12-11-2012 12:00 AM

A Comparative Ontogenetic Study of Biomechanical Adaptations in the Long Bones of South African Khoisan and Sadlermiut Inuit

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A thesis submitted in partial fulfillment of the requirements for the Master of Arts degree in Anthropology

A COMPARATIVE ONTOGENETIC STUDY OF BIOMECHANICAL ADAPTATIONS IN THE LONG BONES OF SOUTH AFRICAN KHOISAN AND SADLERMIUT INUIT

(Spine title: Biomechanical adaptations of the Khoisan and Sadlermiut)

(Thesis format: Monograph)

by

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Graduate Program in Anthropology

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Arts

The School of Graduate and Postdoctoral Studies
The University of Western Ontario
London, Ontario, Canada

THE UNIVERSITY OF WESTERN ONTARIO
School of Graduate and Postdoctoral Studies

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entitled:

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Date	Chair of the Thesis Examination Board

Abstract

This research examines and compares the biomechanical adaptations of juveniles from two different climate-adapted populations: Khoisan foragers from South Africa and Sadlermiut Inuit from Nunavut, Canada. Cortical bone measurements were recorded at three diaphyseal locations on the Sadlermiut and Khoisan humeri, tibiae and femora using biplanar radiographs. Biomechanical strength properties were calculated using the Eccentric Ellipse Method (EEM). EEM calculations were interpreted with consideration to the known behavioural patterns of the two groups. Humeral AP and torsional bending strength were greater in the Sadlermiut compared to the Khoisan – most likely caused by kayak paddling among the Sadlermiut. Few differences were found between the Khoisan and Sadlermiut tibiae and femora. The Khoisan and Sadlermiut may not have been participating in lower body activities with sufficient, or sufficiently different, intensity to produce unique osteogenic responses. The juveniles demonstrated an increase in humeral strength at around age 12 which was concluded to be attributable to the onset of adult activities. However, the strength increases seen in the juvenile tibiae and femora occurred at expected ages for normal growth and could not be fully attributed to the adoption of adult activities.

Keywords

Biomechanics, ontogeny, biological anthropology, South Africa, Khoisan, Southampton Island, Sadlermiut, Stirrup Court.

Acknowledgments

Thank you to my supervisor and mentor, Dr. Andrew Nelson, for his wisdom and guidance through the biggest milestone of my life so far. Thank you to my defense examiners Dr. Tom Jenkyn and Dr. El Molto for their challenging questions and interesting suggestions for this project. Thank you to my thesis advisor, Dr. Ian Colquhoun, for offering his input and advice to me at every step of the way. I would also like to thank Dr. Christine White, Dr. Alexis Dolphin, Dr. Kim Clark and Dr. Lisa Hodgetts for their insight and ideas.

Thank you to the lab staff in the Anthropology Department, particularly Zoe Morris, Dr. Christine Boston, Anna Jung and Renee Willmon for going out of their way to help me and for the reassuring chats. Thank you to Dr. Greg Garvin and Mr. Glenn Schurmans of the Radiology Department of St. Joseph's Healthcare Hospital in London, Ontario for allowing me to use the hospital equipment and for assisting me in the imaging process.

I would also like to say thank you to my cohort for all their feedback and suggestions throughout the past two years. To Emily Wells and Kelly Miller, I cannot thank you both enough for your friendship and support – and the weekly writing-dates, of course. Thank you to my co-workers at Archeoworks for the comments, questions and encouragement in my last few months of writing: Jess Marr, Kass Aldridge, Dan Jang, Jae Park, James White and Alex Rodriguez.

Thank you to my parents, Kevin and Sandra Boucher, for their constant support and encouragement. Thank you to my sister, Krissy Boucher (Nicolucci), for being both a mentor and a friend to me not only now but always. And a heartfelt thank you to my partner, Christopher Tan, for all the happiness you bring.

Dedication

This thesis is dedicated to my friend and companion who passed away before I finished this project. I have never known anyone more good.

Goofy, 1997-2012

"To die will be an awfully big adventure!"
- *Peter Pan* by J.M. Barrie

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Chapter 1

1 Introduction

This thesis is a cross-sectional study of the biomechanical adaptations of two sample populations. Each sample comes from a population adapted to a specific climate. The first sample is from a group of small-bodied foragers from South Africa known as the San or Khoisan. The Khoisan are considered to be adapted to a temperate climate. The second sample is from a group of now extinct Inuit from the Canadian Arctic known as the Sadlermiut. The Sadlermiut sample represents the cold climate-adapted population for this research. A third sample is included in order to act as a reference sample for testing the accuracy of the methodology used for the Khoisan and Sadlermiut. This sample is from the Stirrup Court cemetery located in London, Ontario, Canada. The Stirrup Court sample is adapted to a mild climate as this region of Ontario typically experiences both warm and cold temperatures annually.

This climate distinction is necessary because groups of people living in temperate- and cold-climate regions will exhibit specialized adaptations in their bone morphology. It is not climate, per se, that stimulates this change in bone morphology but climate plays a large role in the structure of the environment; humans then engage in behavioral patterns that are best suited to survival in their environment. Alternately, naturally occurring variation in human populations can be shaped by the context of their environment via the process of natural selection. Therefore, environments shaped and formed by different climates will produce different adaptations in the form of activity patterns and bone structure among the people who live in those environments. This thesis project attempts to examine the biomechanical adaptations that result from these differential ways of living in each location (i.e. South Africa, Canadian Arctic).

Biomechanics is the study of the ways in which living tissues respond to external loading forces, such as exercise and activity. This thesis will examine the biomechanical adaptations of each sample population using three long bones: the humerus, tibia and femur. These three bones were selected for several reasons. First, they are the most commonly used bones in other studies of human biomechanics, which is helpful if comparative analyses are to be made in the future. Second, they are greatly affected by loading forces due to their prominent involvement in strenuous activities (e.g. trekking, climbing, and throwing). Third, it has been demonstrated in previous studies that structural changes that occur in the humerus, tibia and femur can be directly linked to behavioural patterns in humans and in several other animal species (Jones et al., 1977; Ruff and Hayes, 1983a,b; Ruff, 1987; Brock and Ruff, 1988; Ruff and Larsen, 1990; Ruff, 1991; Bass et al., 1998; Mays, 1999; Ruff, 1999; Cowgill, 2008; Ruff, 2008; Harrington, 2010)

The existing body of research on biomechanics incorporates a wide variety of disciplinary perspectives. Biomechanical studies have been carried out in a number of different fields such as kinesiology, engineering, orthopedics, biology, physiology, and anthropology, to name a few. While the field of biomechanics is by no means small, anthropological studies that concentrate on biomechanics are limited; those anthropologists whose biomechanical research will be relied upon in this thesis include Dr. Christopher B. Ruff, Dr. Jay T. Stock, Dr. Susan K. Pfeiffer, and Dr. Libby W. Cowgill.

Dr. Ruff's contributions to the field of anthropology include several biomechanical analyses of both modern and archaeological populations (Ruff and Hayes, 1983a,b; Brock and Ruff, 1988; Trinkaus and Ruff, 1989, 1996; Fresia et al., 1990; Ruff and Larsen, 1990; Larsen and Ruff, 1991; Ruff, 1991, 1995, 1999, 2000, 2008; Trinkaus et al., 1999). Dr. Ruff uses biomechanical properties of various skeletal elements to make connections between behaviour in modern human and primate populations and the structural changes that take place within their bones. He has then used this knowledge to make inferences about behaviour in past populations using cross-sectional measurements of bone. Dr. Ruff's contributions to the theory of biomechanics will be heavily drawn upon for this thesis due to the vast number of applications his work has provided to the field of anthropology.

Dr. Libby Cowgill has made some more recent contributions to the field of biomechanics with a particular emphasis on ontogeny (Cowgill and Hager, 2007; Cowgill 2007, 2008, 2010; Cowgill et al., 2010; Cowgill and Robbins, in prep; Cowgill et al., in prep). Her approach to understanding human and hominin behaviour in the past draws upon three main theoretical perspectives: biomechanical, developmental and anthropological (Cowgill, 2008). This thesis will emulate the theoretical approach taken by Dr. Cowgill in order to make connections between long bone structure and activity patterns in each of the sample populations to be studied.

The samples used in this research have all been previously studied. The current body of research on the Khoisan sample that is most relevant to the approach taken in this thesis comes from studies done by Dr. Jay T. Stock, Dr. Susan K. Pfeiffer and Dr. Lesley Harrington. Stock and Pfeiffer have published one study comparing bone functional adaptations between Later Stone Age foragers of South Africa (Khoisan) from the fynbos and forest biomes and a second study comparing structural variability in the long bones of forager groups from southern Africa and the Andaman Islands (Stock and Pfeiffer, 2001, 2004). These studies will be discussed in further detail in section 2.3 of this thesis and will be relied upon when interpreting the results of this research.

The Sadlermiut were studied by Dr. Charles Merbs whose research focuses on interpreting behavioural patterns among the Sadlermiut from osteological remains (Merbs and Wilson, 1962; Merbs 1974, 1983, 1995, 1996, 2002a,b, 2004; Hawkey and Merbs, 1995). His work focused primarily on pathological evidence and the types of behaviours that could have potentially led to the development of such pathologies (Merbs, 1983). The Sadlermiut population was also used in a comparative analysis of ontogeny done by Dr. Jennifer Thompson and Dr. Andrew Nelson (2000). Thompson and Nelson (2000) observed the ontogeny of femoral length in Neandertal, *Homo erectus,* early modern *Homo sapiens, Gorilla gorilla*, modern Euroamerican and Sadlermiut juvenile specimens in order to view the Neandertal growth trajectory with respect to other human groups. The Sadlermiut sample used in this project was previously studied by Amy Scott (2009). Scott's research focused on reconstructing behaviour from musculoskeletal markers of stress within the Sadlermiut sample. The work of Merbs, Thompson and Nelson, and

Scott will be particularly helpful in making connections between the biomechanical adaptations and behavioural patterns of the Sadlermiut Inuit.

The final sample included in this thesis is from the Stirrup Court cemetery in London, Ontario, Canada. The existing research on the Stirrup Court sample is limited, with the main contributions coming from Dr. Joseph Parish (2000) and Dr. Michael Spence (Cook et al., 1986). Dr. Parish's thesis research on the Stirrup Court sample focused on health and pathologies. The data collected by Parish (2000) and Cook et al. (1986) regarding the activity patterns of the Stirrup Court people will be used in this thesis when testing two separate methodologies for extracting cross-sectional geometric properties of long bones.

This thesis will make use of the theoretical approaches used by Drs. Ruff and Cowgill which will be explained in further detail in Chapter 2. This research will not only contribute an additional study which takes a biomechanical, developmental and anthropological threefold approach, but is a new type of analysis done for each of the sample populations. While there are a number of similarities between this project and the previously mentioned studies by Stock and Pfeiffer (2001, 2004), this project differs in that an ontogenetic perspective is added to the approach. The existing research on the Sadlermiut Inuit does include some ontogenetic studies (Thompson and Nelson, 2000; Holland, 2007) as well as some biomechanical and pathological studies as in the work of Dr. Charles Merbs. However, no research has been done analyzing the long bone cross-sectional morphology of the Sadlermiut sub-adults in order to connect activity patterns to bone functional adaptations. And finally, this project will be the first to produce biomechanical data for the Stirrup Court sample. In addition to these contributions to the existing body of knowledge on each of the sample populations, this research compares two populations that have not been previously studied together.

It was mentioned above that an important factor that distinguishes this study from previous ones is the inclusion of an ontogenetic perspective – in other words, the focus of this thesis is upon the juveniles and the process by which the adult form is reached. This perspective is included because bones are most susceptible to change from external stimuli during the growth period as opposed to when an individual reaches adulthood. While it has been shown that bone still adapts to loading forces during adulthood, the effects are much less pronounced (Bertram and Swartz, 1991; Turner et al., 1995; Lieberman et al., 2004; Pearson and Lieberman, 2004). Adults are still included in this study, however, because the biomechanical adaptations that their bones took on during childhood would be reflected in their adult form. It is also necessary to understand the adult end-point before studying the process by which that end-point was reached.

This study has three main goals; the first is to learn more about the biomechanical adaptations of each of these groups by recording the cortical bone dimensions of the available humeri, tibiae and femora of each sample. I hope to make in-depth interpretations about their separate ecological adaptations by using osteological data in combination with archaeological and ethnographic data. The second goal pertains to the ontogenetic aspect of this project; the goal of this approach is to view the process by which each population developed and matured to reach the adult end-point. As noted, an ontogenetic perspective is helpful due to the susceptibility of juvenile bones to external loading forces. An ontogenetic perspective can be used to observe the timing of biomechanical adaptive responses within each population, particularly when individuals begin to take part in the activities of adults; this is important because it situates the adults in their developmental context, which will undoubtedly vary by population – as argued by Dr. Libby Cowgill (2008). These variations need to be taken into consideration because they are likely to have implications for the results and analysis of this study.

The final, and more general, goal of this project is to discover if the differences in the loading forces placed upon the bones of each population result in visible differences in bone structure, or if the forces produce essentially indiscernible outcomes. This is particularly important for learning if this type of analysis can have future applications in anthropology with respect to reconstructing behaviour and activity patterns in past populations, or if the differences are not significant enough to draw conclusions from. The three goals above will be restated in section 3.4 as research questions along with a set of hypotheses and expectations created to address each question.

To test the aforementioned hypotheses, I will examine the biomechanical adaptations that are exhibited by the Khoisan, Sadlermiut and Stirrup Court populations using cross-sectional geometric calculations. These cross-sectional calculations will be made from measurements taken at the mid-shaft, proximal third and distal third of the shaft length in the available humeri, tibiae and femora within each sample. However, only the mid-shaft results are presented so that they may be explored in detail. The measurements used for these calculations were taken from biplanar radiographs. The geometrical calculations represent the different cross-sectional properties of the bones (e.g. second moments of area, polar moments of area). These cross-sectional properties of the humeri, tibiae and femora will be compared between the Khoisan and Sadlermiut samples to test the hypotheses and expectations found in section 3.4.

This thesis will contribute to the current extent of knowledge regarding the life histories and ecological adaptations of these groups of people by using an approach comprised of three main theoretical perspectives: biomechanical, developmental and anthropological. This study is also important for understanding how the environment affects human variation and behaviour which, in turn, affects the functional structure of bone. Due to the ontogenetic/developmental perspective used in this study, this research will also provide insight into the lives of the Khoisan and Sadlermiut juveniles; studies reconstructing activity patterns in juveniles have been somewhat scarce in physical anthropology and are only recently starting to increase in number within the discipline.

This study bears significance in a wider context in addition to the reasons listed above. First, an increase in our understanding of the ways in which bone adapts to loading forces can contribute to more accurate reconstructions of the lives of past populations. Biomechanical analyses can be taken as a line of evidence to be used in combination with archaeological and historical/ethnographic data. Additional anthropological studies of biomechanical adaptations in humans are required to achieve a more complete picture of the relationship between bone structure and mechanical function. Developing this knowledge means that physical anthropologists will be able to make fairly accurate inferences about behaviour from osteological remains. A biomechanical perspective could also lead to more accurate interpretations of fossil hominin behaviour which would contribute to the process of reconstructing hominin ecology. Contributions to interpreting the ecological adaptations of our ancestors are significant to anthropology because the outcome is a deeper understanding of the evolutionary history of human beings.

The format of this thesis is as follows: an overview of biomechanics theory is presented in Chapter 2, the samples to be used and the populations they represent will be detailed in Chapter 3, the methodology used can be found in Chapter 4, results of the analysis will be given in Chapter 5 and will be discussed in further detail in Chapter 6.

Chapter 2

2 Biomechanics Theory

This chapter presents an overview of the theoretical background necessary for this project. As previously mentioned, there are three main theoretical perspectives to be used in this thesis: biomechanical, ontogenetic (or developmental), and anthropological. This chapter will start with a summary of the aspects of biomechanical study required for interpreting long bone diaphyseal cross-section geometry. The influences of non-mechanical-loading-factors on bone structure will be addressed. Following this, two examples of anthropological studies that utilize biomechanical theory will be presented. The chapter will end with a discussion of the importance of an ontogenetic perspective in this project; specifically, how human ontogeny is affected by biomechanical processes.

2.1 Bone functional adaptation

It has long been known that bone growth can be substantially altered by activity patterns and that such alterations can be physically measured and linked to specific behaviours. The idea that bone structure can adapt to mechanical loading was first explored by Wilhelm Roux (1881) and later by Julius Wolff (1892). Wolff's "Law of Bone Transformation" provides the basic theoretical background necessary for this project:

> Every change in the form and function of a bone or the function alone, results in definitive changes in the internal architecture of the bone and equally definitive changes in the external architecture in accordance with mathematical laws (Wolff, 1892; cited in Weiss, 2001:22).

Roux's principles are also crucial to this project and will be presented as summarized by Roesler (1981):

> 1) Organisms possess the ability to adapt their structure to new living conditions, and 2) bone cells are capable of responding to localized mechanical stress (Roux, 1881; cited in Roesler, 1981; cited in Ruff et al., 2006:485).

