cortical bone loss in children have been shown to be strongly associated with concomitant infections. It is conceivable that the increased endosteal resorption in the Seh Gabi infants may be indirectly related to infection as a result of the relationship between suboptimal nutrition, loss of cortical bone, and decreased immunocompetence. However, in this case it is impossible to determine if the loss of endosteal tissue is related to truly increased disease loads in the Chalcolithic, or is simply a reflection of greater chances of infection as a result of compromised immunocompetence associated with malnutrition.

The poor cortical health in the Seh Gabi babies is an expected result of the transition to agriculture for a number of reasons. Greater population density and increased sedentism have been attributed by many bioarchaeologists as leading to greater exposure to pathogens (Cohen 1989; Lallo et al. 1977, 1978; Goodman and Armelagos 1989). The proximity of domesticates leads to a greater exposure to potential zoonoses (Brothwell 1991). Agriculture leads to an increasingly narrow diet based on a limited number of dietary staples, which are themselves susceptible to failure (Cohen 1977; Flannery 1971 [1969]). This leads to an increasingly narrow and unstable subsistence base. The reduction of biodiversity of wild fauna (and presumably flora), which would normally act as a buffer against nutritional stress, would also contribute to dietary instability. The net result is a poorer diet, which may lead to periodic nutritional deficiency, An unstable dietary base results in periodic acute stressors overlaid upon an already chronically stressed diet. The poor diet of mothers leads ultimately to poorly nourished babies which are at greater risk of contracting infections.

It is an exercise in futility to ascribe the marked differences in cortical bone health in the Ganj Dareh and Seh Gabi babies to specific dietary and environmental factors. As I noted in Chapter V, loss of cortical bone can arise as a result of a number of different nutritional deficiencies, various (rare) genetic conditions, or through illness acting in concert with malnutrition. A number of authors have noted deficiencies of a single nutrient rarely occur in non-industrialised or third world contexts, and nutritional deficiency of a particular nutrient is usually part of a generalised malnutrition of protein, energy, or both (Adair 1987; Alleyne et al. 1977; Martorell 1980; Scrimshaw 1964, 1966). Even if specific deficiencies were to occur it would be unlikely that they would be identifiable in the immature skeleton as the overlying malnutrition and other specific deficiencies would alter the expression of skeletal features attributable to that specific deficiency. Medical research on malnutrition has identified a generalised suite of characteristics including skeletal stunting, cortical thinning, rarefaction of trabeculae, all indicative of a generalised reaction of the infant body to suboptimal nutrition and cessation of growth. In many cases, the characteristic features of specific deficiencies would not be present simply because of the lack of growth in malnutrition.

The Seh Gabi material exhibits a diverse array of skeletal pathologies: cortical thinning, rarefaction of metaphyseal trabeculae, a high frequency of Harris lines, a relatively high frequency of hypoplastic defects for age, as well as growth stunting, orbital resorptive lesions which appear to be of infectious origin, premortem fractures, and possible enthesopathies. In addition, a relatively high number of Seh Gabi babies appear to have died just after birth, or were stillborn (Skinner 1980). The presence of all of the above suggests a marked degree of stress in early infancy and childhood and, by extension, maternal stress.

The skeletal features present in the Seh Gabi babies, in conjunction with archaeological evidence for biocultural change as outlined in chapter 2, suggests the majority of Seh Gabi infants were suffering from generalised protein calorie malnutrition. Cortical thinning, rarefaction of metaphyseal trabeculae, growth stunting, high rates of linear enamel hypoplasia, and high frequencies of Harris lines have been reported in lab animals and children suffering from protein calorie malnutrition (Adams and

Berridge 1969; Barr. et al. 1972; Behar et al. 1964; El Nawaby et al. 1962; Dickerson and McCance 1961; Fleagle et al. 1965; Frandsen et al. 1954; Garn 1966, 1970; Garn et al. 1969; Garn and Rohmann 1964, 1966; Himes et al. 1975; McCance 1960; McCance et al. 1961, 1962; McFie and Wellbourn 1962; Platt 1961; Platt and Stewart 1962; Pratt and McCance 1958, 1960, 1964a,b; Stewart and Platt 1958; Widdowson and McCance 1962). I suggest the Seh Gabi infants were likely suffering from marasmus, a form of PCM characterised by growth stunting (more so than kwashiorkor) and gross wasting of muscle and subcutaneous tissue (Alleyne et al. 1977). Marasmus is a chronic condition, as opposed to the acute nature of kwashiorkor; marasmus also occurs primarily within the first year of life whereas the peak occurrence of kwashiorkor is between one to two/three years of age. Marasmatic children are also predisposed to suffering from multiple infections; in both cases incidence has been linked to shorter duration of breastfeeding (Alleyne et al. 1977).

Malnutrition in underdeveloped third world nations has been identified as the most prevalent nutritional disease today (WHO 1972). Data from Aylward and Jul (1975, in Johnston 1980) indicates that in a cross section of countries from Africa, Central America and Southwest Asia, approximately 20-35% of all children 1-2 years old suffer from moderate to severe PCM, averaging only 75% of the recommended daily allowance of calories and protein. Martorell (1980) indicates that upwards of another 50% may suffer from mild protein calorie malnutrition. Prolonged protein calorie malnutrition can have a dramatic affect on children, as Johnston (1980) notes:

> "... the effects of malnutrition are most profoundly evident in infants, children, and youths, all of whom require additional levels of most nutrients to support the growth of new tissue and the maturation of existing systems. The effects of chronic malnutrition on growth may be permanent and, even if not permanent, may serve as a significant risk factor for the development of subsequent disease states and conditions" (Johnston 1980: 3).

