Craniofacial growth and development in the Roebuck sample

by

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ABSTRACT

The purpose of this research is to better understand the health of the Roebuck Iroquois population through the study of the growth of its children. Four avenues of osteological analysis are employed to investigate this topic: the comparison of craniofacial measurements to dental age, comparison of craniofacial measurements with one another, assessment of fluctuating asymmetry, and comparisons to other populations. The Roebuck subadults demonstrated a pattern of craniofacial growth consistent with the pattern for a normal, healthy child. Growth spurts in the craniofacial complex were more difficult to observe and interpret than spurs in the long bones. Fluctuating asymmetry was not found in any of the bilateral measurements, indicating that any stress experienced by the Roebuck subadults during development was not great enough to have a detectable impact on cranial symmetry. Roebuck appeared to be similar in size and growth to two other populations with similar subsistence strategies and diets.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER ONE: INTRODUCTION

Biological anthropology is the study of the biological evolution and variation of the humans species, past and present (Relethford 2003). Human skeletal remains represent an important source of information on the genetic and physiological responses made by our species to the environmental and sociocultural challenges faced throughout our history (Walker 2000). The study of human skeletal remains from archaeological sites can provide valuable information on past human societies; indeed, human skeletal remains may provide the only avenue of investigation into the past in the absence of cultural evidence (Brothwell 1968). Even when it is present, cultural evidence (artifacts, documents, and oral histories) can be difficult to interpret and subjective; human skeletal remains provide a direct link to the lives and deaths of past (Walker 1997).

Biological anthropology studies human variation; growth is often a focus of this study because it is one process through which variation is produced (Hoppa and FitzGerald 1999). Studies of skeletal growth in past populations contain a basic assumption that the growth of a child is the best single indicator of his or her health and development. The sufficiency of growth exhibited by children allows for insight into the health and adaptation of a population (Johnston 1968, 1969). Archaeological studies of skeletal growth often use linear growth as a proxy for health. Cross-sectional analysis of bone growth is used as a non-specific indicator of nutritional status within subadult samples (Hoppa and FitzGerald 1999). Growth studies most commonly focus on the postcranial skeleton, specifically the long bones of the limbs. Growth research on the craniofacial complex is much less common in bioarchaeological studies. Craniofacial

growth is the focus of this research because it is an underexplored area in biological anthropology.

The Roebuck skeletal collection, formerly curated at the Canadian Museum of Civilization (CMC), represents the largest studied sample of St. Lawrence Iroquois skeletal material. The collection was repatriated to the Akwesasne Mohawk for reburial in 1998; osteological data was collected by osteologists at the CMC prior to repatriation and reburial. These data have been the subject of only limited analysis (e.g. Hoppa et al 2004). The St. Lawrence Iroquois are an intriguing past population because they are not documented in great detail in historical sources, unlike most other Iroquoian groups. The St. Lawrence Iroquois were the first Iroquoians to have direct contact with Europeans in the early sixteenth century, but they disappeared as a distinct entity sometime between A.D. 1535 and 1603 (Wright 1972, Tremblay 2006).

The purpose of this research is to better understand the health of the Roebuck population through the study of the growth of its children. Four avenues of osteological analysis will be employed to investigate this topic, and are outlined in Chapter Three (Materials and Methods). Craniofacial indicators of growth will first be compared to dental development in order to investigate the growth pattern of the sample. These growth indicators will then be compared to each other to investigate the occurrence of growth spurts in the craniofacial complex, and assess their usefulness as a measure of growth and development in a skeletal sample. Fluctuating asymmetry will be assessed in the sample as a measure of stress on the population. Lastly, the Roebuck sample will be compared to other populations to assess its relative health status. The results of these

analyses will be presented in Chapter Four (Results), and the implications of these results are discussed in Chapter Five (Discussion) in the broader context of other studies.

A secondary aim of this research is to assess the usefulness of the data under study. The data set used in this research was collected in preparation for the repatriation and reburial of the Roebuck remains. As such, it was not tailored specifically for a growth study, but represents a set of standard osteological measures. This provides an opportunity to reflect on the sufficiency of the data and suggest areas for improvement, presented in Chapter Five (Discussion).

CHAPTER TWO: LITERATURE REVIEW

HUMAN GROWTH

Physical anthropology has been preoccupied with the study of human variation ever since the field itself was founded; growth is often a focus of this study because it is the process by which variation is produced (Johnston 1969, Hoppa and FitzGerald 1999). Growth can be defined as the progressive incremental changes in size and shape that take place throughout an individual's development. Growth is positively correlated with age, but the relationship is not straight-forward; increases in size and in maturity do not necessarily advance simultaneously. Although growth is a relatively regular process, there are distinct increases in rate: in mid-childhood (6 to 8 years), and during the adolescent growth spurt. Human growth varies between the tissues and organs of the body; between the sexes; between individuals of the same population; and between populations. Differences in growth can be due to both genetic and environmental influences. The most important environmental factors fall into the 'socioeconomic' category: nutrition, disease, and social status (Scheuer and Black 2000:4-5).

The human growth pattern is characterized by three periods: prolonged infant dependency, an extended childhood, and a rapid and large growth spurt at adolescence that leads to physical and reproductive maturity (Bogin 1988:74). Humans exhibit a pattern of growth unique among all animals. Primates have a juvenile stage of development between infancy and adulthood, and this stage sets primate growth patterns apart from other mammals. Humans go one step further by adding a childhood stage

between infancy and juvenescence (the start of the juvenile growth period); childhood prolongs the growth stage, and sexual maturation does not begin until the last third of the growth period (Bogin 1988:57-62). The adolescent growth spurt is a phase of rapid growth at the end of childhood. This spurt is the evolutionary result of two competing selective pressures: a prolonged childhood period for growth, learning and socialization; and a sufficiently long adulthood for reproduction and parental care of offspring (Bogin 1988:62).

The growth pattern of all normal (healthy) children follows a very similar course. Growth during infancy and young childhood is very predictable, both within individuals and between populations (Johnston 1986). Deviations in the expected growth pattern of children can therefore be used as the basis of detecting health disorders on the individual and population levels (Bogin 1988:28).

The Process of Bone Growth

Bone, the major supporting tissue of the body, is one of the strongest existing biological materials. Despite bone's strength, it is also lightweight. This is because bone is a composite material – formed of both protein (collagen) and mineral (hydroxyapatite). Bone is also an interesting support structure because it is a living tissue that can repair and reshape itself in response to external stress (White and Folkens 2000:20).

Osteogenesis (bone development) generally occurs through two mechanisms: endochondral ossification and intramembranous ossification. Endochondral ossification is the process by which most of the bones in the human skeleton grow. In this type of development, bones are preceded by cartilage models. In contrast, intramembranous

5

ossification occurs when bone ossifies by apposition on tissue within a membrane of embryonic connective tissue. There is no difference in the kind of bone that is produced; the only difference between the two types of osteogenesis is the site where they occur (White and Folkens 2000:28).

Endochondral ossification is most often associated with the long bones; the first step is the formation of a bony collar around the midshaft region in the cartilaginous precursor. Periosteal vessels penetrate the bony ring, permitting the osteogenic invasion of the cartilage core; one of these vessels will dominate and become the nutrient artery. Osteoid is then laid down in the walls of the calcified cartilage, and osteoprogenitor cells convert the osteoid into woven bone. Bone cannot grow in size through interstitial development because of the rigid nature of its matrix. As a result, bone grows through a process of apposition (laying down new bone) and remodelling (taking away old bone). As the diameter of the long bone shaft increases, osteoclasts on the endosteal surface remove bone, creating a medullary cavity. At the same time, osteoblasts on the periosteum lay down bone (Scheuer and Black 2000:24).

The initial site of ossification is called the primary centre; the majority of primary centres appear during the embryological and fetal periods (Scheuer and Black 2000:18). A separate area of ossification occurs when the primary centre does not extend into the entire cartilaginous template; this separate area is called a secondary centre of ossification (Scheuer and Black 2000:19). Once the primary centre of a long bone has appeared, a cartilaginous growth plate will develop between the epiphysis (secondary centre) and diaphysis (primary centre). The growth plate is an organized region of rapid growth, and is responsible for most of the growth in length of the diaphysis (Scheuer and Black

2000:25). The cartilage plate 'grows' away from the primary centre; growing cartilage is replaced by bone on the diaphyseal side of the plate (White and Folkens 2000:29). Once the rate of cartilage proliferation is exceeded by the rate of bone deposition, the growth plate narrows and eventually disappears; epiphyseal union occurs and marks the end of longitudinal bone growth (Scheuer and Black 2000:19).

Intramembranous ossification is likely the more ancestral of the two types of ossification; it is the first type to occur, and it continues throughout life in the forms of subperiosteal apposition and bone remodelling (Scheuer and Black 2000:22). Intramembranous ossification is the direct mineralization of a highly vascular connective tissue membrane. The vault and facial bones of the skull are formed through intramembranous ossification. Mesenchymal cells on the surface of a developing bone condense and form the fibrovascular periosteum, which is active in laying down new bone (osteogenesis) for the rest of an individual's life (Scheuer and Black 2000:23)

Some bone development occurs through a third, intermediary process – a membranous template that gradually acquires cartilaginous sites. The clavicle, mandible, and sutural areas of the skull are thought to arise through this process (Scheuer and Black 2000:18).

Growth and Development of the Human Skull

The development of the skull is a blend of the morphogenesis and growth of three main entities derived from the embryological neural crest and paraxial mesoderm tissues: the desmocranium, chondrocranium, and viscerocranium. The desmocranium (calvaria) and the chondrocranium (cranial base) comprise the neurocranium.

The desmocranium is derived from the paraxial mesoderm and the neural crest. The vault bones (frontal, parietals, greater wings of the sphenoid, squamous parts of the temporals, and the upper squama of the occipital bone) arise directly in the membranous tissue covering the brain.

The chondrocranium is of neural crest origin; the cranial base and major part of the nose are preformed in cartilage (basal, lateral parts and lower squama of the occipital; petromastoid parts of the temporals; the body, lesser wings, and medial parts of the greater wings of the sphenoid; the ethmoid; and the inferior conchae).

The viscerocranium (the face, also known as the orognathofacial complex) is derived from the neural crest. The face and nasal capsule (the maxillae, palatines, nasals, lacrimals, zygomatics, and vomer) develop in membranous tissue. The maxilla, mandible, auditory ossicles, styloid process of the temporal, hyoid, and skeleton of the larynx are derived from the pharyngeal arches (Scheuer and Black 2000:38-39; Sperber 2001:77). The skull is a 'mosaic of individual components'. Each of the three skull entities has different characteristics of growth, development, maturation, and function; each unit is so integrated with the others that normal development of the skull requires the coordination of the growth of all three (Sperber 2001:78).

The development of the chondrocranium (cranial base) appears to be strongly determined by genetics, with the environment exerting minimal influence. The basic pattern of the chondrocranium has been maintained throughout phylogeny, from the earliest forms of vertebrates to the most recent; only minor variations occur in some groups of vertebrates. The growth of the desmocranium and viscerocranium, however, appear subject to little genetic determination; they are strongly influenced by local

8

environmental factors. This influence is thought to be due to their more 'recent'

development than the chondrocranium. The face and jaw are common sites for

developmental defects, whereas congenital defects of the base of the skull and the nasal

and auditory capsules are relatively rare (Sperber 2001:78; Scheuer and Black 2000:36-

37).

   After birth, the growth pattern of the skull is a reflection of the relationship

between the neurocranium and the viscerocranium. The neurocranium stops

development much earlier than the nasofacial complex (viscerocranium), which is not

completed until the second decade of life. The change in shape of the skull from birth to

adulthood is caused by a relative increase in the size of the nasofacial complex compared

to the neurocranium. During this period, the volume of the calvaria (desmocranium)

increases four times, while the volume of the facial region increases twelve times. The

overall change in size and shape of the skull is the result of the interaction of 22

individual bones. Each bone has its own individual growth pattern, which may differ in

direction and rate of growth from all other bones (Sullivan 1986:243-4).

Factors that Influence Growth

   Although the formation of the skeleton is genetically controlled, the amount and

speed of growth of individual children, or groups of children, may be affected by

numerous factors. These factors include nutrition, illness, socioeconomic status, physical

environment, and even psychological well-being (Bogin 1988:28). Eveleth and Tanner

(1990:191) state that most environmental factors affecting growth are related to the level

of nutrition and the prevalence of childhood infection. Nutrition is closely correlated

with growth because cells need an adequate amount of energy, amino acids, water, lipids, vitamins, and minerals to grow and multiply (Bogin 1988:126).

A child may survive many insults during growth, but the body must make adaptations for survival. These adaptations may result in a slower tempo of growth, and a smaller body size. After a slow-down in growth due to illness, the body will follow with 'catch-up' growth – a period of rapid growth, which restores the child to the normal growth curve. This catch-up growth will only occur, however, if a child receives adequate nutrition; catch-up growth requires a much greater energy intake than that needed to sustain normal growth. If nutrition is not adequate, the energy required for catch-up growth is not achieved and stunting will occur (Eveleth and Tanner 1990:191).

Studies on twins have shown that body size, body shape, and patterns of growth are strongly influenced by genetic factors (Rallison 1986:7). Smith (1977) found that monozygotic twins have an average height difference of 2.8 cm, versus a 12 cm difference between dizygotic twins of the same sex. Twin studies have also shown, however, that the environment can influence development – especially the uterine environment. For example, many monozygotic twins share a placenta (called a monochorionic placenta) during the prenatal period. As a result, the twins usually do not receive an equal share in the maternal blood supply – one twin can suffer undernourishment and hypoxia (Bogin 1988:164). In a sample of 92 monozygotic twins, Falkner (1966) found that the within-pair difference in birth weight averaged 326.0 g in monochorionic twins and 227.8 g in dichorionic twins (each twin has its own placenta). This example demonstrates that the undernourished twin may adjust its growth rate in response to placental insufficiency (Bogin 1988:164).

Growth and Understanding Past Peoples

        The state of a nation's public health and the average nutritional status of its citizens are accurately reflected by its children's average heights and weight (Eveleth and Tanner 1990:1). Skeletal growth-related studies of past populations contain a basic assumption that the growth of a child is the best single indicator of his or her health and development (Johnston 1969). These studies allow for insight into the overall health of a population and its adaptation to the environment by examining the sufficiency of growth (Johnston 1968; Johnston and Zimmer 1989). Children under the age of five years are often viewed as the members of society most sensitive to environmental and cultural insults. The stress experience of children impacts the overall population's ability to rally from disease in adulthood (Goodman and Armelagos 1989).

        Growth and development can be assessed in two ways: cross-sectional studies and longitudinal studies. Cross-sectional studies measure individual children only once, at one moment in their lives. They are limited in their usefulness, even in large-scale studies. Cross-sectional studies can provide no information on individual increments from one year to the next – individual rates of growth. They can provide the average growth rate of a population, but they cannot express the variability around that average. On the other hand, longitudinal studies measure individuals periodically over many years and can give individual growth rates. These two study types are complimentary, and should both be used for a full understanding of the growth process (Eveleth and Tanner 1990:4-9). When trying to understand growth and development in skeletal populations, one is limited to cross-sectional data only. This is due to the nature of a skeletal sample –

it represents individuals who have died, and are thus captured at only one stage of their lives.

The rate of maturation in longitudinal studies is often measured by the percentage of mature height attained at successive ages. This measure is only possible for an individual after growth has been completed, and is therefore not always useful in cross-sectional studies – particularly those involving archaeological samples. More commonly used measures of maturity in skeletal growth studies are skeletal maturity (bone age) and dental maturity. These measures are not dependent on body size; and, unlike body size or weight, all normal individuals will reach the same final point for both skeletal and dental maturity (Eveleth and Tanner 1990:145). The first effect of under-nutrition is to slow down growth and delay maturation. Not all measures of maturation are affected equally, however. The teeth develop very early in growth, are strongly controlled by genetics, and have relatively little interaction with the environment. Dental maturity is therefore less influenced by the postnatal environment than skeletal maturity, which can be affected more significantly by malnutrition or disease (Eveleth and Tanner 1990:146).

The study of human skeletal growth in archaeological samples was first popularized by Stewart (1954) and Johnston (1962). Johnston (1968) claimed that infants and children were often excluded from the research of physical anthropologists studying the skeletal biology of past populations; his early research in the 1960s on the Indian Knoll skeletal collection from Kentucky was the first contribution in this area (e.g. Johnston 1962). The late 1980s and early 1990s saw an increase in the number of studies looking specifically at subadult growth (e.g. Jungers et al. 1988; Johnston and Zimmer, 1989; Lovejoy et al. 1990; Hoppa 1992, Saunders et al. 1993). The focus of most growth

and development studies has been on the infracranial skeleton, particularly linear growth; bioarchaeological studies on craniofacial growth have been relatively rare (e.g. Markowitz 1995; Steyn and Henneberg 1996).

The Interpretation of Growth and Development

Skeletal growth studies based on archaeological samples often use linear growth as a proxy for health. The growth of a child (or group of children) is thus used to make interpretations about the health and well being of a population. Cross-sectional analysis of long bone growth is used as a non-specific indicator of nutritional status within a subadult sample. Differences in growth between samples are considered evidence for differential growth between populations. It is important to note that growth-related measurements (such as diaphyseal lengths) are non-specific indicators of health. Studies based on these measurements cannot say much about the cause of a detected problem, only that there is a problem within a population (Hoppa and FitzGerald 1999:12-13).

Another issue that may arise in skeletal growth studies is the choice of standards for comparison. Skeletal growth studies are often interpreted by comparing skeletal and dental development to previously published studies or modern standards (e.g. Maresh 1943, 1955, 1970; Ginhart 1973; Moorrees et al 1963a, 1963b). Modern standards have largely been based on North American children of European descent, and it is not clear how well they represent populations that differ in time, space, and ancestry. Moreover, these studies are often based on radiographs taken on living individuals, whereas skeletal growth studies measure dry bones. Lastly, within skeletal growth studies there is no

single consistent methodology for constructing skeletal growth profiles from archaeological samples (Hoppa and FitzGerald 1999:13).

An important issue arising in skeletal growth studies is the fact that the individuals in a burial sample are essentially non-survivors; moreover, the subadults in a sample are individuals who did not survive to complete maturation. As a result, the pattern of growth and development exhibited by the subadults may not be representative of the pattern of growth in the population (Johnston 1968, Saunders 2000). The *Osteological Paradox*, published by Wood et al (1992), thrust this issue into the consciousness of physical anthropologists. The most widely recognized problems associated with human skeletal materials include sex determination and age estimation; inadequate size and unrepresentative skeletal sample composition; variable and selective bone preservation; and the differential diagnosis of skeletal lesion-producing diseases. Fortunately, some of these problems can be addressed by additional excavations, the development of better chronological and contextual controls, the use of reference comparative medical collections, and the continued refinements of field, laboratory, and analytical methods. By contrast, the osteological paradox requires a complete rethinking of the relationships among pathological processes, the risks of death, and the formation of mortality samples (Wood et al. 1992:357).

Paleodemography and paleopathology both presuppose that a direct relationship exists between statistics calculated from archaeological skeletal series, such as frequencies of skeletal lesions or mean age at death, and the health status of the past population that gave rise to the skeletal sample (Wood et al. 1992: 343). 'Health' is a problematic concept because it is a biological characteristic of an individual, but

inferences about the health of a population must be based on aggregate- or population-level statistics (Wood et al. 1992:345).

Wood and colleagues focus on several themes in their article: the possible presence within the study population of multiple, undetected subgroups that experience varying degrees of risk for disease and death; the complex relationship between the degree of stress experienced by an individual, and the likelihood of developing a skeletal lesion; and the possibility that individuals displaying lesions may actually be healthier than some of the individuals without lesions (Wood et al. 1992:345). The last theme concerns the fact that skeletal lesions typically take a longer time to develop, and thus tend to reflect individuals with a chronic disease, rather than an acute one. Individuals exhibiting lesions may also have survived a particular disease, while some individuals without lesions may have been diseased but died before lesions could develop.

One problem outlined by the authors, selective mortality, concerns the fact that skeletal samples represent only those individuals who died at certain ages. It is not possible to have a sample of all the individuals at risk of disease or death at a given age, but only a sample of those who did in fact die at that age. For every individual that dies at a particular age, many other individuals may survive that age and move on in life. This problem cannot be avoided by simply obtaining a larger, more representative skeletal sample because the problem is built into the very structure of the data (Wood et al. 1992:344).

Selective mortality is particularly problematic when dealing with more subtle indicators of poor health, such as short stature. Short stature is known to have many causes, and it is therefore taken as a general indicator of stress. A shorter stature tends to

be interpreted as reflecting increased stress in an individual, but this interpretation does not take into account the differences in stature observable in individuals who died at the same age. Skeletons should be viewed as non-survivors who entered the skeletal sample as a result of selective mortality, acting on heterogeneous frailty. Wood and colleagues argue that when mortality is high a larger fraction of the entire distribution of stature is represented among the dead individuals. As a result, the average stature will be comparatively tall. If the mortality rate falls, however, only the frailest individuals (those of short stature, due to 'health' factors) will die; these low mortality periods will be characterized by a comparatively low average stature among the dead (Wood et al. 1992:351). Therein lies the paradox: a population that is relatively healthy and has a low mortality rate will appear to be unhealthy because of the relative abundance of individuals who died with a short stature.

On the other hand, Lovejoy et al (1990) argued that most infant deaths among earlier groups were likely the result of acute, rather than chronic, diseases. An acute disease would not significantly alter dental or skeletal maturation. Skeletal samples would therefore be similar in growth and development to their surviving counterparts. Saunders and Hoppa (1993) addressed Wood and colleague's (1992) article by examining the literature on survivors and non-survivors in living populations. They found that there was a statistically significant difference between the growth of survivors and non survivors. The actual size of this difference for cross-sectional studies of long bone growth, however, would be minimal – never more than several millimetres. This minimal size difference may be less important than the error introduced by

methodological issues and measurement error (Saunders and Hoppa 1993; Hoppa and

FitzGerald 1999:14; Saunders 2000:148).

Previous Growth Research – Postcranial

The inception of skeletal growth studies can be traced back to the early work of T.

D. Stewart and Francis Johnston. Stewart (1954) measured Eskimo femora from the U.S.

National Museum collections, and produced a generalized postnatal growth curve.

Stewart estimated chronological age at death by subjectively appraising the eruption

stage of the first and second permanent molars.

Johnston (1962) measured a sample of 165 infant and child skeletons from the

Indian Knoll skeletal collection. The study had two purposes: to provide growth

information on a prehistoric, non-European population that subsisted by hunting and

gathering; and to aid in establishing length standards for American Aboriginal children,

to be used by physical anthropologists and archaeologists in ageing other excavated

skeletal material. Six long bones were measured (humerus, radius, ulna, femur, tibia, and

fibula); means, standard deviations, and relative growth rates for one-year intervals from

1.0-5.0 years were calculated. Compared to children of European ancestry, the Indian

Knoll children had similarly shaped, but slower, growth curves. Johnston concluded that

the depressed growth rate could be accounted for by environmental factors, acting in

conjunction with a genetic tendency toward population shortness. Johnson's (1962)

study was significant because it provided data on two previously neglected populations

types: prehistoric populations and non-European populations. Previous growth studies

had focused on modern children of European ancestry.

Y'Edynak (1976) examined pre-nineteenth century Eskimo and Aleut skeletons to determine whether characteristic adult body proportions were established in early adulthood. The author's sample consisted of 24 Aleut, 81 western Eskimo, and 4 unspecified Eskimo/Aleut skeletons, all from Kodiak Island. Individuals ranged in age from newborn to 20 years. Maximum diaphyseal lengths were taken on the six long bones for each individual. The females were found to have longer humeri from 12-15 years, and longer radii and ulnae from 10-14 years. Females also exhibited longer legs from 12-15 years. Males had longer femora after 15 years, but not necessarily longer distal legs (tibia and fibula). Both the forearm and distal leg were found to be shorter relative to the proximal limb bones, indicating that the short forearm and distal leg observed in adults are established in childhood.

Merchant and Ubelaker (1977) studied the postcranial growth of a sample of protohistoric agricultural Arikara from the Mobridge Site in South Dakota. The sample was comprised of 193 skeletons ranging in age from birth to 19 years, and dating from the first half of the 18th century. The maximum diaphyseal length was taken for the humerus, radius, ulna, femur, tibia, and fibula; additionally, the maximum breadth was taken for the ilium. Cross-sectional growth curves were produced by plotting mean measurements against the midpoints of 1-year age categories. When the authors compared the Arikara sample to the Indian Knoll population (Johnston 1962), only minimal differences were found between rates of long bone growth from birth to 9.5 years, and between rates of iliac growth from birth to 6.5 years. Merchant and Ubelaker (1977:70) found these results to be significant, because the two populations were

biologically, culturally, and geographically distinct; moreover, they had different subsistence patterns and were separated in time by more than four thousand years.