However, Wolff's Law and Roux's principles only provide the bare bones of what is required for understanding bone biomechanics. To study bone biomechanics, a narrower frame of reference than that provided by Wolff and Roux is needed. The quotations above represent a very general idea that the shape and form of a bone reflect the function of that bone. Yet, skeletal form arises from a number of interacting functions, of which resistance to strain is only one (Ruff et al., 2006). In addition to this, the original writings of Julius Wolff (1892) were specific to trabecular bone and this thesis focuses upon loading changes that occur in cortical bone only. Because Wolff's Law has become a sort of biological adage in the literature with its original intent often overlooked (Cowin, 1986; Bertram and Swartz, 1991; Pearson and Lieberman, 2004), this thesis will rely more heavily on the theoretical contributions to the study of bone biomechanics made by Dr. Christopher Ruff. It has been proposed by Ruff et al. (2006) that the term "bone functional adaptation" should replace "Wolff's Law" in biomechanical studies as it conveys the same underlying idea that bone form reflects function, yet is more specific and does not have the unnecessary and sometimes erroneous connotations of Wolff's original writings.

2.1.1 *The mechanics*

The central theoretical assumption utilized herein is that bone responds to forces placed upon it during mechanical loading. This response in the bone takes place on a cellular level, meaning that it occurs via osteoblastic and osteoclastic activity. This cellular activity can be thought of as occurring in the form of a feedback loop (Lanyon, 1982; Ruff et al., 2006). Increased use of a bone in a specific direction will increase the amount of force placed upon that bone. In order to resist breakage, bone-forming cells (osteoblasts) are stimulated to produce additional bone in the direction in which the strain is occurring. Alternately, decreased use of a bone leads to the resorption of bone tissue (Ruff et al., 2006). The purpose of this is to achieve a sort of "equilibrium" state where the bone is best designed to resist breakage from external loading forces (Ruff et al., 2006). For a visualization of this feedback loop, see Figure 1.

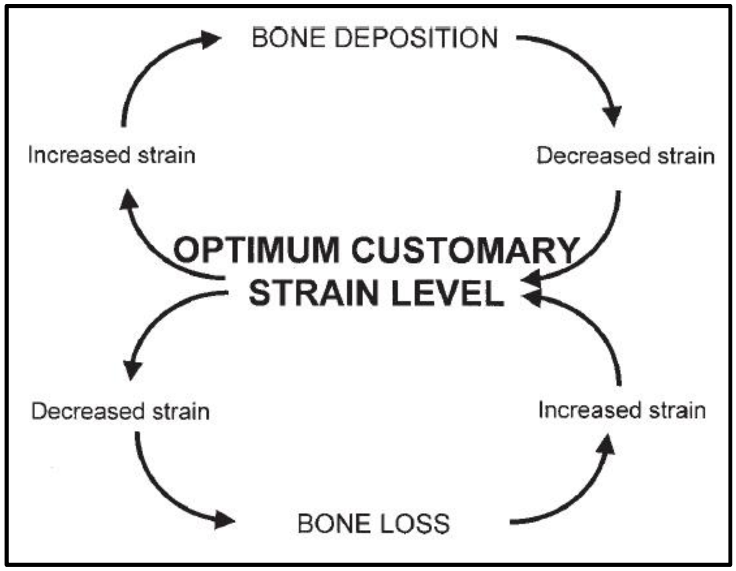

Figure 1. Simple feedback model of bone functional adaptation (Lanyon, 1982; cited in Ruff et al., 2006:485)

For consistency and clarification, some of the more important terms used in studies of biomechanics will be defined here. First, the osteoblastic and osteoclastic activity that occurs as a direct response to mechanical stimuli needs to be differentiated from the bone cellular activity that occurs during normal growth and development. The process by which the skeleton grows and develops until maturity is defined as bone modeling (Martin et al., 1998). Localized bone repair and maintenance, as in the response of bone to mechanical loading, is referred to as bone remodeling (Martin et al., 1998).

The biomechanical properties of bone are usually explained using the terms force, stress and strain. Force is the application of loads to an object, in this case bone. Forces cause internal stress within the object; stress is expressed as force per unit of area (Carter and Beaupre, 2001). Strain is defined as the response of biological tissue to loading forces, which results in deformation. Therefore, mechanical loading forces placed upon a bone cause internal stress within that bone, which, if strong enough, lead to the physical deformation of the bone otherwise known as strain.

Strain and stress in bone can occur in the following ways: tension, compression, torsion, bending and shearing. Mechanical loading forces most often produce compression, bending and torsional strains in bone. Compression means that the external force has pressed on the bone from either end of the vertical plane. Bending is an interaction of two types of strain, compression and tension, which each act upon opposite sides of the bone. And finally, torsion is a twisting form of strain. For clarification, see Figure 2.

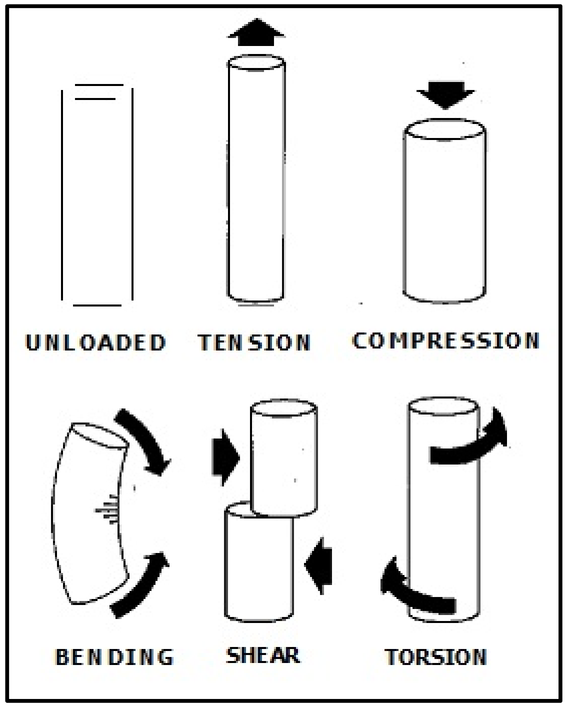

Figure 2. Forces applied to bone (Weiss, 2001:17).

In addition to the direction and type of force, bone remodeling is also determined by the magnitude, rate, distribution and duration of loading. For example, low levels of strain can be osteogenic if the rate and/or frequency at which they are applied is high. Without such repetition, low strain levels would likely not produce any effect. In cases where the magnitude of an applied force is high, bone adaptation could potentially occur even after a single instance of loading. This knowledge is important for understanding which sorts of activities are likely to cause osteogenesis, which involves not only activities with high-level strain but also extends to low-level strain activities that are repeated on a regular basis, including normal daily routines.

2.1.2 *Significance of the environment to biomechanical interpretations*

As indicated, this thesis is an examination of the structural changes that take place in bone as a result of mechanical loading caused by exercise and activity. In order to adequately conduct this examination, it is necessary to understand the environmental context in which these activities occur. This is because the environment plays a large role in determining the types of activities that humans will take part in for survival. This is why human populations from two very different climatic regions were chosen for analysis: it is assumed that different climates will produce different types of environments, and the activities that are optimal for survival in these environments will produce different structural changes in human long bones. These structural changes are the focus of this thesis.

The environment is what helps in understanding how this is possible. While humans may choose to take part in a certain activity (e.g. walking or rowing), the environment is what determines the level of intensity required for that activity. For example, a study done by Dr. Christopher Ruff (1999) on Great Basin Amerind lower limb bones demonstrated that terrain affected femoral morphology to a greater degree than distance travelled. Imagine a comparative study between two groups of foragers and both are known to travel by means of walking: even if both groups walk the exact same distances in their lifetimes, there are likely significant differences in their lower limb structures based on the terrain of the environment in which they were walking. If the terrain was rough and mountainous, this will mean a very high-level of stress was being placed upon the lower limbs. Alternately, if the terrain was flat with little to no obstacles, only low-level stress would be experienced by the bones. In an environment such as the latter, the rate and frequency of the low-level stress impact would have to be very high in order to stimulate bone remodeling, as was discussed above in section 2.1.1. However, in the rough terrain, bone remodeling would likely occur with much fewer repetitions of the activity.

A similar example can be drawn from the work of Dr. Elizabeth Weiss (2001). Dr. Weiss proposed that, when studying the humeral robusticity of rowing peoples, an understanding of their environmental context is essential. Rowing involves the use of oars which are attached to the boat with an oarlock – this creates a fulcrum that the oar pivots upon (Michael et al., 2009). If rowing is done on mostly rough waters, as in the ocean, then the effects on the humeri are likely to be much different than if rowing took place on calmer waters, as in some lakes or rivers (Weiss, 2001). Rowing in rough waters would mean that high-level strains are placed upon the bone. As discussed earlier, instances of high-level strain are able to produce structural changes within bone with a much lower frequency and rate than instances of low-level strain. Therefore, individuals who row in rough waters will exhibit greater humeral strength compared to individuals who row in calm waters, even if the duration of rowing was the same in both instances. The two examples discussed above provide clear evidence of the necessity of understanding the environmental context in which human activities occur.

2.2 Other factors affecting the structure of bone

While this thesis will be focused upon structural changes that occur in bone due to mechanical loading, it is important to note that there are several other factors that contribute to the resulting structure of bone. In order to examine one of these influencing factors (i.e. mechanical loading) it is essential to understand how bone is affected by other factors so that misinterpretations do not result. Therefore, this section will be dedicated to the examination of the many variables that influence bone structure during growth and development. These variables include, but are not limited to: genetics, age, sex, hormones, pathologies, trauma, nutrition, physical environment (e.g. altitude), and mechanical stress. With so many variables to consider, it may seem impossible to differentiate long bone structural changes caused by mechanical stress from other possible factors. However, each of these factors alters bone in different ways. An understanding of the ways in which each variable affects bone structure can help in interpreting the resulting structure observed in the bones of each sample population studied.

Refer to Figure 3 for a flow-chart visualization of the different factors affecting bone structure.

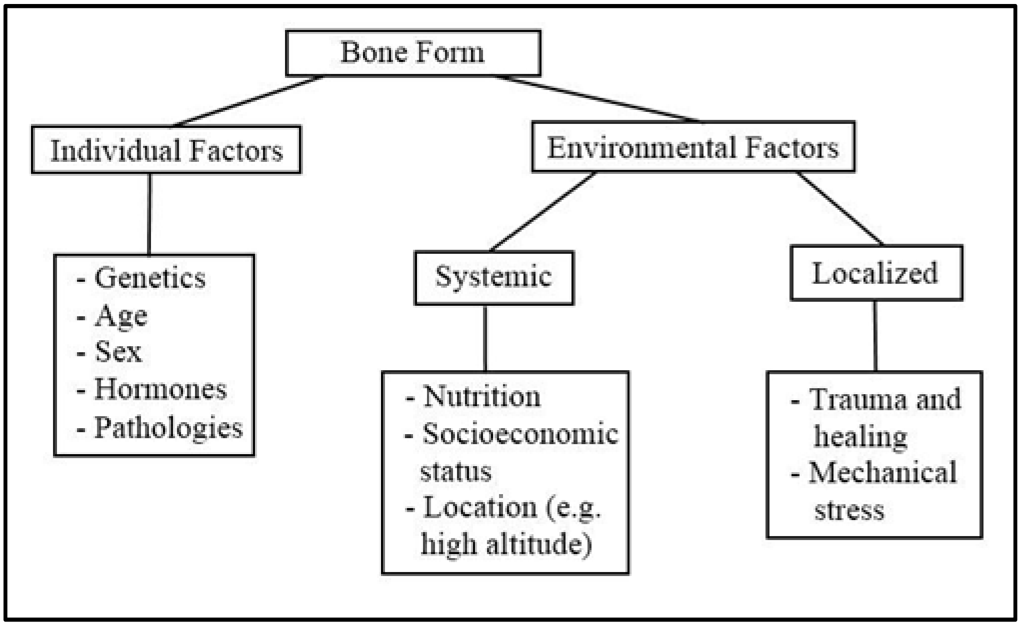

Figure 3. Chart of factors influencing bone form. After Ruff (1992:72).

2.2.1 *Individual factors*

First, bone growth and development is largely determined by genetics. However, genes affecting growth and development are not easily identified; some are known, yet many are not (Wagner and Karsenty, 2001). The matter is further complicated because resulting phenotypes can be produced from genes at several loci, otherwise known as polygenic traits. Gene expression can also change at different points in an individual's lifetime (Towne et al., 2002). It can also vary by environment as some genes are more susceptible to environmental change than others (Towne et al., 2002). Various genetic mutations can also affect growth and development. Several studies on mice and rats have made connections between gene mutations and abnormal bone growth (Deng et al., 1996; Thomas et al., 1997; Satokata et al., 2000). In most of these cases, the result of the mutation is delayed or retarded growth that often persists into adulthood.

Bone structure will also differ depending on the sex of the individual. For example, females have been shown to mature at a faster rate than males (Bogin, 1988). This would mean that skeletally, adolescent males and females of the same chronological age could potentially be assigned to different skeletal ages. With archaeological studies of growth and development, this is a particularly significant problem since sub-adults cannot be sexed. Therefore, differences in growth and development during childhood and adolescence due to sex would be difficult to discern if the sex of individuals cannot be determined. Furthermore, sex and gender differences in behavioural patterns will also affect long bone structure.

Bone growth is also regulated by hormonal signals in the body. A disorder in the endocrine system or a disruption of hormonal signals can influence normal growth and development (Parks, 2002). Endocrine disorders can occur at any point in an individual's lifetime and the cause can sometimes be difficult to determine. For example, reduced thyroid hormone production has been connected to growth retardation (Gothe et al., 1999). This reduction can be caused by either a dysfunctioning thyroid gland or possibly a lack of thyroid hormone receptors (Gothe et al., 1999). Not only it is difficult to determine their true cause, but endocrine disorders can be multifactorial, meaning they can be caused by an interaction of several factors.

There are numerous pathologies that affect normal bone growth and development, such that it would not be possible to present each on in detail within this paper. Therefore, only a few will be mentioned here. Firstly, genetic mutations and chromosomal disorders can lead to congenital disorders affecting normal growth and development. As an example, Down Syndrome is a chromosomal disorder of which short stature is a common feature (Lejeune and Turpin, 1959; cited in Preece, 2002). Other genetic disorders affecting growth are achondroplasia, hypochondroplasia, diastrophic dysplasia and Russell-Silver syndrome (Preece, 2002). Achondroplasia is a form of dwarfism in which the limbs are shortened due to a defect in the maturation of the growth plates of long bones. Hypochondroplasia is a milder form of achondroplasia. Diastrophic dysplasia results in shortening of the extremities with scoliosis and is also associated with genetic mutations. Individuals suffering from Russell-Silver syndrome have asymmetrical limb proportions, which can greatly affect normal growth and development (Russell, 1954; cited in Preece, 2002). Lastly, Cushing's syndrome leads to growth retardation and, in some cases, complete growth arrest in children and adolescents (Cushing, 1932; cited in Magiakou et al., 1994). Those who are diagnosed usually experience shorter stature into adulthood. Pathologies causing overgrowth would also have a significant impact upon growth studies.

2.2.2 *Environmental factors*

Factors pertaining to both the physical and social environment will be discussed in this section. As seen in Figure 3, environmental factors affecting bone can be further categorized into those having a systemic effect and those having a localized effect. Systemic factors affect the entire body whereas localized factors occur only in a particular location. This section will start with the systemic factors: nutrition and the physical environment.

As previously mentioned, growth perturbation is multifactorial and adequate nutrition is just one of the many requirements of normal growth and development. Abnormal growth can result from either overnutrition or undernutrition. Because individuals vary in their dietary requirements, it can be difficult to determine if a person is under- or over- nourished. Average recommended intakes also vary by country, and still may not necessarily be the correct amount for every person in the population. Clinical studies show that undernourished individuals usually experience a reduction in growth. This could be due to several sociocultural factors such as poverty, poor housing, poor schooling, and others. Overall, it is difficult to pinpoint the true cause, especially since growth defects can occur even with a deficiency of a single nutrient. In addition to this, undernourished children are more susceptible to infection which may further impact their growth and development (Norgan, 2002).

Malnourishment can occur at any point in an individual's lifetime, mainly beginning with fetal nutrition and breastfeeding (Norgan, 2002). During early pregnancy, if an individual experiences acute malnutrition in the intrauterine environment, the result could be a decreased birth weight which may turn into permanent growth retardation (Eveleth, 1979; Strauss, 1997). This would be expected if the mother herself was not properly nourished.

From these examples it becomes apparent that nutrition is closely connected to socioeconomic status meaning that this is yet another factor to consider. It is usually the case that individuals of lower socioeconomic status experience slower growth rates and later skeletal maturation than individuals of higher economic status (Eveleth, 1979;

Johnston, 2002). To demonstrate this, Bogin and MacVean (1983) did a study on the relationship between skeletal maturation and socioeconomic status (SES) in urban Guatemalan school children. They found that skeletal growth in height was delayed for boys of middle SES and for girls and boys of low SES. While catch-up growth is a possibility in these children, it is likely that the reduction in stature would be permanent, resulting in adults of low SES, on average, that are shorter than adults of high SES (Bogin and MacVean, 1983).