The overwhelming nature of the paleopathological evidence for early infant and childhood stress in the Seh Gabi sample suggests women of childbearing age during the western Iranian Chalcolithic were also suffering from nutritional and disease related stress. If the mothers of the Seh Gabi children were severely stressed the production of milk may have been severely curtailed both qualitatively and quantitatively. Maternal malnutrition can have a devastating effect on the well being of the developing child and may also affect the quality of maternally acquired immunocompetence as the natural anti-infective properties of milk may be reduced (Faber 1980). If the mothers were malnourished, the malnutrition may have been longstanding, as is often the case in developing nations (Adair 1987; Martorell 1980; Scrimshaw 1964). In such cases the mother has usually been malnourished during pregnancy and in many cases even before;

> "Her body stores have been depleted by chronic malnutrition and, in most cases by previous pregnancies. The stress of her economic situation may be another factor by decreasing her milk output. Furthermore, the odds are that her baby is relatively underweight due to intrauterine malnutrition, and therefore, his post natal nutritional needs are more urgent. Even if those needs are partially met, the mother will pay the price of her infants growth by aggravation of her preexisting malnutrition" (Faber 1980: 36).

This would have set in motion a cycle of infection-malnutrition which would eventually lead to 'cortical dumping' in both women of childbearing age and their infants. Bone tissue would rapidly be resorbed from long bone cortices endosteally in an effort to maintain as close as an approximation to normal somatic growth as possible.

A number of authors have presented evidence suggesting reduced birth spacing and earlier age at weaning in agriculturalists as opposed to hunter-gatherers (Blurton-Jones et al. 1992; Lee 1972; Sussman 1972). Suboptimal nutrition of infants during the Chalcolithic may have been further aggravated by an earlier age at weaning. In what eventually becomes a vicious cycle, earlier weaning age may have been the indirect result of poor maternal milk production which in itself is often related to high parity and associated lower age at weaning. With earlier weaning, cereals or gruels may have been introduced to fill the void caused by poor milk production, further aggravating any existing dietary deficiency. The introduction of cereals and starchy gruels in place of maternal milk has been shown to exacerbate existing deficiencies (Scrimshaw 1964) and lead to increased infection (Martorell 1980).

Malnourished infants are highly susceptible to infection, particularly weanling diarrhoea (Martorell 1980). Most prominent in the second year of life, weanling diarrhoea is the result of "...various environmental and host factors [which] combine to cause a peak in both malnutrition and massive enteric infection during the weaning and post weaning period" (Scrimshaw 1964: 112).

Subadult malnutrition in Iran has been reported by various authors (e.g. Caughey 1970, 1973). Symptoms range from simple growth retardation to those of severe malnutrition, including eunichoid proportions, iron deficiency anaemia, low zinc levels, and hypovitaminosis A. Infectious diseases invariably aggravates existing malnutrition and the consequences are more serious in a malnourished host. Mohadjer and Badalian (1968) found that chronic diarrhoea is probably the most significant factor in inducing malnutrition in Iran; Shigelloses were most frequently found, followed by Salmonella, E. coli and amoebic conditions. These organisms are commonly found in diarrhoea associated with malnutrition (Scrimshaw 1964). Parasitic infestation may also lead to protein malnutrition; Caughey (1973) found that Iranian children suffering from protein malnutrition frequently were infested with ascariasis and helminthes. Protein malnutrition in Iranian infants has also been associated with malabsorption syndromes, in particular tropical sprue, a long term malabsorption of nutrients in the small intestine (Creamer et al. 1970). Halsted and Prasad (1960) in a discussion of the association between delayed skeletal maturation and dwarfism and malnutrition in Iranian children emphasised the interaction of multiple deficiency states in the etiology of malnutrition; a combination of a low protein diet combined with high phytic acid and low vitamin C, resulting in iron deficiency anaemia and low zinc values, characterised childhood malnutrition in this area.

The findings that, in general, the Ganj Dareh infants are much healthier in terms of cortical health and non-specific stressors when compared to the Seh Gabi babies is not really surprising in light of the health effects associated with the agricultural transition. These include reduced birth spacing, earlier age at weaning, increased infant mortality, increased incidence of non-specific stressors associated with poorer maternal nutrition as a result of reduction of dietary breadth, instability of the subsistence base, increased chances of infection associated with higher population density and increased sedentism, as well as exposure to zoonoses, proximity to fecal wastes, and poor sanitation.

In his analysis of the Seh Gabi remains, Skinner (1980) concluded that "... a strong case can be made for suggesting that Seh Gabi and probably other Middle East Late Neolithic [actually Chalcolithic] sites in similar ecological zones were characterised by recurrent bouts of malnutrition and movements of peoples" (Skinner 1980: 280). It is possible that, as a function of the difficulty in eking out a living in a marginal environment, people were forced to move on a regular basis to obtain enough food to ensure their survival.