Hummert and Van Gerven (1983) analyzed the long bone growth of children from two medieval cemeteries in Sudanese Nubia. The sample consisted of 180 subadult skeletons from the Kulubnarti site; 124 individuals from an early Christian period cemetery and 56 individuals from a late Christian period cemetery. Dental ages were assigned using Ubelaker (1978), and 9 developmental age groups were established. The authors measured the maximum diaphyseal length of the left femur, tibia, humerus, ulna, and radius. When mean diaphysis length for each age group was graphed for both cemeteries, the growth patterns were very similar until 8.5 years of age. After this age, individuals in the earlier cemetery fell behind in growth and never caught up completely. The distance curves indicate that individuals from the early cemetery experienced greater stress and slower growth than individuals from the later cemetery. When growth velocity curves were graphed, however, they appeared to contradict this observation. The later cemetery showed a more marked deceleration and slower growth velocity to 4 years, but it appeared to have more advanced growth in the distance curve. Another discrepancy between the growth and velocity curves occurred in the oldest age groups. The later cemetery dropped to a 3 percent increase in growth velocity at approximately 12.5 years, and increased until it was almost tied with the earlier cemetery by 15 years. When looking at the growth distance curves, however, the later cemetery showed greater growth from 8.5 years onward. To interpret these patterns, the authors examined data on probabilities of dying and the frequency of cribra orbitalia. The patterns of mortality and cribra orbitalia indicated that stress was much more severe in the earlier population.

Additionally, the earlier population lacked clearly defined childhood growth spurts or recovery periods, suggesting that the stress was more chronic in nature.

Jantz and Owsley (1984) analyzed long bone growth variation in prehistoric, protohistoric, and historic Arikara samples. The samples derived from three periods: Extended Coalescent (AD 1550-1675), Post-Contact Coalescent (1675-1780), and Disorganized Coalescent (1780-1862). The minimum dental age of the sample was 0.41 years and the maximum age was 11.9 years. The authors plotted femur, humerus, tibia, and radius lengths versus dental age for each time period. The results showed that the Early and Post-Contact Coalescent groups had smaller lengths in early childhood, with Post-Contact having slightly longer lengths; after this time the lines diverged, resulting in longer bones for the Post-Contact group. Conversely, in early childhood the Disorganized Coalescent group had the longest bone lengths but by late childhood they were either shorter than or intermediate between the other two groups. The authors found these results to be in agreement with the archaeological and ethnohistorical accounts of better health in the Post-Contact Coalescent period and deteriorating health in the Disorganized Coalescent period. An interesting result was the discovery that the Disorganized Coalescent had longer lengths, especially in the upper limb, in early childhood; it would be expected that high levels of morbidity and insufficient nutrition would be reflected in reduced linear growth.

Mensforth (1985) examined patterns of tibia growth in two hunter-gatherer populations: Libben Late Woodland (A.D. 800-1100) and Bt-5 Late Archaic (B.C. 3992-2655). Mensforth's goal was to identify differences in relative tibia growth, and evaluate the extent to which the differences could be in agreement with demographic and

epidemiological information on the two groups. The author selected individuals with a

dental age from birth to ten years, with a resulting sample of 85 Libben and 45 Bt-5

tibiae. The tibia lengths were then plotted against dental age. Mensforth found that the

Bt-5 lengths consistently distributed in the high range of the Libben values. Tibia lengths

were found to be comparable between the two groups at birth and from birth to 6 months.

Additionally, growth rates for individuals were found to be comparable between the two

groups from 5-10 years. The Libben group exhibited growth retardation from 6-24

months and a slow recovery to 4 years of age. In general, the Bt-5 sample showed

preadolescent growth performance and health status superior to the Libben sample.

Mensforth states that the rate and timing of the Libben samples growth modification is

largely restricted to the weaning period. The frequency of periosteal reactions in the

Libben subadults was significantly greater than that in the Bt-5 sample, indicating the

Libben subadults experienced a higher frequency of infection – likely exacerbated by the

malnutrition induced by the weaning process.

Owsley and Jantz (1985) tested fetal growth effects by comparing two Arikara

perinatal infant samples. Individuals from 7 sites were pooled into two temporally

defined samples: 4 sites, with 447 individuals, representing the late prehistoric-early

protohistoric period (A.D. 1600-1733); and 3 sites, with 42 individuals, representing the

late protohistoric-historic period (A.D. 1760-1835). The authors wished to determine

whether increased maternal physiological stress during the later time period resulted in

fetal underdevelopment and prematurity. Owsley and Jantz measured long bone

diaphyseal length (most often the femur) to determine the age of the individual. The

sample was limited to babies with an estimated gestational age of 41 weeks or less (using

Scheuer et al 1980); the youngest assigned age was 26 weeks. The authors found a

higher percentage of smaller long bone lengths (and thus younger ages) in the later

sample than the earlier sample. This may indicate a higher frequency of preterm births

and babies that were small-for-gestational-age in the later sample.

Saunders and Melbye (1990) examined two samples of children's bones from two

historic period Iroquoian ossuaries in southern Ontario (Kleinburg and Ossossane). The

authors' purpose was to evaluate the severity of any skeletal disruptions due to nutritional

disturbances or chronic disease stress. All immature right mandibles were examined and

dental age estimates were plotted for both ossuaries. From the Kleinburg ossuary, all

complete left femoral and radial diaphyses were examined; measures of maximum

diaphyseal length were taken. The authors used the standards of Merchant and Ubelaker

(1977) to estimate age based on diaphyseal length, and again plotted the sample. It was

found that the Kleinburg sample had a low mortality profile, with few adolescent deaths;

conversely, the Ossossane sample displayed a high mortality profile with substantial

adolescent deaths. Saunders and Melbye (1990) also found that both samples had the

highest proportion of individuals between two and three years of age. They attributed

this phenomenon to a peak in mortality at weaning age, which likely began in the second

year of life.

More recently, Steyn and Henneberg (1996) examined the infracranial growth of

children from the Iron Age site of K2 in Southern Africa, and compared it to that of other

populations. Forty-five subadult skeletons with dental age from 0 to 18 years were used,

and diaphyseal lengths of the humerus, radius, ulna, femur, tibia and fibula were taken.

Diaphyseal lengths of long bones were plotted against each other within the same

individual in order to reveal allometric growth. The authors found that the K2 children

had bones that were at least as long as those of other groups; the Libben population

(Lovejoy et al. 1990) was the closest in length of the comparison groups. Although the

K2 sample had longer bones, their growth curve was similar to that of other populations.

The authors concluded that similar growth curves in geographically and temporally

distinct samples indicates that most human populations were able to provide similar

developmental conditions for their children (Steyn and Henneberg 1996:395).

Previous Growth Research – Craniofacial

Research on craniofacial growth and development is much less common than

infracranial research. There have been, however, a number of studies conducted within

the last twenty-five years that can be used as comparison samples. Some studies are

based on subadult skeletal samples, while others are based on radiographs of living

children.

Studies of Contemporary Populations

Palomino et al. (1978) studied 322 residents from the altiplano communities of

Turco and Toledo in Bolivia. The population is ethnically heterogeneous, but individuals

can be classified as either Aymara or Mestizo. Facial, dental arch and dental

examinations were made on all individuals six years of age or older, and horizontal and

central measurements were taken. The authors found that while dental arch width and

height dimensions were significantly larger in adults than children, dental arch lengths

were larger in children than adults. Moreover, four dental arch indexes (length:width)

were calculated, and in all four cases the indexes were larger in children than adults. This indicated that the width of the face increased with age, but the length decreased comparatively. The length of both the upper and lower dental arches was found to decrease with age, but the lower length decreased more significantly. The authors also found male children to be larger than female children, but only significantly so in horizontal dimensions (bicondylar and bigonial widths). The authors suggested that this sexual dimorphism resulted from these dimensions attaining a large percentage of total growth before six years of age (Palomino et al. 1978:165). Overall, this article focuses on the measurement of variables with little interpretation with regard to growth patterns. The authors compare their adult Bolivian data to five other populations (Australian aborigines, Swedes, Aleuts, Taiwan Ami and Taiwan Atayal), but they do not compare their child data to these populations. Moreover, they work with absolute measurements only. They do not interpret the child data in terms of percentage of adult growth attained. As a result, this article is mainly useful as a source of comparative data. Unfortunately, only two age categories are used (6 to 14 years, and 15 years and older), and the measurements taken are not comparable with the present study.

Buschang et al. (1983) investigated the differential growth of the craniofacial complex with the aim of elucidating whether craniofacial dimensions follow discrete or continuous patterns of variation in maturity. The authors studied cephalograms taken by the Child Research Council in Denver, Colorado. Fifty-one individuals were included in the study, ranging in age from 4 to 16 years. Each individual had a series of cephalograms taken at approximately yearly intervals and one taken to represent adult status, for a minimum of 9 and a maximum of 13 cephalograms. Twelve landmarks were

identified on each cephalogram, and 9 measurements were derived from these landmarks. Each dimension was computed as the percentage of adult size attained at each age. The authors found that at 4.5 years, males exhibited a maturity gradient proceeding from head height (91%), through anterior cranial base (86.5%), posterior cranial base and maxillary length (80%), upper facial height (73%), corpus length (70%), ramus height (66.5%), and stature (60%) (Buschang et al. 1983:376). This pattern was generally maintained through growth; females were found to exhibit the same general pattern as males, although they were more mature at all ages than males. With the exception of two measures (anterior maxillary height and mandibular height), yearly maturation rates appeared to maintain or decrease slightly until adolescence. During adolescence, there was evidence of an acceleration of growth. This acceleration was most pronounced for ramus height, which matured 7.0% and 7.5% per year for males and females, respectively. As a comparison, statural growth increased by approximately 5% per year during adolescence (Buschang et al. 1983:376)

Krieg (1987) examined the incidence of growth spurts for three craniofacial dimensions: sella-gnathion (S-Gn), sella-nasion (S-N), and nasion-gnathion (N-Gn). These landmarks were chosen because they are all located in the sagittal plane, thus minimizing identification and measurement error. Serial lateral cephalometric radiographs of 21 male and 19 female children of European ancestry were obtained from the Center for Human Growth and Development at the University of Michigan, Ann Arbor; the radiographs were part of an extensive longitudinal growth study originated in the 1930s by the University's School of Education. Radiographs were taken annually on the subject's birthday, from 5 to 12 years. Krieg observed that early craniofacial growth

spurts were common, with great variation in timing and minimal correlation with facial dimensions. Growth spurts of the face (S-Gn, N-Gn) had a higher incidence and greater magnitude than spurts in the cranial base (S-N). Early facial growth spurts occurred more often in males than females, but there was little difference in the peak velocity of the spurts between the sexes. Moreover, the peak velocity of the growth spurts tended to be greater during the childhood growth period than the juvenile period (Krieg 1987:60-61).

Waitzman et al (1992) conducted a study to define the normal values for some craniofacial measurements, and to evaluate the growth patterns of these measurements. The authors studied 542 CT scan series from 401 skeletally normal children, primarily of European ancestry. The children ranged in age from newborn to 17 years. Fifteen measurements were taken on each CT scan: intercoronal distance, cephalic length, cephalic width, anterior interorbital distance, lateral orbital distance, mid interobital distance, intertemporal distance, medial orbital-wall length, lateral orbital-wall length, globe protrusion, medial orbital-wall protrusion, lateral orbital-wall angle, interzygomatic-buttress distance, interzygomatic-arch distance, and zygomatic-arch length. The oldest subjects in the study (seventeen year-olds) were considered adults, and the percentage of adult size was calculated by dividing the mean value for the variable in question by the mean value at age 17. The authors found that each region of the craniofacial complex exhibited a unique growth pattern. All the dimensions experienced rapid growth in the first few years of life, followed by a levelling off. The cranium was virtually finished growing by 6 years of age, while the midfacial region experienced a more gradual increase in size and continued growing later into childhood.

The authors also found that individuals measurements in a region were often correlated, exhibiting similar growth patterns.

Vidarsdóttir et al. (2002) examined the interpopulation variations in the facial skeleton of 10 modern human populations, from an ontogenetic perspective. They aimed to investigate the extent to which the distinctive features of the adult populations are present in the early post natal period, as well as the extent to which scaling and growth trajectories throughout life contribute to distinct facial forms (Vidarsdóttir et al. 2002:211). The study examined 334 human skeletons (from infancy to adulthood) from 10 geographically distinct populations: Polynesians, Papua New Guineans, Australians, Egyptians, Alaskan Inupiaq Eskimo, West African Ashanti, Aleutians, Arikara Plains Indians, African Americans, and French/British. Twenty-six unilateral landmarks were collected from each individual in three dimensions using an electromagnetic digitizer. The three-dimensional coordinates of the landmarks were analyzed using geometric morphometric techniques: generalized Procrustes analysis (GPA) and principal components analysis (PCA). The authors found that all the populations could be distinguished based on aspects of facial shape, meaning that there are distinct morphological characteristics unique to each population. Moreover, this morphological distinctness was found to occur regardless of age of the individual. The authors state that population-specific morphological features likely develop early in life – prenatally or early in the postnatal period. The youngest individuals in their study (in the first year of life) exhibited population-specific morphological features. In the second part of their study, the authors found that the differences in facial shape between some populations arise partly through differences in growth trajectory through out life. This result only

applied to differences between some of the populations in the study; it was not sufficient to explain all the differences in adult facial shape between populations. The authors concluded that variation in adult facial form can arise in three ways: the very early development of major aspects of population-specific morphology; differences in growth trajectories between populations; and the lengthening or shortening of allometries (i.e. scaling) - meaning two populations may share a growth trajectory but one may experience an elongation or truncation of that trajectory relative to the other group.

Little et al. (2006) investigated the underlying causes of changing craniofacial dimensions among indigenous Oaxacan children in an isolated community, between 1968 and 2000. The subjects were schoolchildren in rural, agrarian community in the Valley of Oaxaca; this population had previously been characterized as mildly-to-moderately undernourished, with growth-stunting in 1968 and 1978. Cross-sectional anthropometric surveys of schoolchildren aged 6 to 13 years were conducted in 1968, 1978, and 2000. Four craniofacial dimensions were measured: head length, head breadth, bizygomatic diameter, and bigonial breath. A total of 1037 children were included in the analysis. Broken down by survey, the samples were: 151 males and 157 females in 1968; 179 males and 184 females in 1978; and 180 males and 186 females in 2000. The authors found a significant trend over time in several of the craniofacial dimensions, as well as the cranial index. This trend included a move toward shorter head length, both relatively (brachycephalization) and absolutely; remodelling over time resulted in a small tendency toward a narrower face, with the midface changing less rapidly than the lower face among males. The authors suggest three forces associated with the changes over time: the decreased food (maize) coarseness, relating to masticatory functional stress; a

28

relaxation of natural selection, resulting in a change in population genetic structure; and the interaction of the previous two factors during development (Little et al. 2006:134).

Osteological Studies

Markowitz (1995) examined craniofacial growth and development in the Arikara collection housed at the Smithsonian Institute. The author examined 52 subadults ranging in age from 1 to 19 years, using 61 craniometric measurements. The author demonstrated that the Arikara share a pattern of craniofacial development with many Asian populations; this pattern consists of increases in craniofacial width, posterior and total facial height and a significant decrease in the gonial angle during the subadult years. The Arikara were also found to exhibit significant nasal development – both in length of the midface, and anterosuperior relocation of the nasion during the subadult years; this development is inconsistent with some Asian populations. The older range of the Arikara population exhibits considerable craniofacial width; Markowitz demonstrates that this width develops secondarily to a longer and more intense period of width increase in the middle cranial fossa than is seen in similarly aged North American white, African American, or British samples.

Humphrey (1998) examined the diversity of growth patterns in the modern human skeleton. The study analyzed the growth of cranial and postcranial skeletal dimensions, using a collection of identified skeletons. The purpose of the study was to identify variation in the developmental schedule of different functional regions. Differences in these developmental schedules was thought to reflect energetic and time constraints operating during growth (Humphrey 1998:57-58). Three London, UK, collections with

known age and sex were used in the study: St Bride's Church, St Barnabus Church, and Christ Church. The study sample was comprised of 94 subadults aged between birth and 20 years, and 98 adults aged between 20 and 60 years. Thirty-four cranial measurements and 25 postcranial measurements were taken. Measurements included many standard anthropological measures, as well as additional measurements that could be taken on disarticulated infant crania. Each variable used in the study could be measured on an isolated bone. A modified Gompertz curve was fitted to each of the 59 variables. Comparisons between growth curves were made on the basis of percentage of adult size attained at successive chronological ages. Each variable was placed into one of five groups, depending on the age of attainment of 70% and 90% of adult size. The groups were: early-early (90% by age 6), early-intermediate (70% by age 6, 90% between 6 and 12 years), early-late (70% by age 6, 90% between 12 and 18 years), intermediate-late (70% between 6 and 12 years, 90% between 12 and 18 years), and intermediate-very late (70% between 6 and 12 years, 90% between 18 and 24 years).

Humphrey (1998) found a range of growth patterns in the human skeleton, ranging from early growing parts of the cranium to slow growing long bone diameters. The earliest growing variables were measured on the frontals and occipitals, which reflects the growth of the brain, eyes and spinal column. Humphrey (1998:70) suggested that this patterns indicates a growing child's initial functional requirement of establishing the basis for full neurological capacities. The early-intermediate growth patterns involve the midface region (zygomatics and orbits) and occipital breadths. The early-late growth patterns involve the palate and breadths across the mandible. This group is characterized by fairly rapid early growth, and more variable attainment of adult size. Humphrey

(1998:70) states that this rapid growth of the palate and mandible satisfies the early requirement of suckling, and is necessary to accommodate the deciduous dentition and the developing permanent tooth crowns.

Okazaki (2004) examined the growth patterns of prehistoric Japanese people by analyzing skeletal remains from prehistoric, historic, and modern samples. The author examined 144 subadult skeletons from three times periods (300 BC–300 AD, 1400-1600 AD, and 1900-1950 AD), and took standard osteological measurements for the skull. Okazaki found that the shape of the overall face became higher and narrower with age, and the height of the lower face increased much more than that of the upper face. Additionally, the angle of the frontal process of the maxilla appeared to stop changing early in childhood. A comparison between two geographically separated prehistoric groups demonstrated that differences in facial morphology were present by the two years of age; a comparison between the medieval and modern groups demonstrated that differences in mandibular morphology related to chewing stress are developed after the age of 13-15 years (Okazaki 2004:229-230).

Sardi and colleague (2005) aimed to study the growth trajectories of functional cranial components (FCCs) in individuals between birth and 20 years of age, and to estimate the proportion of growth attained in each FCC at different ages. The study included 228 skulls of known age at death from birth to 20 years, and 121 skulls from 21 to 39 years as an adult reference. The skulls were housed at the Museu Antropologico of Coimbra, Portugal, and the Musée de l'Homme of Paris, France. The sex of most individuals was known, and was balanced across the ages. Those individuals with an unknown sex were mostly between birth and 5 years of age. The authors employed a

modified version of the method used by Pucciarelli et al (1990) in a study on squirrel

monkey skulls. The neurocranium and face were each divided into four FCCs:

anteroneural, midneural, posteroneural, and otic; and optic, respiratory, masticatory, and

alveolar, respectively. The length, breadth, and height of each FCC were measured.

Volumetric indices (VI), a representation of the geometric mean of the three dimensions,

were used to estimate variation in size. Growth trajectories of the FCCs were then fitted

with a non-parametric smoothing spline. The quantity of growth was measured at birth

and 7, 14, and 20 years of age, with the averages of the adult volumetric indices as a

reference. The growth rate of each FCC was also evaluated as a percentage of adult size

at birth, 7, 14, and 20 years. The authors found that two groups of FCCs were

distinguished by similarities in trajectories, while the alveolar FCC exhibited a trajectory

different than all others. The first distinct group included the anteroneural, midneural,

posteroneural, and optic FCCs. This group exhibited a rapid growth period up to 3 to 5

years; at this time an acute point of inflection was present, and was followed by a slow

growth rate. The second distinct group included the respiratory, masticatory, and otic

FCCs. This group experienced a period of rapid growth, but was less pronounced than

the first group. Its inflect point was less acute, and subsequent growth rate was greater

than the first group. The alveolar FCC exhibited a different trajectory than the two

groups. It exhibited two periods of greater growth, from birth to 4 years, and after 14

years. When looking at percentage of adult size, the authors found that most of the FCCs

showed 50-60% at birth. The midneural FCC was most advanced at birth, while the

masticatory FCC was least advanced. At ages 7 and 14, the neural FCCs were most

advanced than the facial FCCs. From 7 to 14 years, the most dynamic (greatest growth

rates) were the otic, respiratory, masticatory, and alveolar FCCs. From 14 to 20 years, the alveolar and masticatory FCCs show the greatest rates. Sardi et al (2005) concluded that the growth trajectories of different regions of the skull can be classified into two groups according to growth rate and change in growth rate (location of inflection point). Additionally, they found that FCCs can grow independently of their location (neurocranium or face).

TOOLS IN HUMAN GROWTH STUDIES

Mathematical Description of Growth

Human growth can be described mathematically by fitting curves to series of longitudinal data – measurements taken on the same children at different ages (Marshall and Tanner 1986:175). This mathematical description is useful for summarizing many measurements in a few constants, before investigating individual and group differences in growth (Marubini et al 1972:511).

An equation commonly used to model human growth is the Gompertz curve (a skewed S-shaped curve) (Gompertz 1825), which was originally used to predict survivorship and only of interest to actuaries (Winsor 1932). Winsor (1932) examined its applicability as a growth curve, and found it to be a useful tool for representing growth. Deming (1957) was the first researcher to fit the Gompertz curve to longitudinal growth data (Marshall and Tanner 1986:175). Deming (1957) described the general pattern of human growth in length as sigmoid: infancy and early childhood involves a continually decelerating curve, which flattens to essentially a sloping straight line in later childhood; at the beginning of puberty there is a sudden change in growth following an 'S' shape,

with a sharp acceleration in the growth rate for a period of time, followed by a period of deceleration. The growth curve approaches horizontal while nearing adulthood (Deming 1957:83). The author attempted to describe only the 'S' shapes portion of the growth curve, and not the entire growth period from birth to maturity. Deming (1957:85) chose the Gompertz curve for three reasons: empirical evidence suggested the adolescent growth curve could be fitted satisfactorily with it; the essential nature of the equation appeared to be logical for describing the growth process; and the calculations involved in fitting the curve were less laborious than other S-shaped exponential curves.

Preece and Baines (1978) aimed to develop a new function or family of functions that could describe the whole growth curve. The authors found that a simple family of differential equations could be used to cover the entire growth curve, with the additional advantage of not requiring final height because it could be estimated by the equation. Other models have been developed by Shohoji and Sasaki (1987), Jolicoeur et al (1988, 1992). These models were all confirmed to be robust when fit to human growth data (Hansen et al 2003).

Morphometric Analysis

Studies of skeletal growth and development generally focus on linear size measurements of long bones as well as indicators of skeletal maturity (Hoppa and FitzGerald 1999). More recently, the area of craniofacial growth has experienced an increase in attention due to geometric morphometric methods of analysis (O'Higgins and Vidarsdottir 1999). Growth in the craniofacial bones involves not only the increase in size of individual elements, but the change in spatial relationships and shapes of these

elements (Enlow 1975). The importance of craniofacial growth is not limited to bioarchaeology; in a forensic context, differences in craniofacial shape and growth patterns could be used to classify individuals by geographic regions or populations – thereby assigning ancestry in the identification process (Vidarsdottir and O'Higgins 2003).

The field of morphometrics encompasses all methods used to describe and statistically analyze the variation in shape among samples of organisms; this analysis often looks at the change in shape due to growth, experimental treatment, or evolution. Morphometric methods are employed when the description and comparison of shapes or organisms (or particular structures) are required (Rohlf and Marcus 1993).

Traditional morphometric methods (also known as multivariate morphometrics) have been in use for several decades and are described by Rohlf and Marcus (1993). Traditional methods involve the application of statistical methods to sets of variables; these variables generally correspond to measured distances, while these distances can include lengths, widths, and distances between landmarks. The measured variables are combined linearly, and results are presented numerically and graphically. Traditional methods include principle component analysis, canonical variate analysis, discriminant functions, and generalized distances. The limitation of traditional methods is the inability to recover the shape of the original form from the typical sets of data. 'Form' refers to the spatial organization of an object independent of its location, and can be subdivided into 'shape' and 'size' (O'Higgans and Vidarsdottir 1999). These types of analyses are therefore not as powerful as they would be if the form information were taken into account. Rohlf and Marcus (1993) emphasize, however, that there is nothing 'wrong'

with this type of analysis; it is merely not as powerful as other methods. Moreover, traditional methods can be useful when validating the results of geometric morphometric analyses.