The physical environment also plays an important role in human growth and development. Such factors include climate, temperature, altitude, season, and others. For example, the human growth period in warm environments is generally prolonged while the growth period in cold environments is shorter (Schell and Knutsen, 2002). At high altitudes, newborns experience a reduction in birth weight and height and are usually short-statured throughout adulthood (Schell and Knutsen, 2002). There can also be seasonal population variation in growth due to factors such as resource availability and amount of sunlight. Additionally, length of residency within a population would result in exposure to different environments (Schell and Knutsen, 2002). Therefore, migration could also potentially influence growth. This raises important considerations when studying growth in archaeological populations when it may not be known what individuals were migrating to and from the area. If it was not known which individuals had been living in other environments, the resulting patterns of growth and development might be erroneously attributed to other causative factors.

The last two factors to be discussed both cause localized effects. This makes them very easy to distinguish from the systemic factors listed above. Firstly, there are numerous pathological factors that can have localized effects on bone (as opposed to the pathologies previous listed, all of which have systemic effects). For example, pathological lesions can be localized to a specific area. In addition to this, trauma would also have localized effects on bone. After-breakage deposition of new bone will produce a callus which greatly affects the structure of bone at that location. Luckily, factures and calluses are easily detected on biplanar radiographs and can be avoided when extracting data.

And finally, growth and development are also affected by physical activity and exercise – the main focus of this thesis. Because the effects of physical activity on bone structure were extensively discussed in the first half of Chapter 2, there is no need to repeat this information here.

2.2.3 *Considerations for this study*

Knowledge of these different factors means that their influences can be minimized as much as possible through careful consideration. Ruff et al. (2006) have proposed that in studies of bone biomechanics, the influences of many of these factors can be limited by using individuals of the same species, restricting direct comparisons to the same bone and same location on that bone, and with a thorough understanding of the lifestyles of each population. In this thesis, all of these conditions are satisfied.

Differences in bone structure that would be attributable to sex can be monitored for the adults of both samples. However, the majority of the individuals to be studied are sub-adults and unfortunately their sex could not be determined. This is something that cannot be rectified but can still be taken into consideration in the analysis through an understanding of the normal growth and behavioural patterns related to sex within the two groups.

Bone loss due to old age will certainly be present but is not a confounding factor in this study. Some individuals in the sample populations have been aged up to 60 years. However, as the main focus of this thesis is with sub-adults, this factor is deemed negligible.

Hormonal effects on bone can be genetic or stimulated by the environment. Little can be done about their impact but it is hoped that as Ruff et al. (2006) propose, the data are less likely to be skewed (in this case, by hormonal effects) if comparisons are made between the same bone and the same location on that bone.

Individuals with pathologies that noticeably affect the cross-sectional shape of the long bones utilized were excluded from the Khoisan and Sadlermiut samples. The same could not be done for the Stirrup Court population, however, as this sample had a disproportionally large number of individuals exhibiting pathologies. Instead, if a measurement at the mid-shaft, proximal third, or distal third of the shaft length was skewed due to a lesion, this measurement was discarded rather than exclude the entire individual from the study.

Differences in nutrition are expected to be minimized in this study due to the fact that both the Khoisan and Sadlermiut are forager groups. They are likely to have received adequate nutrition unless there was some alternative factor that affected their ability to obtain resources, such as a drought or disease. It should be noted here that the Sadlermiut population went extinct because of disease. However, the disease spread so rapidly throughout their population that it is unlikely the effects of the disease would be seen in their bones after such a short period of time. Socioeconomic status is also not likely to be a factor of concern among the Khoisan and Sadlermiut because both groups were egalitarian.

The effects of the environment are certainly pervasive but unfortunately, cannot be controlled. However, the effects of the physical environment (e.g. temperature, altitude) are systemic which means that they affect bone differently from how mechanical loading affects bone. Therefore, population differences in bone structure that are attributable to the physical environment are going to vary from population differences caused by mechanical loading. In addition to this, even if differences in bone structure caused by the physical environment cannot be fully accounted for, simply having the knowledge that the growth period differs between warm-climates and cold-climates will be useful in interpreting the results.

2.3 Anthropological applications of biomechanical theory

Within this section two examples of anthropological studies that make use of biomechanics theory will be discussed. The purpose of these examples is to demonstrate how biomechanics is used to make anthropological inferences and they will be referred to again in the discussion portion of this thesis. The first example is on Later Stone Age foragers from South Africa and the second is from Medieval England.

2.3.1 *Example #1: South Africa (Stock and Pfeiffer, 2004)*

The first anthropological study to be discussed was done by Stock and Pfeiffer (2004) who compared robusticity of the humeri, ulnae, femora and tibiae of Late Stone Age foragers from South Africa. They looked at individuals from both the forest and fynbos biomes (see section 3.1.1 for clarification). They found differences in long bone robusticity between the groups and within them. Male lower limb robusticity was found to be higher than female lower limb robusticity in both populations which would indicate a higher degree of mobility in males. Female lower limb robusticity was generally homogeneous between the two populations. When comparing lower limb robusticity between the males of the two groups, the forest males were found to have higher robusticity, possibly indicating a greater degree of mobility in the forest. Males from the forest also showed higher levels of bilateral asymmetry in upper limb robusticity than the males from the fynbos. This would indicate unilateral loading on the upper limbs, possibly from the use of spears or other projectiles in the forest. In the fynbos, bows and arrows would have been preferred, due to the lack of tall foliage. This would result in symmetrical loading on the upper extremities.

On average, the females of the forest had slightly more robust lower extremities than the females of the fynbos, possibly indicating forest women were more mobile or adapted to a more challenging terrain. Females of both biomes were found to be similarly robust in their upper limbs, with bone strengthening occurring in the anterior-posterior direction. This is most likely because they made use of digging sticks to unearth roots in the forest, or shellfish by the coast. There is clearly a system of gender-based division of labour occurring in both of the sample populations. However, Stock and Pfeiffer noted that the disparity between the sexes seemed to be greater in the forest biome, which would have implications for sociocultural interpretations of their behavioural patterns.

In this study, we begin to see how different environments place different requirements upon people. It follows that the chosen activities that people were engaging in were the most optimal choices for survival based on their environment. For example, it would not be very efficient for someone in the fynbos to use a spear since they could be more successful in hunting with a bow and arrow. A bow and arrow would allow them to make kills from further distances than a spear would, thus decreasing the chance of alerting the game to human presence. As Stock and Pfeiffer have shown, bone structure can reveal a great deal about general group trends regarding activity within differing environments.

2.3.2 *Example #2: England (Mays, 1999)*

The second example that will be referred to was done by Simon Mays (1999). Mays looked at a medieval human skeletal sample of male and female layfolk and male monks from York, England. He found that differences in their long bone structure could be linked to gender and occupation. He measure long bone diaphyseal cortical widths from radiographs – the same methodology used in this thesis – and made same-bone same-location comparisons among the three aforementioned groups.

From adolescence, the male skeletons were stronger and more robust than the females which would indicate inherent differences between the sexes. However, males were found to exhibit asymmetrical robustness of the humeri while the females did not. Because there is no inherent tendency for greater humeral asymmetry in one sex or another, he was able to conclude that these differences were a result of activity patterns. One would initially be inclined to think that this difference in upper arm strength was because men were more actively engaged in laborious tasks than women. However, historical records state that both men and women participated in trade crafts such as carpentry and blacksmithing. Therefore, the difference in humeral robusticity was most likely due to the fact that men tended to specialize in a single craft whereas women participated in a variety of tasks because employment for them would have been relatively intermittent. Regarding the male layfolk and male monks, Mays found that the skeletons of the male layfolk were only slightly more robust than those of the male monks, indicating that the brethren still participated in strenuous tasks but perhaps not to the extent that the layfolk did.

2.4 Ontogenetic biomechanics

While the above case studies incorporate an anthropological perspective within a biomechanical analysis, an ontogenetic perspective was not considered in either example.

This raises the question: If a biomechanical study can be done without an ontogenetic perspective, why consider ontogeny at all? In response to this, an ontogenetic perspective has much to contribute to studies of human biomechanics, as will be seen in this section.

During growth and development, bone stability is constantly being compromised with sudden increases in bone length, body mass and muscle growth (Cowgill, 2008). This means that the growth period is a crucial time for remodeling; bone must continuously acclimate to these changes in growth in order to preserve structural integrity and avoid breakage. Therefore, in addition to activity level, the process of growth and development (i.e. ontogeny) contributes greatly to the biomechanical processes that take place in human bone. To ignore the ontogenetic pattern of biomechanical adaptations in humans would result in an incomplete understanding of said adaptations.

An analysis of biomechanical adaptive responses in bone during growth is also important because bone is most susceptible to mechanical loading forces during growth (Bertram and Swartz, 1991; Turner et al., 1995; Lieberman et al., 2004; Pearson and Lieberman, 2004). The adult form of bone is usually a reflection of the biomechanical adaptations that occurred during childhood as bone minimally responds to mechanical loading after maturity (Kriska et al., 1986; Karlsson et al., 1995, 2000; Teegarden et al., 1996; Bass et al., 1998; Khan et al., 1998; Micklesfield et el., 2003). Therefore, it becomes necessary to understand the process by which that "final" adult form is reached and this can be done with the inclusion of an ontogenetic perspective. As an example, a study on the humeri of professional tennis players compared the cross-sectional properties of individuals who began playing tennis before maturity to those who had only started playing after maturity (Jones, 1977). The result was that adults who had begun to play tennis prior to skeletal maturity had significantly more robust humeri than adults who took up tennis after maturity (Jones, 1977). This example shows the particular significance of the growth period to biomechanical adaptations in humans.

With an understanding that growth and development is useful when studying human biomechanics, this thesis will turn to the question: How do we interpret the biomechanical adaptations that occur during growth and development? This is particularly important to consider because the timing of biomechanical adaptations is highly influenced by environmental context, which includes not only the physical environment but also the social environment. Factors that influence biomechanical outcomes pre-maturation usually can be connected to the process of enculturation experienced by an individual (Cowgill, 2008). Enculturation is a term for the process by which a child learns the norms and values of the society they were born into. Therefore, enculturation will vary depending on the society; as a reminder to the reader, populations from different climatic locations were chosen for comparison because it is assumed that cultural adaptations will differ based on the environmental context. This means that bone structure is influenced by the combined effect of the physical environment and the social environment in which an individual lives.

In order to fully understand the different biomechanical adaptations that occur in each sample population, knowledge of the process of enculturation within each group is necessary. However, such information is not always available due to the limited amount of literature concerning the activities of children. It can be assumed that the activity patterns of the adults provide a reflection of the activity patterns of the children since these are the behaviours that are likely to be taught during enculturation. In fact, some practices are quite common to the enculturation process in a variety of different cultures. A few examples are: sitting up without assistance, walking, gathering food, hunting small animals, carrying items, and travelling long distances (Cowgill, 2008). Depending on the societal norms, the extent to which these tasks are carried out will vary. Whether children are assisted in the learning process or expected to adopt the behaviour independently will also depend on cultural beliefs. This is why ethnographic data are useful for biomechanical studies: not only does the environment shape the activity patterns of people but parental techniques also have a hand in the timing and magnitude of biomechanical adaptations in young children (Cowgill, 2008).

It should also be noted that some difficulties can arise when interpreting growth data from a biomechanical perspective. In this thesis, three diaphyseal points were used to calculate cross-sectional properties. These diaphyseal locations of interest were found using overall diaphyseal length. In adults, these locations can be compared because they represent roughly the same location. However, in the humerus the proximal epiphysis contributes 80% of longitudinal growth which would cause the diaphyseal locations (i.e. mid-shaft, proximal third, distal third) measured on a juvenile humerus to be in slightly different locations than those measured on an adult humerus. This is a factor than cannot be controlled for in this thesis but may have some relevance to future studies.

To conclude, an ontogenetic perspective is important for the following reasons: Human bones are most susceptible to mechanical loading during the growth period. An analysis of the structural changes that take place during growth will result in a better understanding of the adult form of bone and also the process by which the adult form arises. Finally, a study of the bone structures of children, both within and between populations, can reveal a different aspect of societal life compared to an analysis of adult bone alone. The structure of bone during childhood can lend an understanding to the process of enculturation practiced within a given society.

Chapter 3

3 Materials

This chapter is an overview of each sample population studied. The environmental context of each population will be described as well as any archaeological or osteological evidence that may provide some information regarding the activity patterns of each group. Where possible, studies on the growth and development patterns of probable living descendants will be briefly outlined in the hopes that such information can shed light on the growth patterns of the groups studied.

3.1 Khoisan sample

The remains of the individuals used in this thesis are currently located within the Department of Anatomy and Cell Biology at the University of Cape Town, South Africa. Biplanar radiographs were taken for 27 individuals from this sample by Drs. Andrew Nelson and Jennifer Thompson in July, 1998. Aging and sexing of this sample was done by Drs. Nelson and Thompson. Of the 27 individuals for whom there are radiographs, 25 were considered to be usable for this study. For a detailed list of Khoisan individuals, see Appendix A-1. The majority of the individuals in the sample (i.e. 19 individuals) were under the age of 18 years at the time of death. Six individuals were sexed as male, four as female and two as possible females. The remainder could not be sexed due to the nature of sub-adult osteological remains. The individuals range in their radiocarbon dating from 9100 years B.P. to approximately 2000 years B.P. (Morris, 1992a,b). This time period in South Africa is known as the Later Stone Age and so the term “Later Stone Age foragers” is often used interchangeably with the name “Khoisan.”

3.1.1 *Environment*

South Africa, particularly the Cape region, is an ecologically diverse area. The burials used in this study were found within a 700 km range across the Cape of South Africa. This region spans several different ecological biomes which will be discussed in further detail below. Eleven of the 25 individuals studied came from sites located within the forest biome, three were from a fynbos biome, two were from the grassland biome, and two from a karoo biome. It is not known specifically where each individual was from, only the biome is known. Despite the fact that they were excavated from a specific biome, it is likely that the Khoisan people of the Later Stone Age were exposed to several of these different environments due to the relatively close proximity of at least five separate ecological biomes in the Cape. See Figure 4 for a map of the biomes referred to above.

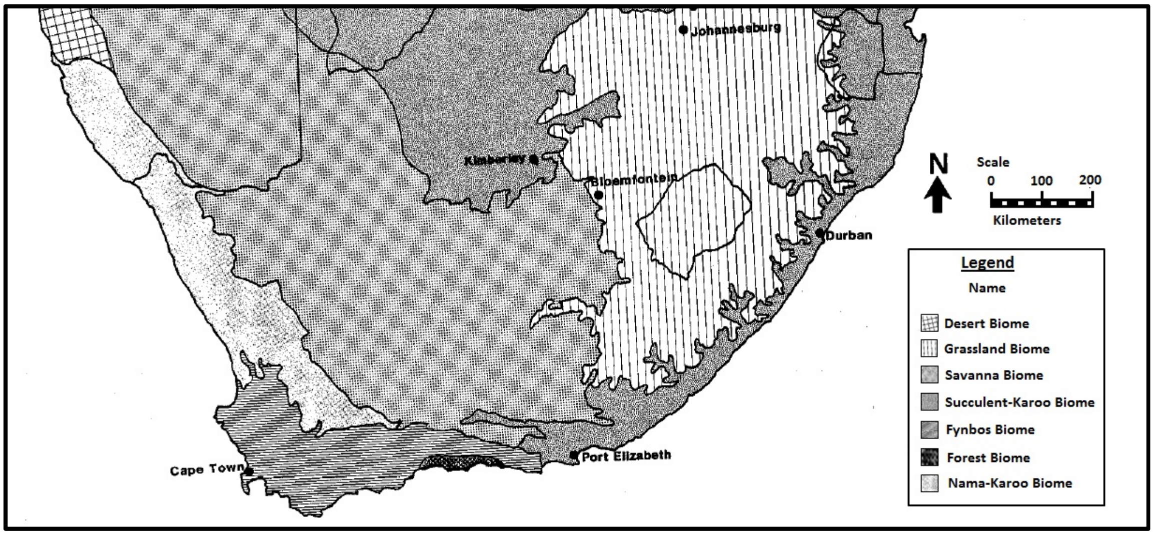

Figure 4. Map of the environmental biomes in South Africa (Morris, 1992a:138).

The forest biome is located along the coast of South Africa in the region of Knysna which is between the modern cities of Cape Town and Port Elizabeth. The forest spans a distance of approximately 200 km and has been characterized by Rutherford and Westfall (1994) and Morris (1992a) as being dominated by evergreen trees. The forest reaches as far inland to an escarpment known as the Cape Fold Belt. Patches of forest can be found along the southern side of this mountainous region. Most of the individuals excavated from the forest biome were found in rock shelters such as the Nelson Bay Cave and the Oakhurst Rock Shelter. The faunal remains found at the Later Stone Age sites of the forest biome represent relatively small game. Small bovids are also frequent finds, with large bovids being rare but not absent (Klein, 1974; Churchill and Morris, 1998).