It appears that the advent of the Chalcolithic and its technological and social concomitants had a deleterious effect on infants and children in other areas of the Middle East as well. Kurth and Rohrer-Ertl (1981, in Smith et al. 1984) have observed that subadults from the Levantine Chalcolithic site of Ghassul exhibited poorly developed and thinned long bone cortices for size in relation to length. They also found all individuals displayed Harris lines (average of 6 lines per individual), enamel hypoplasias and cribra orbitalia. However, the authors did not quantify these observations. Smith et al. (1984) suggested a shift in subadult health, similar to that found here, may exist between

Levantine Neolithic and Chalcolithic. The authors found a dramatic increase in adult hypoplasias from the Neolithic (34-38%) to the Chalcolithic (80-100%) and also noted that enamel hypoplasias appeared with some regularity in the Chalcolithic primary dentition. Smith et al. (1984) suggested that children were being weaned at an earlier age during the Chalcolithic than the Neolithic and that this finding was comparable with a presumed decrease in birth interval. Like Kurth and Rohrer-Ertl, Smith et al. (1984) did not quantify these observations, but they do hint at the possibility of fairly substantial biological consequences associated with the intensification of agriculture from the Neolithic to Chalcolithic throughout the Middle East.

It is apparent that malnutrition was prevalent during the Chalcolithic in the Zagros; the question becomes one of how malnutrition and associated illness interacted with the weaning process. It is plausible that malnutrition (or at least suboptimal nutrition) may have a hand in reduction of weaning age as poor maternal milk production would have to be supplemented by traditional weaning foods at an early age. However, while the problem is an intriguing one, it is too complex to deal with in any detail here, but warrants future consideration.

Skinner's assertion that the Chalcolithic period in the region was characterised by movements of people and recurrent bouts of malnutrition may actually be reflected in the archaeological record of the region. Sedentary agricultural hamlets seem to have been the rule throughout most of the Zagros region in the Early Chalcolithic (Henricksen 1985 a,b), possibly as a result of climatic amelioration which began in the Late Neolithic. While village life in the Chalcolithic may have been widespread in the western Zagros, it may have been a difficult proposition in some areas, particularly along the periphery of newly expanded habitation zones. For example, McDonald (1979) has found evidence of repeated abandonment and resettlement in the Early Chalcolithic occupation at Seh Gabi. Prior to the Shanabad phase occupation, the area appears to have been unoccupied The high altitude and location in an intermontane saddle may have rendered Seh Gabi susceptible to small climatic oscillations.

In a regional perspective, Henricksen (1985a,b) has indicated a wholesale abandonment of sedentary agricultural villages in the western portion of the Zagros during Middle and Late Chalcolithic times associated with a shift to nomadic pastoralism. The stimulus appears to have been a climatic deterioration which made sedentary (or at least semi-sedentary) agriculture untenable, and after a period of instability, as reflected by a decrease in site size and density, most people in the region appear to have reverted to a nomadic pastoralist adaptation. Such a drastic change in settlement pattern was probably the result of the simple untenability of agriculture under less than optimal environmental conditions. This was probably the result of poor crop yields and frequent crop failures interacting with increasing population density and a reduction of wild flora and fauna within the catchment area of the agricultural villages.

The reversion to nomadism was probably not as difficult as some authors have argued (e.g. Redman 1978), as pastoralism may have played a supporting role in even the most sedentary Neolithic and Chalcolithic agricultural communities in the Zagros. It is conceivable that the importance of pastoralism in the prehistoric Zagros lay in the fact that it provided a readily available source of protein and fats, something especially important in light of the decrease in available protein often associated with the agricultural transition. For example, Cohen (1989) has suggested that the sedentism associated with agriculture has the net effect of reducing access to animal foods by restricting group movement and by accelerating the disappearance of wild game in the vicinity of human settlements (Cohen 1989:58). This latter point is reflected in the local zooarchaeological record (Bökönyi 1977). Another benefit of reverting to pastoralism would be an increase in accessibility to wild flora and fauna; in an area of low resource density one can increase accessibility simply by increasing area of coverage. In effect, by increasing the foraging area of a group, pastoralism would allow for a more diversified diet in humans as well as stock.

It would appear that the Ganj Dareh people (or at least their infants and young children) were healthier than expected. This may be explained in part by the fact that Ganj Dareh was an Early Neolithic site; the inhabitants were just beginning the long process of the agricultural transition. The drawbacks associated with the agricultural transition had yet to reach levels where they became detrimental to human health and the local environment. It is interesting to note that Smith et al. (1984) found a similar pattern in the Natufian/Neolithic transition in the Levant.

The general impression is that the Ganj Dareh peoples were actually quite healthy in terms of skeletal pathologies. But what could account for such a pattern? Analysis by Agelarakis (1989) does not indicate an appreciable deterioration in health from the Proto-Neolithic to Neolithic, a finding which runs contrary to the prevailing generalisations regarding deterioration of health with the transition to agriculture. As I have already noted, even though the Ganj Dareh peoples are Neolithic, they were probably just beginning to experience many of the drawbacks associated with the agricultural transition. There is also the possibility that the people of Ganj Dareh engaged in a mode of subsistence that represented an optimal combination of subsistence strategies for the Zagros highlands during the Early Neolithic. Incipient agriculture in combination with an already existing seasonal transhumance established in the Epipaleolithic and Proto-Neolithic and some early form of pastoralism may have permitted a substantial degree of seasonal sedentism. A diversified subsistence strategy combining the benefits of incipient agriculture, hunting and gathering of seasonally abundant resources, and the incipient domestication of sheep/goats and/or sustained culling of local wild herds would have been an optimal subsistence strategy in the relatively pristine Early Neolithic environment. Low population density would have permitted relatively unrestricted mobility and unhindered access to resources and hunting yields would certainly have been superior to those of the Chalcolithic as population densities of the Early Neolithic would have not had a substantial impact on forest clearance and density/diversity of wild resources. Seasonally available plant resources could be effectively gathered in nearby upland valleys by small task groups, whom at the same time may have engaged in some form of limited pastoralism or culling activity. The development of substantial means of storage and durable architecture, coupled with a diversified subsistence base would have enabled the inhabitants to reside in the village for greater lengths of time. Whether full time sedentism was possible or even occurred is a point yet to be resolved