Geometric morphometric analysis is a relatively new technique – new, at least, in its application to anthropological investigations (Hennessy and Stringer 2002). Geometric morphometric methods have been applied with increasing frequency in the last decade to the study of the human form (Perez et al. 2006). This type of morphometrics allows for the results of statistical analyses of shape to be visualized as deformations in shape from a mean shape. It is advantageous because it provides an unambiguous interpretation of the statistical analysis performed (Hennessy and Stringer 2002). Geometric morphometric analysis begins by capturing the geometry of the structure under study, either in two- or three-dimensional coordinates; these coordinates are generally morphological landmarks on the structure or object under study. An appropriate function is then fitted to these points in order to expose the relationships among them. The most common methods of analysis are the Procrustes method and Euclidean distance matrix analysis (EDMA) (Rohlf and Marcus 1993).

Fluctuating Asymmetry Analysis

Deviations of an organism (or part of an organism) from perfect symmetry can be grouped into three categories: directional asymmetry, antisymmetry, fluctuating asymmetry.

Directional asymmetry involves the tendency for one side of a bilaterally present trait to develop more than the other side, and it is possible to predict which side will be

larger before the element has started growing. Directional asymmetry can be detected

when the mean values of a character differ systematically between two sides.

Antisymmetry occurs when asymmetry is normally present but variable in which side

exhibits greater development; it is not possible to predict which side will be larger.

Antisymmetry is detected by a bimodal distribution of signed differences between the

sides. Lastly, fluctuating asymmetry (FA) is asymmetry that results from the inability of

an organism to develop in precisely determined pathways. It occurs as random

differences between quantitative measures of the trait. FA may be expected to appear as

a normal distribution of signed differences between sides whose mean is zero (Van Valen

1962, Palmer and Strobeck 1986, Gawlikowska et al. 2007).

The influence of stress factors on human development can be estimated by

analyzing FA. The presence and degree of FA in an individual or population depends on

the type, duration, and intensity of stress factors, as well as the ability of the individual to

stabilize development in stressful conditions (Gawlikowska et al. 2007:161). FA has

been said to provide a measure of 'developmental noise', or environmentally induced

departures from the ideal development pathway (Palmer and Strobeck 1986:391). There

is also evidence to suggest that there is a strong negative correlation between FA and

heterozygosity in individuals and populations – meaning individuals who are

heterozygous in genetic makeup may have a better ability to buffer against

environmentally induced disturbances during development (Livshits and Kobyliansky

1991:442, Palmer and Strobeck 1986:392).

The majority of anthropological studies investigating FA in the skull have focused

on the dentition. Doyle and Johnston (1977) analyzed 60 Alaskan Eskimo skulls and 50

Arizona Pueblo skulls from the collection at the Smithsonian Institution's Museum of Natural History. These two samples were compared to a Neanderthal sample and sample of modern male of European ancestry from Ohio. The Eskimo and Pueblo samples were found to exhibit fluctuating dental asymmetry equal in magnitude to that of the Neanderthal sample; these three samples have greater fluctuating dental asymmetry than the Ohio sample. While the Neanderthal sample was considered to be derived from a very homozygous population, the Eskimo and Pueblo samples were considered to be quite heterozygous; therefore, it was concluded that some environmental stress caused the level of fluctuating asymmetry observed.

Perzigian (1977) compared dental fluctuating asymmetry in three samples characterized by different socioeconomic and nutritional status: Late Archaic Period hunter-gatherers (Indian Knoll site in Kentucky), two later agricultural groups (the Middle Mississippian Period Campbell site in Missouri, and the Post-Contact Coalescent Horizon Larson site in South Dakota) and modern individuals of European ancestry (Hamann-Todd Collection in Cleveland, Ohio). The author found, not unexpectedly, that the Indian Knoll population was the most asymmetrical in the dentition. This population also exhibited a high frequency of Harris lines, prevalent enamel hypoplasia, a slow rate of long bone growth, and a small adult stature – all indicators of severe metabolic distress. Moreover, the Indian Knoll population would have utilized a less diverse and reliable food resource base than the later agricultural groups (Perzigian 1977: 86). When comparing the archaeological groups, the author found that the degree of fluctuating asymmetry coincided with growth markers, and paralleled environmental conditions. By comparing dental fluctuating asymmetry and femur length, the author found that the taller

(and presumably better nourished) individuals from Indian Knoll had larger, less asymmetrical teeth than shorter individuals. Perzigian (1977:86-7) emphasized that differences between the study populations were due to environmental, rather than genetic, factors. Although endogamous mating (less genetic variation) could be used to explain the pronounced dental asymmetry of the small hunter-gatherer population at Indian Knoll, the association between endogamous mathing and bilateral asymmetry is unpredictable. Since dental asymmetry is more likely associated with environmental stress during development, the author suggests that dental asymmetry provides an important tool for studying growth and development, and estimating the health and nutritional status of populations (Perzigian 1977:87).

The study of fluctuating dental asymmetry has not proceeded without criticism. Smith et al. (1982) suggested that sample sizes of several hundred individuals are needed to have the required statistical power to detect population differences in dental asymmetry. Small differences between right minus left tooth size variance will not be detected without significantly larger sample sizes. The authors believed that due to this limitation, fluctuating dental asymmetry was not established as a reliable measure of general stress in human populations.

Hershkovitz et al. (1993) aimed to examine the methodological aspects of studying fluctuating dental asymmetry, in part to address the concerns raised by Smith et al (1982). The authors outlined two areas that had not been fully explored in the literature: the relationship between the magnitude of FA and trait measurements, and the relationship between the mode (most frequently occurring) and extreme phenotypes. The study measured the dentition of 262 Bedouin boys, aged 5 to 14 years. The population

was highly endogamous and subject to extreme levels of climatological and nutritional stress. It was expected that a great number of individuals would exhibit elevated FA levels. The authors found that tooth class and position both displayed a significant relationship with dental asymmetry; the distal teeth exhibited higher levels of FA than the mesial teeth. Using principal component analysis, the authors found that FA in the dentition appeared to be a function of environmental stress.

Anthropological studies of FA in the craniofacial skeleton are much less common that those of dental FA. While it is a well developed topic area in the orthodontic literature, studies focused on archaeological populations are few. Currently, the most common method for studying asymmetry in the skull is cephalometric radiographic image analysis. Prior to the adoption of this technique, direct measurement on dry skulls was the method commonly employed (Rossi et al. 2003).

A seminal study on skull asymmetry in past populations was conducted by Woo (1931). Woo measured 800 male Egyptian skulls, dating from the 26th to 30th dynasties. Twenty-five bilateral chord and arc measurements were included. The author found that the human skull was markedly asymmetrical, as opposed to the view that bones in individual crania differed from a symmetrical norm. It was also found that the right side generally had dominance over the left in size. The upper face (maxillae, zygomatics) and the forehead (frontal) were found to have the highest correlation between the size of the right and left sides.

Costa (1986) investigated the differing sizes of right and left mandibular condyles. The aim of the study was to determine whether a correlation existed between condylar asymmetry and the habitual use of one side of the dentition, or if this was a case

of fluctuating asymmetry. Seventy-two individuals (41 males, 31 females) from the Haida collection at the Field Museum of Natural History were included in the study. The greatest anteroposterior width of the condyle was multiplied by the greatest mediolateral length to give an area. The FA calculation used was (L-R)/(L+R). Dental wear was assessed using an 11 stage scale (stages zero to ten) developed by the author. Each tooth was graded for amount of occlusal wear based on the appearance of the crown. Wear values were averaged for first and second premolars and molars in each dental quadrant. Quadrant scores were combined to form right and left averages, which were then compared in each individual to determine the worn side (Costa 1986:120). No significant relationship was found to exist between the larger of the condyle pair and the side of the dentition exhibiting the greatest wear. The distribution of the FA index (normal, with a mean very close to zero) indicated that the asymmetry observed in the sample could be explained as a case of fluctuating asymmetry. Since the author included only those individuals with enough teeth present to give a good indication of attrition in each dental quadrant, the asymmetry of the condyles could not be explained by unilateral antemortem tooth loss.

The purpose of Rossi et al's (2003) study was to test the hypothesis that craniofacial symmetry exists before the chewing habit is established. Ninety-five skulls of known age and sex from the Museum of Anatomy Collection of the Federal University of Sao Paulo-Paulista School of Medicine were included in the analysis. The sample was divided into four groups: fetuses (four to nine months of intrauterine life), infants (one day to six months), children (six months to seven years) and adults (20 to 50 years). Children between 7 and 20 years were not included in the study, and no reason was given

for the cut-off age of 7 years. Four distances were measured: infraorbital foramen to anterior nasal spine, greater palatine foramen to posterior nasal spine, spinous foramen to basion, and spinous foramen to zygomatic arch on zygomatic-temporal suture. Asymmetry was calculated by (R-L)/R x 100. The authors found that craniofacial asymmetry existed throughout the whole sample. For the first three measurements, all groups expressed the same degree of asymmetry. For the last measurement, infants exhibited the largest degree of asymmetry, followed by fetuses, children, and adults. The authors therefore rejected the hypothesis that symmetry is established before the establishment of masticatory function.

Gawlikowska et al. (2007) studied the FA and changes in skull morphology over time in two Polish skull samples. The study sample consisted of 77 mediaeval skulls from the University of Wrocław and the Polish Academy of Sciences, and 82 modern human skulls from the Pomeranian Medical University. Radiographs were taken in posteroanterior and basal projections, and 30 bilateral distances were measured. Three FA indices were used: (R-L)/0.5(R+L), $1-r^2$, and the absolute difference between sides scaled on trait mean total size. The authors found that the levels of FA in the two samples differed significantly in 14 traits. The modern skulls exhibited significantly higher asymmetry levels in traits of the cranial base, whereas the mediaeval skulls exhibited significantly higher asymmetry levels in the skull vault. The modern skulls showed an overall higher level of asymmetry than the mediaeval sample. The authors suggest that since the modern skulls dated to the beginning of the 20th century, it is possible that stress factors such as environmental pollution, toxins and tobacco smoking

may have contributed to the high FA levels. Nutritional status was not thought to have changed significantly between the two time periods under study.

Tools Used in This Study

The data used in the present study was not collected with morphometric analysis in mind (measurements between landmarks were not taken). Therefore, changes in shape of the skull of the Roebuck sample cannot be assessed. The data does, however, lend itself to asymmetry analysis since many bilateral measurements were taken. Fluctuating asymmetry analysis will therefore be used to explore the health of the population. This approach is advantageous because it involves relatively simple statistical procedures, and common indices have been established in the literature. The major limitation stems from sample size. It is unclear if the present study sample will be large enough to study fluctuating asymmetry in a meaningful way.

SUMMARY

Growth is a regular process, with distinct increases in rate in mid-childhood (6-8 years) and adolescence. The growth pattern of all normal, healthy children follows a similar course. Deviations in this expected growth pattern can be used as the basis of detecting health disorders on the individual and population levels. The development of the skull involves three entities: the desmocranium (calvaria), the chondrocranium (cranial base), and the viscerocranium (face). The development of the chondrocranium is strongly regulated by genetics, while the other two cranial regions are strongly influenced by local environmental factors.

Skeletal growth is genetically controlled, but the amount and speed of growth may be affected by nutrition, illness, the physical environment, and psychological well-being. The sufficiency of children's growth allows for insight into the overall health of a population. Skeletal growth studies based on archaeological samples often use linear growth as a proxy for health; the growth of children is thus used to make interpretations about the health and well being of a population.

Growth research on archaeological populations originated with the work of Stewart (1954) and Johnston (1962). Postcranial linear growth studies are more common, and generally focus on the long bones of the skeleton. Cranial growth studies are much less common, and lack the relatively standardized methodology seen in postcranial studies.

CHAPTER THREE: MATERIALS AND METHODS

St. Lawrence Iroquois Origins and 'Disappearance'

Three cultural groups were present in Ontario during the Terminal Woodland period (ca. 1000 AD to the Historic Period). The Algonquians were present in northern Ontario, while southern Ontario was divided between the Ontario Iroquois (south-west) and the St. Lawrence Iroquois (north-east) (Wright 1972:64-65). The Roebuck site is associated with the St. Lawrence Iroquois (SLI). The SLI were an independent group of Iroquoian people, found along the upper St. Lawrence Valley in southern Quebec, eastern Ontario, and adjacent New York State (Wright 1972:86).

The cultural base for the development of the SLI is thought to be the northeastern expansion of the Pickering culture, some time prior to 1300 AD. The Pickering culture also gave rise to the Ontario Iroquois (Huron, Petun, Neutral, Erie) to the west. The SLI developed in a locally distinct fashion: instead of practicing ossuary burials, they buried their dead in flexed positions throughout the village; their pottery and pipes were decorated distinctively; and they made greater use of bone for their tools (Wright 1972:87).

The lifestyles of most Iroquoian groups have been documented in detail in various historical sources, starting from the early seventeenth century, as well as through archaeological investigation. Unfortunately, the SLI are not among those groups (Tremblay 2006:29). The SLI were the first Iroquoians to have direct contact with Europeans in the early sixteenth century (Wright 2004). There are a few historical accounts of the SLI from between 1534 and 1543, mostly written by Jacques Cartier on his three voyages to Canada. Cartier mentioned a large number of Iroquoian villages,

including Hochelaga on Montreal island and Stadacona (near present-day Quebec City). Cartier never travelled further upriver than Montreal island, however (Tremblay 2006:29-31).

The SLI disappeared as a distinct entity some time between the visits of Cartier (A.D. 1535) and Samuel de Champlain (A.D. 1603) (Wright 1972:86). The SLI villages reported by Cartier, including Stadacona and Hochelaga, were abandoned by Champlain's arrival. This 'disappearance' was part of a long and complex sequence of events that had started around A.D. 1400, and ended under the influence of the European invasion in the late sixteenth century (Pendergast 1998). Huron sites along the Trent waterway, dated to the mid-sixteenth century, possess a high percentage of distinctive SLI pottery; this pottery has even been found as far west as Toronto-area Huron sites (Wright 1972:90). It has been speculated that the Huron on the Trent River system successfully waged war against the SLI to the east. Conquered women and children would be taken back to the victors' villages and adopted into the new community; captured women would continue to manufacture their traditional pottery (Wright 1972:90). On the other hand, distinct SLI smoking pipes have not been found at these Huron sites. Since pipes were made by men rather than women, the absence of pipes would reinforce the idea that the SLI were conquered by the Huron (Wright 1972:90).

Snow (1994) suggests that the SLI were conquered because they stood between the Ontario Iroquois and their trade with the Europeans. As early as the late-sixteenth century, Southern Iroquois were aware of European (French) goods, and wanted to acquire these goods in exchange for animal pelts. The problem for the Southern Iroquois

was that the SLI stood between them and French traders on the lower St. Lawrence River (Snow 1994:75-76).

Roebuck Site and Skeletal Remains

The Roebuck site (BeFv-4) is a precontact palisaded village site in Augusta Township, Grenville County, Ontario. The site is located 13 km north of the St. Lawrence River, and is one of seven villages in the Prescott cluster. At 3.2 hectares, Roebuck is the largest of the St. Lawrence Iroquois villages in Ontario. The site was surrounded on three sides by swamps (which at one time may have been open water of the South Nation River), with the remaining side defended by an earthwork (Wright 2004:1260-1261). Roebuck has been estimated to have contained up to forty longhouses, with a population as large as two thousand people (Wright 1987:57). Interestingly, the site appears to have represented a single construction event – meaning that the population came in as a single body, rather than being absorbed from smaller villages as Roebuck expanded. The site has been radiocarbon dated to approximately A.D. 1390 +/-100 by the CMC; the sample, lab number M-1538, was submitted by J.F. Pendergast. Taken from areas of ash and midden, the sample consisted mainly of wood charcoal, but included some corn, beans, and cherry and plum pits (Canadian Archaeological Radiocarbon Database). Roebuck appears to be an initial pioneer village into Ontario. This idea is supported by pottery and pipe stylistic trends (Wright 2004:1261).

The Roebuck site was first described by Guest in 1856, and excavated by W.J. Wintemberg in 1912 and 1915 under the supervision of Harlan Smith at the Geological Survey of Canada, and by J.V. Wright in 1970 (Wintemberg 1936, Jamieson 1983,

Pendergast 1983, Wright 1987). Eighty-three burials (see below) were excavated from the site, primarily containing the skeletal remains of women and children. The burials were located throughout the village with no discernible orientation, and most individuals were buried in the traditional flexed position. Burial depths ranged from 9 to 43" (approximately 23-109 cm); the well-drained, sandy soil in which the burials were interred likely contributed to the excellent overall preservation of the skeletal material (Wintemberg 1936).

The Roebuck collection represents the largest studied sample of St. Lawrence Iroquois skeletal material. The number of burials involved in the site has been revised over the years: Wintemberg (1936) originally reported that 83 skeletons were recovered; Knowles (1937) revised the total to 84 skeletons, with 43 adults and 41 subadults. The most recent examination of these materials by Janet Young at the Canadian Museum of Civilization (CMC) led to a total count of 87 individuals – 47 adults and 40 subadults (Wright 2004:1291). The Roebuck collection was repatriated to the Akwesasne Mohawk for reburial in 1998; osteological data was collected by osteologists at the CMC prior to repatriation and reburial. These data have been the subject of only limited analysis (e.g. Hoppa et al 2004).

In his 1936 report, Wintemberg focused mainly on the condition of the burials and body positioning within the graves. Knowles (1937) conducted a more thorough analysis of the remains, including age and sex analysis, measurements, and descriptions of pathological lesions. Unfortunately, only two paragraphs detail the subadult remains, and solely for the purpose of separating the subadults from the adult remains (Knowles 1937:8).

More recently, Hoppa et al. (2004) examined data collected from the Roebuck sample in order to assess selective mortality, and to assess the evidence for the timing of the growth spurt. The authors assessed mortality bias in the sample by comparing morphometric variation in both children and adults. Two variables were examined: lumbar vertebral neural canal size, and permanent molar size. It was found that there were no significant differences between survivors (adults) and non-survivors (children) based on comparisons of mean neural canal size and permanent molar size. To assess the timing of the growth spurt in the sample, the authors analyzed differential growth between the femur, humerus, third metacarpal, and second metatarsal length. Three individuals were identified as having growth in one bone slightly greater than anticipated by the other bone. All three individuals had dental age estimates (using Trodden 1982) of approximately 9-10 years; thus the timing of the growth spurt may be around 10 years of age (Hoppa et al. 2004).

The data set under study contains cranial and postcranial measurements for 38 of the 40 Roebuck subadults (see Table 1 and Fig. 1 for age distributions) and was collected by Lynda Wood and Janet Young in 1997-8. Individuals range in skeletal age from fetal to 21 years. As can be seen in Table 1, some individuals fell into two age categories. For Fig. 1, the individual bridging two age categories was divided in two, with 0.5 going into the counts for each age category.

Table 1: CMC Identification Number, Age and Sex of Roebuck Subadults

CMC Unique ID	Skeletal Age (yrs)	Dental Age (yrs)	Age category (yrs)
X111-F:1	4-7	5.79	0-4, 5-9
X111-F:3	5-7	6.72	5-9
X111-F:4	2-3	3.46	0-4
X111-F:5	11-12	9.12	10-14
X111-F:6	8-10	9.05	5-9, 10-14
X111-F:7	14-16	15.95	10-14, 15-19
X111-F:10	1		0-4
X111-F:12	12-15		10-14, 15-19
X111-F:18	12-15	11.31	10-14, 15-19
X111-F:19	1-3		0-4
X111-F:20	5-7	5.64	5-9
X111-F:23	1.5-2.5	3.21	0-4
X111-F:25	6-8	7.44	5-9
X111-F:29	15-21		15-19, 20+
X111-F:32	5-7	5.47	5-9
X111-F:33	5-7	6.12	5-9
X111-F:185	0.75-1		0-4
X111-F:186	5-7		5-9
X111-F:193	5-7		5-9
X111-F:195*	2-3		0-4
X111-F:197	perinate		~birth
X111-F:220	5-7	4.18	5-9
X111-F:244	10-12		10-14
X111-F:245*+	6-8		5-9
X111-F:245a	1-3		0-4
X111-F:246*	foetus		~birth
X111-F:247*	1-3		0-4
X111-F:253*	2-3	3.40	0-4
X111-F:254	4-6	5.20	0-4, 5-9
X111-F:257	7-10		5-9, 10-14
X111-F:260	5-7		5-9
X111-F:264	foetus		~birth
X111-F:265	2-4		0-4
X111-F:266*	foetus		~birth
X111-F:266a*	foetus		~birth
X111-F:267*	1-2		0-4
X111-F:268	0.5 - 1 yr		0-4
X111-F:269*	foetus		~birth

+ Is a postcranial skeleton, may belong with XIII-F:244 which is only a skull; discrepancy in ages may be due to the fact the postcranial skeleton's growth may be slowed due to disease process that affected spine, sacrum and left ilium

Fig. 1: Skeletal Age Distribution of Roebuck Sample
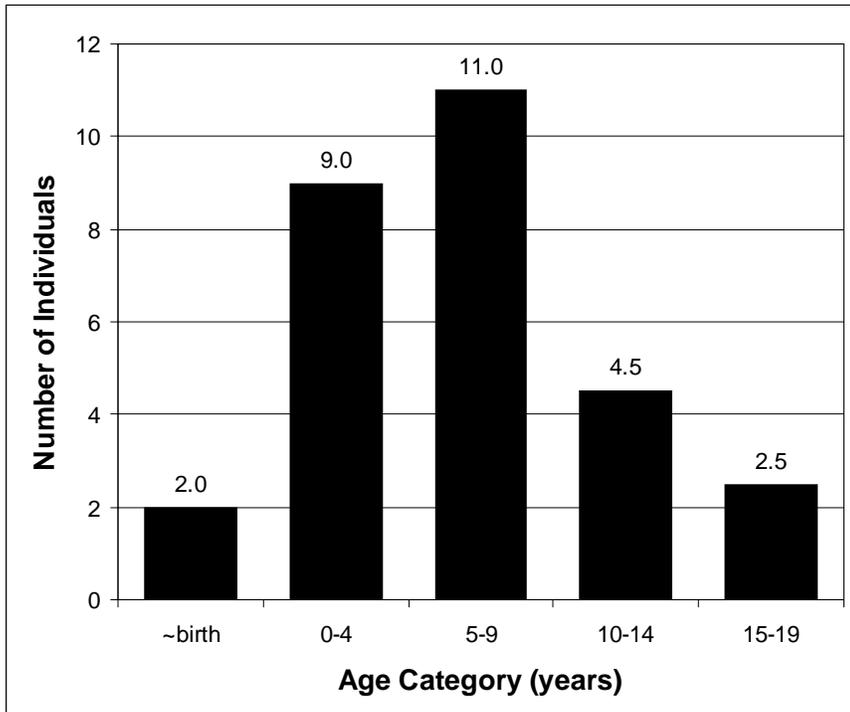
Seventy-eight variables that were measured on the skull are presented below (Table 2). The variables are standard measurements taken from Buikstra and Ubelaker (1994) and Brothwell (1981), using calipers and a tape measure, and recorded to the nearest 0.5 mm. The number of measurements available for each individual varies widely, from about 5 measurements per individual to a complete set. Nine individuals had no cranial measurements (marked with * in Table 1), leaving 29 available for analysis. Dental ages were determined using Trodden (1982). Fifteen individuals were aged in this way; one of these individuals had no craniofacial measurements available, so 14 individuals with dental ages were used in the analysis relating to age.

Table 2: Craniofacial Measurements Used in Study

Measurement Name	Measurement Name
Maximum cranial length	Height of mandibular body
Maximum cranial breadth	Breadth of mandibular body
Minimum frontal breadth	Mandibular length R/L*
Maximum frontal breadth	Mandibular length goniometer R/L*
Bizygomatic diameter	Bigonial breadth
Biasterionic breadth	Bicondylar width
Basion-bregma height	Symphyseal height
Basion-nasion length	Ramus height R/L*
Basion-prosthion length	Ramus height goniometer R/L*
Basion-opisthion length	Minimum ramus breadth R/L*
Foramen magnum breadth	Gonial angle
Upper facial height	Maximum malar length
Upper facial breadth	Coronoid height R/L*
Total facial height	Distance between mental foramina
Mastoid length	Maximum projective mandibular length
Orbital Height R/L*	Inferior malar length R/L*
Orbital Breadth R/L*	Maximum internal palate breadth
Nasal height	Maximum internal palate length
Nasal breadth	Maximum occipital condyle breadth R/L*
Alveolar length	Posterior inter-occipital condylar distance (midpoint)
Alveolar breadth	Posterior inter-occipital condylar distance (posterior point of contact with foramen magnum)
Bimaxillary breadth	Anterior inter-occipital condylar distance (midpoint)
Biorbital breadth	Anterior inter-occipital condylar distance (anterior point of contact with foramen magnum)
Interorbital breadth	Minimum occipital breadth basilar
Biauricular breadth	Minimum occipital breadth squamous
Nasion-bregma chord/arc	Mandibular notch breadth R/L*
Bregma-lambda chord/arc	Bi-coronoid distance
Lambda-opisthion chord/arc	Coronoid-condyle distance R/L*
Auricular height	Condylar process height R/L*
Bregma-porion height	Mandibular condyle breadth R/L*
Basion-porion	

*Bilateral measurements used in asymmetry analysis

Data Analysis

Data analysis was divided into three main components. The first examined the

relationship between dental age and each of the 78 measurements. The second section

examined the relationship between the measurements themselves. The third section

tested the data for fluctuating asymmetry. All data analysis was conducted using SPSS 17.0.