The second biome of significance to this project is the fynbos biome. As seen in Figure 4, the fynbos biome surrounds the forest biome entirely, with the exception of the coastal exposure of the forest. The fynbos cover a much greater area than the forest, extending from the westernmost part of the Cape to end 50 km west of modern Port Elizabeth – a distance of about 700 km. The region is characterized by dwarf-shrub woodland vegetation that rarely exceeds three metres in height. The escarpment of the Cape is predominately fynbos vegetation (Rutherford and Westfall, 1994; Morris, 1992a). Similar to the forest biome, faunal species diversity is low – the majority of which are small solitary browsing animals (Churchill and Morris, 1998). Also similar to the forest, the fynbos foragers relied heavily upon small bovids with megafauna being almost entirely absent (Klein, 1974; Churchill and Morris, 1998).

The grassland biome can be found further inland from the Cape, spreading across the eastern portion of South Africa. The grasslands occupy some of the Cape escarpment as well as the plains that lie north of the escarpment. The majority of the plant species in this biome are grasses, making vegetation height quite low, which is similar to the fynbos biome (Morris, 1992a)

There are two karoo biomes in South Africa: the succulent karoo and the nama-karoo. This study includes a single individual from each of these karoo biomes. Both karoo biomes lie further inland from the fynbos and forest biomes and north of the escarpment. The succulent karoo biome, the larger of the two, extends northwards into central South Africa and continues into the more westerly regions as well. The nama-karoo biome is bordered by the western coast and the western side of the succulent karoo biome. The two karoo biomes are very similar; both are semi-desert like in appearance with a low amount of vegetation. The main difference is that of the few grasses that do exist in the karoo, those of the succulent karoo follow a C3 photosynthetic pathway while those of the nama-karoo follow a C4 pathway (Rutherford and Westfall, 1994; Morris, 1992a).

The region of interest to this study (i.e. coastal Cape area) is characterized as having a Mediterranean climate meaning that summer months have high temperatures and low rainfall while winter months are slightly cooler with light precipitation (Pritchard, 1969; Meadows and Sugden, 1993; Sealy and Pfeiffer, 2000). Average summer temperatures are around 24^{o} Celsius and winter temperatures tend to average at

13^o Celsius. Palaeoenvironmental studies in this region have found that climatic conditions in the early Holocene would have been very similar to modern conditions with only minor vegetational changes (Meadows and Sugden, 1993; Churchill and Morris, 1998).

The study area is also marked by differences in terrain. The most notable feature is the escarpment that runs along the coast of southern Africa from Angola to Rhodesia in a nearly continuous chain that ranges in height from 1,300 to 3,500 metres. The escarpment and coast are usually in close proximity with only 10 kilometers of distance between the two in some areas of the forest biome. Inland of the escarpment is the interior plateau which is an immense plain with limited vegetation. This area is predominantly karoo and is not particularly productive, nor would it have been in the early Holocene, and so foragers would likely not venture so far north (Morris, 1992a). This idea is supported by the lack of archaeological sites in the plateau region (Morris, 1992a).

3.1.2 *Archaeological evidence*

Archaeological data are an invaluable resource for learning more about the daily activity patterns of the Later Stone Age Khoisan foragers. Several archaeological studies have been done on Later Stone Age forager groups and will be used within this section to understand how they engaged with their environment. It should be noted that this archaeological data will be used to make generalized assumptions about the activity patterns of the Khoisan (the same is true for the Sadlermiut patterns of activity). Discrepancies can arise from such generalizations particularly when the time period of the sample spans thousands of years and the environmental context is very diverse. Activity patterns almost certainly differed through time yet it seems likely that the Khoisan consistently took part in the main activities discussed in this thesis (e.g. bow and arrow use, digging). However, it is almost certain that idiosyncrasies in activity patterns through time also played a role in the development of bone strength. Unfortunately, these idiosyncrasies cannot be studied in detail in this thesis but with additional archaeological data a clearer picture of Khoisan behaviour throughout time may be achieved.

A number of archaeological studies have shown that the diet of coastal Later Stone Age foragers was comprised of both marine and terrestrial foods, with a particular increase in marine foods from 4,000 to 2,000 B.P. (Klein, 1974; Sealy and van der Merwe, 1985; Morris et al., 1987; Churchill and Morris, 1998; Jerardino, 1998; Deacon and Deacon, 1999; Sealy and Pfeiffer, 2000). Because the forest biome borders the Cape coast and supports a wide range of game, it is unlikely that Later Stone Age foragers encountered food shortages at any point in the year (Sealy and Pfeiffer, 2000). Isotopic evidence suggests that shellfish were primarily collected in the winter months, possibly indicating seasonal mobility (Klein, 1974; Sealy and Pfeiffer, 2000). However, due to the availability of resources, it is likely that the level of mobility among coastal groups was relatively low for a hunter-gatherer group (Sealy and Pfeiffer, 2000). Even if mobility was minimal, the terrain would have been quite mountainous, which is hypothesized to have a greater effect on bone strength compared to distance travelled (Ruff, 1999)

Churchill and Morris (1998) believe that because forest fauna were slightly larger than fynbos fauna the handling costs of hunting would be quite high in the forest when compared to the fynbos. Because of the nature of available game in the forest, Churchill and Morris (1998) hypothesized that bone robusticity should be greater among foragers from the forest compared to foragers of the fybos. This is an important point to consider, given the fact that the majority of the LSA individuals used in this study were found in the forest biome.

The extraction of marine resources also would have involved highly intensive work (Churchill and Morris, 1998). Marine foods have been found at archaeological sites in both the forest and fynbos with the forest showing slightly higher instances of marine resource extraction (Klein, 1974). It has been proposed that shellfish collecting was primarily a female activity (Churchill and Morris, 1998).

An isotopic analysis was done by Pfeiffer and Crowder (2004) on a Khoisan child from the Byneskranskop rock shelter (located in the fynbos biome approximately 10 km from the coast) radiocarbon dated to 4,820 ± 90 B.P. The child most likely suffered from hypertrophic rickets in life which led to retarded growth and cortical thickening of long-bone shafts (Pfeiffer and Crowder, 2004). The results of the analysis appeared to indicate that the child was fed a mixed diet of terrestrial and marine foods indicating the importance of both resources among coastal foragers. The child was also weaned at a relatively late age which has been observed among modern San forager groups (Draper, 1976; Konner, 1976). This information could indicate an increased period of dependence in Khoisan children. It will be important to consider this possibility of an increased period of dependence in combination with information regarding the growth patterns of South African foragers when interpreting cortical bone thickness in this sample.

Musculoskeletal stress markers found on the bones of Khoisan foragers reveal a difference in the amount of stressed placed upon the bones of men and women (Churchill and Morris, 1998). In a study by Churchill and Morris (1998), Khoisan men were consistently found to have higher MSM scores than Khoisan women, meaning that mechanical loading experienced by males would be much greater than that experienced by women. This would mean that men took part in activities that were more strenuous on both the upper and lower limbs compared to women. The results of this study also showed that musculoskeletal markers of stress were more common among men of the forest compared to men of the fynbos, possibly indicating a higher level of activity among the forest foragers. Interestingly, Khoisan women from different biomes were found to not differ in MSM scores; their MSM scores were also found to be much lower than males of both the forest and fynbos biomes.

In terms of material culture, the tool-kit used by the Khoisan is classified as being part of the Wilton assemblage which replaced the Albany industry between 8,000 and 7,000 B.P. (Klein, 1974; Morris, 1992b). The Wilton assemblage is characterized by small scrapers, crescent-shaped microliths, and backed microliths which would have been ideal for attaching to arrows or spears (Deacon 1969; Deacon, 1972). The tool-kit also includes bows and arrows, wooden spears, clubs, digging sticks, kwe stones (a type of weight similar to a net sinker), fish hooks and possible traces of traps and snares (Deacon 1969; Deacon, 1972; Klein, 1974). Some of the more coastal sites where Wilton tools have been found contain fewer backed elements (Klein, 1974). Klein (1974) has stated that a high incidence of backed elements would imply that larger game was being hunted and that sites containing backed elements should also show evidence of larger fauna. While some rock shelters near the coast have small bovids, with the Nelson Bay Cave being the only site to contain a Cape buffalo (Churchill and Morris, 1998), the lack of large fauna seems to coincide with the decreased incidence of backed elements. This has led Klein to suggest that a decrease in the amount of backed elements implies that the foragers of the Cape made use of traps and snares to hunt smaller game. However, evidence of traps is scarce – probably because they were constructed with organic material which would not preserve well (Churchill and Morris, 1998).

3.1.3 *Growth patterns*

This section will discuss evidence regarding the normal growth trajectory expected of Later Stone Age foragers from South Africa. This can be done by studying growth and development patterns of possible living descendants or close relatives of the group of interest. Unfortunately, there is no clear evidence as to the identity of the living descendants of LSA Khoisan foragers. It has been suggested that the modern hunter-gatherer groups of South Africa as well as southern Namibia and Botswana known collectively as the "San" are possible candidates (Schultz, 1928; Klein 1986). It is also possible, however, that the Khoi pastoralist groups of South Africa are more closely related to the Later Stone Age foragers (Schapera, 1930; Barnard 1988; Wilson and Lundy, 1994; Deacon and Deacon, 1999; Morris, 1992b; Schuster et al., 2010).

It is important to consider the differences in growth and development patterns among sample populations used in studies of biomechanical adaptations and ontogeny. Growth patterns can vary greatly; if these variations are not understood, it may lead to erroneous interpretations of bone structure. Imagine a comparison between the long bone structures of similarly aged individuals from two separate populations: a difference in bone structure due to populational differences in growth rates could be misinterpreted as a difference caused by mechanical loading, and vice versa. This is why it is important to understand the growth trajectory that is normal for the populations being studied.

Stature will be the first element of Khoisan growth discussed. Wilson and Lundy (1994) conducted a study comparing the statures of prehistoric Khoisan from the South

African Cape, modern San forager groups, modern Khoi groups and modern South African Negros. Using the femora to estimate living stature, it was found that the statures of prehistoric forager groups were similar to those of the modern San sample. Both prehistoric and modern San foragers were smaller in average height than the Khoi and all San and Khoi were smaller in stature compared to modern South African Negros. The statures of prehistoric foragers were found to differ slightly between men and women with males being slightly taller than females on average. Because of the absence of evidence of dietary stress among South African forager groups (Smith et al., 1992), it is likely that the small stature exhibited by modern San foragers and modern Khoi reflects their genetic heritage (Tobias, 1962; Sealy and Pfeiffer, 2000). This suggests that prehistoric foragers of the Later Stone Age were also small statured.

It is also necessary to consider the rate of growth in each sample population in order to understand when major changes in bone structure tend to occur in an individual's life. In a study of modern Khoi growth, Singer and Kimura (1981) compared body height and weight in Khoi, Namibian, American and Capetonian children aged 1 to 21 years. This study is particularly interesting because the authors were able to plot results against both skeletal age and chronological age. For both chronological and skeletal age, American and Capetonian children were much higher in stature and larger in body weight compared to the Khoi children throughout the entire growth period. The Namibian children were closer in size to the Khoi, particularly with regards to stature. However, differences in body weight between the Khoi and Namibia youth became evident at the chronological age of 15 for boys and 13 for girls, with Khoi children having lower body weight than Namibia children. While skeletal age appears to be closely correlated to chronological age among the Khoi children, minor differences can be noted. For example, when using skeletal age, the Khoi children are almost identical in their growth trajectories compared to the Namibian and even the Capetonian children. However, with chronological age, Khoi children's growth values are lower for both stature and body weight. This seems to indicate that Khoi children have a delayed period of growth.

This information hints at the possibility that LSA foragers of South Africa experienced a slow rate growth. It could be said that in the past, Khoisan foragers would not have been marginalized as modern Khoi groups are and that therefore the growth retardation exhibited by the Khoi is caused by low socioeconomic status and not genetics. However, Singer and Kimura (1981) compared the Khoi to Namibia Rehoboths who are of similar socioeconomic status and found that even compared to the Rehoboths, the Khoi growth rate was retarded. Because the Khoi are assumed to be descended from the LSA foragers, it can be assumed that like the modern Khoi, the LSA foragers may have also experienced retarded growth. Furthermore, a more recent study by Pfeiffer and Harrington (2010) found that linear growth rates of South African forager juveniles indicate a normal tempo of growth with a small-bodied adult end-point. Pfeiffer and Harrington (2010) found no evidence to support the idea that growth occurred rapidly among LSA foragers.

From the evidence gathered it can be assumed that the adult Khoisan would have been small in stature and size. The data collected by Wilson and Lundy (1994) support the claim for small stature and Singer and Kimura's (1981) results are indicative of both small stature and small body mass. These studies have shown that the modern Khoi pastoralists are an appropriate proxy for learning more about LSA forager growth patterns.

3.2 Sadlermiut sample

The Sadlermiut individuals used in this study were excavated in 1954 and 1955 by Dr. Henry B. Collins (Collins, 1956) and in 1959 by Drs. William Laughlin and Charles Merbs (Merbs, 1974). The Sadlermiut once resided on Southampton Island, Nunavut, Canada. However, their population had been dwindling throughout the late 19th century, as noted by American whaling master, Captain George Comer (1910). In 1897, a permanent whaling station was constructed in the southwestern portion of the island by a Scottish firm. In Comer's account (1910) he explains that the Sadlermiut tended to keep their distance from the whaling station. On occasion, a few individuals would trek to the station from their main village at Native Point – or Tunermiut – to trade with the American and Inuit men working there. On one of these occasions, the Sadlermiut returning from the whaling station had contracted an unknown disease which spread to their entire population. From July 1902 to the early winter months of1903, the disease brought about the deaths of every Sadlermiut with the exception of one woman and four children.

There are a total of 30 Sadlermiut individuals included in this study (see Appendix A-2). The main criterion for inclusion was the preservation of the long bones used for study (i.e. humerus, femur, tibia) and associated cranium. The x-rays were taken as part of a larger study on variability in long bone growth (Thompson and Nelson, 2000). Individuals with pathological lesions were not included in the study, particularly if such lesions affected areas of interest (i.e. mid-shaft, proximal third, distal third). While most of the individuals likely perished in the 1902 epidemic, it is possible that some of the individuals may date up to 500 years B.P. (Merbs, 1974).

This section will discuss the environment in which the Sadlermiut lived, the relevant archaeological findings, and the existing osteological studies of Sadlermiut remains. Studies of growth and development on this particular population are scarce. Using the available information, interpretive assumptions will be made regarding the growth trajectory of the Sadlermiut population.

3.2.1 *Environment*

Southampton Island is located in the northwestern portion of Hudson Bay. There are three major capes on the island: to the west is Cape Kendall, to the south is Cape Low and to the north is Cape Munn. The easternmost portion of Southampton Island is named Bell Island, however, it is not separated from Southampton Island by water but by a small peninsula about 22 km in width. Southampton Island is approximately 350 km wide from the easternmost portion of Bell Island to the westernmost portion of Cape Kendall. The length of the island is around 315 km from the southernmost tip of Cape Low to the northern coast of Cape Munn. The Sadlermiut also lived on Coats Island, a small body of land (approximately 130 km at the widest point) just a few kilometers south of Southampton Island. Sadlermiut also frequented Walrus Island, a tiny land mass (6 km in length) to the north of Coats Island. This island gets its name from the high concentration of walrus that live on the island (Manning, 1936). To better view these landmarks, refer to Figure 5.

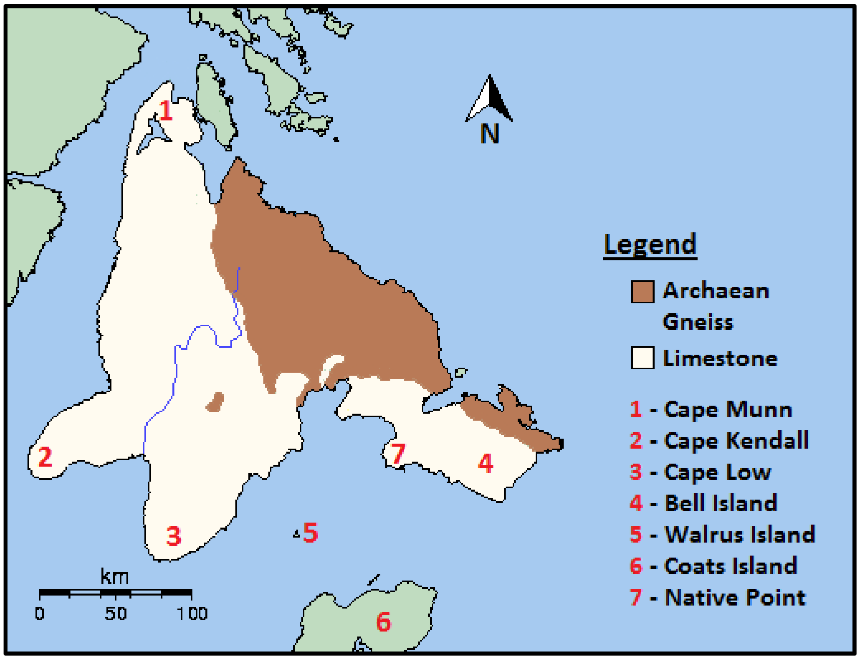

Figure 5. Southampton Island, Nunavut, Canada. Adapted from Merbs (1983:7) and Wikipedia (after http://en.wikipedia.org/wiki/Southampton_Island).