Recommendations for Future Research

A natural extension and companion to research on cortical bone area would be to examine the microscopic histology of the two samples as Huss-Ashmore (1978, 1981) has done with the Wadi Halfa sample. Since preservation of histological structures in both subadult samples is excellent, microradiography of the cross sections would enable an estimation of the relative ratios of forming versus resting and resorptive bone surfaces and quantification of active bone formation. This information could then be used to independently confirm or dispute the results of the cortical area analysis.

Trace element analysis would yield invaluable evidence of paleonutrition, particularly the presence of deficiency states. While most multiple element studies have focused on zinc, copper, manganese, magnesium, and strontium, most single element studies have focused on strontium and lead, and to a lesser extent, iron (Sandford 1992). Schoeninger (1981) examined strontium/calcium ratios in the Ganj Dareh adults as well as a Neolithic sample from Hajji Firuz in Azerbaijan, concluding that the strontium calcium ratios from the two sites reflected the traditional emphasis on sheep and goats in the Zagros. Gilbert (1985) has suggested that, based on a dietary analysis of foods eaten by agriculturalists and hunter-gatherers, that elements like zinc and copper should increase in high meat consumers (hunter-gatherers), while magnesium and manganese and strontium levels have been predicted to be higher in vegetable consumers (agriculturalists). The analysis of trace elements would go a long way to clarifying the transition from hunting and gathering to agriculture in western Iran, and in particular, would aid in delineating the position of nomadic pastoralism in this continuum.

More specifically, the analysis of single elements would help to shed some light on the time depth of particular dietary practices and their affects on human growth and health. For example, a number of authors have demonstrated the potentially deleterious affects of a heavy reliance on unleavened unprocessed cereals in Iran. As a result of high phytate concentrations, a number of trace element deficiencies have been observed in the modern population, most notably, zinc deficiency. Zinc deficiency has been observed to produce skeletal stunting as well as a number of other skeletal anomalies and has been detected in archaeological populations as a concomitant of the transition from hunting and gathering to agriculture (Gilbert 1975). It would be interesting to carry out a long term diachronic analysis of zinc levels in prehistoric populations from the region; in addition to demonstrating zinc deficiency (obviously of great interest to paleopathologists) it would also give us an indication of the time depth involved in the reliance of unprocessed cereal grains as a dietary staple, as Bisel (1981) has done for Greek materials.

The possibility of a shift in infant weaning practices from the Neolithic to Chalcolithic is intriguing. As the data on enamel hypoplasia and Harris lines lines have hinted, there may be a shift in the age at which infants began to be actively weaned, and / or earlier supplementation of the weaning diet in the Chalcolithic. In fact, it appears that this shift in weaning age may be found in other areas as well during the Neolithic and Chalcolithic (e.g. the Levant). Trace element analysis would also be able to help in determining if there really is a difference in weaning pattern. Sillen and Smith (1984) and Yuorinen et. al (1990) have detected changes in the age distribution of strontium/calcium ratios, which they attribute to the advent of introduction of weaning foods. If it were possible to obtain large enough skeletal samples for the Neolithic and Chalcolithic it may be possible to conduct an analysis of Sr/Ca ratios in an effort to detect the timing and differences of weaning.

However, as Smith and Peretz (1986) argue, high rates of enamel hypoplasia during the first year of life may be more indicative of chronic stress and malnutrition in infants and mothers. Clearly, the differentiation between weaning stress and malnutrition/chronic stress during the Chalcolithic needs to be resolved. To answer such a question, larger sample sizes with more individuals in all age classes is needed. The age at formation of Harris lines and enamel hypoplasias (not systematically investigated here) would provide invaluable information which could potentially separate the two processes, or perhaps give some insight into the relationship between the two.

Despite moderate to heavy attrition, analysis of age at formation of linear enamel hypoplasias and Harris lines in adults may also help clarify the exact timing and intensity of weaning stress in the Neolithic and Chalcolithic. Preliminary analysis by Agelarakis (1989) indicates that both the Proto-Neolithic Shanidar sample and the Ganj Dareh sample display relatively high rates of linear enamel hypoplasia. Quantification of the timing and frequency of hypoplasias between the samples and according to sex would provide an indication of any shift in weaning practices and childhood stresses, as well as any indication of differential access to resources by sex, or maternal stressing, as Lukacs (1992) has found in Harrappan agriculturalists. However, this may only be possible for the Proto-Neolithic and Neolithic as very few adult skeletal remains have ever been recovered from Chalcolithic contexts in western Iran.