Analysis began by examining the relationship between each of the craniofacial measurements and dental age for the 14 individuals for which dental age was available. Any outliers or interesting patterns were identified. Percentage of growth attained was explored by dividing each individual measurement by the corresponding mean adult size for that measure. Forty-seven adult individuals with craniofacial measurements were available for inclusion in the averages, which were not divided by sex. The decision to pool male and female adult values together was made for a number of reasons: sex had not been determined with any certainty for any of the subadults; out of 47 adults, 39 were determined to be female or probable female, while 5 individuals were of indeterminate sex and only 3 individuals were classified as male or probable male. As a result, the averages are heavily weighted towards adult female size.

Since less than half of the sample had dental ages available, other avenues needed be explored to assess information regarding growth and development. Therefore, indicators of growth were compared directly with one another; for example, maximum cranial length was graphed against maximum cranial breadth. Comparing each of the 78 measurements against all others resulted in a large number of comparisons. For this reason, matrix scatter plots were used to identify interesting comparisons. Nine matrix scatter plots were graphed, with measurement groupings for the cranial vault, the basicranium, the face, the mouth, and the mandible. The matrix scatter plots also allowed any data entry errors to be visually identified. Fifty-six comparisons of interest were identified and graphed individually. Comparisons of interest were identified based on the

appearance of a strong relationship between the two measurements, or based on the presence of one or many outliers. Correlations between measures were assessed , and outliers were identified by their CMC number. The number of outliers was narrowed down by examining percentage of attained adult size, and assessing which individuals were actually set apart form the group – and which ones only appeared that way as a result of natural variation within the group.

The third component of analysis involved testing for fluctuating asymmetry (FA). The methodology employed by Gawlikowska et al (2007) was used as a model. Twelve bilateral (right and left) measurements were available in the Roebuck data set (see Table 2, above). Two of the three FA indices used by Gawlikowska et al (2007) were calculated in this study. $FA1 = R-L / (0.5)(R+L)$ and $FA2 = 1-r^2$ (where r is the coefficient of correlation between the sides). The Wilcoxon matched-pairs signed ranks test was used to compare right and left sides for the FA1 index.

The results of these analyses were compared to the sample's long bone growth, as well as to two other populations. The most in-depth comparison was made to Markowitz's (1995) craniofacial data on the Arikara; comparison was also made to Little et al's (2006) modern Oaxacan data.

Observations of pathology in the Roebuck subadults are presented in Table 1 in Appendix A. All observations were made by Janet Young at the CMC, and this information is included for the purpose of aiding interpretation of the results of the above analyses.

CHAPTER FOUR: RESULTS

Part A – Dental Age versus Craniofacial Measurements

The relationships between the craniofacial measurements and dental age were explored by plotting one against the other. Of particular interest were dimensions which were highly or poorly correlated with age. This section of analysis also explored the growth pattern of the population, and the range of individual variation in growth within the population.

Percentage of Adult Growth Attained

Percentage of adult growth attained (Table 3) was included in this study to examine the general craniofacial growth pattern of the sample. Roebuck appears to follow the general growth pattern of an early developing neural complex, a later developing masticatory complex, and an intermediate growing mid-facial region.

Table 3: Percentage of Growth Attained in the Roebuck Sample

Area of Skull	% of Growth Attained
Neural	
Maximum cranial length	90-102
Maximum cranial breadth	90-102
Maximum frontal breadth	81-106
Orbital height R	89-101
Facial	
Bizygomatic diameter	74-90
Upper facial height	71-94
Upper facial breadth	78-95
Nasal height	66-95
Nasal breadth	69-86
Masticatory	
Height of mandibular body	42-98
Mandibular length L	46-91
Symphyseal height	35-96
Minimum ramus breadth R	48-93
Coronoid height L	36-93

Correlation Analysis

Table 2 in Appendix A lists the results of the correlation analysis, and Figures 1-30 in Appendix B, show plots of those variables that appear to be strongly correlated with dental age. Correlation coefficients ranged from 0.032 (nasion-bregma arc) to 1.00 (mandibular length goniometer L, with only three individuals graphed). The measurements most highly correlated with dental age fell into four general groups: the basicranium (involving the occipital condyles and occipital breadth); the face (face height/breadth, nasals, malar); the upper mouth (alveolar and palate length/breadth); and the mandible. Of the 29 measurements taken on the mandible, 16 are highly correlated (higher than 0.7) and 10 show a good correlation (between 0.6 and 0.7).

Another interesting result involves the orbits. Interorbital breadth and biorbital breadth both have very high correlation values, at 0.843 and 0.854 respectively. Meanwhile, right and left orbital heights have weak correlation values (0.381 and 0.077, both nonsignificant) and right and left orbital breadths have correlation coefficients just over 0.5 but not significant. This indicates that the distances across both orbits and between the medial edges of the orbits increases in a relatively predictable fashion with age, while the actual dimensions of the orbits themselves are more variable. This is an interesting area to look at for asymmetry, and will be examined in a later section.

Visual Outliers

Individuals who placed away from the rest of the group in each plot are listed in Table 4 (pg. 58). Visual outliers are illustrated in Figures 31-42 in Appendix B and are identified by their CMC identification number, dental age, and measurement value. They

are listed as placing either above or below the general pattern of the graph. Of the 14

individuals used in the dental age analysis, 10 had at least one visual outlier. Three

individuals (XIII-F:23, XIII-F:25, XIII-F:254) had only one outlier occur, and two

individuals (XIII-F:1, XIII-F:33) had two outliers. Two individuals had multiple outliers

occurring in only one direction. Individual XIII-F:7, with a dental age of 15.95 years,

had 9 outliers all below the distribution of the group. Individual XIII-F:18, with a dental

age of 11.31, had 4 outliers all above the distribution of the group. The percentage of

attained adult size is included for each outlier in Table 4, in order to ascertain which

individuals are truly ahead or behind the group in terms of growth. Humphrey's (1998)

data is included where applicable, with the ages at which 70% and 90% of adult size were

attained in that sample. Waitzman et al's (1992) data is used to supplement Humphrey's,

which does not include maximum cranial length or breadth or biorbital breadth. The data

from Waitzman et al (1992) is presented as percentages of adult size obtained at three

ages: neonate, 1 year, and 5 years.

Table 4: Dental Age Comparison Visual Outliers

CMC ID	Dental Age	Measurement	Above/Below?	% Adult Size	Humphrey (1998) or Waitzman et al (1992) (where applicable)	Comments
XIII-F:1	5.79	Mandibular condyle breadth R	Above	85	70% by 6.3 yrs	**Very high % for age**
		Bicondylar width	Below	61	70% by 2.4 yrs	**Very low % for age**
XIII-F:5	9.12	Bimaxillary breadth	Above	119		**Very high % for age**
		Biorbital breadth	Above	89	88% by 5 yrs	Comparable to others
		Auricular height	Below	88		Low % for age
		Bregma-porion height	Below	90		Low % for age
XIII-F:6	9.05	Basion-nasion length	Above	94		High % for age
		Nasal height	Above	95		High % for age
		Basion-porion	Above	n/a*		n/a
		Nasal breadth	Below	69		**Very low % for age**
		Lambda-opisthion chord	Below	91		Low % for age
		Lambda-opisthion arc	Below	87		**Very low % for age**
XIII-F:7	15.95	Maximum cranial length	Below	95	96% by 5 yrs	Slightly low for age
		Maximum cranial breadth	Below	96	95% by 5 yrs	Slightly low for age
		Foramen magnum breadth	Below	100	90% by 5.3 yrs	Normal (smaller sized individual?)
		Nasal height	Below	89		Slightly lower for age
		Bregma-porion height	Below	92		Low % for age
		Ramus height R	Below	77	70% by 6.0 yrs 90% by 13.0 yrs	**Very low % for age**
		Ramus height L	Below	78	70% by 6.0 yrs 90% by 13.0 yrs	**Very low % for age**
		Ramus height goniometer R	Below	79		**Very low % for age**
		Ramus height goniometer L	Below	79		**Very low % for age**
XIII-F:18	11.31	Bicondylar width	Above	97	90% by 16.4 yrs	Slightly high for age

		Distance b/n mental foramina	Above	104	90% by 9.1 yrs	Comparable to others (normal)
		Bicoronoid distance	Above	102	90% by 11.7 yrs	Slightly high for age
		Mandibular condyle breadth R	Above	85	70% by 6.3 yrs 90% by 18.3 yrs	Comparable to others (normal)
XIII-F:20	5.64	Maximum cranial breadth	Above	102	95% by 5 yrs	High % for age
		Minimum frontal breadth	Above	95		Slightly high for age
		Maximum malar length	Above	149*		Error in data
		Distance b/n mental foramina	Above	99	90% by 9.1 yrs	High % for age
		Ramus height goniometer R	Below	55	70% by 6.0 yrs 90% by 13.0 yrs	**Very low % for age**
		Bicoronoid distance	Below	63	70% by 0.9 yrs 90% by 11.7 yrs	**Very low % for age**
XIII-F:23	3.21	Ramus height goniometer L	Below	45	70% by 6.0 yrs 90% by 13.0 yrs	Slightly low for age
XIII-F:25	7.44	Foramen magnum breadth	Above	110	70% by birth 90% by 5.3 yrs	Comparable to others (normal)
XIII-F:33	6.12	Lambda-opisthion chord	Above	96		Comparable to others (normal)
		Basion-porion	Below	n/a		n/a
XIII-F:254	5.20	Minimum frontal breadth	Below	86		Comparable to others (normal)

XIII-F:7, 15.95 years and XIII-F:18, 11.31 years

XIII-F:7 exhibited the most number of visual outliers, and they were all placed below the distribution of the group. The measurements involved included maximum cranial length and breadth, foramen magnum breadth, nasal height, bregma-porion height, and ramus height (left and right). XIII-F:18 exhibited four visual outliers, all placed above the distribution of the group and all involving the mandible: bicondylar width, distance between mental foramina, bicoronoid distance, and right mandibular condyle breadth. The relationship between these two individuals is difficult to interpret based on only this information. For its four outliers, XIII-F:18 is clearly higher than the younger group of individuals and the older XIII-F:7. There are two ways to interpret this situation. Either XIII-F:18 does lie outside the distribution of the group, and the position of XIII-F:7 represents the continuation of the growth pattern established by the early individuals; or, XIII-18 represents the continuation of the growth pattern, during or after a growth spurt, and XIII-F:7 is actually below the distribution of the group. Fig. 2 and Fig. *3* (bicondylar width and ramus height) illustrates the latter scenario, where the majority of individuals appear to fit into a curved line. In Fig. 4 and Fig. *5* (distance between mental foramina, bicoronoid distance), the younger individuals appear to line up reasonably well with the 16 year-old XIII-F:7. Fig. 6 (mandibular condyle breadth) is inconclusive – it could fall into either scenario because the younger individuals are more widely scattered.

Fig. 2: Bicondylar Width by Dental Age
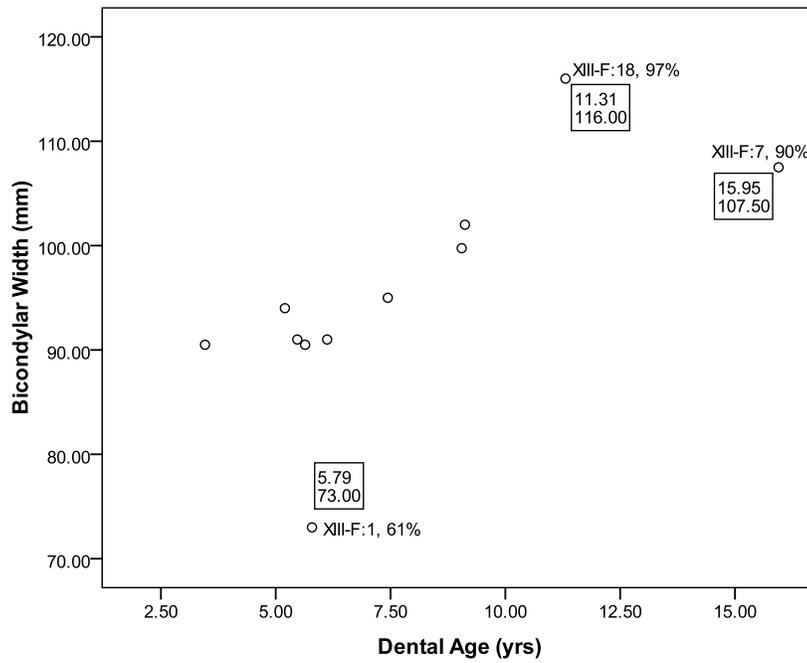
Fig. 3: Ramus Height by Dental Age
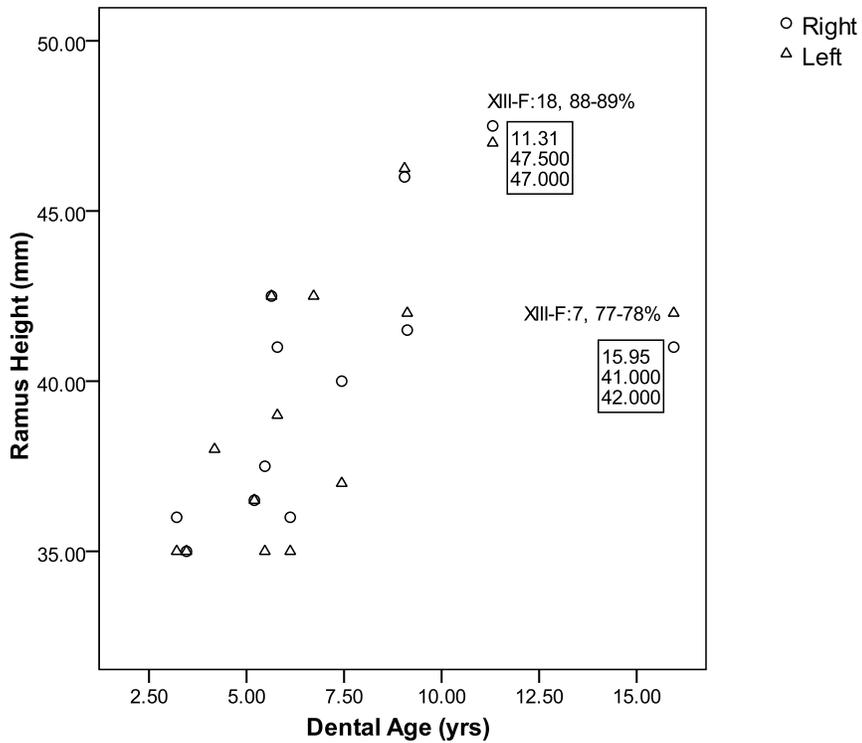
Fig. 4: Distance Between Mental Foramina by Dental Age
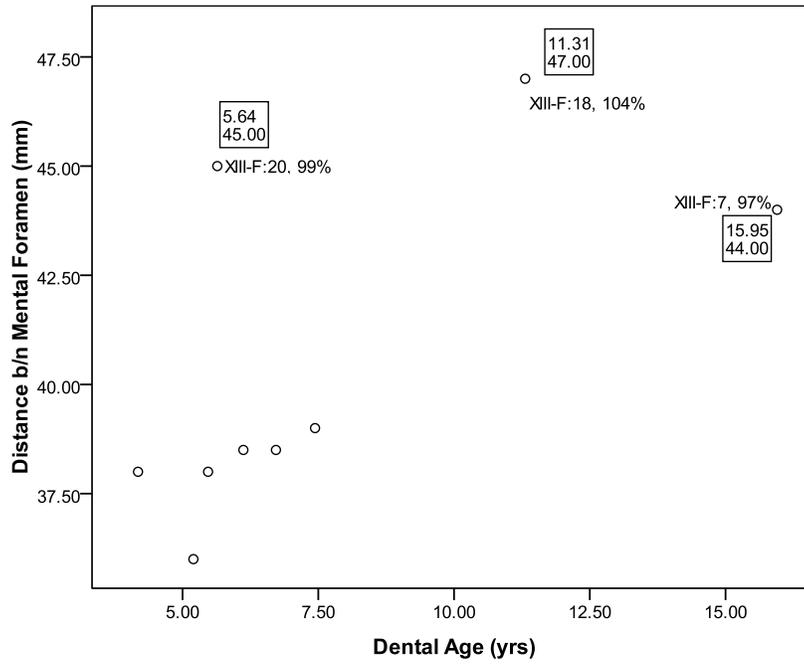
Fig. 5: Bicoronoid Distance by Dental Age
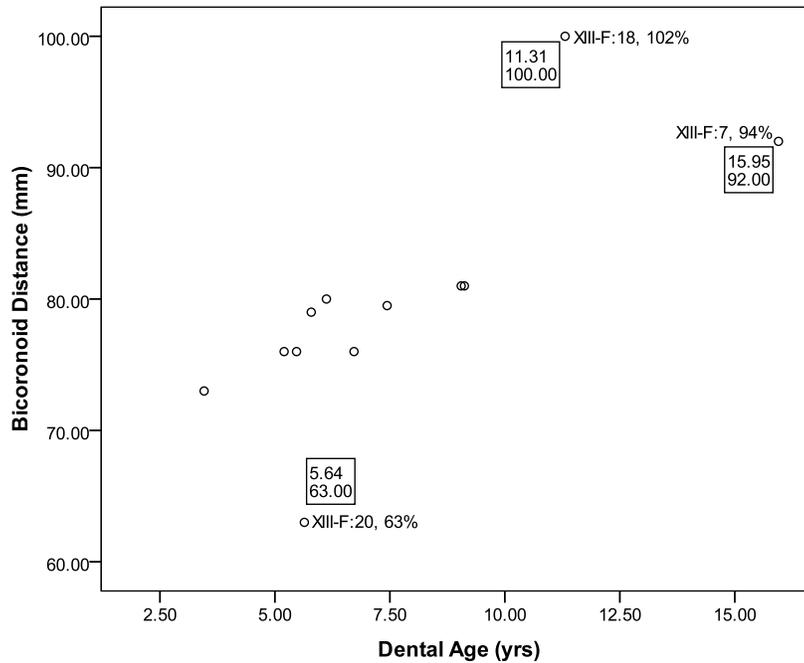
Fig. 6: Mandibular Condyle Breadth by Dental Age
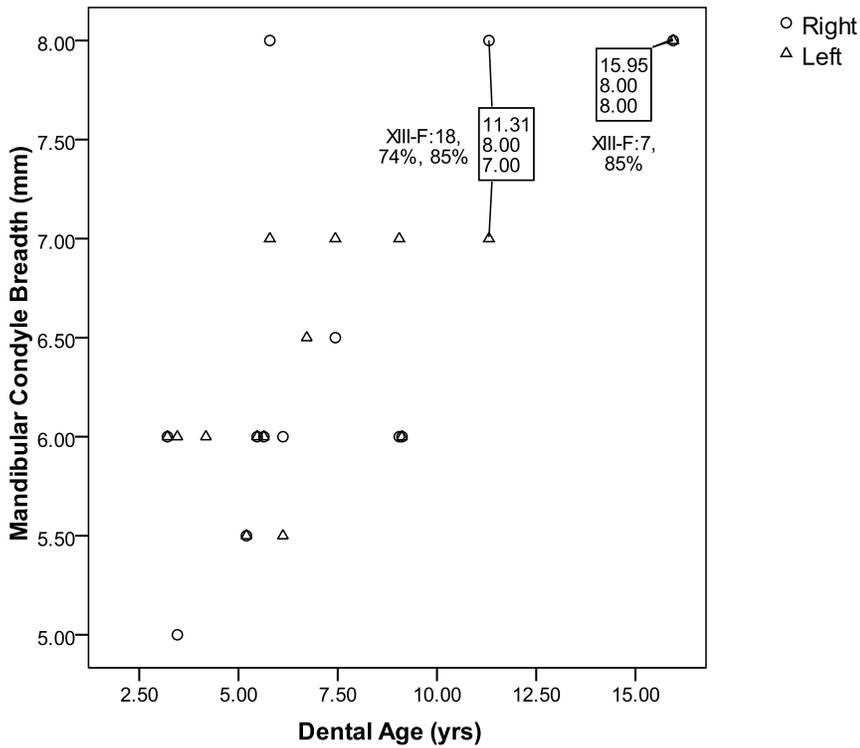
The relationship between XIII-F:7 and XIII-F:18 can be made clearer by taking into consideration the percentage of adult size attained by each individual (Table 3, pg. 55). Of the 9 visual outliers exhibited by XIII-F:7, only the four ramus height outliers exhibit a very low percentage of attained adult growth. Humphrey (1998) found that in her sample, 90% of adult size was attained by 13 years of age. XIII-F:7 has a dental age of 15.95 years, but has attained only 77-79% of his or her ramus height. The remaining 5 outliers show normal or slightly low-for-age growth percentages. For XIII-F:18, two outliers exhibited only slightly higher growth than normal, and two outliers were actually within the normal range of size for the population (based on the percentages exhibited by other individuals, and on comparison with Humphrey's (1998) data). Distance between mental foramina and bicoronoid distance both exhibited over 100% attainment of adult

63

growth, but this may indicate that XIII-F:18 is a male. Since the adult data is heavily

weighted toward female size, a percentage over 100 for a later developing skeletal

measure could indicate the individual is growing toward male size.

Putting together the information from the above five plots (bicondylar width,

ramus height, distance between mental foramina, bicoronoid distance and mandibular

condyle breadth) and from the attainment of adult size data, it can be seen that XIII-F:7

falls into the normal range of growth for the population – except in ramus height. The

combination of XIII-F:7 being slightly small for age in many variables and XIII-F:18

being slightly larger for age contribute to the appearance of two potential growth curves

for the sample. The true growth curve for Roebuck subadults likely follows a path

between these two older individuals.

XIII-F:5, 9.12 years and XIII-F:6, 9.05 years

XIII-F:5 exhibited four visual outliers: two above (bimaxillary breadth and

biorbital breadth) and two below (auricular height and bregma-porion height). When

compared to attainment of adult size, only one dimension stands out: bimaxillary breadth,

with 119% of adult size. While this individual's dental age was estimated to be 9.12

years, his or her skeletal age was estimated to be 11-12 years. Since skeletal

development is ahead of dental development, it is reasonable to suggest this individual

may be female.

XIII-F:6 exhibited six visual outliers: three above (basion-nasion length, nasal

height, basion-porion) and three below (nasal breadth, lambda-opisthion chord, lambda-

opisthion arc). Again taking into consideration attainment of adult size, only two

dimensions stand out: nasal breadth (69%), and lambda-opisthion arc (87%).   Both

dimensions exhibit a very low percentage of attained adult size, compared to the rest of

the sample. XIII-F:6's dental age was estimated to be 9.05 years, while his or her

skeletal age was estimated to be 8-10 years. Since skeletal development is not ahead of

dental development, it is reasonable to suggest that this individual may be male.

Take together, XIII-F:5 and XIII-F:6 provide a good opportunity to examine the

variation in size and growth that can be present in a population.

In summary, it appears that the growth pattern for the Roebuck subadult sample

lies somewhere between the two oldest individuals in the sample: XIII-F:7 and XIII-F:18.

Neither individual appears to be outside the range of growth variation of the sample.

Moreover, most of the visual outliers identified in the comparisons of cranial measures to

dental age were found to be within a normal range of variation, being only slightly larger

or smaller for age.

Comparison with Long Bone Growth Profiles

Lengths for the long bones (humerus, radius, ulna, femur, tibia, and fibula) were

graphed against dental age for comparison with craniofacial data (Fig. 7 and Fig. 8). All

plots appear to be highly correlated (Table 5), and individual XIII-F:7 (dental age 15.95

years) appears to be directly in line with the younger individuals. This is in contrast to

the craniofacial data, where the individual often appears below the growth curve.

Unfortunately, long bone length data for XIII-F:18 (dental age 11.31 years) is limited to

the left humerus (Fig. 7). In that comparison, XIII-F:18 falls directly in line with the

younger individuals and the older XIII-F:7. Another interesting pattern concerns

individuals XIII-F:5 (9.12 years) and XIII-F:6 (9.05 years). For the arm bones, XIII-F:5

is always longer; whereas XIII-F:6 is longer for the femur and tibia. This may represent

an occurrence of a differential growth spurt.