The island is dominated by low, flat limestone plains as shown in Figure 5. There are some shrubby grasses in this area, but plant species diversity is minimal. The limestone plains also contain marshes and numerous small lakes, characteristic of a wetland habitat (Comer, 1910; Munn, 1919; Manning, 1936; Campbell, 2006). The northeastern portion of the island not covered in limestone is a long, low mountain range composed of Archaean gneiss rock (Comer, 1910; Munn, 1919; Manning, 1936). The mountain region contains much less vegetation than the limestone plains, most of which is lichen (Campbell, 2006).

The Sadlermiut individuals studied in this thesis came from the site of Native Point, also known as Tunermiut. Native Point is located on the eastern side of South Bay – see Point 7 on Figure 5. Approximately 25-30 km from Native Point, the terrain begins to take shape in the form of foothills which precede the gneiss mountain (Manning, 1936). It is likely that the Sadlermiut travelled across not only the flat limestone plains but also across the foothills and mountains to the north, meaning they encountered a variety of terrain types.

Due to the marshy nature of the limestone plains, many water dwelling birds can be found in this area (Comer, 1910). The frequency of small lakes also means fresh water fishing can be done with relative ease. Trout, salmon and shrimp can usually be found within these small lakes and rivers that dominate the plains (Comer, 1910; Munn, 1919; Manning, 1936). The plains are also occupied by several terrestrial mammal species such as caribou, polar bears, wolves and foxes (Comer, 1910; Munn, 1919; Manning, 1936). In the summer, caribou herds and other terrestrial mammals migrate towards the mountains (Comer, 1910). Within South Bay are many small islands which are frequented by a number of sea mammals, most notably seal and walrus (Manning, 1936; Comer, 1910).

In July and August, the island is entirely free of snow (Comer, 1910). The average summer temperature ranges from 7.2^{o} to 10^{o} Celsius and sea ice is scarce along the coast at this time (Manning, 1936). In the winter, however, ice sheets hug the island coast, making sea travel difficult (Comer, 1910; Manning, 1942). In addition to this, the many inland lakes and rivers are frozen from September until the end of winter making it more difficult to catch fish in this area (Manning, 1936).

3.2.2 *Archaeological evidence*

The Sadlermiut individuals studied in this thesis were excavated from the site of Native Point, Southampton Island, Nunavut, Canada. Native Point is located on an elevated plateau situated slightly inland of a low peninsula on the east side of South Bay – see Figure 5 (Pelly, 1987). Most scholars who have written about the Sadlermiut tend to make a point of noting that the Sadlermiut lived differently from other mainland Inuit groups (Comer, 1910; Munn, 1919; Mathiassen, 1927; Manning, 1943; Pelly, 1987; Ross, 1990). It appears as though contact between the Sadlermiut with mainland Inuit groups was rare and almost non-existent prior to the establishment of the whaling station. Even after the station was erected, the Sadlermiut were noted to not have much interest in making contact with the station operators except for the occasional trade (Comer, 1910).

This section will cover Sadlermiut archaeological and osteological evidence in order to obtain a picture of the daily activity patterns of the Sadlermiut people. First, the Sadlermiut tool-kit was characterized by flint knives, scrapers, scraper blades, arrow heads, harpoons and bone needles (Munn, 1919; Mathiassen, 1927; Hawkey and Merbs, 1995). The majority of these tools were primarily used for hunting. Harpoons were the tool of choice for hunting large game such as whale, walrus, seal and polar bear (Mathiassen, 1927). Despite the evidence for use of bows and arrows, they were not likely to have been used frequently for hunting (Hawkey and Merbs, 1995), probably only being necessary for catching small game such as water birds. The other tools mentioned, such as scrapers, scraper blades and bone needles would have been used for clothing preparation, an activity that was likely solely done by women (Merbs, 1983; Hawkey and Merbs, 1995). Preparing clothing would have been a strenuous activity, involving heavy lifting and continuous upper limb movement (Hawkey and Merbs, 1995).

Faunal remains found at Native Point indicate that the Sadlermiut diet consisted of both terrestrial and marine food sources. The major source of food seems to have been seal (i.e. bearded seal and ringed seal) but the following faunal species have also been found: walrus, whale, caribou, polar bear, arctic fox, and marine birds (Comer, 1910; Munn, 1919; Manning, 1936, 1943; Collins, 1956; Taylor, 1960; Pelly, 1987). Hunting would have been primarily a male task (Merbs, 1983; Hawkey and Merbs, 1995). The majority of the above animals would have been hunted with long harpoons or lances.

Sadlermiut houses were constructed differently from mainland Inuit houses, which are largely composed of blocks of snow. Houses from the site of Native Point were built using limestone rocks, whale bones and sod (Comer, 1910; Munn, 1919; Mathiassen, 1927; Manning, 1943). The huts were circular in shape and built partially underground. The limestone rocks made the base, over which whale jaw and rib bones were placed and covered with sod (Comer, 1910; Munn, 1919; Manning, 1943). These houses were permanent constructions and would have been returned to each winter (Mathiassen, 1927). In the summer, these houses were abandoned and temporary skin tents were erected not far from the permanent dwellings (Comer, 1910; Mathiassen, 1927). The building of winter houses would not have occurred very frequently due to the stability of these structures.

Based on the evidence, it does not appear as though the Sadlermiut had to travel very far to find what they needed. It also seems as though they had lived at Native Point for quite some time, meaning they rarely moved settlements. It is possible, however, that they had to travel greater distances in order to find terrestrial game and to reach the freshwater ponds inland to fish. There is archaeological evidence that the Sadlermiut used sledges to travel across the land during the winter months, such as walrus-tusk sled constructions and dog remains at Native Point (Munn, 1919; Manning, 1936). Sledging would have been possible from September to mid-June, while the island was still covered in snow (Manning, 1936). The limestone plains would have been particularly ideal for sledging due to the lack of hills and obstructions. The use of umiaks (similar to a kayak) on the sea water would have been quite common as well. Umiaks were used by both men and women, although much more frequently by men (Merbs, 1983; Hawkey and Merbs, 1995). It is most likely that only men used umiaks for hunting and women used umiaks primarily for transportation and sea scavenging (Hawkey and Merbs, 1995).

As mentioned in section 3.2, it is likely that many of the Sadlermiut individuals used in this study perished in the 1902 epidemic. Three diagnoses have been proposed: typhoid, dysentery (Munn, 1919: Mathiassen, 1927; Collins, 1956; Ross, 1977), and syphilis (Borden, 1904; cited in Ross, 1977). It is unlikely that this disease would manifest itself on the skeletons of the individuals. The vessel carrying the disease arrived at Cape Low in July of 1902 (Mathiassen, 1927; Ross, 1977). At this time, four Sadlermiut men were visiting the station on one of their occasional trading exploits (Mathiassen, 1927). The men returned to Native Point not long after this time. In the early months of 1903, visitors to Native Point arrived to find the bodies of the Sadlermiut scattered across the village; the disease had caused the deaths of every individual (with the exception of one woman and four children) within the span of approximately 6-8 months. With such a rapid progression of the disease, it is unlikely that the mystery disease had time to affect the bones of the Sadlermiut. In addition, the only probable disease that affects bone – syphilis – is the least likely suspect of the three.

3.2.3 *Osteological research*

The majority of Sadlermiut osteological studies have been done by Dr. Charles Merbs, one of the original excavators of the Native Point site. Merbs's work focused on determining patterns of activity from pathological evidence, making his work very relevant to this study. He has found high frequencies of vertebral defects among the Sadlermiut such as spondylolysis, sagittal clefting and caudal shifting (Merbs, 1974, 1996, 2002a,b, 2004). The general trend among the Sadlermiut appears to be that both sexes exhibit vertebral defects but that more males are affected than females. He has also noted that spondylolysis and sagittal clefting occur frequently children (Merbs, 2002a,b, 2004). This could mean that vertebral defects decrease the chance of survival in children (Merbs, 2004). It could also mean that the activities producing defects of the vertebral column were being taken part in at an early age among the Sadlermiut. This supports the idea mentioned in section 2.4 that children of forager groups are likely to mimic the activities of adults at an early age. These activities will produce a more pronounced effect among children compared to adults which supports the use of an ontogenetic perspective in this project.

Merbs has also been able to infer several other Sadlermiut activity patterns from pathological evidence. In his book *Patterns of activity-induced pathology of a Canadian Inuit population* (1983) he describes several of these activities. Some of these activities include: arrow shooting, bow drill use, driving and riding a sledge, lifting, carrying, dragging, and using teeth as tools. The main activities he found to be carried out by men were harpoon throwing and rowing, which agrees with the ethnographic evidence collected above. It should be noted here that the "rowing" done by the Sadlermiut was actually paddling because the oar (or rather, paddle) would not have been connected to the watercraft and, therefore, would not have involved the use of a fulcrum to pivot upon. Merbs found that the activities most frequently engaged in by women were clothing preparation and sewing. Preparation of skins was a very strenuous task, as mentioned above. Clothing preparation would have involved constant lifting and repositioning of the heavy animal skin. The skin would have had to have been cut with sharp tools which would mean that the right hand (or left, depending on handedness) would move the knife in a vigorous back and forth motion while the left hand held up the skin. After the skin was cut, it would have been softened by the women, who would have used their teeth to accomplish this task. Not surprisingly, Merbs has noted a high prevalence of vertebral compression and anterior tooth loss among Sadlermiut women – the vertebral compression was possibly caused by a combination of carrying skins and hunching over them during preparation. Males were found to have a higher prevalence of osteoarthritis in the lower limb, shoulder and elbow. The shoulder and elbow arthritis is likely a response in the bone to harpoon throwing.

3.2.4 *Growth patterns*

Unfortunately, there have not been many studies concerning the growth and development patterns of the Sadlermiut Inuit, therefore, studies of growth in possible Sadlermiut relatives will be relied upon. Genetic similarities have been noted among the Sadlermiut and Alaskan Eskimo groups such as the Aleuts (Popham, 1953; Merbs, 1974, 2002b, 2004; Holland, 2007). For this reason, stature estimates of Aleut and other Alaskan children and adults will be used to represent Sadlermiut statures. In 1941, Ales Hrdlicka obtained heights and weights for a group of Kuskokwin children from a small town in Alaska. He compared these values to the heights and weights of white children from Michigan. The result was that the Kuskokwin children were consistently shorter in stature and lesser in body weight compared to the Michigan children in every age category sampled (6 to 15 years). The data collected from the Kuskokwin children seem to indicate that the adult end-product of Arctic populations is short-statured – an end-product similar to that seen in the Khoisan.

Garn and Moorress (1951) also note the growth patterns of the Kuskokwin Alaskan Eskimo group. They found that the growth trajectory of the Kuskokwin was greatly exceeded by Aleut children. This could mean that the “normal” rate of growth for Arctic children is relatively retarded, a conclusion also seen Holland’s work (2007) which will be discussed below.

A study of growth and development done by Thompson and Nelson (2000) provides some insight into the rate of growth experienced by the Sadlermiut. Thompson and Nelson (2000) compared proportional femoral growth throughout ontogeny among Neandertal, *Homo erectus,* early modern *Homo sapiens, Gorilla gorilla,* modern Euroamerican and Sadlermiut juvenile specimens. It was found that the Sadlermiut and the modern Euroamericans exhibited a similar trajectory for proportional femoral growth despite the fact that the Sadlermiut exhibit a much lower adult stature (Thompson and Nelson, 2000). This suggests that the rate of relative growth among the Sadlermiut was neither retarded nor accelerated when compared to modern Euroamerican groups.

The Alaskan group known as the Inupiat will also be relied upon as a reference sample for interpreting Sadlermiut growth. In 2005, Ruff et al. conducted an analysis to determine body size from stature estimates of 67 Alaskan Inupiat young adults aged 20 to 39 years. Similar to the studies above, they found that the Alaskan group was relatively short-statured. Their results showed that in addition to being short-statured, the Inupiat possessed broad, stocky bodies with the male body size mean being 68.6 kg and the female mean being 59.6 kg. Based on the gathered evidence from populations assumed to be genetically similar and also living in similar environmental conditions, it will be assumed for the purposes of this study that the Sadlermiut adult end-product was short in stature but stocky and broad in physique. However, the previous studies mentioned do not provide convincing data concerning the Sadlermiut rate of growth.

In her Master's thesis, Emily Holland (2007) studied Sadlermiut children from the Native Point site on Southampton Island. She found a high prevalence of infant mortality – particularly among female children. Holland also compared the Sadlermiut growth trajectory to growth in modern European children and North American Aboriginals. She found that the Sadlermiut period of growth was retarded when compared to the European and Aboriginal children. Returning for a moment to the Khoisan, it is known that Khoisan adults were small-bodied and presumed that their growth trajectory was relatively retarded compared to modern American, Namibian and Capetonian children (Singer and Kimura, 1981). This seems to indicate that the rate of growth between the Sadlermiut and Khoisan was similar.

The last Sadlermiut study to be discussed is Amy Scott's Master's thesis (2009) on stress patterns during Sadlermiut growth and development. Scott found indicators of stress on Sadlermiut osteological remains at every stage of growth, with a higher occurrence of stress among females. Once at adolescence, Scott found that the Sadlermiut males appeared to show reduced evidence of stress. Females, however, displayed skeletal evidence of stress throughout adolescence. Following adolescence, the Sadlermiut females exhibited a period of catch-up growth (see also Hrdlicka, 1941). This is an important point to consider for the current project. If there appears to be a large difference in bone thickness among similarly aged adolescents, the difference may be attributable to the delayed growth period experienced by females. Also, if Sadlermiut children were experiencing instances of stress starting from early childhood, this could mean that as a population, the Sadlermiut growth trajectory may have been retarded.

3.3 Stirrup Court sample

The Stirrup Court cemetery was located in northwest London, Ontario, Canada. The individuals from the Stirrup Court cemetery were excavated in 1982 by William Fox of the Ontario Ministry of Culture and Dr. Michael Spence of the University of Western Ontario (Cook et al., 1986). The Stirrup Court population is included in this study as a reference sample, used to validate the methodology used for the Khoisan and Sadlermiut data as will be explained later in section 4.5. There were 30 burials uncovered at the site. The site was found during residential construction; because of this, 9 of the burials were disturbed and/or damaged by heavy machinery. The individuals studied were selected for inclusion if they had at least one complete humerus, tibia or femur. This criterion produced 18 matches. For a list of the Stirrup Court individuals studied in this thesis, see Appendix A-3.

The individuals of Stirrup Court were 19^{th} century middle-class residents of a peri-urban community of British ancestry (Parish, 2000). Peri-urban means that they lived on the outskirts of an urban center – the settlement area was rural yet the urban world was easily accessible. This peri-urban area would have contained a number of family farms. The majority of the people buried at Stirrup Court would have worked on these farms for most of their lives. Because of their close proximity to the city, residents of these farms could travel to and from the city within a single day by either walking or riding in a horse-drawn carriage (Parish, 2000). The purpose of these visits could have been to purchase and sell items at a market, attend church or other town meetings and other personal errands (Parish, 2000). Most of the Stirrup Court individuals are of advanced age and exhibit evidence of osteoarthritis. However, in order to include as much information as possible, individuals with bone pathologies were not completely discarded (this would eliminate nearly the entire sample from the study) but instead if a measurement of interest was skewed due to a lesion, this measurement was omitted.

3.4 Sample expectations

There are three main research questions central to this thesis. Based on the information provided above regarding each sample population, several hypotheses and expectations will be made in order to address each research question. These hypotheses will be referred to in Chapters 5 and 6 and the actual results will be presented in Chapter 5 with respect to the expected results discussed here.

The first research question is: How do biomechanical adaptations differ in temperate- and cold-climate adapted populations (i.e. the Khoisan of South Africa and the Sadlermiut of Southampton Island)? This question can be addressed through an examination of the adult sample specimens. By looking at the biomechanical adaptations of adult specimens, an understanding of the “adult end-product” difference among the sample populations can be reached. The analysis of adult specimens will follow the approach taken by Stock and Pfeiffer (2004) (see section 2.3.1). This study was chosen as a reference for the adult portion of this thesis for several reasons: it is a biomechanical analysis of a forager group, cross-sectional measurements were taken using biplanar radiographs, only adult specimens were included, similar variables were studied, and, lastly, the study was done using LSA foragers. Following Stock and Pfeiffer (2004), the adult mean and standard deviation will be taken for each sample, long-bone, location and biomechanical property studied. Only the mid-shaft locations will be discussed so that a detailed analysis can be made rather than a brief examination of all three locations. The proximal third and distal third results can be found in the Appendix. A Mann-Whitney U test will be performed for each property to test if the difference between the samples is significant.

Three hypotheses have been made regarding the outcome of a comparative biomechanical analysis between the Khoisan and Sadlermiut adults. Along with each hypothesis, the expected results of the biomechanical analysis are provided.