The results of the analysis of the Seh Gabi infants are very intriguing. The high rate of pathology exhibited by the sample suggests that the mothers of these children were themselves seriously stressed. As such it would be interesting to obtain skeletal samples of women of childbearing age from the western Iranian Chalcolithic to see if the stresses seen in the Seh Gabi babies are reflected in child bearing women. Stress would be reflected in pelvic inlet diameter and height, cortical bone dimensions, osteonal turnover rates, linear hypoplasias, Harris lines, fluctuating dental and postcranial skeletal asymmetry, high sexual dimorphism, etc... .

If there is any future work to be done with subadults in the region a set of reliable growth standards needs to be established, to which one can refer to. The samples analysed here are far too small to be of any use in constructing reliable growth standards. It would be of inestimable value to derive growth standards from a reasonably large sample, such as the sample of over 200 subadults identified at the northern Mesopotamian site of Tell es-Sawwan (Singh 1974). However, as is the case with many sites in the region, it is not known if the remains were actually excavated and removed, and if they were, were the exact location of the remains is. Other Chalcolithic samples from the region should be examined to see if the same pattern of stress is present. Small samples of infants and children (n=<20) have been recovered from Chalcolithic sites to the north in Azerbaijan (Dalma Tepe, Tepe Seavan).

The question of malnutrition in infants is an interesting one and a potentially exciting topic in paleopathology. Paleopathologists should, when dealing with suspected cases of malnutrition, examine and radiograph infant remains for evidence of skeletal indicators of malnutrition such as coarsened trabeculae in metacarpals and metatarsals and multiple or anomalous centres of ossification. Obviously, this kind of detailed work would require the aid of field archaeologists excavating remains from such sites; care should be taken to recover all podial elements and centres of ossification should be bagged and identified separately.

Finally, the issue of resolution between using cortical bone area as an indicator of nutritional stress or as a biomechanical indicator in subadults needs to be resolved. The point at which childhood activity patterns obscure the ability of cortical bone area as an indicators or stress and health needs to be delineated. It would be of great interest to physical anthropologists in general if one could determine by means of biomechanical analysis the point in life at which subadults began to take on adult responsibilities and duties (see Appendix A).

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APPENDIX A

Area Measurements and Biomechanics

In the past the analysis of adult cortical bone dimensions has been used as a means of assessing nutritional and general health status within and between skeletal samples (Carlson et al. 1976; Dewey et al. 1969; Ericksen 1976; Owsley 1985; Van Gerven 1973; Van Gerven et al. 1969). However, the biomechanical study of cortical bone indicates that measures of area, while in part related to nutritional status, are more a function of axial compressive and tensile mechanical loadings and do not reflect age changes in geometry and associated properties other than simple bone density (Bridges 1984; Ruff and Hayes 1983 a, b; Ruff 1992).

Recent research by Van Gerven et. al, (1984, 1985), Sumner (1984), and Ruff (n.d. in Ruff 1992) has cast some doubt on the traditional nutrition based interpretive framework of cortical area in subadults as well (e.g. Cook 1984; Hummert 1983b; Huss-Ashmore 1981; Keith 1981; Mays 1985). Nutritionally based interpretations of PCA have hinged on the assumption that a decline in area measures like CA and PCA and an increase in MA are the direct result of nutritional stress or disease processes and represent the loss of ability cope with whatever external stressors are acting upon the given individual or sample. However, recent work by Van Gerven et al. (1984, 1985, 1993), Ruff and Hayes (1983 a,b), Ruff (n.d. 1992) and Sumner (1984) has indicated that bone loss, particularly as measured by PCA, must be interpreted with great caution.

While the application of a biomechanical paradigm has led most authors to discount the value of cortical bone as an indicator of health in adults, the problem is not as clear cut in dealing with subadults. Ruff and Van Gerven and co-workers have demonstrated, in the course of normal subperiosteal expansion (leading to larger TA's) and concomitant endosteal resorption (leading to larger MA's), a decrease in PCA (as has been noted by

Van Gerven et al. 1984,1984, 1993 in later childhood) may actually indicate an increase in bending and torsional strength. Such as decrease in PCA and a concomitant increase in CSMI (cross sectional moment of inertia) will occur when there is an expansion of the total area within the subperiosteal envelope. Van Gerven et al. (1993) have found this to be the case with Puebloan juveniles and Van Gerven et al. (1984, 1985) have found the same pattern in Nubian juveniles as well. These findings have led Ruff (1992) to argue that the interpretation of negative trends (such as a drop in PCA) as necessarily detrimental to skeletal integrity is unwarranted.

The interpretation of area values and PCA in later childhood should probably be within a biomechanically based context. However, our understanding of the biomechanical behaviour of infants and young children is almost non-existent and there are a few factors which I argue would confound an orthodox biomechanical interpretation. First, it appears that long bone diaphyses in infants contain 'extra' bone tissue, a condition termed infantile cortical osteosclerosis (Caffey 1978). The amount of bone tissue present in infants is clearly related to the needs of the rapidly growing infant skeleton and soft tissues. The extra bone tissue seen in subadults may simply be an evolutionary mechanism by which the body ensures there is an ample supply of materials necessary for growth. The 'extra' bone acts an a buffer to the environment; thus even in times of nutritional stress the body still has enough tissue to maintain growth. As is well known, infants and young children are highly susceptible to growth disturbance; in cases where evidence of cortical loss is backed up by multiple non-specific indicators of stress (such as here), I think an argument can be made that measurement of bone area is a valid tool for the assessment of health in infants and young children. In these cases PCA can be seen as a true indicator of nutritional and environmental stress.