Fig. 7: Humerus, Radius, and Ulna Maximum Lengths by Dental Age
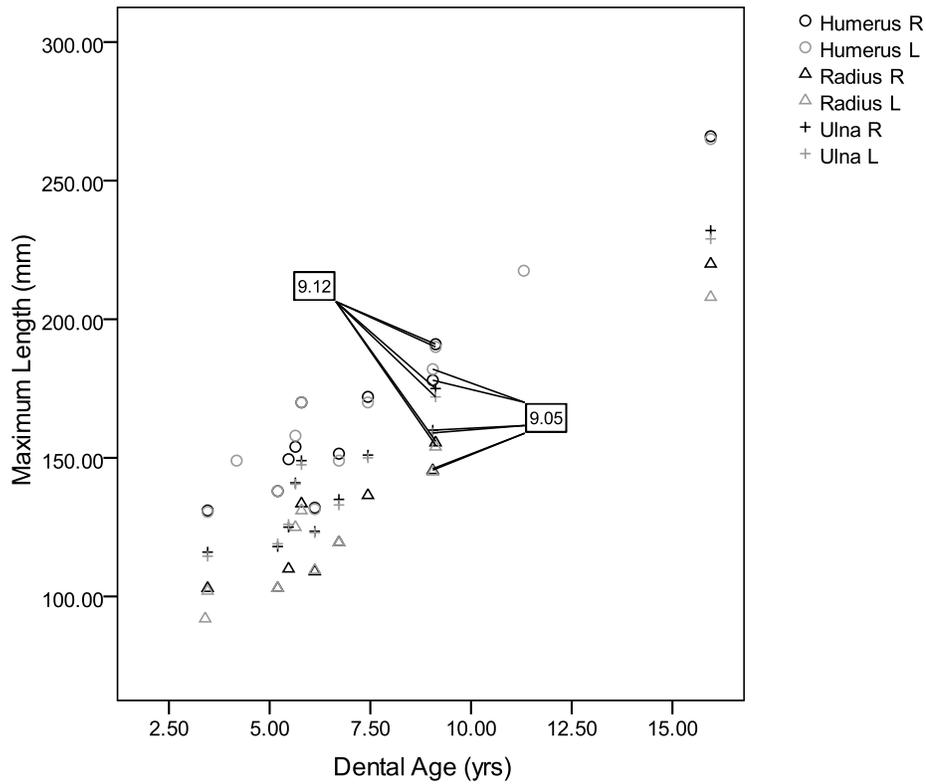
Fig. 8: Femur, Tibia, and Fibula Maximum Lengths by Dental Age
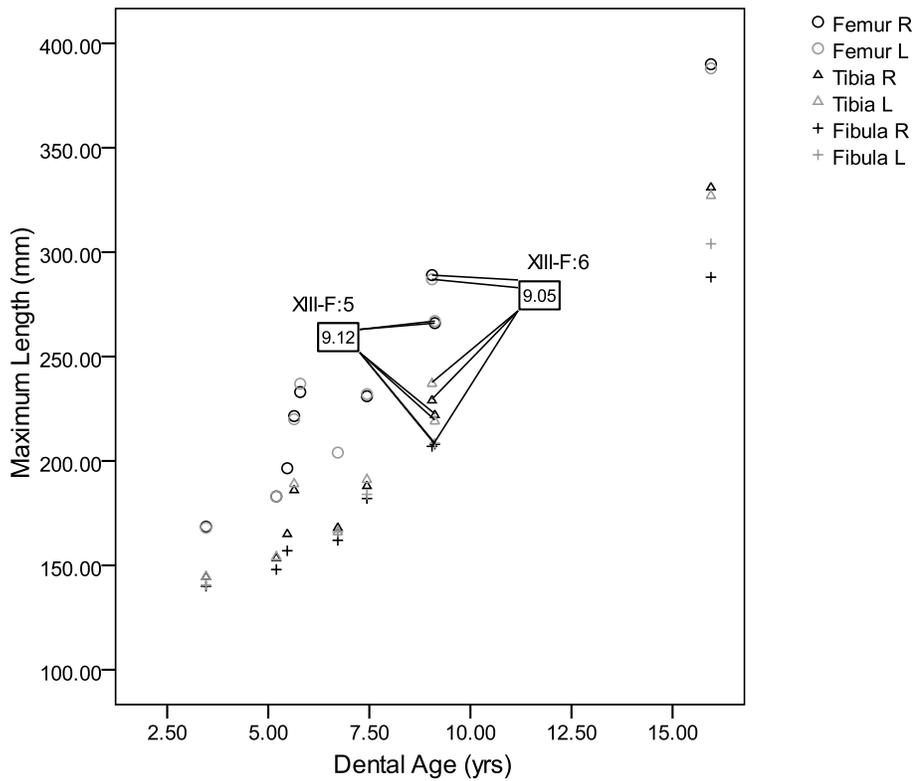
Table 5: Long Bone Maximum Lengths and Dental Age Correlation Coefficients

Measurement	r
Humerus maximum length R	0.959
Humerus maximum length L	0.955
Radius maximum length R	0.970
Radius maximum length L	0.971
Ulna maximum length R	0.963
Ulna maximum length L	0.965
Femur maximum length R	0.979
Femur maximum length L	0.970
Tibia maximum length R	0.983
Tibia maximum length L	0.975
Fibula maximum length R	0.992
Fibula maximum length L	0.994

Part B – Measurement vs Measurement

Since less than half of the Roebuck subadult sample had dental ages, other techniques were required to assess the growth of the population. The craniofacial measurements were plotted against each other to explore how the dimensions changed in relation to one another (how well or poorly they correlated). This also allowed for the observation of differential growth – individuals who were larger in one dimension than would be predicted by the size of another. A purpose of this section of analysis was to determine if growth spurts in the skull could be detected, using standard osteological measurements from a cross-sectional sample.

Correlation Analysis

Table 3 in Appendix A lists the results of the correlation analysis for all of the cranial metrics. All statistically significant (0.05 level) correlations were included, as well as some correlations that visually appeared to have a strong relationship but in fact did not. Comparisons within the mandible represent the largest group, with 122 of 189 comparisons. Within the mandible, 120 of 122 comparisons were significant. Plots with very strong linear correlations (r>0.90) are produced in Appendix B (Figures 55-74).

The trend within the orbit measurements observed in the dental age comparisons was found again in this section of analysis. The comparison of right and left orbital heights has a relatively low correlation value (r=0.534, Fig. 9), and right and left orbital breadths places slightly higher (r=0.547). Both comparisons yielded a lower correlation coefficient than would be expected for a bilateral measurement Examples of highly correlated bilateral measurements include inferior malar length (r=0.982, Fig. 10),

mandibular length (r=0.992), minimum ramus breadth (r=0.975), coronoid height (r=0.933) and maximum occipital condyle breadth (r=0.979). Meanwhile, the comparison of biorbital breadth to interorbital breadth has a high correlation value (r=0.841). The dimensions of the face (upper facial height, upper facial breadth, total facial height, bizygomatic diameter, and minimum frontal breadth) exhibit significantly high correlations with one another (r≥0.8). Left orbital breadth significantly correlates with only upper facial breadth (r=0.733) and biorbital breadth (r=0.737). Both right and left orbital heights, as well as right orbital breadth, do not significantly correlate with any measurements of the face.

Fig. 9: Left Orbital Height by Right Orbital Height
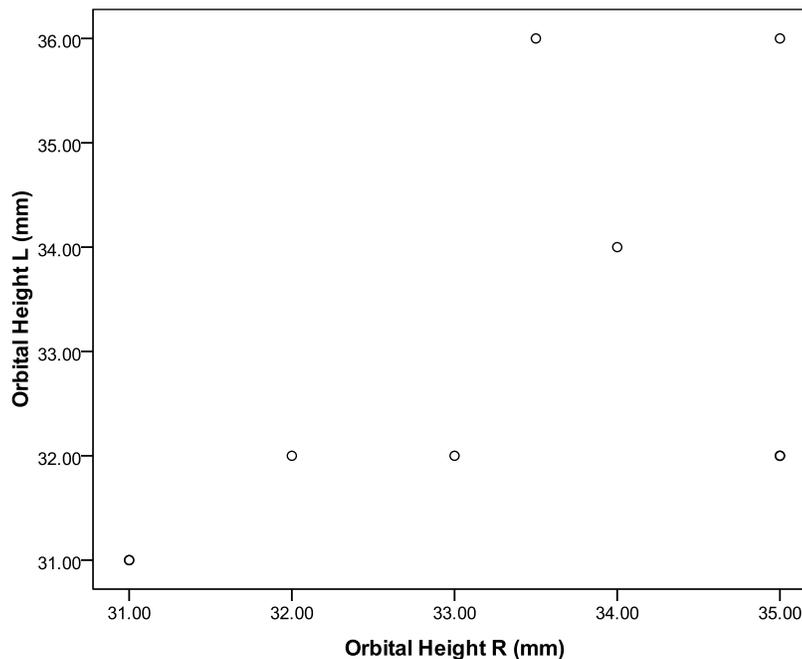
Fig. 10: Left Inferior Malar Length by Right Inferior Malar Length
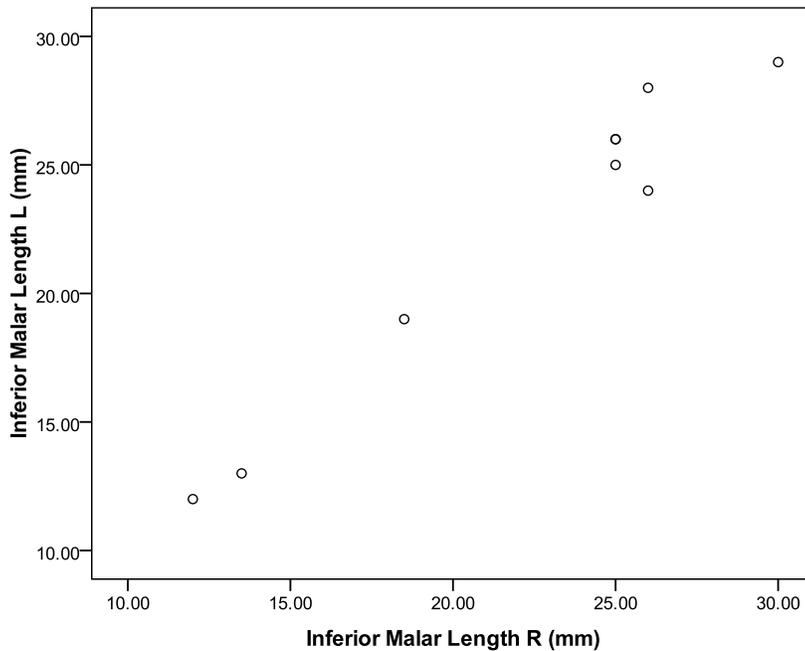
Another trend in the face involves the nasals. Nasal height and nasal breadth are not significantly correlated (r=0.456). This is interesting because other comparisons of length versus breadth pairs resulted in high correlation values. Examples include upper facial height vs upper facial breadth (r=0.891) and alveolar length vs alveolar breadth (r=0.907). Upper facial height and nasal height are significantly correlated (r=0.921), as are upper facial breadth and nasal breadth (r=0.871). When upper facial height is compared to nasal breadth, there no significant correlation (r=0.584); the same is observed for upper facial breadth and nasal height (r=0.657)

Visual Outliers

Individuals who placed away from the rest of the group in each plot are listed in Table 6. They are listed as placing either above or below the general pattern of the graph.

Of the 28 total individuals available for analysis, 12 appeared as outliers. Of the

individuals who exhibited more than one outlier, two individuals had outliers in only one

direction. Individual XIII-F:25 had two outliers above the group, while XIII-F:244 had

two outliers below the group. The rest of the individuals either had only one outlier, or

had multiple outliers that were both above and below the group. Visual outliers are

illustrated in the Figures 75-94 in Appendix B and are identified by their CMC numbers.

Table 6: Measurement Comparison Visual Outliers

CMC ID	Dental Age	Measurement 1	% Adult Size	Measurement 2	% Adult Size	Above/ Below
XIII-F:1	5.79	Maximum frontal breadth	99	Bizygomatic diameter	74	Below
		Height of mandibular body	84	Bicondylar width	61	Below
		Bigonial breadth	93	Bicondylar width	61	Below
		Maximum occipital condyle breadth R	56	Minimum occipital breadth squamous	90	Above
XIII-F:5	9.12	Alveolar breadth	95	Bimaxillary breadth	119	Above
		Lambda-opisthion arc	98	Auricular height	88	Below
XIII-F:6	9.05	Upper facial height	91	Nasal breadth	69	Below
		Upper facial breadth	86	Nasal height	95	Above
		Upper facial breadth	86	Nasal breadth	69	Below
		Biauricular breadth	83	Basion-porion	n/a	Above
XIII-F:7	15.95	Maximum cranial length	95	Bizygomatic diameter	90	Above
		Auricular height	100	Bregma-porion height	92	Below
XIII-F:18	11.31	Height of mandibular body	78	Bicondylar width	97	Above
XIII-F:25	7.44	Basion-prosthion length	77	Foramen magnum breadth	110	Above
		Orbital breadth R	81	Orbital breadth L	92	Above
XIII-F:33	6.12	Maximum cranial breadth	97	Biasterionic breadth	87	Below
		Maximum frontal breadth	102	Bizygomatic diameter	75	Below
		Post inter occ mdpt	90	Ant inter occ mdpt	75	Above
XIII-F:186	n/a	Post inter occ mdpt	92	Ant inter occ mdpt	100	Above
XIII-F:244	n/a	Nasion-bregma chord	106	Basion-porion	n/a	Below
		Biauricular breadth	88	Basion-porion	n/a	Below
XIII-F:245a	n/a	Post inter occ mdpt	92	Ant inter occ mdpt	82	Above
XIII-F:254	5.20	Maximum cranial length	91	Minimum frontal breadth	86	Below
		Maximum cranial breadth	90	Biasterionic breadth	84	Below
		Nasion-bregma arc	92	Bregma-lambda arc	111	Above

		Post inter occ mdpt	80	Ant inter occ mdpt	71	Above
XIII-F:268	n/a	Coronoid height R	52	Mandibular condyle breadth R	85	Above

There does not appear to be any pattern to these incidents of differential growth, but there are a few interesting occurrences. For example, XIII-F:1 (5.79 years) appears as a visual outlier on comparison of maximum frontal breadth and bizygomatic diameter (Fig. 11), as does XIII-F:33 (6.12 years). Unfortunately, XIII-F:254 (5.20 years) does not have a value for bizygomatic diameter. It is possible that a growth spurt occurs in maximum frontal breadth at around 5.5 or 6 years of age. Looking at Fig. 11, it is clear these two individuals have a larger maximum frontal breadth than would be predicted by the size of their bizygomatic diameter. Waitzman et al (1992) reported that interzygomatic arch distance (equivalent to bizygomatic diameter) should reach approximately 86% of adult size by 5 years of age, while intercoronal distance (similar to maximum frontal breadth) should reach approximately 89% of adult size by 5 years of age. XIII-F:1 and XIII-F:33 have reached 74% and 75%, respectively, of bizygomatic diameter adult size, and 99% and 102%, respectively, of maximum frontal breadth adult size. Both individuals appear to be overachieving maximum frontal growth, although they could be male and therefore growing towards a larger adult size than the average size calculated for this sample (largely based on female size). Both individuals appear, however, to be actually underachieving bizygomatic growth.

Fig. 11: Bizygomatic Diameter by Maximum Frontal Breadth
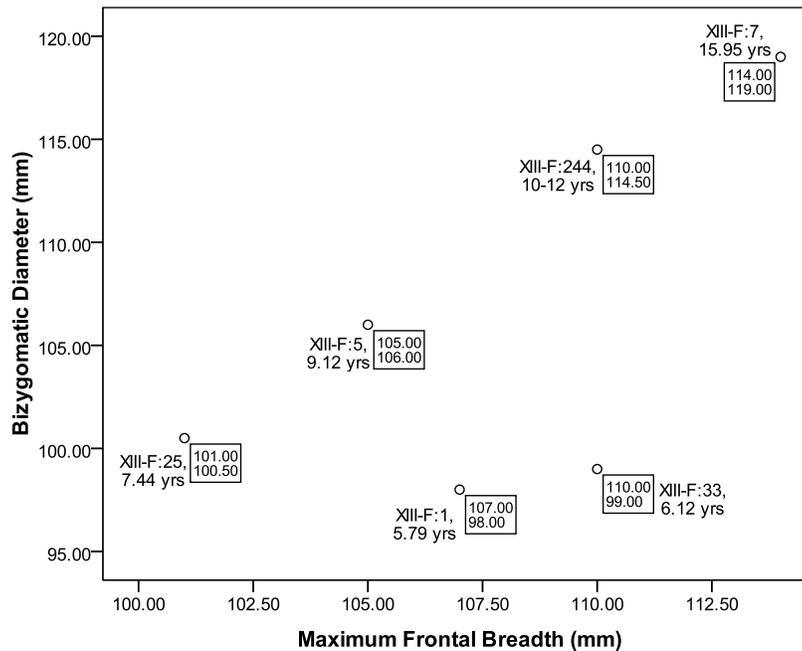
Four other individuals are present on the plot of maximum frontal breadth versus bizygomatic diameter. Looking at how they compared to the two outliers in achievement of adult growth is helpful. Fig. 12 shows each individual with percentages of adult size (maximum frontal breadth on top, bizygomatic diameter on bottom). Individuals XIII-F:1 and XIII-F:33 appear to be achieving a normal bizygomatic diameter size for their age, as compared to the four other individuals. In fact, all 6 individuals are underachieving bizygomatic diameter size as compared to Waitzman et al's (1992) results. This could mean that the facial breadth of the Roebuck sample develops later in life than the modern, mainly European-descendent sample used by Waitzman et al (1992).

Fig. 12: Bizygomatic Diameter by Maximum Frontal Breadth, with Percentage Attained Growth
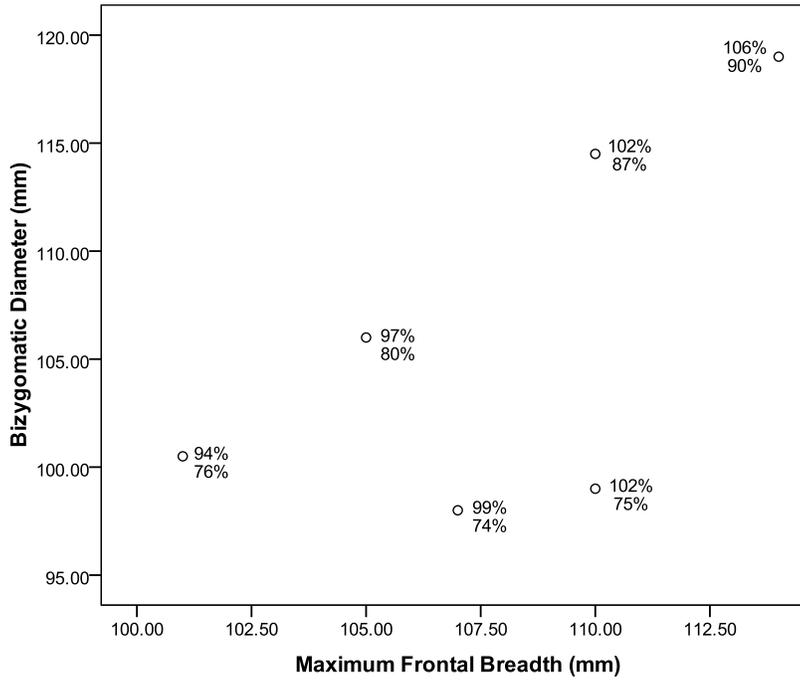
Part C – Asymmetry Analysis

The Roebuck sample was tested for fluctuating asymmetry in order to gauge the level of stress experienced by the population. The results of the asymmetry analysis are presented in Table 7. Two fluctuating asymmetry indices used by Gawlikowska et al (2007) were employed in this analysis: FA1= (R-L)/0.5(R+L); and FA2=1-r^2 where r is the correlation coefficient of the right and left side. For FA1, the mean difference between right and left sides is presented along with standard deviation and the p-values represent the results of a Wilcoxon Matched-Pairs Signed Ranks Test. The Wilcoxon test is a non-parametric test used to test the median difference in paired data (it is the non-parametric equivalent of the paired *t*-test) (Zar 1999). For FA2, the r values represent the

correlation between right and left sides. The FA2 index is included only for the purpose of comparison with other studies.

The values for the FA1 index are all low. Orbital height has the highest level of asymmetry, but the difference is not statistically significant. The low values for FA1 may indicate that the Roebuck subadults were not greatly stressed, or that their bodies were well able to handle the stress. The FA2 index shows that the right and left sides of the measurements were highly correlated, with the exception of the orbit measurements.

Table 7: Fluctuating Asymmetry Indices by Measurement

Variable	FA1			FA2	
	Mean	**SD**	*p*	*r*	**1-r^2**
Orbital Height	0.012	0.052	0.414	0.534	0.714844
Orbital Breadth	-0.013	0.047	0.655	0.547	0.700791
Mandibular Length	0.023	0.026	0.051	0.992	0.015936
Ramus Height	0.008	0.041	0.371	0.968	0.062976
Ramus Height Goniometer	-0.008	0.065	0.798	0.910	0.171900
Minimum Ramus Breadth	0.007	0.034	0.214	0.975	0.049375
Coronoid Height	0.012	0.049	0.341	0.933	0.129511
Inferior Malar Length	-0.003	0.048	0.733	0.982	0.035676
Maximum Occipital Condyle Breadth	0.005	0.060	0.771	0.979	0.041559
Mandibular Notch Breadth	-0.026	0.066	0.222	0.918	0.157276
Condylar Process Height	-0.009	0.072	0.906	0.864	0.253504
Mandibular Condyle Breadth	0.001	0.088	0.862	0.818	0.330876

Part D – Comparison with Other Populations

The Roebuck sample was compared with other populations to determine if its health relative to other groups could be elucidated.

The study most directly comparable to the Roebuck data is Markowitz's (1995) study of the craniofacial development of the Arikara. For each measurement used, Markowitz provides a table with the mean, minimum, maximum value for each age group (ages 1 to 19). This allows for construction of graphs directly comparing the Arikara

sample to the Roebuck sample. Twenty-two measurements were directly comparable

between the two data sets; these are listed in Table 8. Markowitz used both

craniometrically and radiographically derived data, and these are identified in the table.

Additionally, some of Markowitz's measurements had different names than those in the

Roebuck set, but they involved the same points on the skull. For this reason, the table

includes both names where they differ.

Table 8: Measurements Directly Comparable to Markowitz (1995)

Roebuck Measurement	Markowitz Name (if applicable)	Markowitz – Craniometric or Radiographic
Basion-opisthion length	Foramen magnum length	Radiographic
Basion-nasion length	Nasion-Basion	Radiographic
Biasterionic Breadth		Craniometric
Basion-bregma height		Craniometric
Maximum cranial length		Craniometric
Maximum cranial breadth	Maximum parietal breadth	Craniometric
Maximum frontal breadth	Maximum breadth at coronal suture	Craniometric
Minimum frontal breadth	Minimum frontal diameter	Craniometric
Total facial height	Nasion-gnathion anterior facial height	Craniometric
Upper facial height	Nasion-prosthion height	Craniometric
Nasal height	Nasion-anterior nasal spine	Craniometric
Orbital height (L)		Craniometric
Orbital breadth (L)	Dacryon-ectoconchion	Craniometric
Bizygomatic diameter	Maximum bizygomatic breadth	Radiographic
Interorbital breadth		Craniometric
Nasal breadth	Maximum width pirifom aperture	Craniometric
Alveolar breadth	Maximum maxillary alveolar breadth	Craniometric
Bicondylar width		Craniometric
Bigonial breadth	Bigonial width	Craniometric
Distance bn mental foramina	Bi-mental foramen breadth	Craniometric
Mandibular length	Basal mandibular length	Craniometric

Four plots comparing the Roebuck and Arikara samples also included Little et al's

(2006) data on rural modern Oaxacans: maximum cranial length, maximum cranial

breadth, bizygomatic diameter, and bigonial breadth. The mean value for males and females is presented for ages 6 to 13. The Arikara and Oaxacan data both represent the average size of the sample per age category, whereas the Roebuck sample represents individual data. The Arikara data was based on 1 to 8 observations per age category, while the Oaxacan data was based on 4 to 37 observations per age category.

The Roebuck and Arikara individuals generally scatter within similar ranges of values (Figures 95-115 in Appendix B). Without looking at percentage of growth attained, it is difficult to determine if they are similar because of similar body sizes. They could appear to be similar while one sample is really underachieving adult growth.