Hypothesis #1 – *Overall humeral strength (compressive, bending and torsional) will be greater in the Sadlermiut individuals compared to the Khoisan due to a greater involvement in strenuous upper body activities such as paddling and harpoon throwing.* Cortical area, total area and percent total area are needed to examine humeral compressive strength while bending and torsional strength can be seen in the variables I_x, I_y and J (Ruff, 1992). It is expected that the Sadlermiut means for all aforementioned variables will be higher than the Khoisan means at the mid-shaft. Humeral strength is hypothesized to be greater in the Sadlermiut individuals because the Sadlermiut engaged in more vigorous upper body activity than the Khoisan, particularly paddling. The main upper body activities of the Khoisan would have been shellfish digging for the women and bow and spear use for the men (Deacon, 1969; Deacon, 1972; Klein, 1974; Churchill and Morris, 1998) whereas both Sadlermiut men and women relied on their upper body for transportation (sledging and paddling) (Merbs, 1983). Paddling places a high amount of torsional stress upon the humerus (Alexander 1968; cited in Weiss, 2001). There does not appear to be an activity undertaken by the Khoisan that would have placed a significant amount of torsional stress upon the humerus. While the Khoisan were a coastal group, there is almost no mention of Khoisan watercraft use in the literature. In addition to this, Sadlermiut men used harpoons for hunting which often needed to be driven through a thick layer of ice and Sadlermiut women would have spent several hours involved in the strenuous activity of clothing and skin preparation (Munn, 1919; Mathiassen, 1927; Merbs, 1983; Hawkey and Merbs, 1995).

Hypothesis #2 – *Tibial and femoral compressive strength and AP bending strength will be greater in the Khoisan compared to the Sadlermiut due to a higher level of mobility in a more mountainous and rugged terrain.* Cortical area will be used to examine tibial and femoral compressive strength and I_y is needed to view AP bending strength. It is expected that the Khoisan cortical area and I_y means will be higher than the Sadlermiut means for the tibial and femoral mid-shafts. This hypothesis was made because the South African landscape is more rugged and varied than that of Southampton Island. Trekking across a mountainous region would not only have placed compressive forces upon the bone but also would have caused bending to occur in the AP direction. In addition to this, the means of mobility used by the Sadlermiut mainly involved upper body use rather than lower body (i.e. sledging and paddling). It has been suggested that the level of mobility among both the Khoisan (Sealy and Pfeiffer, 2000) and the Sadlermiut (Comer, 1910; Mathiassen, 1927) was relatively low for hunter-gatherers. However, as Ruff has demonstrated in his study on Great Basin Amerinds (1999), terrain has a greater effect on bone strength compared to distance travelled. For this reason, it has been hypothesized that the mountainous terrain of South Africa would place a higher level of compressive and AP bending stress upon the Khoisan lower limbs than the limestone plains of Southampton Island would place upon the lower limbs of the Sadlermiut.

Hypothesis #3 – *Tibial and femoral ML bending strength and torsional bending strength is likely to be greater in the Sadlermiut compared to the Khoisan because of the strenuous lower limb involvement in sledging activities.* In order to examine tibial and femoral ML and torsional bending strength, the variables I_x and J are required. It is expected that the Sadlermiut means for I_x and J will be higher than the Khoisan means for the tibial and femoral mid-shafts. This hypothesis derives from the observation that the Sadlermiut are expected to have been better adapted to resisting ML bending forces and torsional forces placed upon the lower limb bones primarily because of sledge use (Munn, 1919; Manning, 1936; Merbs, 1983). While sledging requires upper body strength it is also necessary to maintain control of the lower limbs when sledging over uneven ground. For the sledge driver to maintain their balance, their lower limbs would need to be locked in place and move side to side or rotate as the sledge bounces and turns. This motion would place ML bending stress and torsional bending stress upon the bone, probably more so on the tibia than the femur.

The second research question for this thesis pertains to the juvenile specimens: How does biomechanical strength develop ontogenetically in temperate- and cold-climate adapted populations? The following hypotheses are based on the second research question and are intended to examine the process by which the adult end-product is reached for the Khoisan and the Sadlermiut. The analysis of juvenile specimens will follow the approach taken by Libby Cowgill (2008). In her dissertation, Cowgill (2008) plots logged ratios of strength properties against age and uses a LOESS curve to view the change that occurs throughout ontogeny. Cowgill (2008) is interested in strength proportions throughout development which is why she uses ratios strength properties. Yet, the focus of this thesis is the development of strength properties, not strength proportions, and so individual properties will be plotted against age rather than property ratios. This thesis will also follow Cowgill (2008) in her use of the LOESS curve to analyze ontogenetic results.

Hypothesis #4 – *Overall humeral strength (compressive, bending and torsional) will be greater in the Sadlermiut compared to the Khoisan throughout ontogeny. The difference between Khoisan and Sadlermiut humeral strength will become more pronounced as individuals begin to take part in the activities of adults.* To examine this hypothesis, each strength property (i.e. CA, TA, %CA – or CA/TA, I_x, I_y, J) must be plotted against age in order to view how a given property develops throughout ontogeny. A growth curve will be drawn for each property (see section 4.6). It is expected that for every strength property at each humeral location, the Sadlermiut growth curve will be above the Khoisan growth curve. It is expected that when the juveniles of each sample begin to take part in the activities of adults, the Sadlermiut values for each strength property will increase greatly.

Hypothesis #5 – *Tibial and femoral compressive strength and AP bending strength will be greater in the Khoisan compared to the Sadlermiut once Khoisan juveniles begin to take part in the activities of adults such as trekking over mountainous terrain.* To test this hypothesis, tibial and femoral CA, TA, CA/TA and I_y will be plotted against age for the mid-shaft locations. The Khoisan LOESS curves for each property will lie above the Sadlermiut curves once juveniles begin to take part in the activities of adults. It should be noted here that it is possible for the opposite to occur meaning that the Sadlermiut adolescents may display a greater resistance to compressive forces placed upon their lower limbs than the Khoisan adolescents. This is because the Sadlermiut adults, on average, have a greater body mass than Khoisan adults – a difference which is likely to begin manifesting after puberty and thus increase the compressive strength of the Sadlermiut lower limbs. It is not yet known if the increased stress from greater body mass would result in the Sadlermiut adolescents and adults having a higher amount of overall compressive strength placed upon their lower limbs when compared to the Khoisan adolescents and adults.

Hypothesis #6 – *Tibial and femoral ML bending strength and torsional bending strength will be greater in the Sadlermiut compared to the Khoisan once Sadlermiut juveniles begin to take part in the activities of adults, particularly sledging.* Tibial and femoral I_x and J will be plotted against age in order to address this hypothesis. It is expected that the Sadlermiut growth curve will surpass the Khoisan growth curve for both properties once juveniles begin taking part in the activities of adults. The Sadlermiut may exceed the Khoisan individuals in this respect due to the higher level of torsional and ML bending forces experienced through sledge use.

The third research question is meant to reflect on the practicality of biomechanical analyses in anthropology: Is bone structure an accurate reflection of behaviour in the sample populations (i.e. Khoisan and Sadlermiut)?

Hypothesis #7 – *There are differences in the biomechanical adaptations of the Khoisan and Sadlermiut samples which correspond appropriately to what is known about their respective activity patterns from archaeological records.* This hypothesis can be supported or disproven depending on the results of Hypotheses 1 through 6. If Khoisan and Sadlermiut bone structure is found to differ from what is hypothesized of their activity patterns from archaeological and ethnohistoric data, then bone structure can be taken as an accurate reflection of behaviour. This hypothesis can be disproven if differences in Khoisan and Sadlermiut bone structure are either non-existent or do not correspond to what is known about Khoisan and Sadlermiut activity patterns.

Chapter 4

4 Methods

This chapter will describe the methodology used in this thesis. Cross-sectional measurements were taken from biplanar radiographs; this process will be explained in detail below. Following this, the different cross-sectional properties calculated from the radiograph measurements will be defined and their respective equations provided. A description of the macro program model used to calculate cross-sectional properties from radiograph data will be given. The moulding technique used on the Stirrup Court sample will be detailed. The cross-sectional properties obtained from radiograph data and moulding data will be compared for the Stirrup Court sample and the results presented in section 4.5. The chapter will end with a discussion of the statistical methods used for the analysis of Khoisan and Sadlermiut radiograph data.

4.1 Samples

The cross-sectional measurements used in this study were extracted from biplanar radiographs provided by Dr. Andrew Nelson. The Khoisan individuals were radiographed in 1998 at the Groote Shuur Hospital of the University of Cape Town (UCT), Cape Town, South Africa. Adult individuals were x-rayed at 50 peak kilovoltage (kVp) and 500 milliampere seconds (mAs), children at 50kVp and 400mAs, and juveniles at 50kvp and 300mAs. The radiographs were labeled according to UCT identification number (see Appendix A-1 for a list of individuals). The Khoisan individuals were aged and sexed where possible by Drs. Andrew Nelson (University of Western Ontario) and Jennifer Thompson (University of Nevada Las Vegas); this information was relied upon for use in this thesis due to the fact that the author was unable to access the osteological material.

The Sadlermiut individuals were radiographed in 1997 at the Canadian Museum of Civilization in Gatineau, Quebec, Canada. The machine used was a 2-cabinet Faxitron HP43805 and x-rays were taken for all individuals at 75kVp and 225mAs for 85 seconds (no intensifying screens were used). Similar to the Khoisan radiographs, the Sadlermiut radiographs were labeled according to CMOC identification number (see Appendix A-2 for a list of individuals). Sadlermiut individuals were aged and sexed by Drs. Andrew Nelson and Jennifer Thompson.

Only one side was radiographed for the humeri, tibiae and femora of each Khoisan and Sadlermiut individual – usually the left. In the case of the lower limbs, the use of only one side in examining biomechanical strength is not of great concern because strength asymmetry is minimal in these elements. However, using a single side to represent humeral strength may cause problems, particularly when one side must be substituted for the other. In this project, the left humerus was used when available and substituted by the right humerus where the left was not present. Instances of these substitutions were closely monitored for possible error in the analysis portion of this thesis. The literature suggests that both the Khoisan and Sadlermiut were right hand-dominant (Merbs, 1983; Hawkey and Merbs, 1995; Stock and Pfeiffer, 2004). However, it is possible that some left hand-dominant individuals are present within the samples. If a disproportionate number of left-handed individuals were studied, the results could potentially result in a Type 2 error in which a false null hypothesis is accepted. Accepting the possibility of a Type 2 error is a more conservative approach than risking a Type 1 error. Therefore, if handedness impacts the results of this study, it will not show that a false relationship exists between activity and bone structure – instead it would result in an incorrect lack of a relationship.

The majority of the Khoisan radiographs provide a full view of the bone; however, the epiphyses of some femora and tibiae extend off the edge of the radiograph. Fortunately, diaphyseal measurements were not affected by an incomplete view of epiphyses. Unlike the Khoisan radiographs, however, several of the Sadlermiut radiographs only offer a diaphyseal view of the bone, meaning that only the mid-shaft measurements could be taken. See Table 1 for the number of Sadlermiut radiographs that offer only this diaphyseal view.

Element	Radiographs	
	Only Mid-shaft	Entire Bone
Humerus	13	14
Tibia	13	15
Femur	15	15

Table 1. Number of Sadlermiut radiographs that offer either only a diaphyseal view or a view of the entire bone.

The Stirrup Court sample used in this study was aged and sexed at the University of Western Ontario (Cook et al., 1986). External measurements were taken by the author in the Bioarchaeology Lab in the Anthropology Department at the University of Western Ontario. These measurements were taken with an osetometric board and with a digital 6" pointed tip Mitutoyo caliper. A list of these external measurements can be found in Appendix B-5. The locations of interest for radiograph measurements were labeled on each bone with strips of copper tape so that they could be easily located on the radiograph images. See Appendices F1-6 for Stirrup Court external measurement tables.

The Stirrup Court radiographs were taken at the University of Western Ontario, London, Ontario, Canada, in winter of 2011 by the author. The machine used was a Faxitron 43855A programmed to 60kVp and mA for 5 seconds. The distance from the x-ray source to bone was approximately 60 cm, while the distance from the bone to detector was between two and five centimeters, depending on the bone. This resulted in a maximum magnification of 1.05 which was not found to be significant and therefore did not merit alteration of the radiograph measurements. Bones were x-rayed on a cassette with an intensifying screen containing a sheet of Kodak T-Mat film. Following exposure, the film was developed immediately in film developer and fixer solution then left to set in a running water bath.

Due to the small size of the machine, only the humeri and tibiae could be x-rayed in the Faxitron machine at UWO. On February 17, 2012 the Stirrup Court femora were taken to the Radiology Department of St. Joseph's Healthcare Hospital in London, Ontario. The femora were x-rayed with a GE Definium 8000 digital radiography unit at 42kVp and 160mAs for 62.5 milliseconds with a magnification of 5.45. These radiographs were taken in the Department of Diagnostic Imaging at St. Joseph's

Healthcare Hospital in London, Ontario under the supervision of technologist Mr. Glenn Schurmans and radiologist Dr. Greg Garvin. The radiographs were uploaded onto a compact disc for future use.

When x-raying the Stirrup Court sample, each bone was carefully placed in the x-ray machine in order to ensure that the radiograph views were consistently in the same anatomical plane. For the anterior-posterior view of the humeri, the bone was placed medial-side-up with the trochlea and capitulum perpendicular to the plate. In the medial-lateral humerus view, the humerus was placed anterior-side-up with the trochlea and capitulum parallel to the plate. Tibia anterior-posterior view: medial-side-up with the proximal condyles perpendicular to the plate. Tibia medial-lateral view: anterior-side-up with the proximal condyles parallel to the plate. Femur anterior-posterior view: medial-side-up with distal condyles perpendicular to the plate. Femur medial-lateral view: anterior-side-up with distal condyles parallel to the plate. Foam pieces were used to keep the bones balanced in the positions listed above.

4.2 Extracting cross-sectional data

The radiographs of the Khoisan, Sadlermiut and Stirrup Court samples were all measured on a light box using pin-point digital Mitutoyo calipers and rounded to the nearest 0.1 millimeter. The areas of interest on the humeri, tibia and femora of the Khoisan, Sadlermiut and Stirrup Court samples are the mid-shaft, proximal third of shaft length and distal third of shaft length – resulting in a maximum of nine possible diaphyseal locations measured for a single individual. The mid-shaft is located at 50% of the shaft length; the proximal third is located at 30% of the shaft length, calculated from the proximal end; the distal third is located at 70% of the shaft length, calculated from the proximal end. Shaft lengths for the humeri, tibiae and femora were calculated according to the method used by Nelson (1995).

Humeral shaft length, as defined by Nelson (1995), is the “distance from the most inferior point of the margin of the head to the most medial point of the olecranon fossa” (p. 77). In juveniles, where the head and distal epiphysis are absent, humeral shaft length is the distance from the most inferior point on the proximal epiphyseal plate where the head would be expected to connect to the shaft, to the distal epiphyseal plate. See Appendix B-1 for adult shaft length and diaphyseal locations.

Tibial shaft length, as defined by Nelson (1995), is the length of the bone from the most superior point of the spinous process to the most inferior point of the medial malleolus; Tibial shaft length for juveniles is calculated in the same manner. Refer to Appendix B-2 for adult tibia shaft length and diaphyseal locations.

Femoral shaft length, as defined by Nelson (1995), is the "distance from the middle of the lesser trochanter to the horizontal plane formed by the proximal margins of the distal articular condyles" (p. 77). In juveniles, femoral shaft length is measured from the middle of the lesser trochanter to the most inferior point of the distal epiphyseal plate. See Appendix B-3 for adult femur shaft length and diaphyseal locations.

These shaft lengths were defined in order to allow the examination of homologous measurements in the entire ontogenetic sample, from sub-adult to adult (Nelson, 1995).

At each of the possible nine locations (humerus mid-shaft, humerus proximal third, humerus distal third, tibia mid-shaft, etc.) six measurements were taken using the digital calipers. In the anterior-posterior view, medial lateral diameter was measured as well as the thickness of the medial and lateral cortical walls. In the medial-lateral view, anterior posterior diameter and anterior and posterior cortical wall thickness were measured. The result is similar to taking a cross-section of bone except that only two planes of measurement are available due to the fact that the radiographs measured are two-dimensional images. Refer to Figure 6 for a visual representation of the measurements taken from the radiographs and their placement on a diaphyseal cross-section.

For a list of the radiograph measurements taken, see Appendix B-4 and B-5. The form used to record radiograph measurements can be found in Appendix C-1. For Khoisan cross-sectional radiograph measurements: Appendix D-1 to 3. Sadlermiut cross-sectional radiograph measurements: Appendix D-4 to 6. Stirrup Court cross-sectional radiograph measurements: Appendix F-7 to 12. All radiograph measurements were recorded twice; only the second set of measurements was included on the assumption that this set would be more accurate due to practice. However, if the difference between the first measurement and the second measurement taken was greater than 2.00 mm, the measurement was retaken a third time and the third measurement was used instead.