The problem becomes one of trying to differentiate between nutritional and health related changes in cortical bone area measures, and changes related to the development of activity patterns. Exactly when the subadult skeleton begins to respond to mechanical stress and reflect culturally controlled activity patterns is an issue that has yet to be investigated (Knüsel 1993). While not exactly the same as adult activity patterns, children should be expected to display a general pattern of bone adaptation related to activity regime. The question of when children begin to assume adult related tasks is important in the development of bone areas and cross sectional geometry, as assumption of adult duties and tasks will lead to substantial alterations in cross-sectional geometry (e.g. Van Gerven et al. 1993). One could also expect differences between groups with different subsistence patterns that should be reflected in the cortices of the late children to adolescents. For example, hunter-gatherer children would be more likely to travel longer distances than agriculturalists while agriculturalist children may be expected to engage in manual labour in the fields at an earlier age than hunter-gatherer children would be expected to contribute to household labour. General considerations like topography should also have the same effect that it does in adults.

This may explain the substantially different area values for the Kulubnarti sample in comparison to Ganj Dareh. While I have suggested here that the lower area values displayed by Kulubnarti in comparison to Ganj Dareh may have been a result of prolonged weaning stress and childhood illness, they may be partially a result of mechanical stress.

Ruff et al. (1984) interpret the reduction in TA, CA, and MA from Georgian Coast preagriculturalists to agriculturalists as evidence for change in activity;

> "(T)he percentage decline in medullary area (MA) is larger than in CA or total subperiosteal area (TA). Thus, CA tends to be relatively more tightly distributed about the section centroid in the agricultural group, with a relatively smaller medullary canal (i.e., the MA/TA ratio is smaller). The declines in the maximum second moment of area (I max), minimum second moment of area (I min), and polar second moment of area (J) in the agricultural group result from both a decline in absolute CA and this inward redistribution of bone area"

(Ruff et al. (1984: 128).

Thus, while cortical bone area relative to bone length remained approximately constant, the distribution of bone area changed, with a relative reduction in both medullary (MA) and subperiosteal (TA) dimensions in the later agricultural group, leading to a tighter distribution of bone area about the section centroid. This in turn decreases second moments of area of the sections, thus reducing bending and torsional strength of the femur in the later sample. So, in the case of a large cross section with the same amount of bone as a comparatively smaller cross section, the larger cross section would have a more optimal distribution of bone, thus higher bending and torsional strength.

The Ganj Dareh material not only displays consistently larger MA and TA values than the Kulubnarti sample (thus by extension greater bending and torsional strength) but also has greater cortical areas up to 8 to 9 years in comparison to the Kulubnarti samples. Is the substantial difference in TA/MA/CA between Ganj Dareh and Kulubnarti after 2 to 3 years of age a result of nutritional differences or biomechanical environment? Local environment and terrain and differences in technology and subsistence/activity regimes might account for the observed differences between the samples. In late childhood and onwards, the Ganj Dareh subadult cortices are robust; could this be a result of rugged terrain and subsistence patterns? The consideration of developmental patterns of cortical bone growth and cross sectional geometry in older children and adolescents from archaeological samples warrants further consideration. After all, as Knüsel (1993) points out, adult bone geometry does not suddenly appear in adulthood, but is the result of lifelong forces shaping the bones.

Appendix B, Table 1. Seh Gabi raw bone area scores

	Right femur				Left femur				Right tibia				Left tibia			
B.#	TA	MA	CA	PCA	TA	MA	CA	PCA	TA	MA	CA	PCA	TA	MA	CA	PCA
1	31.00	4.50	26.83	86.55					26.33	6.67	19.83	75.31				
2	55.33	10.5	43.67	78.93					66.83	26.33	42.0	62.85				
3	46.00	15.83	31.33	68.11					38.33	12.83	27.0	70.44				
4					106.33	50.33	55.0	51.73					91.67	51.0	41.67	45.46
5	24.67	3.83	20.33	82.41												
6	22.83	3.00	20.33	89.00					21.0	2.67	17.33	82.52				
7	27.67	3.50	23.33	84.32					29.0	5.83	23.0	79.31				
8	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	
9	35.67	10.17	25.67	71.97					31.83	8.5	23.33	73.30				
10	38.67	6.33	31.33	81.02					33.0	10.67	26.00	78.79				
11	58.33	14.5	44.5	76.29					52.0	19.83	32.67	62.83				
12	36.17	8.33	28.17	77.88					34.0	9.17	25.00	73.53				
13	45.67	18.0	27.67	60.59									44.5	18.33	26.5	59.55
14	41.67	12.5	29.17	70.00									38.33	12.83	25.5	66.53
15	46.0	20.67	22.17	48.20					43.5	21.5	25.33	58.23				
16	67.67	24.83	42.83	63.29					53.67	19.5	34.17	63.67				
17	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	
18	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	
19	13.0	2.0	11.0	84.62					11.17	2.17	9.00	80.57				
20	29.67	5.0	24.67	83.15									30.0	5.83	24.17	80.57
21	35.17	6.33	28.83	81.97					33.83	5.33	28.50	84.25				
22	33.17	4.0	29.17	87.94					31.17	5.00	26.17	83.96				
23	34.17	3.5	30.67	89.76					30.50	5.67	24.83	81.41				
24	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	
25	53.0	8.0	45.0	84.91					52.83	12.83	40.33	76.34				
26	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	
27	50.67	8.17	42.83	84.53					41.00	10.67	30.33	73.96				
28									89.75	49.00	40.75	45.40				
29	101.5	40.67	60.83	59.93									91.67	35.83	55.5	60.54
30	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	
31	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	