The majority of the Roebuck data scatter widely around the Arikara data. In four cases, Roebuck clusters more closely to the values and pattern of Arikara: upper facial height, total facial height, nasal height, and alveolar breadth. There are three cases in which all the Roebuck individuals (or all but one) place above the Arikara: basion-bregma height, minimum frontal breadth, and bicondylar width. Lastly, there are three cases in which the Roebuck place below the Arikara: maximum frontal breadth, bizygomatic diameter, and mandibular length L. It is important to note that there is a great deal of variation in how the Roebuck individuals relate to the Arikara – they are not consistently above, below, or in line with the Arikara.

The plot of bizygomatic diameter by dental age (Fig. 13) illustrates an interesting comparison between the three samples, because all three trend lines have high R-sq values. Roebuck and Oaxaca appear to have similar growth trajectories, although Roebuck is smaller by about 15 mm; the gap narrows to just over 10 mm by adulthood. This indicates that while the Oaxacan sample is larger in absolute bizygomatic size (most

likely due to the inclusion of soft tissue in the measurements), they achieve a smaller amount of growth than the Roebuck sample. The Arikara sample has a much steeper growth trajectory than the two other samples; it starts approximately 5 mm larger than Roebuck, and this difference doubles by adulthood. This may indicate the Arikara were, on average, healthier than the Roebuck sample because they attained greater growth. It must be remembered, however, that there is a gap in the Roebuck data for bizygomatic diameter, occurring between 9 and 16 years. Roebuck is only represented by 5 individuals for this dimension. Moreover, the upper end of the age range is represented by only one individual in the Roebuck sample (XIII-F:7); this individual appears to have been small in size for his or her age. It may be possible that Roebuck and Arikara would have similar growth trajectories if the Roebuck sample were more representative in the upper age range.

Fig. 13:Comparison to Arikara and Oaxaca - Bizygomatic Diameter by Dental Age
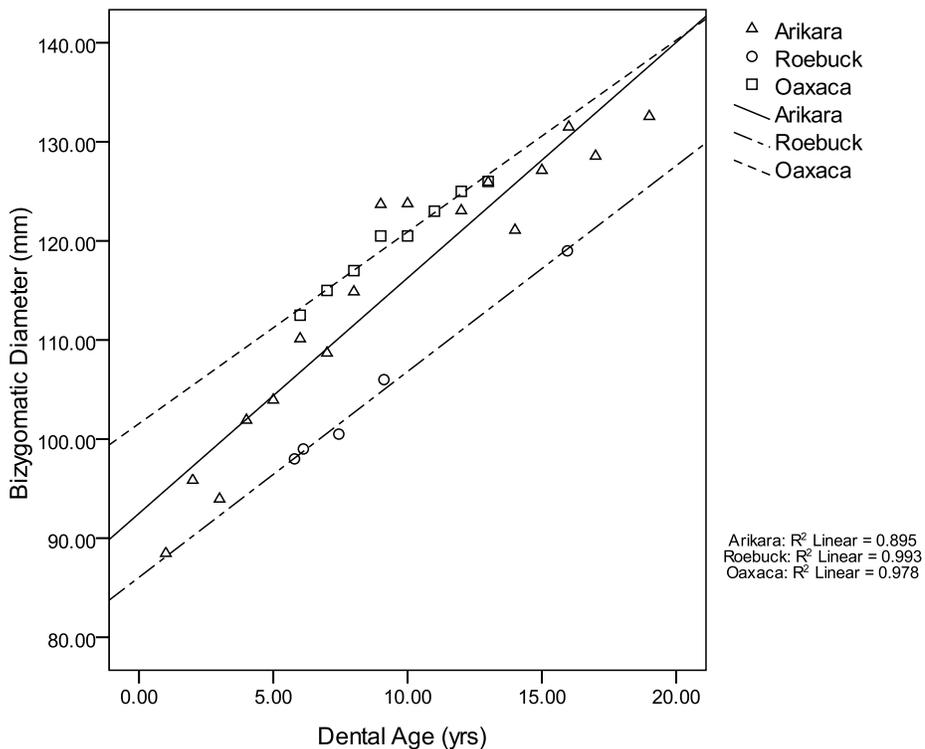
The pattern exhibited in the bizygomatic diameter comparison is not consistent. For example, Roebuck and Arikara exhibit very similar growth trajectories for basion-nasion length, alveolar breadth, bigonial breadth, and mandibular length L (Fig. 14Fig. 15Fig. 16Fig. 17). Another pattern involves Roebuck being initially larger in size, and being overtaken by Arikara between 5 and 10 years of age. This pattern involves total facial height, upper facial height, and nasal height (Fig. 18Fig. 19Fig. 20).

Fig. 14: Comparison to Arikara - Basion-Nasion Length by Dental Age
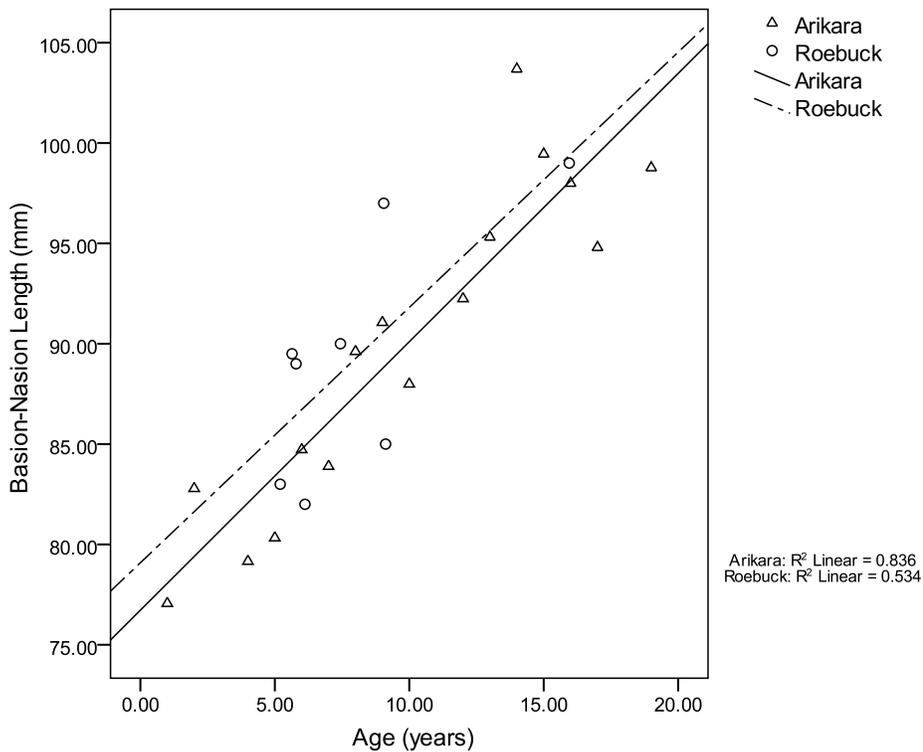
Fig. 15: Comparison to Arikara - Alveolar Breadth by Dental Age
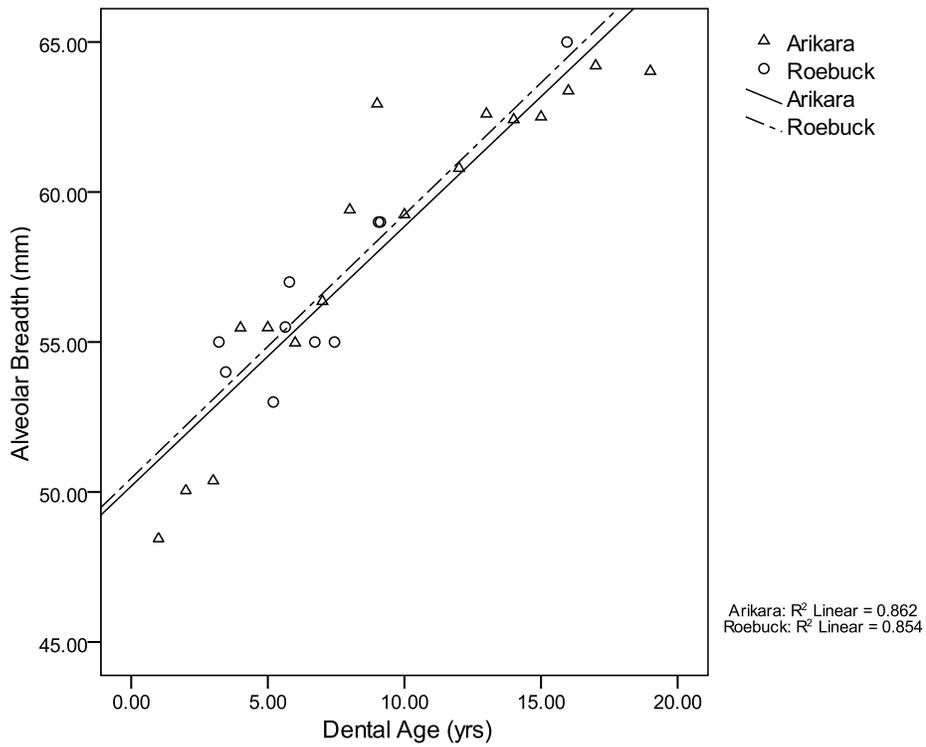
Fig. 16: Comparison to Arikara and Oaxaca - Bigonial Breadth by Dental Age
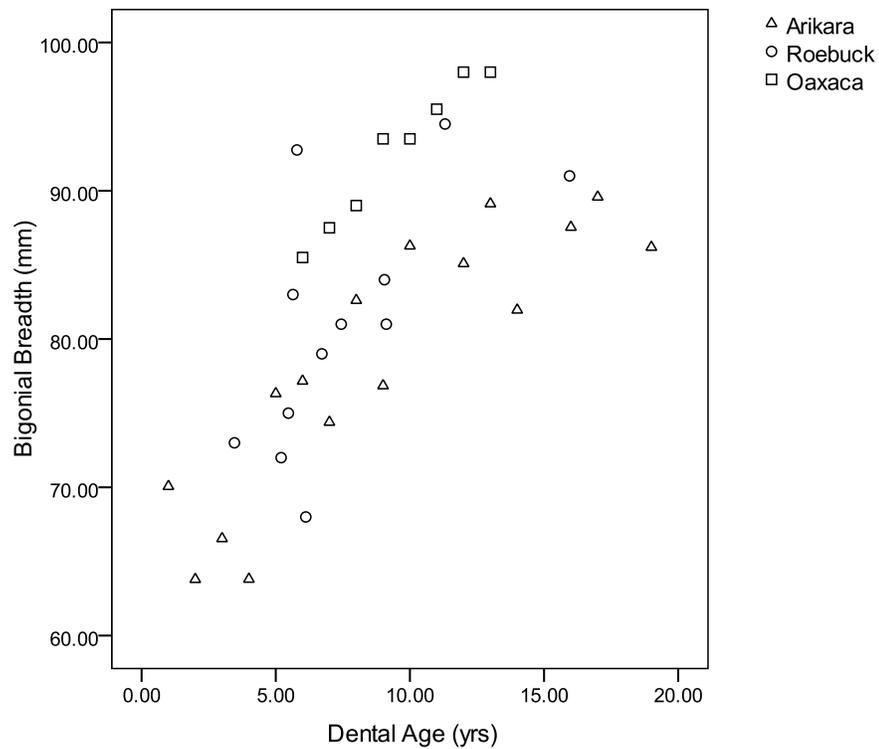
Fig. 17: Comparison to Arikara - Left Mandibular Length by Dental Age
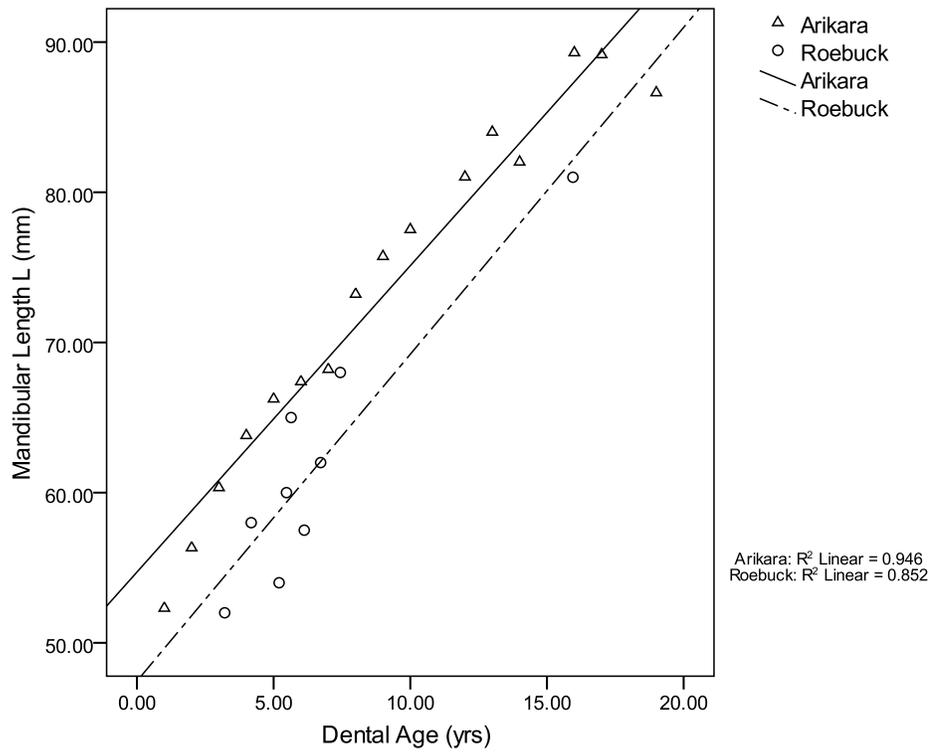
Fig. 18: Comparison to Arikara - Total Facial Height by Dental Age
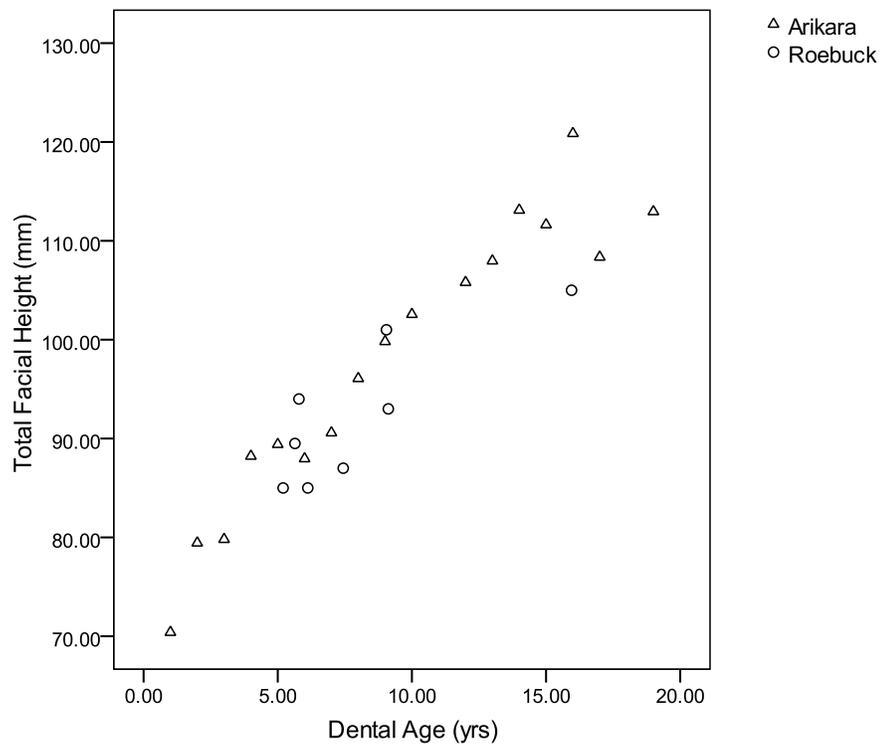
Fig. 19: Comparison to Arikara - Upper Facial Height by Dental Age
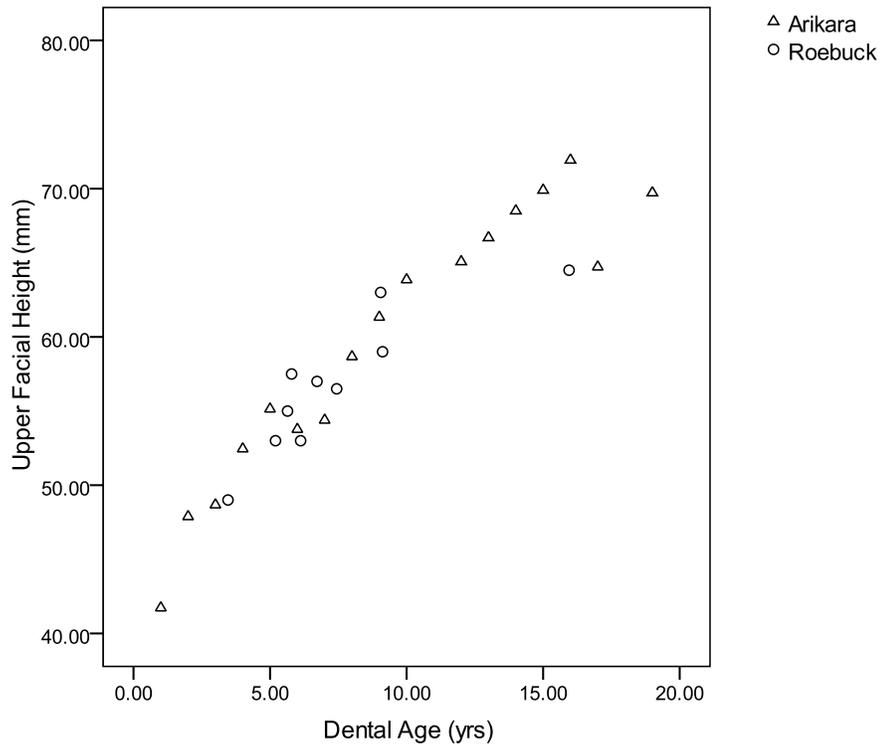
Fig. 20: Comparison to Arikara - Nasal Height by Dental Age
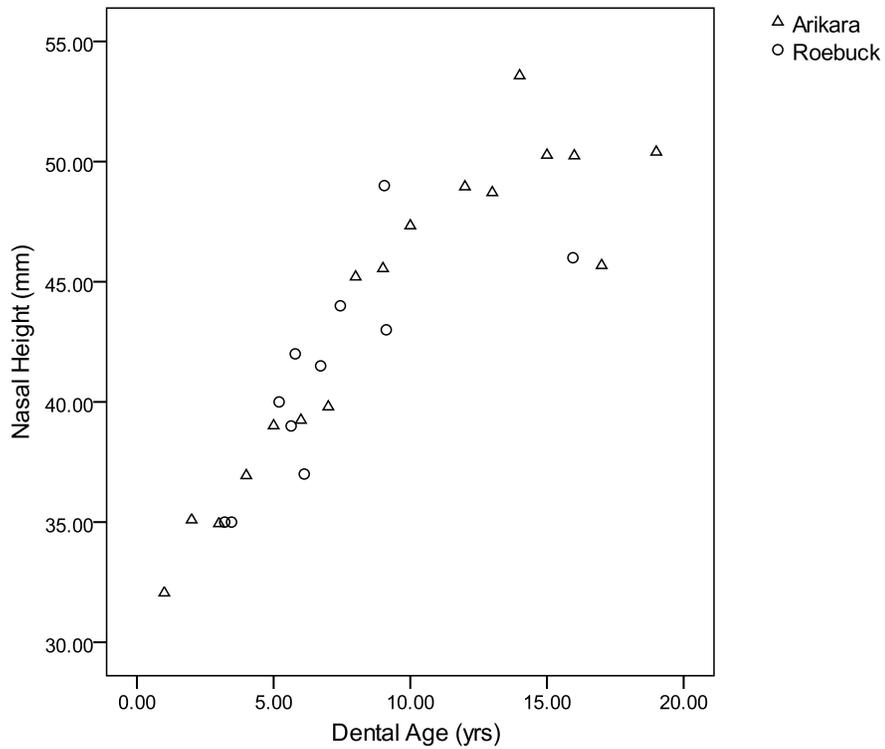
CHAPTER FIVE: DISCUSSION

THE IMPORTANCE OF CHILDREN IN (BIO)ARCHAEOLOGY

In the early twentieth century, subadult skeletons from archaeological contexts were often overlooked. At that time, researchers were focused on the descriptive and metric aspects of human taxonomy. Researchers in physical anthropology, such as Hrdlička (1924), were focused on comparative craniometry; this required adult crania. Subadults were deemed useless because their crania were often found disarticulated (Halcrow and Tayles 2008:197-8).

In the 1970s a new type of anthropology, feminist anthropology, was on the rise. This area sparked interest in the place of children in the archaeological record. The main archaeological emphasis of this movement, however, was on the place of women in prehistory (Scott 1997:6-7). Researchers, for the most part, were still uninterested in focusing on children. Archaeology had traditionally held two main views about children: that children are not important because they do not make a significant contribution to communities and societies as a whole; and children are unknowable through the archaeological record because their behaviour leaves few material traces, child burials being the exception (Baxter 2006:2).

Lillehammer's 1989 paper 'A child is born. The child's world in an archaeological perspective' is considered the start of the archaeological investigation of childhood (Baxter 2005:1). Lillehammer (1989) advocated an approach that focuses on the child's relationship with the environment and the adult world. Since that paper, there has been a fair amount of archaeological research from the social perspective of children

85

and childhood (Halcrow and Tayles 2008:199). The rise of gender theory in the 1990s resulted in the emergence of the study of children and childhood in bioarchaeology. Archaeological studies on children and childhood had existed prior to this time, as had similarly themed studies in biological anthropology. The 1990s, however, brought the focus onto the growth and health of the children themselves (Lewis 2007:10). Baxter (2006:2) comments, however, that almost every publication on the archaeology of childhood contains a section where the author or editor justifies research on children, and presents evidence that children are important in archaeological research. Childhood is significant because it is the stage in the human life cycle when individuals are taught to be members of their society as a whole. Despite cross-cultural variation in the definitions, roles, and meanings of 'child' and 'childhood', individuals identified as children are present in all documented human social groups (Baxter 2006:2). Moreover, children determine the majority of day-to-day activities of family life – in terms of the care provided to them, the contribution they make to the household and to society, and their social relationships with parents, siblings, and extended family. Indeed, bioarchaeologists may unwittingly portray children as passive victims of their environment if they do not look at the construction of childhood and the role children play in society (Halcrow and Tayles 2008:200).

Halcrow and Tayles (2008) report, however, that there is a rising tension between the approaches employed by social archaeologists and bioarchaeologists in the study of human skeletal remains (Sofaer 2006, for example). A large part of this tension arises from the assumption that 'biological' age can be linked to 'social' age (Halcrow and Tayles 2008:203). Questions are being asked about the appropriateness of the

terminology and age categories used in subadult bioarchaeological analyses (such as infant, child, juvenile, adolescent, and adult); age categories themselves have important implications for the analysis and interpretation of biological data (Halcrow and Tayles 2008:191-2). Sofaer (2006:126-7) states that the distinctions between age categories, particularly between child and adult, are a product of the limitations of current age estimation techniques. By using biological development standards for age estimation, bioarchaeologists are constructing artificial divisions of social and mental development between the categories.

Kamp (2001) has suggested that bioarchaeologists take a different approach in the use of age categories. Instead of starting with a definition of groups logical to the investigator, and then testing for differences between those groups, Kamp (2001:10) suggests that the exploration of data should begin by looking for differences that might imply local age definitions. Halcrow and Tayles (2008:204) point out two potential problems for this approach. The first problem is that is requires a sufficiently large sample size. The second problem is that of deriving social age categories from past populations, especially prehistoric ones where historical records of child and adult status, social roles, and relationships are not available.

Sofaer Derevenski (2000:9-11) suggests that through the consideration of how body changes in children correspond with changes in social and cultural identity, the biological and the sociocultural may be linked. Perry (2005:92) identifies the developmental stages of weaning and puberty as stages that may be identifiable on the human skeleton; additionally, these stages may categorize the transition from one socially defined age group to another. The response to weaning may result in the slowing or

cessation of normal growth, and can be expressed as dental enamel hypoplasias and/or Harris lines. Other indicators of weaning and related stress are periosteal reactions and porotic hyperostosis. The other developmental stage of interest, puberty, may be identified by the initiation of the adolescent growth spurt (Perry 2005:92-4).

The children of the St. Lawrence Iroquois have received very little attention from physical anthropologists and archaeologists. The Roebuck skeletal collection represents the largest sample of SLI skeletal material that has been available for study, but only one research project has focused on the subadults (Hoppa et al 2004). Due to the small size of the Roebuck subadult sample, there was no need to divide individuals into age categories (thereby avoiding the issue of the appropriateness of these age categories). The present study aimed to examine craniofacial growth and the timing of growth spurts, enabling the identification of the adolescent growth spurt. Unfortunately, the weaning period could not be studied because the youngest individuals in the sample were not represented by cranial measurements.