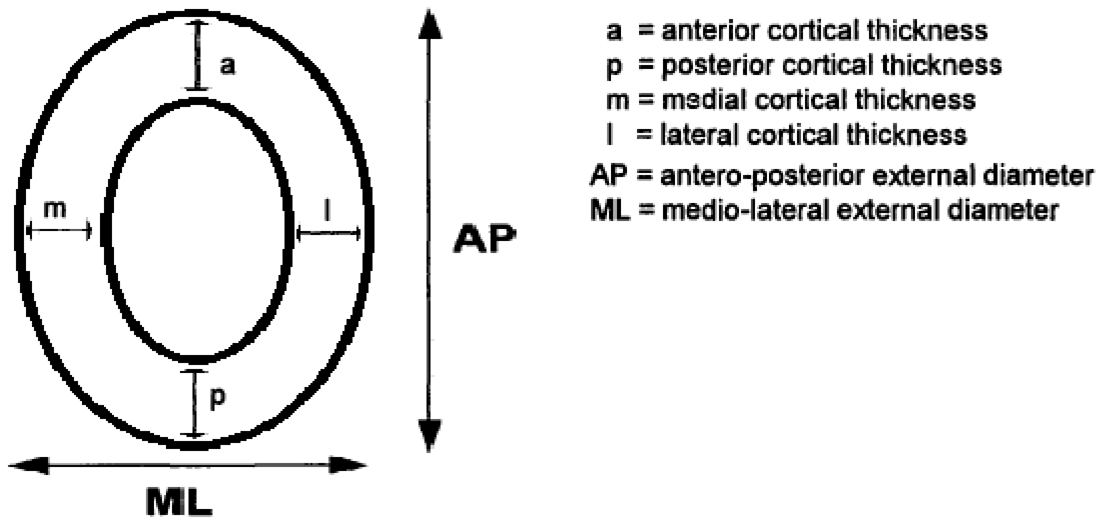

Figure 6. Radiograph measurements and their relative position on a diaphyseal cross-section of bone. After Nelson (1995:224).

With these measurements, cross-sectional geometric properties can be calculated without taking a physical cross-section of bone (see section 4.4). Cross-sectional properties are calculated from radiograph measurements on the assumption that the endosteal contour is in the shape of an ellipse, which is often not the case. Therefore, while this method is non-destructive there is a higher possibility of error compared to the more complete view of a cross-section obtained by invasive methods. The Stirrup Court sample has been included in order to compare the resulting calculations from the radiograph method to calculations from the more reliable latex casting method which will be explained further in section 4.5. Due to the availability of the Stirrup Court remains, it was possible to take latex moulds which produce a more accurate reconstruction of a diaphyseal cross-section (section 4.5). Cross-sectional geometric properties were calculated using both methods for the Stirrup Court sample meaning that the radiograph method could be compared to the casting method and tested for reliability. This comparison will be necessary for understanding what kind of variability might be present in the Khoisan and Sadlermiut data that is specifically attributable to the method used rather than biomechanical adaptation.

4.3 Cross-sectional geometry

The cross-sectional properties used in this thesis can be found in Table 2. For a list of each property calculated for each element, see Appendices B-4 and B-5.

Property	**Abbr.**	**Units**	**Definition**
Cortical area	CA	mm^2	Area of cortical bone in cross-section – a measurement of compressive/tensile strength
Total subperiosteal area	TA	mm^2	Area within the outer surface of the cross-section
Medullary area	MA	mm^2	Area within the medullary cavity of the cross-section
Second moment of area about the ML (x) axis	I_x	mm^4	Anterior-posterior bending strength
Second moment of area about the AP (y) axis	I_y	mm^4	Medial-lateral bending strength
Polar second moment of area	J	mm^4	Torsional bending strength
Biomechanical shape	I_x/I_y		Measurement of proportional bending strength
Percent cortical area	%CA, CA/TA	%	The percentage of cortical bone within the entire cross-section

Table 2. Biomechanical cross-sectional properties studied, after Ruff (1992:72-73).

As described in Table 2, the cortical area of a cross-section is a representation of the strength of a bone when subjected to compressive and tensile forces. CA and TA are responsive to compressive and tensile forces. CA and TA are absolute variables meaning they can be influenced by other factors, particularly body mass. The second moments of area about the medial-lateral (ML) and anterior-posterior (AP) axes are representative of the bending strength of a bone in their respective planes. Second moments of area need to be calculated with reference to an axis, which is why there are two separate measurements: one calculated about the ML (x) axis and one calculated about the AP (y) axis (Lovejoy et al., 1976; Ruff and Hayes, 1983a,b). Fortunately, second moments of area and polar moment of area are normalized variables and, therefore, are unaffected by the influences of body mass.

There is another type of moment of area that is representative of bending strength that is calculated with reference to the maximum and minimum breadths of a cross-section. These measurements, called the maximum (I_{max}) and minimum (I_{min}) moments of area respectively, are a reflection of the maximum and minimum bending strength of a bone, unlike their counterparts, I_x and I_y, which only provide a representation of bending strength about the x- and y-axes (Ruff and Hayes, 1983a,b). Unfortunately, I_{max} and I_{min} could not be included in this study due to the methodology employed. The methodology used for the Sadlermiut and Khoisan samples – biplanar radiographs and the elliptical model for calculating cross-sectional parameters – cannot determine the maximum and minimum diameters that are necessary for the calculation of I_{max} and I_{min}. The latex casting method, however, does allow for this calculation as can be seen in section 4.5 of this thesis.

The polar second moment of area (J) can be either the sum of the second moments of area about the ML and AP axis or the sum of the maximum and minimum second moments of area. For this thesis, J will be calculated using the second moments of area about the ML and AP axis due to the fact that I_{max} and I_{min} cannot be calculated as discussed earlier. The polar second moment of area is a representation of the torsional strength of a bone. This means that J is indicative of the ability of a bone to resist breakage from torsional forces. Unlike the second moments of area which are calculated with respect to an axis, the polar second moment of area is calculated about the centroid – the geometric centre of an irregularly shaped object (Lovejoy et al., 1976; Ruff and Hayes, 1983a,b).

Biomechanical shape can be calculated by dividing the second moment of area about the ML axis (I_x) by the second moment of area about the AP axis (I_y). The resulting ratio represents the distribution of cortical bone in the cross-section which is indicative of the circular or elliptical form of the cross-sectional shape (see Figure 7). The same type of ratio could be derived from maximum and minimum second moments of area, which would produce an even more accurate picture of cross-sectional shape. To help explain this property better, imagine a perfectly circular hollow beam. If a cross-section were to be taken of that beam and second moments of area and maximum and minimum second moments of area calculated, the ratios of I_x/I_y and I_{max}/I_{min} would both be equal to one. A ratio that deviates from the value of one means that the shape deviates from circularity, but its distribution can still be understood in light of the actual ratio value.

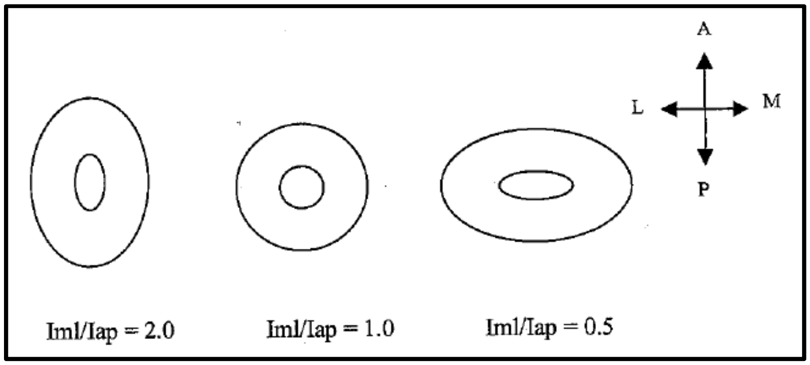

Figure 7. Biomechanical shape ratios (Ruff, 1987; cited in Weiss, 2001:20)

4.4 Eccentric Ellipse Model (EEM)

All of the above properties were calculated for all three locations (mid-shaft, proximal third, distal third) of every available element (humerus, tibia, and femur) for each sample population. Khoisan and Sadlermiut cross-sectional geometry calculated from radiograph measurements can be found in Appendix E (Appendix B-4 contains the corresponding key for these charts). For Stirrup Court cross-sectional geometry calculated from radiograph measurements, see Appendix F-13 to 18 (Appendix B-5 contains the corresponding key for these charts). The following section will describe how these geometrical properties were calculated using the cross-sectional measurements taken from the radiographs.

Calculations were made using a macro created for Microsoft Excel. The macro calculates geometric properties using an eccentric ellipse model (EEM) and was created by Dr. Christopher Ruff. The eccentric ellipse model calculates cross-sectional geometric properties on the assumption that the subperiosteal margin of the diaphysis and the endosteum are both in the shape of an ellipse (Milgrom et al., 1989; Biknevicius and Ruff, 1992; Ohman 1993). The model, however, does not assume that the ellipses are concentric, meaning that asymmetrical distribution of cortical bone is accounted for (Ohman, 1993). This method of calculating cross-sectional geometric properties has been previously tested for validity and found to produce reasonably accurate results with a tendency to overestimate most properties with the exception of medullary area which tends to be underestimated (Ruff 1989; Fresia et al., 1990, cited in Stock and Pfeiffer, 2004; Runestad et al., 1993; Stock, 2002; O'Neill and Ruff, 2004; Cowgill, 2008). The equations used by the EEM macro can be found in Table 3; refer to Table 4 for a complete list of abbreviations.

Cross-Sectional Property	Equation
Cortical Area	$CA = TA - MA$
Total Subperiosteal Area	$TA = \pi \frac{(AP \times ML)}{4}$
Medullary Area	$MA = \pi \frac{(AP - a - p)(ML - m - l)}{4}$
Centroid – ML axis (X_0)	$X_0 = \frac{(l - m)(AP - a - p)(ML - l - m)}{(2[ML(a + p) + (l + m)(AP - a - p)])}$
Centroid – AP axis (Y_0)	$Y_0 = \frac{(a - p)(AP - a - p)(ML - l - m)}{(2[ML(a + p) + (l + m)(AP - a - p)])}$
Second Moment of Area, ML (x) plane	$I_x = TA\left(\frac{ML^2}{16} + X_0^2\right) - MA\frac{[16X_0(X_0 + l - m) + 5(l^2 + m^2) - 2l(3m + ML) + ML(ML - 2m)]}{16}$
Second Moment of Area, AP (y) plane	$I_y = TA\left(\frac{AP^2}{16} + Y_0^2\right) - MA\frac{[16Y_0(Y_0 + a - p) + 5(a^2 + p^2) - 2a(3p + AP) + AP(AP - 2p)]}{16}$
Polar Second Moment of Area	$J = I_X + I_Y$

Table 3. Equations used to calculate cross-sectional geometric properties from radiograph measurements (from Harrington, 2010:41; after Ohman, 1993; after Milgrom et al., 1989). The equation to find the centroid is included above yet it should be noted that this property is only significant in this study for its use in calculating I_x and I_y.

Abbr.	Definition
AP	Anterioposterior subperiosteal diameter
a	Anterior cortical wall breadth
p	Posterior cortical wall breadth
ML	Mediolateral subperiosteal diameter
m	Medial cortical wall breadth
l	Lateral cortical wall breadth
CA	Cortical area
TA	Total subperiosteal area
MA	Medullary area
I_x	Second moment of area about the ML (x) axis
I_y	Second moment of area about the AP (y) axis
I_{max}	Maximum moment of area
I_{min}	Minimum moment of area
J	Polar second moment of area
I_x/I_y	Biomechanical shape
%CA	Percent cortical area (also CA/TA)

Table 4. Complete list of abbreviations used in this thesis.

4.5 Latex-Casting Method (LCM)

In order to test the validity of the previous method which uses radiographs and the EEM program, the Stirrup Court sample was used as a validation sample. Since the bones of the Stirrup Court sample were available for study, a reportedly more reliable method of calculating geometric properties could be used and thus compared to the EEM method. This more reliable method is known as the latex casting method (LCM). The differences between the EEM and LCM calculations for the Stirrup Court sample should provide some insight into possible discrepancies in the geometrical properties calculated for the Khoisan and Sadlermiut samples – for whom latex-casting was not possible. For a visual representation of the differences between these two methods, see Figure 8.

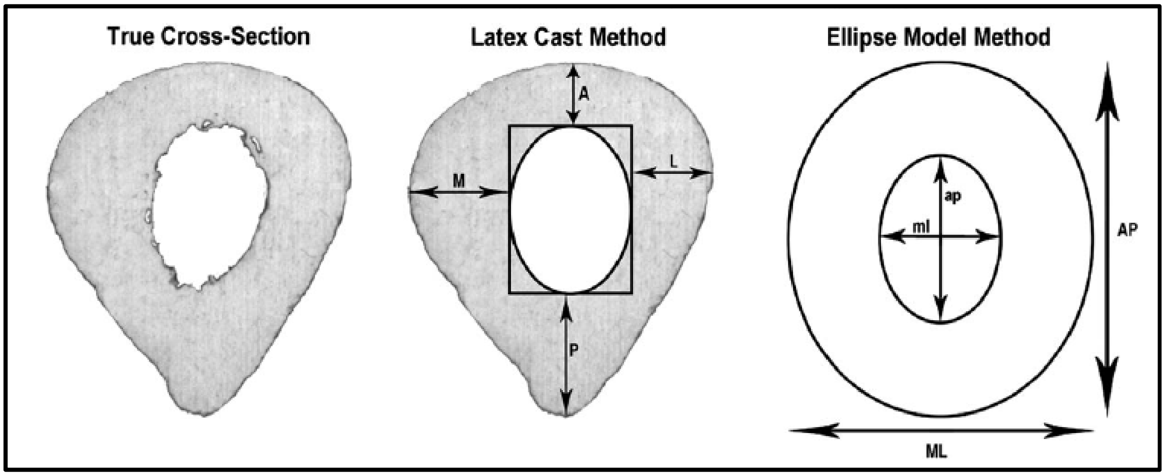

Figure 8. A comparison of methods for obtaining cross-sectional geometry (O'Neill and Ruff, 2004:224). The latex-cast method is more reliable than the EEM method due to the fact that the subperiosteal contour is more accurately portrayed compared to the ellipse model. In the latex-cast method, the endosteal contour is shaped as an ellipse which very closely resembles the true shape of the endosteal contour. It should be noted that the above figure displays a representation of the Ellipse Model Method which calculates cross-sectional geometry as though both subperiosteal and endosteal ellipses are concentric, with the same centroid (Ohman, 1993). However, this project makes use of the Eccentric Ellipse Model which places the centroid of the endosteal ellipse eccentrically within the subperiosteal ellipse (O'Neill and Ruff, 2004). This increases accuracy slightly, especially in cases of greater asymmetry, yet does not resolve the main downfall of the ellipse method which is a misrepresentation of the subperiosteal contour (O'Neill and Ruff, 2004).

To begin the latex cast process, silicone moulds were taken at the mid-shaft of every available Stirrup Court humerus, tibia and femur using dental mould putty. The moulds were left to dry overnight. Before removing the moulds from the bones each side was marked as anterior, posterior, medial or lateral according to how the bone would have been placed in the Faxitron machine (see section 4.2). The moulds were then carefully removed from the bones using a utility knife. Immediately after removal, the moulds were scanned (see Figure 9).

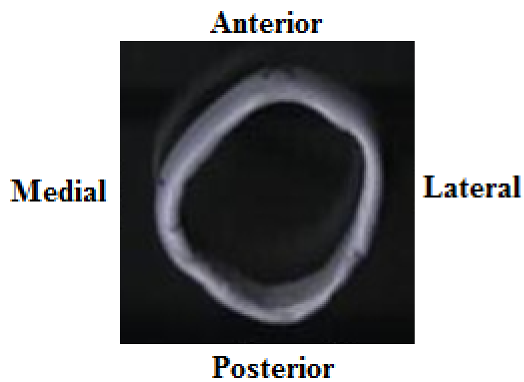

Figure 9. Scanned mould of a humerus mid-shaft.

Using the inner edge of the mould as a guide, a subperiosteal contour was traced using Adobe Photoshop CS5 and a drawing tablet. After the outer contour was drawn, the rest of the cross-section was filled in completely. With the LCM method, an elliptical medullary cavity must be drawn. The dimensions of this ellipse were calculated using the measurements taken from biplanar radiographs. Ellipse height was measured by subtracting anterior and posterior cortical wall thickness from the total anterioposterior diameter. The width of the ellipse was found by subtracting medial and lateral cortical wall thickness from the total mediolateral diameter. Using all four cortical bone widths (i.e. a, p, m, l) the ellipse was accurately positioned within the cross-section. For an example of a cross-section drawn from a silicone mould, see Figure 10.

The drawings of Stirrup Court mid-shaft cross-sections were uploaded to an image processing program called ImageJ. A plugin created by Dr. Christopher Ruff called MomentMacroJ v1.3 was downloaded into the ImageJ program. This macro plugin, when activated in ImageJ, can be used to calculate cross-sectional properties, such as areas, second moments of area and maximum and minimum moments of area. Each cross-section drawing was run through the ImageJ program twice to ensure that mistakes were not made during input. The geometric calculations were exported as .txt files and were immediately transferred to Microsoft Excel spreadsheets.

Figure 10. Computer drawn humerus mid-shaft cross-section.