Appendix B, Table 2. Ganj Dareh raw bone area scores

	Right femur				Left femur				Right tibia				Left tibia			
B.#	TA	MA	CA	PCA	TA	MA	CA	PCA	TA	MA	CA	PCA	TA	MA	CA	PCA
2					125.0	24.00	101.33	81.06	122.3	26.33	96.33	78.75				
2 dist									122.7	28.00	92.67	75.54				
7	28.33	3.33	26.33	92.94					25.67	4.16	20.83	81.15				
10	248.0	90.33	163.0	65.73					211.7	57.00	152.2	71.89				
10prox									217.3	67.50	155.0	71.32				
10dist																
	12	30.66	4.33	26.33	85.88									28.00	4.33	23.17
82.75																
12B													29.17	5.50	23.50	80.56
14	103.3	38.00	68.33	66.13									135.5	43.33	89.00	65.68
14prox	102.3	35.00	68.66	67.10												
14dist													129.0	37.17	93.33	77.00
14B	132.7	38.66	94.33	71.11												
14Bprox	141.7	42.17	99.33	70.12												
14Bdist	142.7	54.22	87.33	61.22												
16	169.7	68.00	100.3	59.14					154.3	59.50	99.33	64.36				
16dist									147.2	46.33	100.3	68.17				
21					23.33	9.17	14.00	60.01					18.67	8.50	9.5	50.88
25	65.66	14.00	49.33	75.13					44.50	12.33	32.67	73.42				
25dist									43.83	13.00	26.67	60.85				
26	20.33	4.33	15.66	77.03									19.00	5.67	13.33	70.16
27					20.66	5.33	14.66	70.96								
32	41*	12*	30*	73.17												
36	92.0	25.83	65.17	70.84					18.67	8.50	9.50	50.88				
38					120.3	40.00	78.66	65.37					98.33	26.83	67.67	68.82
38 dist													96.67	27.83	68.00	70.34
1153	36.33	8.33	25.66	70.63					30.33	8.17	22.33	73.62				

Appendix B, Table 3. Seh Gabi tibia and femur length

B.#	Right femur	Left femur	Right tibia	Left tibia
1	75.5	est mdshft	66.0	est mdshft
2	97.05	est mdshft	----unsided	-est mdshft----
3	95.45	95.15	82.35	-----------
4	------------	102.2 (125)	------------	107.1*
5	est mdshft	est mdshft	------------	-----------
6	63.4	63.7	56.05	56.5
7	79.4	------------	68.15	67.95
8	------------	------------	------------	-----------
9	86.95	84.3*	73.6*	75.7
10	84.95	est mdshft	71.3	est mdshft
11	est mdshft	est mdshft	------------	78.05
12	83.0*	------------	75.7 [?]	-----------
13	82.4 (frag)	------------	70.75*	est mdshft^
14	89.0	89.6	75.15	75.1
15	96.6	94.4	75.8 *	74.8*
16	105.0 (115.0)	est mdshft	90.5	est mdshft
17	------------	------------	------------	------------
18	------------	------------	------------	------------
19	46.25	------------	39.7	39.6
20	65.45	est mdshft	unsided-	est mdshft
21	75.25	75.0	65.0	64.65
22	77.2	77.65	65.25	64.9
23	82.0	82.9	69.7	69.25
24	------------	------------	------------	------------
25	118.0*	118.65	90.9	90.15
26	------------	------------	------------	------------
27	102.95	est mdshft	87.2	86.05
28	------------	------------	est mdshaft	est mdshft
29	------------	144.4	119.75	117.85
30	------------	------------	------------	------------
31	------------	------------	------------	------------

* - slight post-mortem erosion of articular surface

Appendix B, Table 4. Ganj Dareh tibia and femur length (unsided)

B.#	Femur	Tibia
1	----------	----------
1a	----------	----------
2	233	----------
7	64.75	54.5
10	311	----------
12	71.6	68.65
14	167 (est)	154 (est)
14b	214 (est)	----------
16	169 (est)	----------
21	57.2	51.3
25	101.5	----------
26	----------	----------
26a	59.1	52.2
26b	127 (est)	----------
27	67.8	58.4
32	105 (est)	----------
36	131.65	----------
38	150.25	128 (est)
39	----------	----------
1153	74.25	64.55

*estimated lengths were based on a comparison of archaeological reference standards (Johnston 1967; Merchant and Ubelaker 1977) and other complete long bones from the same individual (ulna, radius, humerus, clavicle). Long bone lengths were estimated primarily in an effort to determine the approximate location of the midshaft.