METHODOLOGICAL CONSIDERATIONS

Age Estimation

Skeletal age estimation was not conducted as part of this study, but rather by the original data collectors at the CMC. Dental age estimation was completed by Hoppa et al (2004), using Trodden's (1982) technique on radiographs of the Roebuck individuals. Trodden (1982) tested the mean age and range of variation for the calcification and eruption of the permanent teeth in Canadian Aboriginal populations. Specifically, the study was based on aboriginal children from reserves in Manitoba, Saskatchewan, and

north-west Ontario, and Inuit children from settlements in the former Keewatin zone of the Northwest Territories (now mostly part of Nunavut).

Since only Trodden (1982) was used to estimate dental age, this introduces a major limitation to this study: the Trodden method cannot produce an age estimate younger than 3 years. This is because the method is based on the calcification and eruption of the permanent teeth only. Trodden provides tables for the mean ages of the dentition at three stages of eruption: pre-eruption, alveolar emergence, and gingival emergence. To be included in the pre-eruption stage, a tooth must reach a calcification score of '6' – meaning that the crown is fully formed. The first permanent molar, which is the first permanent tooth to erupt, is already present as a tooth bud at birth and could allow for the determination of ages younger than 3 years. Unfortunately, this is not possible with Trodden's methodology. There are multiple individuals (up to 7) present in the sample who were likely under three years of age, and therefore do not have dental ages. Further research on this sample should include those individuals using another dental age technique (i.e. Liversidge et al 1993).

Due to the small size of the sample, individuals were not grouped into age categories. As a result, each individual is represented as a data point on a graph, rather than being part of the mean value for the age group.

Age Distribution of Sample

The sample's age distribution is provided in Table 1 (pg. 50). Eleven of the individuals with dental ages cluster between 3 and 7 years; 2 individuals are 9 years, while 11 years and 16 years are each represented by 1 individual. Young to mid-

childhood is represented, while the pubescent (adolescent) years are poorly represented; the infant period is not represented at all in the dental age sample.

The sample's skeletal age distribution is presented in Fig. 1 (pg. 51) When looking at the skeletal ages of the sample, 23 of 29 individuals with craniofacial measurements are under 10 years of age. Again, the adolescent/pubescent period is underrepresented – this is unfortunate because this is the period during which a major growth spurt occurs. Due to this uneven age distribution, caution must be employed when interpreting the results – especially those involving the older individuals in the sample.

DENTAL AGE VERSUS CRANIOFACIAL MEASUREMENTS

The comparisons of dental age to craniofacial measurements yielded a wide range of relationships. The highly significant correlation with dental age for elements of the basicranium is unsurprising, since it is considered to be under strong genetic control (assuming the absence of any major biomechanical modification). The number of highly correlated mandibular measurements is interesting, and suggests that elements of the mandible may grow with age in a very predictable and constant manner. This has important implications for the use of the mandible in subadult age estimation, which will be discussed in more detail below.

One interesting result involves the area around the eyes. While the distance across both orbits and between the medial edges of the orbits increases with age in a predictable fashion, the dimensions of the orbits themselves are more variable. Additionally, upper facial height and breadth correlate well with age, as do nasal height

and breadth. The areas surrounding the eyes therefore grow in a predictable fashion. The variability in the orbits observed here corresponds with the normal pattern of growth reported by Waitzman and colleagues (1992) They observed that the orbits displayed the most variability in growth. It is possible, however, that fluctuating asymmetry is causing this discrepancy between the orbits and the surrounding area. This will be explored in the section on asymmetry. It is also possible that biomechanical or pathological influences may result in abnormal orbit dimensions.

Humphrey (1998) investigated cross sectional growth patterns in a skeletal sample of known age and sex. The author looked at the proportion of adult size attained at birth, and the subsequent rate of attainment of adult size. Humphrey's (1998) study used samples consisting of individuals of European descent (St Bride's, St Barnabus, and Spitalfields collections). While the exact ages and ordering of individual variables may differ across populations, it is reasonable to apply the general developmental pattern to other populations. Humphrey (1998) found a growth pattern that reflected early growing neural structures, a later growing masticatory apparatus, and an intermediate growing mid-facial region. A similar pattern was found by Markowitz (1995:156): an early achievement of posterior cranial width and greatest parietal breadth (vault dimensions), discontinuous increase in upper facial height and width, and a later enlargement of lower facial height and depth (palate and mandible). Lastly, this pattern was found by Waitzman et al (1992): rapid cranium growth in the first few years of life followed by a levelling off, with growth virtually complete by 6 years of age; and a more gradual increase in upper midface size, with growth that lasts longer into childhood than the cranium. It was also found that most of their orbital measurements were finished

growing by 1 year of age, with the exception of lateral orbital distance (similar to biorbital distance). An examination of the Roebuck sample's attainment of adult size data confirms that it follows this basic pattern of growth.

Plots of craniofacial measurements versus dental age showed that the two oldest individuals with dental ages were often not in line with one another. Individual XIII-F:7 (16 years) generally fell in line with or below the distribution of the rest of the group, while XIII-F:18 (11 years) generally fell in line with or above the rest of the group. This led to the hypothesis that one, or both, individuals may be experience abnormal growth. Taking into account percentage of adult growth attained, it appeared that XIII-F:7 was slightly smaller for age and XIII-F:18 was slightly larger for age, but other were within the normal range of variation for the population. The overall growth curve for the Roebuck subadults would likely fall somewhere between these two individuals.

LONG BONE GROWTH PROFILES

One interesting pattern that emerged from the plots of dental age versus long bone length was the relationship between the two individuals with dental ages of 9 years (XIII-F:5 and XIII-F:6). XIII-F:5 exhibits longer arm bones and shorter femora and tibiae, while XIII-F:6 exhibits longer femora and tibiae and shorter arm bones. Hoppa et al (2004) demonstrated that neither individual exhibits a linear growth deficit for age. It is possible that this may represent an occurrence of differential growth. XIII-F:6 may have been undergoing (or already have experienced) a growth spurt in the femora and tibiae. Another consideration is the fact that lower limbs undergo periods of more rapid growth than the upper limbs; consequently, the leg bones are more greatly affected by nutritional

stress and disease than the arm bones (Sciulli 1994). XIII-F:5's skeleton was extensively affected by an infectious disease process (possibly tuberculosis), and it is reasonable to suggest that his or her growth was therefore delayed.

MEASUREMENT VS MEASUREMENT

The measurement comparisons tended to be more widely scattered than those presented by Hoppa et al (2004), which were all highly linearly correlated. The plots comparing various mandibular measurements tended to be the most consistently significantly correlated, indicating that elements of the mandible may experience constant linear growth relative to one another. This may have important implications for studies of age estimation in subadults. Two articles have been published on the use of mandibular ramus height as an indicator of subadult age: Norris (2002) and Franklin and Cardini (2007).

Norris (2002) examined 53 prehistoric Native American skeletal infants from the Southwest Skeletal Collection at the National Museum of Natural History in Washington, DC. The ages of the individuals were unknown, therefore the author used diaphyseal length and dental age charts to assign age. After being assess for aged, an individual was placed in one of four six-month age categories (birth-6 months, 6 months to 1 year, 1 year to 1.5 years, 1.5 years to 2 years). The purpose of Norris' analysis was to determine whether the sample could be aged based on a mandibular measurement, and which dimension most accurately predicted infant age within a six-month range. Seven measurements were tested: length of the body, full length of half the mandible, height of mandibular body, minimum ramus breadth, maximum ramus breadth, maximum ramus

height, and gonial angle. Norris found ramus height to be the only variable that was significantly influenced by age, as well as able to statistically separate the four age groups. Unfortunately, a great deal of overlap existed between the second and third age groups; while ramus height could easily differentiate between the first and fourth age groups, it could not differentiate so easily between second and third (6 months-1 year, and 1-1.5 years).

Franklin and Cardini (2007) focused on ramus height in their analysis of 79 known age subadults from a South African Bantu-speaking sample (R.A. Dart Collection) and an African American sample (Hamann-Todd Collection). Linear measurements of ramus height were obtained from the conversion of three-dimensional landmark data (between *condylion superior* and *gonion*). Franklin and Cardini found that using regression analysis, age was predicted with an error smaller than 2 years in just under 70% of subadults when adolescents (individuals over 10 years) were included; the percentage rose to over 90% when the children were analyzed independently of adolescents.

Norris (2002) and Franklin and Cardini (2007) both focused on the relationship of one mandibular measurement with age. The present study has found that many dimensions of the mandible grow in predictable ways relative to one another. A possible avenue for exploration would be an age estimation technique based on two dimensions of the subadult mandible – perhaps two dimensions that are usually well preserved in the archaeological record, and that also have a significantly high correlation with each other.

Measurement Comparisons - Visual Outliers

Plotting two measurements against each other is useful for examining comparative growth patterns. Individuals who have one measurement that is larger than would be anticipated by the other measurement can be identified. Hoppa et al (2004) examined patterns of comparative long bone growth in the Roebuck sample. Maximum lengths of the femur, humerus, third metacarpal, and second metatarsal were compared to one another. Three individuals were identified as having growth in one dimension larger than predicted by the other: XIII-F:5, XIII-F:6 and XIII-F:257. XII-F:5 and 6 have dental age estimates of about 9 years, and XIII-F:257 has a skeletal age estimate of 7-10 years. Since none of the individuals showed a growth deficit for age (as determined by graphing maximum femur length against age), it was hypothesized that 9-10 years represented the age range of early to mid puberty in the sample.

In the present study twelve individuals appeared as visual outliers, but there was no consistent pattern like the one identified in the comparisons to dental age. These outliers may represent growth spurts or deficiencies in one of the dimensions involved, or simply personal variation in the sample.

The measurement comparison section of analysis had two purposes: to evaluate how craniofacial dimensions change in relation to one another, and to determine if growth spurts could be detected in cross sectional data. The nature of the data under study made it difficult to pursue the first purpose of this section. The available data consists of craniofacial measurements between standard osteological landmarks, as well as some measurements included specifically for the purpose of studying growth. The

majority of measurements pass over at least two articulated cranial bones, or involve an opening that is comprised of more than two bones. For example, maximum cranial breadth involves both parietals; as for openings, the orbital margin is comprised of the frontal, zygomatic, maxillae, and lacrimal. As a result of the inclusion of these types of measurements, it is very difficult to evaluate the growth of a single bone, or how the growth of a set of articulated bones relates to the growth of each component bone.

The second purpose of this section related to the observation of growth spurts in the sample. Occurrences of differential growth were observed in many individuals, but attributing the spurt to the growth of a specific bone is more difficult – for the same reason as mentioned above. In this study it was not possible to tell if a spurt in maximum cranial length, for example, was due to sudden changes in the frontal, parietals, or occipital, or a combination of all components. The bizygomatic diameter was found to be slower in achieving adult size as compared to a modern sample (Waitzman et al 1992); this may indicate that the Roebuck sample experienced mid-facial growth later into childhood/adolescence, with a later attainment of full facial breadth.

Krieg (1987) observed that early craniofacial growth spurts (earlier than the adolescent growth spurt) were common in his modern American sample, but the timing and magnitude of these spurts exhibited great variation. Kreig's conclusion is in agreement with the results of this study. The comparisons of measurements exhibited no general pattern: individuals experiencing a period of differential growth ranged in age from infant to 16 years. Krieg (1987) also observed that early growth spurts in the face had a greater incidence and magnitude than growth spurts in the cranial base. Of the 27 incidents of differential growth observed in the measurement comparison section of this

study, 12 were in the facial region, 11 in the cranial base, and 4 in the mandible. The magnitude of these 'spurts' cannot be measured due to the cross-sectional nature of the data. Kreig (1987) reports that a pre-pubertal spurt in facial growth often occurs between 9 and 11 years in females, and between 11 and 13 years in males. Unfortunately only six individuals in the Roebuck sample fall into this age range (XIII-F:5, 6, 12, 18, 244, and 257). Of these, two individuals (XIII-F: 5 and XIII-F:6) exhibit differential growth in the facial region. The age distribution of the individuals available for inclusion in this study prevents any observations of craniofacial growth in the early years of life (under 3 years).

ASYMMETRY ANALYSIS

Twelve bilateral measurements were tested for fluctuating asymmetry, using two indices employed by Gawlikowska et al (2007). Using a Wilcoxon matched-pairs signed ranks test, no significant differences were found between the right and left sides for all measurements. The absence of asymmetry in these measurements indicates that either the individuals under study did not experience any significant environmental or physiological stress during development, or they were able to buffer against any such stress. Perzigian (1977) interpreted a high level of dental asymmetry in the hunter-gatherer Indian Knoll sample as being reflective of stress during development. Other markers of metabolic stress in the Indian Knoll sample included a high frequency of Harris lines, prevalent enamel hypoplasia, a slow rate of long bone growth, a small adult stature, and a high infant mortality rate. Comparing Indian Knoll to later agricultural groups, Perzigian (1977) found the later groups to have less dental asymmetry. This was explained by the agricultural groups using a more reliable and diverse food resource base.

The Roebuck population employed maize agriculture, but continued to hunt and fish. They therefore would have had access to a nutritionally varied diet (Wintemberg 1936). Moreover, Roebuck represents a pre-contact population; they would not have been exposed to the stress of European diseases. Warfare with other groups would have occurred, as evidenced by the intentionally cut and broken human remains found at the site (Wintemberg 1936, Larocque 2006). The stress from this conflict does not appear to be enough to cause asymmetry in to the craniofacial complex.

The absence of asymmetry is most surprising for the measurements of orbital height and breadth, since they did not exhibit significant correlations with dental age, nor with each other. It was proposed earlier that fluctuating asymmetry may be the cause of this phenomenon. It is interesting to note that while the FA1 index (using the Wilcoxon test) did not detect asymmetry, the FA2 ($1-r^2$) index may have. Orbital height and orbital breadth have the highest values for this index, at FA2=0.715 and FA2=0.701 respectively; the next highest value belongs to mandibular condyle breadth, and is much lower at FA2=0.331. The possibility of asymmetry between the orbits is in contrast with some previous studies of craniofacial asymmetry (Hershkovitz and Kobyliansky 1990, Gawlikowska et al 2007). The face has historically been regarded as the most symmetrical part of the skull, due in large part to Woo's (1931) substantial study of Egyptian skulls.

The FA2 results for the orbits cannot be used to conclusively state the presence of asymmetry. In their review of indices used to analyze fluctuating asymmetry, Palmer and Strobeck (1986) suggested that the FA2 index should only be used in combination with other indices in order to obtain objective results. This is because the value of the index is

heavily dependent on the size of the examined trait. Gawlikowska et al (2007) states that

the FA2 index is generally only used when there is a need to compare results to other

reports which have used it.

There are a few problems with the present asymmetry analysis. Measurements

were only taken to the nearest 0.5 mm, and rounding can mask the true size of the

dimension. The magnitude of the size differences between sides was very small

compared to the magnitude of the measurements themselves. Lastly, the sample size for

Roebuck is quite small and could affect the usefulness of both asymmetry indices

employed – at most, 14 individuals were available for asymmetry analysis. Asymmetry

analysis of orbital height was based on 10 individuals, while orbital breadth was based on

6 individuals. This is not a very representative selection of the 38 Roebuck individuals

under study, nor the Roebuck population as a whole. While it appears that fluctuating

asymmetry was not present in the 12 bilateral dimensions involved in this analysis, the

conclusion that the sample was not physiologically or environmentally stressed must be

stated with caution.

COMPARISONS WITH OTHER POPULATIONS

The Roebuck data was plotted against 22 measurements from Markowitz's (1995)

data on the historic Arikara, and this was the most direct comparison of all the available

craniofacial growth studies. Four plots also included Little et al's (2006) data on modern

rural Oaxacans: maximum cranial length, maximum cranial breadth, bizygomatic

diameter, and bigonial breadth. These comparison samples are especially appropriate

because all three populations employed a subsistence strategy heavily dependent on

maize agriculture; subsistence strategy affects the health and biomechanical considerations for each population.

The Arikara sample spans over two hundred years, from approximately A.D. 1600 – 1832. This sample would include temporally earlier individuals from when the Arikara were most successful and healthy, and later individuals from when the population was significantly less healthy and under more economic stress. Any changes over time in growth status would likely be masked by the use of average measures for each age. As a result, the Arikara sample would be of moderate health and growth.

The Oaxacan data is taken from a 1968 survey of an indigenous rural community in the Valley of Oaxaca in southern Mexico. At this time, the community was largely dependent on subsistence maize agriculture. The population was sedentary, with little population flow into or out of the community. The community was reportedly well-established in the mid-1500s, and there is evidence it was founded around A.D. 1000 (Little et al 2006). The Oaxacan data is part of a set of three surveys, conducted in 1968, 1978, and 2000. The 1968 sample was chosen for comparison because at that time the community was still largely dependent on subsistence agriculture; later surveys indicated the population was consuming more non-traditional foods and fewer individuals were farming. The 1968 sample has been characterized as mildly-to-moderately undernourished with growth-stunting (Little et al 2006:127).

Although the Roebuck population employed maize agriculture, fish and meat, as well as other protein sources, were not abandoned; it is likely that they enjoyed a nutritionally varied diet (Wintemberg 1936, Saunders and Melbye 1990). Since Roebuck is a precontact site, the population would not have been exposed to the stress incurred by

European diseases. The Roebuck sample does, however, show evidence of tuberculosis and anemia, as well as non-specific inflammatory reactions on bone surfaces (periostitis). Periostitis and anemia can be attributable to diet deficiencies and/or infections. Moreover, the population likely experienced stress in the form of conflict with other neighbouring Aboriginal groups. Many charred, intentionally cut and broken human remains were found at the site. These remains belonged to mostly young and middle-age men, thought to be enemies that were captured or killed in warfare (Wintemberg 1936, Larocque 2006).

As stated in Chapter 4 (Results), the Roebuck sample generally scatters within the Arikara sample. When the Roebuck sample does place above or below the Arikara sample, it generally still lies within the range of variation reported by Markowitz (1995). While minor differences in skull size and shape must be taken into account, it appears that the Roebuck and Arikara samples were similar in growth and health. Little et al (2006) measured the skulls of living children, therefore their measures would be larger due to soft tissue. The Oaxacan population consistently places in the upper range of variation of the other two samples. Taking into account tissue depths, it appears that the Oaxacan children are similar in size to both the Arikara and Roebuck.

LIMITATIONS OF STUDY AND AREAS FOR FUTURE IMPROVEMENT

This study has been faced with three major limitations: the type of data available, the size of the sample, and the availability of studies for comparison. The data was collected near the beginning of the CMC's Repatriation Project, in 1998. The data collection sheets for both adults and subadults were created by Janet Young specifically

for this purpose, although they have been revised and augmented in the years since. As a result, the choice of craniofacial measurements could not be tailored to suit this study. Fortunately, one portion of the data was collected specifically for a potential growth and development study.

The range of measurements available was a limitation in one major respect: many measurements were not available for the youngest members of the sample because they require articulation of two or more bones. For example, the metopic suture joining the frontals closes by about 9 months of age (Vu et al 2001). This means the two frontals must be held together to take the standard measurements for the adult, fused frontal. Measurements such as maximum cranial length, minimum frontal breadth, and bizygomatic diameter are not possible on fetuses, perinates and infants because the appropriate bones are joined by fibrous sutures. These fibrous sutures generally do not last in the archaeological record, and the cranial bones exist as separate entities. As a result of these limitations, data from up to eight of the youngest individuals in the sample was not collected. Generally, these individuals are represented in some mandibular measurements (ex. mandibular length), which are possible to take at very young ages, but are not represented in any other measurement area.

This study would have benefitted from having a larger sample, with representatives from the youngest ages. Even if this youngest group had its own special set of measurements, this data would be useful in elucidating growth patterns in the earliest stage of life; these could then be used in conjunction with the data from the group with the 'adult-like' craniofacial measurements. Partly in order to avoid situations like this, where the youngest individuals in a sample are left out of measurement taking, the

CMC's subadult data collection sheets were overhauled by this author in 2008. Two sets were created – one for fetal/infant remains with age-appropriate cranial and postcranial measurements, and one for older children with articulated crania but immature postcranial measurements. This study illustrates the importance of not only collecting data for future researchers' use, but of making sure to include as many appropriate measurements as possible – regardless of the age of the individual under study.

Sample size is the second major limitation of this study. Although there were 38 individuals included in the sample, only 29 had associated craniofacial measurements. Furthermore, only 14 individuals were available for the analysis involving dental age. Any conclusions drawn from the results, or comparisons made to other populations, must therefore be broad in nature. In the future, it would be useful to combine this data with that of related Aboriginal skeletal samples (i.e. from eastern and southern Ontario, southern Quebec, and northern New York State) and complete a similar type of analysis. Although the samples may not represent the same cultural grouping, they would be more closely related to the Roebuck sample than would a sample from British Columbia or Nunavut.

Lastly, there is a paucity of similar anthropological studies on skeletal remains – specifically, growth and development studies on the craniofacial region. As discussed earlier, only two studies were available for direct comparison with the Roebuck results. Hopefully this area of research will continue to grow and develop itself – the skeletal collections exist, they just need to be utilized.

CHAPTER 6: CONCLUSIONS

Children are the most vulnerable members of society, and how healthy they are provides information on the general health of the population to which they belong. The growth of a child is an excellent indicator of his or her health; longitudinal growth is used in growth and development studies as a non-specific indicator of nutritional status. The long bones of the limbs are the most common source of data for growth studies. The present study looked at growth data from the skull to assess its usefulness in this area of analysis. Children under five years of age are considered the most sensitive to environmental and cultural insults (Goodman and Armelagos 1989). This early period of life is when most of the growth of the cranium occurs. Consequently, the craniofacial complex provides a valuable opportunity to assess the health status of a child during early childhood.

Overall, this study found that the Roebuck sample exhibits a pattern of craniofacial growth consistent with the normal pattern demonstrated by Humphrey (1998) and Waitzman et al (1992). The one area of growth where Roebuck diverged from this pattern was a slower attainment of facial breadth. The older end of the general growth curve for the sample would lay somewhere between the two oldest individuals. Growth spurts in the craniofacial complex were more difficult to observe and interpret than spurts in the long bones. One interesting result of this study was the confirmation that the mandible is a good candidate for the development of subadult age estimation techniques. Fluctuating asymmetry was not found in any of the bilateral measurements. This indicates that any stress experienced by the Roebuck subadults during development was

104

not great enough to have a detectable impact on cranial symmetry. On comparison, Roebuck appeared to be similar in size and growth to two other populations with similar subsistence strategies and diets. The Arikara and Oaxaca comparison samples were considered to be mildly to moderately undernourished, which means Roebuck would be at about the same level of health. The fact that the population employed maize agriculture (with possible periods of crop failure and times of fewer resources) in combination with the stress imposed on the population by warfare would both support a slightly undernourished subadult population.

The archaeology of childhood is a very important area of investigation in anthropology. Childhood is the period of the human life cycle when individuals learn how to be members of their society, and individuals identified as 'children' are present in all documented human social groups (Baxter 2006). A major stumbling block in the investigation of childhood through archaeology and bioarchaeology, however, is the linking of biological age and social age (Halcrow and Tayles 2008). By using biological development standards to estimate the age of human skeletal remains, bioarchaeologists are constructing artificial divisions of social and mental development (Sofaer 2006). One way around this problem is to focus on life events that may characterize the transition between socially defined age groups – events such as weaning and puberty (Perry 2005). The timing of weaning in the Roebuck St. Lawrence Iroquois could not be assessed due to the lack of cranial data for the youngest children in the sample. Instead, this study focused on investigating the adolescent growth spurt using the craniofacial complex. Unfortunately, the age distribution of the sample was not appropriate for determining when the adolescent growth spurt might occur.

The present study, with its biological focus, cannot say anything about the childhood experienced by Roebuck individuals – other than the children appeared to have relatively adequate access to the resources required for growth. The investigation of childhood requires a broader scope; future analysis of the Roebuck data should combine cranial and postcranial measurements, archaeological site information, and a more thorough analysis of pathological observations (including analysis of available radiographs). The combination of these avenues of investigation will no doubt provide a deeper understanding of the lives of the Roebuck children.