Appendix B, Table 5. Seh Gabi pathological data (Skinner 1980[modified])

Mound	ID	Grid #	Dentalage	Skeletage	Stunt?	HlinesD	HlinesM	Raref'	LHPC	LHypo	Other path?
C	1	AA20	36 wksIU	37 wksIU	0	0	0	0	-	0	stillborn?
C	2	AA21	0.45	0.35	0.1?	x	x	x	0	0	
C	3	BB21	0.55	0.45	0.1?	x	x	0	x	0	
C	4	AA21	1.6	1.3	0.3	x	x	0	x	x	
C	5	G20-9	0.0	preterm	-	0	0	x	-	-	
C	6	G20-41	30wks IU	32wks IU	0	0	x	x	-	0	
C	7	G21	34wks IU	40+wksIU	0	x	x	x	-	0	
C	8	G20-47	36wks IU	40wks IU	0	0	0	0	-	0	
C	9	G20-60	0.25	0.35	0	0	x	x	-	0	orbit, tibia fracture
C	10	G18-37	0.45	0.20	0.25	x	x	x	0	0	orbit resorption
B	11	G20B309	0.5	-	-	0	-	-	0	0	frontal, double cortex
B	12	G20-18A	0.55	0.35	0.20	x	x	0	0	x	clavicle
B	13	G20-18B	0.35	0.35	0.0	-	-	-	x	0	clavicle
B	14	H-19	0.55	0.35	0.20	x	x	0	0	x	
B	15	G18-36	0.6	0.35	0.25	0	x	0	x	0	cranial deformation
B	16	G20-304/	1 .8	0.6	0.20	x	x	0	0	0	cranial deformation
B	17	G20-47B4	-	0.75	-	x	-	-	-	-	
B	18	Q44-408A	-	preterm	-	0	0	x	-	-	
B	19	Q44-408B	-	26wks IU	-	0	0	x	-	-	
B	20	Q44383B3	32wks IU	30wks IU	0	-	-	x	-	0	
B	21	Q44383B4	35wks IU	36wks IU	0	0	x	x	-	0	
AEF	22	F47-391	36wks IU	40wks IU	0	-	0	0	-	0	
AEF	23	F47-378	36wks IU	40wks IU	0	x	x	x	0	0	orbit,clavicle
AEF	24	Q43-408	-	40+wksIU	-	-	0	0	-	-	stillborn?
AEF	25	F47-389A	0.6	0.5	0.1?	x	x	x	-	0	orbit
AEF	26	F47-389B	0.6	0.5	0.1?	x	0	0	-	0	
AEF	27	F46-20	0.7	0.5	0.20	x	x	0	x	0	orbit, gluteal tuberosity
AEF	28	F46-B1	0.9	-	-	x	x	-	0	0	
AEF	29	Q43-B1	3.3	1.7	1.6	x	0	0	x	x	
AEF	30	Q44-336	4.5	-	-	-	-	-	x	0	
AEF	31	Q44-341	-	-	-	-	-	-	-	-	clavicle only

Stunt?-evidence of growth stunting as denoted by lag between dental and skeletal age assessments
HlinesD- Harris lines within long bone diaphysis
HlinesM- Harris lines within long bone metaphyses
Raref'- long bone bone rarefaction, cortical thinning, 'ground glass' metaphyses, coarsening of trabeculae
LHPC- localised hypoplasia of the primary canine
Lhypo- linear hypoplasia

Appendix B, Table 6. Ganj Dareh pathological data (Meiklejohn n.d; Agelarakis 1989 [revised])

ID	Level	Dental age	Skelet age	HlinesD	HlinesM	LHPC	LHypo	Cribra	PorHyper	Infect	Other path?
1	B	4.5-5.75 yrs	3.5-5 yrs	0	x	-	-	0	?	0	
1a	B	0-6 mo	0-6 mo	0	x	-	-	0	0	x	
2	D	6-8 yrs	4.5-6.5 yrs	x	x	x	x	0	?	x	
7	A or B	-	term	0	0	-	-	0	0	0	
10	Late B	10 ±.75 yrs	11-15 yrs	0	x	x	x	0	0	0	
12	B or D	0-6 mo	0-6 mo	0	0	0	0	x	x	x	
14	unkwn	4-5 yrs	-	0	x	0	0	0	0	x	puncture-tibia
14b		-	4-6yrs	0	0	-	-	-	-	0	
16	unknwn	6.5 yrs	-	0	x	x	x	0	0	x	sinustitis
21	D	-	34 wks I.U.	0	x	0	0	0	0	0	
25	BorD	6.5-9 mo	6-18 mo	0	x	x	0	x	x	x ?	anemia? rickets?
26	D	4 y± 12 mo	3-7 yrs	0	0	0	0	0	0	0	
26a	D	-	preterm	0	0	-	-	0	0	0	
26B	D	-	6-18 mo	-	-	-	-	-	-	0	
27	unkwn	term	0-3 mo	0	0	0	0	0	0	0	
30a	D	-	-	-	-	-	-	-	-	-	
32	EarlyD	6 mo	6 mo	0	x	x	0	0	?	0	
36	D	18±6mo/2.5-3.5y	-	0	0	x	0	0	0	x	
38	D	24 ± 8 mo	-	x	x	x	0	x	x	x	
39	D	3y±12mo/4y±9mo	2-3 yrs	0	0	x	?	x	0	x	periostitis-ribs
1153		-	0-6 mo	0	0	-	-	-	-	0	

HlinesD- Harris lines within long bone diaphysis
HlinesM- Harris lines within long bone metaphyses
LHPC- enamel hypoplasia of the primary canine
LHypo- linear hypoplasia
Cribra- Cribra orbitalia
Por Hyper-Porotic hyperostosis
Infect- infection as denoted by periostitis, osteomyelitis

- not applicable/scorable   0 absent   x present