APPENDIX A: TABLES

Table 1: Observed Pathological Conditions in the Roebuck Subadults

Individual	Skeletal Age (yrs)	Dental Age (yrs)	**Observed Pathological Lesions** (observations made by Janet Young, CMC)
X111-F:1	4-7	5.79	Periostitis on right ilium and left fibula
X111-F:3	5-7	6.72	Non-specific infection (periostitis) on two separate areas of right tibia, has been partly remodelled into lamellar bone
X111-F:4	2-3	3.46	Abnormally extensive dental caries (possibly due to enamel defects on dentition)
X111-F:5	11-12	9.12	Extensive lesions in lower spine which appear to be consistent with tuberculosis; minor infection of left femur, minor infection on left twelfth rib; linear enamel hypoplasia and pitting on anterior dentition
X111-F:6	8-10	9.05	Possible healed maxillary abscess (LP2), linear enamel hypoplasia on erupting mandibular canines
X111-F:7	14-16	15.95	Linear enamel hypoplasia
X111-F:10	1		All long bones exhibit periostitis, with some evidence of integration into lamellar bone
X111-F:12	12-15		Non-specific infection between articular surfaces of proximal third metatarsals and distal articular surfaces of lateral cuneiforms; minor linear enamel hypoplasia on maxillary first incisors
X111-F:18	12-15	11.31	Cribra orbitalia visible on left orbit in form of linked porosities (right orbit not present); linear enamel hypoplasia and dental caries; degenerative type lesions on T10-12
X111-F:19	1-3		None observed
X111-F:20	5-7	5.64	Extensive caries on maxillary Rm1 and mandibular Rm2
X111-F:23	1.5-2.5	3.21	None observed
X111-F:25	6-8	7.44	Dental caries
X111-F:29	15-21		Dental caries, linear enamel hypoplasia on top and bottom anterior dentition
X111-F:32	5-7	5.47	None observed
X111-F:33	5-7	6.12	Dental caries
X111-F:185	9-12 mos		None observed
X111-F:186	5-7		Dental caries
X111-F:193	5-7		Dental caries
X111-F:195*	2-3		Cribra orbitalia (minor porosity) visible on both inner superior surfaces of orbits, with coalesced

			porosity in some spots; dental caries
X111-F:197	perinate		All long bones exhibit periostitis on surfaces of shafts
X111-F:220	5-7	4.18	Dental caries
X111-F:244	10-12		Cribra orbitalia visible on inner superior surface of both orbits, with some coalesced porosity; dental caries, linear enamel hypoplasia
X111-F:245*	6-8		Spine/sacrum/left ilium exhibit lesions that are lytic in nature with no blastic activity, may be tuberculosis
X111-F:245a	1-3		None observed
X111-F:246*	foetus		None observed
X111-F:247*	1-3		None observed
X111-F:253*	2-3	3.40	None observed
X111-F:254	4-6	5.20	None observed
X111-F:257	7-10		Dental caries
X111-F:260	5-7		Dental caries
X111-F:264	foetus		None observed
X111-F:265	2-4		Dental caries
X111-F:266*	foetus		None observed
X111-F:266a*	foetus		None observed
X111-F:267*	1-2		None observed
X111-F:268	0.5 - 1 yr		None observed
X111-F:269*	foetus		None observed

*Individuals without craniofacial data

Table 2: Dental Age Comparison Correlation Coefficients

Variable	r	Variable	r
Max cranial length	0.448	Mandibular length L	0.923
Max cranial breadth	0.126	Mandibular length goniometer R	0.455
Min frontal breadth	0.744	Mandibular length goniometer L	1.000
Max frontal breadth	0.616	Bigonial breadth	0.640
Bizygomatic diameter	0.996	Bicondylar width	0.726
Biasterionic breadth	0.573	Symphyseal height	0.857
Basion-bregma height	0.588	Ramus height R	0.617*
Basion-nasion length	0.731	Ramus height L	0.650*
Basion-prosthion length	0.823	Ramus height goniometer R	0.677
Basion-opisthion length	0.164	Ramus height goniometer L	0.745
Foramen magnum breadth	0.540	Min ramus breadth R	0.733
Upper facial height	0.868	Min ramus breadth L	0.720
Upper facial breadth	0.883	Gonial angle	0.170
Total facial height	0.823	Max malar length	0.214
Mastoid length	0.420	Coronoid height R	0.943
Orbital height R	0.381	Coronoid height L	0.910

Orbital height L	0.077	Distance b/n mental foramina	0.645
Orbital breadth R	0.512	Max proj mandibular length	0.915
Orbital breadth L	0.537	Inferior malar length R	0.632
Nasal height	0.754	Inferior malar length L	0.796
Nasal breadth	0.806	Max internal palate breadth	0.850
Alveolar length	0.858	Max internal palate length	0.806
Alveolar breadth	0.924	Max occ condyle breadth R	0.868
Bimaxillary breadth	0.561	Max occ condyle breadth L	0.894
Biorbital breadth	0.854	Post inter-occ mdpt	0.800
Interorbital breadth	0.843	Post inter-occ post	0.621
Biauricular breadth	0.823	Ant inter-occ mdpt	0.796
Nasion-bregma chord	0.345	Ant inter-occ ant	0.443
Nasion-bregma arc	0.032	Min occ breadth basilar	0.759
Bregma-lambda chord	0.077	Min occ breadth squamous	0.789
Bregma-lambda arc	0.141	Mandibular notch breadth R	0.891
Lambda-opisthion chord	0.853	Mandibular notch breadth L	0.850
Lambda-opisthion arc	0.604	Bicoronoid distance	0.769
Auricular height	0.214	Coronoid-condyle distance R	0.619
Bregma-porion height	0.672	Coronoid-condyle distance L	0.675
Basion-porion	0.548	Condyle process height R	0.661
Height of mandibular body	0.758	Condyle process height L	0.676
Breadth of mandibular body	0.176	Mandibular condyle breadth R	0.673
Mandibular length R	0.823	Mandibular condyle breadth L	0.771

Table 3: Measurement Comparison Correlation Coefficients

Measurement 1	Measurement 2	r
Max cranial length	Min frontal breadth	0.790*
Max cranial length	Bizygomatic diameter	0.695
Max cranial breadth	Biasterionic breadth	0.668*
Min frontal breadth	Upper facial height	0.812*
Min frontal breadth	Upper facial breadth	0.895*
Min frontal breadth	Total facial height	0.726*
Min frontal breadth	Max frontal breadth	0.785*
Max frontal breadth	Bizygomatic diameter	0.642
Max frontal breadth	Upper facial height	0.688*
Bizygomatic diameter	Upper facial height	0.922*
Bizygomatic diameter	Upper facial breadth	0.945*
Bizygomatic diameter	Total facial height	0.896*
Basion-nasion length	Basion-prosthion length	0.797*
Basion-nasion length	Foramen magnum breadth	0.723*
Basion-prosthion length	Foramen magnum breadth	0.479
Upper facial height	Upper facial breadth	0.891*
Upper facial height	Total facial height	0.978*
Upper facial height	Nasal height	0.921*

Upper facial height	Nasal breadth	0.584
Upper facial breadth	Total facial height	0.856*
Upper facial breadth	Nasal height	0.657
Upper facial breadth	Nasal breadth	0.871*
Upper facial breadth	Orbital breadth L	0.733*
Total facial height	Nasal height	0.808*
Orbital height R	Orbital height L	0.534
Orbital breadth R	Orbital breath L	0.547
Orbital breadth L	Biorbital breadth	0.737*
Nasal height	Nasal breadth	0.456
Alveolar length	Alveolar breadth	0.907*
Alveolar length	Max cranial length	0.282
Alveolar length	Max internal palate length	0.953*
Alveolar breadth	Bimaxillary breadth	0.560
Alveolar breadth	Biorbital breadth	0.760*
Alveolar breadth	Max cranial breadth	0.418
Alveolar breadth	Bizygomatic diameter	0.957*
Alveolar breadth	Upper facial breadth	0.915*
Alveolar breadth	Max internal palate length	0.915*
Biorbital breadth	Interorbital breadth	0.841*
Nasion-bregma chord	Nasion-bregma arc	0.901*
Nasion-bregma chord	Lambda-opisthion chord	0.799*
Nasion-bregma chord	Lambda-opisthion arc	0.731*
Nasion-bregma chord	Auricular height	0.734*
Nasion-bregma arc	Bregma-lambda chord	0.581
Nasion-bregma arc	Bregma-lambda arc	0.336
Nasion-bregma arc	Lambda-opisthion chord	0.770*
Nasion-bregma arc	Lambda-opisthion arc	0.747*
Bregma-lambda chord	Bregma-lambda arc	0.891*
Lambda-opisthion chord	Lambda-opisthion arc	0.883*
Lambda-opisthion arc	Auricular height	0.448
Auricular height	Bregma porion height	0.722*
Height of mandibular body	Mandibular length R	0.661*
Height of mandibular body	Mandibular length goniometer R	0.726*
Height of mandibular body	Mandibular length L	0.777*
Height of mandibular body	Bigonial breadth	0.817*
Height of mandibular body	Bicondylar width	0.470
Height of mandibular body	Symphyseal height	0.883*
Height of mandibular body	Ramus height R	0.726*
Height of mandibular body	Ramus height L	0.737*
Height of mandibular body	Ramus height goniometer R	0.678*
Height of mandibular body	Ramus height goniometer L	0.697*
Height of mandibular body	Min ramus breadth R	0.868*
Height of mandibular body	Min ramus breadth L	0.818*
Height of mandibular body	Mandibular condyle breadth R	0.692*

Height of mandibular body	Coronoid condyle distance R	0.583*
Mandibular length R	Mandibular length L	0.992*
Mandibular length R	Bigonial breadth	0.928*
Mandibular length R	Bicondylar width	0.664*
Mandibular length R	Symphyseal height	0.814*
Mandibular length R	Ramus height R	0.827*
Mandibular length R	Ramus height L	0.814*
Mandibular length R	Min ramus breadth R	0.811*
Mandibular length R	Min ramus breadth L	0.843*
Mandibular length R	Coronoid height R	0.942*
Mandibular length R	Coronoid height L	0.917*
Mandibular length R	Mandibular notch breath R	0.756*
Mandibular length R	Mandibular notch breadth L	0.747*
Mandibular length R	Condylar process height R	0.717*
Mandibular length R	Condylar process height L	0.773*
Mandibular length R	Mandibular condyle breadth R	0.797*
Mandibular length R	Coronoid condyle distance R	0.871*
Mandibular length R	Coronoid condyle distance L	0.762*
Mandibular length L	Bigonial breadth	0.952*
Mandibular length L	Bicondylar width	0.885*
Mandibular length L	Symphyseal height	0.871*
Mandibular length L	Ramus height R	0.769*
Mandibular length L	Ramus height L	0.741*
Mandibular length L	Min ramus breadth R	0.882*
Mandibular length L	Min ramus breadth L	0.888*
Mandibular length L	Coronoid height L	0.709*
Mandibular length L	Mandibular condyle breadth L	0.717*
Bigonial breadth	Bicondylar width	0.491
Bigonial breadth	Symphyseal height	0.786*
Bigonial breadth	Ramus height R	0.869*
Bigonial breadth	Ramus height L	0.818*
Bigonial breadth	Min ramus breadth R	0.870*
Bigonial breadth	Min ramus breadth L	0.874*
Bigonial breadth	Coronoid height R	0.819*
Bigonial breadth	Condylar process height R	0.654*
Bigonial breadth	Mandibular condyle breadth R	0.851*
Bigonial breadth	Mandibular condyle breadth L	0.790*
Bigonial breadth	Coronoid condyle distance R	0.875*
Bigonial breadth	Coronoid condyle distance L	0.767*
Bicondylar width	Symphyseal height	0.735*
Bicondylar width	Ramus height R	0.671*
Bicondylar width	Ramus height L	0.717*
Bicondylar width	Coronoid height R	0.896*
Bicondylar width	Coronoid height L	0.845*
Bicondylar width	Mandibular notch breadth R	0.730*

Bicondylar width	Mandibular notch breadth L	0.763*
Symphyseal height	Ramus height R	0.773*
Symphyseal height	Ramus height L	0.683*
Symphyseal height	Min ramus breadth R	0.780*
Symphyseal height	Min ramus breadth L	0.790*
Symphyseal height	Mandibular notch breadth R	0.605*
Ramus height R	Ramus height L	0.968*
Ramus height R	Min ramus breadth R	0.755*
Ramus height R	Min ramus breadth L	0.732*
Ramus height R	Condylar process height L	0.705*
Ramus height R	Coronoid condyle distance R	0.860*
Ramus height R	Coronoid condyle distance L	0.734*
Ramus height L	Min ramus breadth R	0.790*
Ramus height L	Min ramus breadth L	0.764*
Ramus height L	Coronoid height L	0.743*
Ramus height L	Mandibular notch breadth R	0.648*
Ramus height L	Mandibular notch breadth L	0.647*
Ramus height L	Condylar process height L	0.795*
Ramus height L	Coronoid condyle distance R	0.845*
Ramus height L	Coronoid condyle distance L	0.778*
Min ramus breadth R	Min ramus breadth L	0.975*
Min ramus breadth R	Coronoid height L	0.850*
Min ramus breadth R	Mandibular notch breadth R	0.713*
Min ramus breadth R	Mandibular notch breadth L	0.640*
Min ramus breadth R	Condylar process height R	0.630*
Min ramus breadth R	Condylar process height L	0.823*
Min ramus breadth R	Mandibular condyle breadth R	0.628*
Min ramus breadth R	Coronoid condyle distance R	0.688*
Min ramus breadth R	Coronoid condyle distance L	0.775*
Min ramus breadth L	Coronoid height L	0.872*
Min ramus breadth L	Mandibular notch breadth R	0.761*
Min ramus breadth L	Mandibular notch breadth L	0.667*
Min ramus breadth L	Condylar process height R	0.721*
Min ramus breadth L	Condylar process height L	0.848*
Min ramus breadth L	Mandibular condyle breadth R	0.607*
Min ramus breadth L	Mandibular condyle breadth L	0.621*
Min ramus breadth L	Coronoid condyle distance R	0.718*
Min ramus breadth L	Coronoid condyle distance L	0.726*
Coronoid height R	Coronoid height L	0.933*
Coronoid height R	Mandibular notch breadth R	0.859*
Coronoid height R	Mandibular notch breadth L	0.852*
Coronoid height R	Condylar process height R	0.893*
Coronoid height R	Condylar process height L	0.789*
Coronoid height R	Coronoid condyle distance R	0.686*
Coronoid height L	Mandibular notch breadth R	0.818*

Coronoid height L	Mandibular notch breadth L	0.819*
Coronoid height L	Condylar process height R	0.792*
Coronoid height L	Condylar process height L	0.792*
Coronoid height L	Mandibular condyle breadth R	0.896*
Coronoid height L	Mandibular condyle breadth L	0.773*
Coronoid height L	Coronoid condyle distance R	0.666*
Coronoid height L	Coronoid condyle distance L	0.649*
Mandibular notch breadth R	Mandibular notch breadth L	0.918*
Mandibular notch breadth R	Condylar process height R	0.612*
Mandibular notch breadth R	Condylar process height L	0.703*
Mandibular notch breadth R	Coronoid condyle distance R	0.571*
Condylar process height R	Condylar process height L	0.864*
Condylar process height R	Coronoid condyle distance R	0.751*
Condylar process height L	Coronoid condyle distance R	0.816*
Condylar process height L	Coronoid condyle distance L	0.543*
Mandibular condyle breadth R	Mandibular condyle breadth L	0.818*
Mandibular condyle breadth R	Coronoid condyle distance L	0.626*
Mandibular condyle breadth L	Coronoid condyle distance L	0.495*
Coronoid condyle distance R	Coronoid condyle distance L	0.876*
Max occipital condyle breadth R	Max occipital condyle breadth L	0.979*
Max occipital condyle breadth R	Post inter occ post	0.654*
Max occipital condyle breadth R	Ant inter occ mdpt	0.818*
Max occipital condyle breadth R	Ant inter occ ant	0.709*
Max occipital condyle breadth R	Min occipital breadth basilar	0.864*
Min occipital condyle breadth R	Min occipital breadth squamous	0.712*
Max occipital condyle breadth L	Post inter occ mdpt	0.772*
Max occipital condyle breadth L	Ant inter occ mdpt	0.794*
Max occipital condyle breadth L	Ant inter occ ant	0.799*
Max occipital condyle breadth L	Min occipital breadth basilar	0.869*
Max occipital condyle breadth L	Min occipital breadth squamous	0.763*
Post inter occ mdpt	Post inter occ post	0.867*
Post inter occ mdpt	Min occipital breadth basilar	0.592*
Post inter occ mdpt	Min occipital breadth squamous	0.910*
Post inter occ post	Ant inter occ ant	0.615*
Post inter occ post	Min occipital breadth squamous	0.899*
Ant inter occ mdpt	Ant inter occ ant	0.687*
Ant inter occ mdpt	Min occipital breadth basilar	0.787*
Ant inter occ ant	Min occipital breadth basilar	0.710*
Min occipital breadth basilar	Min occipital bread squamous	0.705*
Alveolar length	Max internal palate length	0.953*
Alveolar breadth	Bizygomatic diameter	0.957*
Alveolar breadth	Upper facial breadth	0.915*
Alveolar breadth	Max internal palate length	0.915*
Inferior malar length R	Inferior malar length L	0.982*

Fig. 1   *Fig.2*

Dental Age vs Bizygomatic Diameter

Dental Age vs Basion-Prosthion Length

Fig. 3   *Fig.4*

Dental Age vs Upper Facial Height

Dental Age vs Upper Facial Breadth

Fig. 5   *Fig.6*

Dental Age vs Total Facial Height

Dental Age vs Nasal Breadth

Fig. 7

Dental Age vs Alveolar Length

Fig. 8

Dental Age vs Alveolar Breadth

Fig. 9

Dental Age vs Bimaxillary Breadth

Fig. 10

Dental Age vs Biorbital Breadth

Fig. 11

Dental Age vs Interorbital Breadth

Fig. 12

Dental Age vs Biauricular Breadth

Fig. 13

Dental Age vs Lambda-Opisthion Chord

Fig. 14

Dental Age vs Mandibular Length R

Fig. 15

Dental Age vs Mandibular Length L

Fig. 16

Dental Age vs Bicondylar Breadth

Fig. 17

Dental Age vs Symphyseal Height

Fig. 18

Dental Age vs Ramus Height R

Fig. 19

Dental Age vs Ramus Height L

Fig. 20

Dental Age vs Ramus Height Goniometer R

Fig. 21

Dental Age vs Ramus Height Goniometer L

Fig. 22

Dental Age vs Coronoid Height R

Fig. 23

Dental Age vs Coronoid Height L

Fig. 24

Dental Age vs Max Projective Mandibular Length

Fig. 25

Dental Age vs Max Internal Palate Breadth

Fig. 26

Dental Age vs Max Internal Palate Length

Fig. 27

Dental Age vs Max Occipital Condyle Breadth R

Fig. 28

Dental Age vs Max Occipital Condyle Breadth L

Fig. 29

Dental Age vs Post Inter-Occipital Condylar Distance (mdpt)

Fig. 30

Dental Age vs Mandibular Notch Breadth L

118

Fig. 31

Dental Age vs Max Cranial Length

XIII-F:3
6.72
176.00

XIII-F:7
15.95
171.00

Fig. 32

Dental Age vs Max Cranial Breadth

XIII-F:20
5.64
141.50

XIII-F:7
15.95
134.00

Fig. 33

Dental Age vs Foramen Magnum Breadth

7.44
32.50
XIII-F:25

15.95
29.50
XIII-F:7

Fig. 34

Dental Age vs Nasal Height

XIII-F:6
9.05
49.00

15.95
46.00
XIII-F:7

Fig. 35

Dental Age vs Lambda-Opisthion Arc

9.05
100.00 XIII-F:6

Fig. 36

Dental Age vs Auricular Height

XIII-F:5
9.12
101.50

119

Fig. 37

Dental Age vs Bregma-Porion Height

Fig. 38

Dental Age vs Basion-Porion

Fig. 39

Dental Age vs Max Malar Length

Fig. 40

Dental Age vs Distance b/n Mental Foramen

Fig. 41

Dental Age vs Mandibular Condyle Breadth R

Fig. 42

Dental Age vs Bicoronoid Distance

Fig. 43

Dental Age vs Humerus Max Length R

Fig. 44

Dental Age vs Humerus Max Length L

Fig. 45

Dental Age vs Radius Max Length R

Fig. 46

Dental Age vs Radius Max Length L

Fig. 47

Dental Age vs Ulna Max Length R

Fig. 48

Dental Age vs Ulna Max Length L

Fig. 49

Dental Age vs Femur Max Length R

Fig. 50

Dental Age vs Femur Max Length L

Fig. 51

Dental Age vs Tibia Max Length R

Fig. 52

Dental Age vs Tibia Max Length L

Fig. 53

Dental Age vs Fibula Max Length R

Fig. 54

Dental Age vs Fibula Max Length L

Fig. 55

Fig. 56

Bizygomatic Diameter vs Upper Facial Height

Bizygomatic Diameter vs Upper Facial Breadth

Fig. 57

Fig. 58

Upper Facial Height vs Total Facial Height

Upper Facial Height vs Nasal Height

Fig. 59

Fig. 60

Alveolar Length vs Alveolar Breadth

Nasion-Bregma Chord vs Nasion-Bregma Arc

123

Fig. 61

Mandibular Length R vs Mandibular Length L

Fig. 62

Mandibular Length R vs Bigonial Breadth

Fig. 63

Mandibular Length L vs Bigonial Breadth

Fig. 64

Mandibular Length R vs Coronoid Height R

Fig. 65

Mandibular Length R vs Coronoid Height L

Fig. 66

Ramus Height R vs Ramus Height L

124

Fig. 67

Min Ramus Breadth R vs Min Ramus Breadth L

Fig. 68

Coronoid Height R vs Coronoid Height L

Fig. 69

Mandibular Notch Breadth R vs L

Fig. 70

Max Occipital Condyle Breadth R vs L

Fig. 71

Post Inter Occ Mdpt vs Min Occipital Breadth Squamous

Fig. 72

Alveolar Length vs Max Internal Palate Length

Fig. 73

Alveolar Breadth vs Max Internal Palate Length

Fig. 74

Inferior Malar Length R vs L

Fig. 75

Max Cranial Length vs Min Frontal Breadth

Fig. 76

Max Cranial Length vs Bizygomatic Diameter

Fig. 77

Max Cranial Breadth vs Biasterionic Breadth

Fig. 78

Max Frontal Breadth vs Bizygomatic Diameter

126

Fig. 79

Fig. 80

Basion-Prosthion Length vs Foramen Magnum Breadth

Fig. 81

Fig. 82

Upper Facial Height vs Nasal Breadth

Upper Facial Breadth vs Nasal Height

Upper Facial Breadth vs Nasal Breadth

Fig. 83

Fig. 84

Orbital Breadth R vs Orbital Breadth L

Alveolar Breadth vs Bimaxillary Breadth

127

Fig. 85

Biauricular Breadth vs Basion Porion

Fig. 86

Nasion-Bregma Chord vs Basion Porion

Fig. 87

Nasion-Bregma Arc vs Bregma-Lambda Arc

Fig. 88

Lambda-Opisthion Arc vs Auricular Height

Fig. 89

Auricular Height vs Bregma Porion Height

Fig. 90

Height of Mandibular Body vs Bicondylar Width

128

Fig. 91

Bigonial Breadth vs Bicondylar Width

Fig. 92

Coronoid Height R vs Mandibular Condyle Breadth R

Fig. 93

Max Occipital Condyle Breadth R vs Min Occipital Breadth Squamous

Fig. 94

Post Inter Occ Midpt vs Ant Inter Occ Mdpt

Fig. 95

Dental Age vs Basion-Opisthion Length

Fig. 96

Dental Age vs Basion-Nasion Length

Fig. 97

Dental Age vs Biasterionic Breadth

Fig. 98

Dental Age vs Basion-Bregma Height

Fig. 99

Dental Age vs Max Cranial Length

Fig. 100

Dental Age vs Max Cranial Breadth

Fig. 101

Dental Age vs Max Frontal Breadth

Fig. 102

Dental Age vs Min Frontal Breadth

133

Fig. 103

Dental Age vs Total Facial Height

Arikara: R^2 Linear = 0.907
Roebuck: R^2 Linear = 0.678

Fig. 104

Dental Age vs Upper Facial Height

Arikara: R^2 Linear = 0.896
Roebuck: R^2 Linear = 0.754

Fig. 105

Dental Age vs Nasal Height

Arikara: R² Linear = 0.826
Roebuck: R² Linear = 0.569

Fig. 106

Dental Age vs Orbital Height L

Fig. 107

Dental Age vs Orbital Breadth L

Fig. 108

Dental Age vs Bizygomatic Diameter

Fig. 109

Dental Age vs Interorbital Breadth

Fig. 110

Dental Age vs Nasal Breadth

Fig. 111

Dental Age vs Alveolar Breadth

Fig. 112

Dental Age vs Bicondylar Width

Fig. 113

Dental Age vs Bigonial Breadth

Fig. 114

Dental Age vs Distance between Mental Foramen

Fig. 115

Dental Age vs Mandibular Length L

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