The geometrical properties calculated for the Stirrup Court mid-shafts from the LCM method and ImageJ program were then compared to the geometrical properties obtained from radiograph measurements and the EEM macro. This was done by graphing the LCM values against EEM results for each comparable biomechanical property (i.e. TA, MA, CA, I_x, I_y, J, %CA, I_x/I_y). The program used to graph these results was IBM SPSS Statistics Version 19 (see Appendix F-25 to 27 for results of EEM and LCM method comparison). A linear regression analysis was done for each comparison; the resulting slopes and Y-intercepts can be used to view the difference between the LCM and EEM results for Stirrup Court. See Tables 5-7 for these values.

Property	***Right***			***Left***		
	Slope	**Std. Error**	**Y-int**	**Slope**	**Std. Error**	**Y-int**
TA	***0.92***	0.05	38.45	***1.08***	0.07	-30.03
MA	1.01	0.01	2.97	1.01	0.01	2.78
CA	0.93	0.07	18.53	1.02	0.07	-13.82
I_x	***0.85***	0.07	1113.96	1.02	0.06	-788.40
I_y	0.96	0.06	882.68	1.06	0.08	-747.41
J	***0.91***	0.06	1847.12	1.05	0.06	-1718.51
I_x/I_y	***0.80***	0.11	0.13	0.95	0.15	0.01
%CA	1.01	0.04	-1.36	1.03	0.04	-3.53

Table 5. Humeral comparison of Stirrup Court cross-sectional properties calculated by EEM and ImageJ.

Property	*Right*			*Left*		
	Slope	**Std. Error**	**Y-int**	**Slope**	**Std. Error**	**Y-int**
TA	1.08	0.16	-2.39	1.12	0.13	-35.41
MA	1.01	0.01	2.84	1.00	0.01	3.95
CA	1.07	0.13	1.80	1.04	0.12	4.12
I_x	***0.79***	0.14	4400.26	1.01	0.13	-970.24
I_y	1.04	0.24	1697.21	1.12	0.17	-242.24
J	0.91	0.17	4889.68	1.08	0.11	-2058.33
I_x/I_y	0.98	0.33	-0.17	0.90	0.20	-0.03
%CA	***0.85***	0.04	12.64	0.95	0.06	4.04

Table 6. Tibial comparison of Stirrup Court cross-sectional properties calculated by EEM and ImageJ.

Property	*Right*			*Left*		
	Slope	**Std. Error**	**Y-int**	**Slope**	**Std. Error**	**Y-int**
TA	***1.12***	0.07	-55.35	***1.13***	0.06	-51.35
MA	***1.02***	0.00	1.17	***1.02***	0.00	0.95
CA	1.06	0.07	-13.22	1.06	0.07	-1.48
I_x	***1.09***	0.06	-1213.94	1.05	0.09	339.64
I_y	***1.09***	0.08	-1488.92	1.05	0.06	-827.27
J	***1.08***	0.07	-2845.05	***1.10***	0.07	-1352.93
I_x/I_y	1.01	0.18	0.02	***0.53***	0.09	0.42
%CA	1.00	0.04	0.60	***0.93***	0.03	5.40

Table 7. Femoral comparison of Stirrup Court cross-sectional properties calculated by EEM and ImageJ.

The bolded slope values indicate instances in which a slope of 1.00 does not fall within one standard of error unit of the calculated slope. Therefore, the bolded values represent situations in which the EEM and LCM Stirrup Court slopes differ significantly from geometric similarity. As several other studies have shown (Fresia et al., 1990, cited in Stock and Pfeiffer, 2004; Biknevicius and Ruff, 1992; Ohman, 1993; Runestad et al., 1993; O'Neill and Ruff, 2004; Cowgill, 2008), the results above indicate that the EEM program produces reasonably accurate results which do not match the LCM results in all respects but are at least comparable.

Based on the slopes obtained from a comparison of EEM and LCM cross-sectional geometry, the properties that are most affected by method of calculation are total area, I_x and biomechanical shape (I_x/I_y). Biomechanical shape shows the greatest deviation from 1.00 of all the slopes at the femur mid-shaft (a slope of 0.53 with a standard error of 0.09). This difference in biomechanical shape calculations is understandable due to the fact that the EEM program assumes that the subperiosteal contour is in the shape of an ellipse whereas the LCM method can more accurately reconstruct cross-sectional shape because it is not restricted to two planes of view like the EEM method. In addition to this, the combination of two calculations (i.e. I_x and I_y) would lead to an increased likelihood of error in the resulting calculation. The low slope exhibited by I_x/I_y is not overly concerning because true biomechanical shape can only be obtained where I_{max} and I_{min} are available which can only be calculated with a physical cross-section, a CT scan or a mould and imaging software. Therefore, because the slope between biomechanical shape values from EEM and LCM is very low at the femur mid-shaft, biomechanical shape will not be a property that is relied upon in this study. Total area and I_x will still be included in the analysis of the Khoisan and Sadlermiut because their deviations from a slope of 1.00 were not as great as the particular instance of femoral biomechanical shape mentioned above. However, these variables should be monitored closely in the discussion.

Another observation can be made regarding the element analyzed. For example, EEM and LCM slope ranges include a slope of 1.00 for most humeral and tibial properties. However, the EEM and LCM slopes for both the right and left femur are somewhat erratic – more than half of the slope ranges do not include a slope of 1.00. There are two probable explanations: either the cause is a small sample size or, more likely, the triangular shape of a femur diaphysis, which is very different from the idealized ellipse. However, the tibia diaphysis is also triangular in shape yet the tibia slope ranges for almost all variables included a slope of 1.00. The elliptical assumption made by the EEM program seems to produce more accurate results in the tibia than the femur.

This thesis project is an ontogenetic comparison of the biomechanical adaptations of two sample populations. The cross-sectional properties to be compared in the analysis portion of this thesis were all obtained using the same method. The increased risk of inaccuracy in the EEM program would be a concern if multiple methods were required to calculate cross-sectional geometry. While the calculations from EEM may not be identical to the true cross-sectional geometry, the ways in which EEM geometry deviates from true geometry are going to be the same for all populations for whom the EEM method is used; therefore, comparisons between the two populations are not likely to be affected so long as the method of calculation is the same. The only concern is future applications of these data. There is no issue if the Khoisan and Sadlermiut EEM properties are compared to EEM calculations of other populations in future studies. However, if the cross-sectional properties calculated in this study were to be compared to cross-sectional properties obtained by any other method (except perhaps the Ellipse Model Method), the EEM calculations would have to be corrected (see O'Neill and Ruff, 2004 for regression equations used to correct overestimation in EEM geometry).

4.6 Statistical analysis

The calculations of biomechanical properties made from the EEM macro for the Khoisan and Sadlermiut samples were transferred from Microsoft Excel into Microsoft Access – a program intended for storing large amounts of data in a database system. Using the program IBM SPSS Statistic Version 19, the means and standard deviations were calculated for each biomechanical property, diaphysis location and long bone of all sample adults. Boxpots were created using SPSS in order to view the range of values for each property. A non-parametric Mann-Whitney U test was performed for each property which was necessary to test if the difference between the sample means was significant.

For the juvenile specimens, each biomechanical property was plotted against age for both the Khoisan and Sadlermiut samples using the program IBM SPSS Statistic Version 19. Because this is a study meant to examine the ontogeny of biomechanical adaptations, an average was taken for the property values of individuals over the age of 20 years. For example, when plotting the cortical area of the humerus mid-shaft against age for the Khoisan, the cortical areas of any individuals over 20 years were averaged and the resulting value used to represent a single, average individual recorded as being 20 years. The reason for this was to avoid any possible alterations in the growth curves because of varied adult values. Only the mid-shaft graphs are analyzed in detail in Chapter 5 due to the fact that the proximal third and distal third locations are often a repetition of the mid-shaft pattern for each property.

After plotting the individual points, each graph of juvenile results was fitted with a LOESS curve. The LOESS curve, otherwise known as locally weighted scatterplot smoothing, is commonly used in studies of human growth because it models the data more accurately than an exponential growth curve. The curve is "weighted" because it is based on several regression functions contained within a certain data span. The span for which each regression line is created can be entered into SPSS by the user. The smaller the span for each regression, the more closely the resulting curve will follow the data. However, if the span is too small, the curve may be too varied with no visible patterns emerging. With a reasonable span for each regression, a smoothed curve can be created which allows the user to view the patterns of change during ontogeny in a given property. The LOESS curve used for this study is based on the weight function kernel, Epanechnikov (see Epanechnikov, 1969). The percentage of points fitted to each curve was 50, except in the case of juvenile humeral torsional strength which needed to be changed to 70% due to a drastic dip in the Sadlermiut curve which occurred at age 10 that was not representative of the data.

There are disadvantages to using a LOESS curve. LOESS is best suited for large amounts of data and the maximum number of individuals included in any graph for this study is 29. Also, LOESS curves are not easily represented by mathematical formulae which can lead to some difficulty in interpreting the results of a LOESS analysis.

Chapter 5

5 Results

This chapter is divided into two sections based on the research questions and corresponding expectations presented in section 3.4 of this thesis. The first section provides the data necessary for exploring the first research question: How do biomechanical adaptations differ in temperate- and cold-climate adapted populations (i.e. Khoisan of South Africa, Sadlermiut of the Canadian Arctic)? This section includes the means and standard deviations of each cross-sectional property for sample adults only as per the method used by Stock and Pfeiffer (2004). A Mann-Whitney U test will be performed for each biomechanical property to test the significance of population differences. The purpose of including only adult data in this analysis is to view the differences in the adult end-product between the two groups.

The second section of the results chapter will present graphed data for individuals 18 years and under, following Cowgill (2008), so that the process by which the adult end-product is reached can be viewed. This section is meant to address the research question: How does biomechanical strength develop ontogenetically in temperate- and cold-climate adapted populations? In order to address each research question, compressive strength, bending strength and torsional strength need to be known for each sample. The variables CA, TA, %CA (or CA/TA), I_y, I_x and J are needed to understand these properties of strength. Cortical area and total area are indicative of compressive and tensile strength in a bone; I_x is a measure of a bones ability to resist ML bending forces; I_y is a measure of a bones ability to resist AP bending forces; and J is required to view torsional strength of a bone (Ruff, 1992).

5.1 Adult results

The following results include data from the Khoisan and Sadlermiut adults for the mid-shaft location of each element studied.

5.1.1 *Upper limb*

The humerus results for the adults will be discussed first. The results will be given with consideration to the expectations outlined in section 3.4 for the first research question.

Cross-Sectional Property	Statistic	Khoisan N = 6	Sadlermiut N = 10	Mann-Whitney U Test	Hypothesized Comparison
CA	mean	208.12	187.47	U = 23.00	
mm^2	sd	72.27	36.64	p = 0.45	S > K
	MW U rank	9.67	7.80		
TA	mean	237.08	330.91	U = 7.00	
mm^2	sd	62.73	69.81	p = 0.01	S > K
	MW U rank	4.67	10.80		
CA/TA	mean	0.77	0.58	U = 7.00	
	sd	0.14	0.09	p = 0.01	S > K
	MW U rank	12.33	6.20		
I_x	mean	4491.48	7360.03	U = 13.00	
mm^4	sd	2334.37	2681.78	p = 0.07	S > K
	MW U rank	5.67	10.20		
I_y	mean	4232.43	6993.11	U = 11.00	
mm^4	sd	2228.16	2659.43	p = 0.04	S > K
	MW U rank	5.33	10.40		
J	mean	8723.91	14353.14	U = 10.00	
mm^4	sd	4545.45	5248.58	p = 0.03	S > K
	MW U rank	5.17	10.50		

Table 8. Humeral mid-shaft cross-sectional properties of Khoisan and Sadlermiut adults with Mann-Whitney U test results (significant at $p < 0.05$).

Hypothesis #1 – *Overall humeral strength (compressive, bending and torsional) will be greater in the Sadlermiut individuals compared to the Khoisan due to a greater involvement in strenuous upper body activities such as paddling and harpoon throwing.* The variables necessary for viewing compressive strength are cortical area (CA), total area (TA) and percent cortical area (CA/TA). The mean for cortical area at the humerus mid-shaft is larger for the Khoisan adults compared to the Sadlermiut adults yet the Mann-Whitney U (MWU) test did not reveal this difference to be significant (Table 8). The box plots show that the Khoisan have a much wider range of values for humerus mid-shaft cortical area than the Sadlermiut (Figure 11).

The Sadlermiut sample includes an individual with a mid-shaft cortical area that is fairly low given the respective total area (XIV-C:181, TA = 437.239, CA = 181.79611). No pathology was recorded for this individual and the calculations were double-checked for possible error. This individual was noted to be of particularly old age so it is possible that cortical degeneration occurred due to lower activity levels. When this individual is removed from the data set, the calculated mean does not greatly differ ($\bar{x}$ = 188.10).

The mean for total area at the humeral mid-shaft is greater in the Sadlermiut compared to the Khoisan; this difference was found to be significant by the MWU test. The box plots (Figure 12) show the Khoisan adults as having much lower values for total cross-sectional area than the Sadlermiut adults. The mean for percent cortical area at the humeral mid-shaft is greater in the Khoisan compared to the Sadlermiut; this difference was found to be significant by the MWU test. The box plots for percent cortical area (Figure 13) show the Khoisan and Sadlermiut as having a similar range in values with the Khoisan values being much greater than the Sadlermiut values.

The observed humeral mid-shaft total area means were as expected according to Hypothesis 1. However, the larger cortical area and percent cortical area means exhibited by the Khoisan would indicate that the Khoisan were better able to resist compressive forces placed upon their humeri than the Sadlermiut. There are no outliers visible which could have led to this difference. It could be that the total cross-sectional area of the Sadlermiut adults is greater because the Sadlermiut are larger and stockier in build than the Khoisan.

To examine humeral bending and torsional strength, the variables I_y, I_x and J are required. For the calculated means and standard deviations of these variables, see Table 6. As hypothesized, the means for I_x, I_y and J are greater in the Sadlermiut compared to the Khoisan. The difference between sample means was found to be significant for I_y and J yet not for I_x. These results suggest that the Sadlermiut were better adapted to resisting AP and torsional bending forces acting upon their humeri; yet, the two samples appear to have been similarly adapted to resisting ML bending forces placed upon their humeri. The observed humeral mid-shaft I_y and J results were as expected according to Hypothesis 1 yet the observed results for I_x were not as expected.

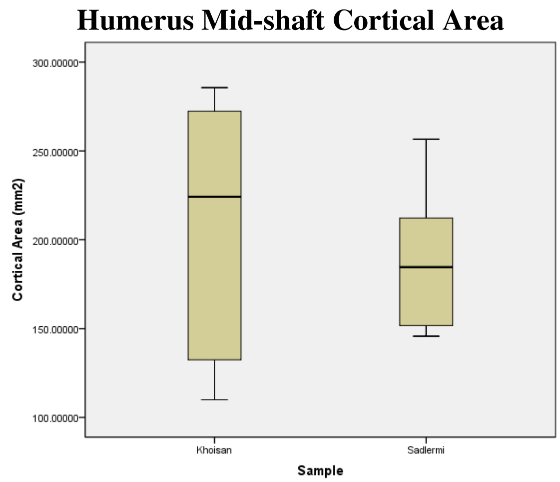

Figure 11. Humeral mid-shaft cortical area box plots of Khoisan and Sadlermiut adults.

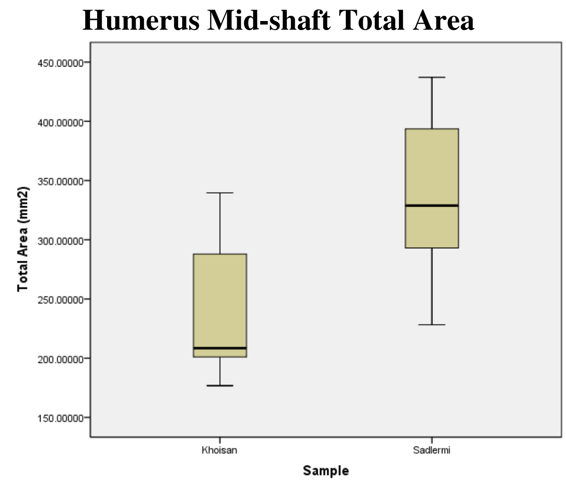

Figure 12. Humeral mid-shaft total area box plots of Khoisan and Sadlermiut adults.

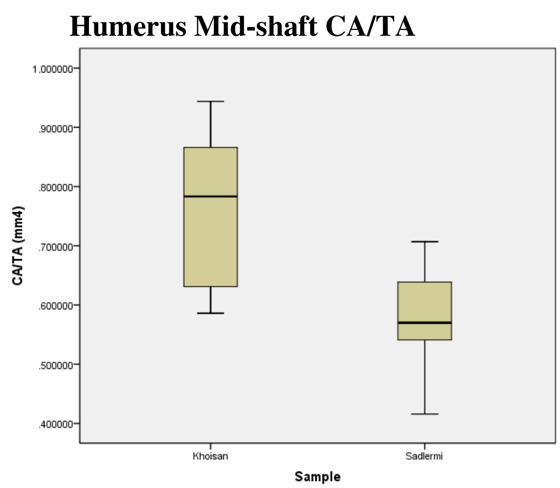

Figure 13 . Humeral mid-shaft percent cortical area box plots of Khoisan and Sadlermiut adults.

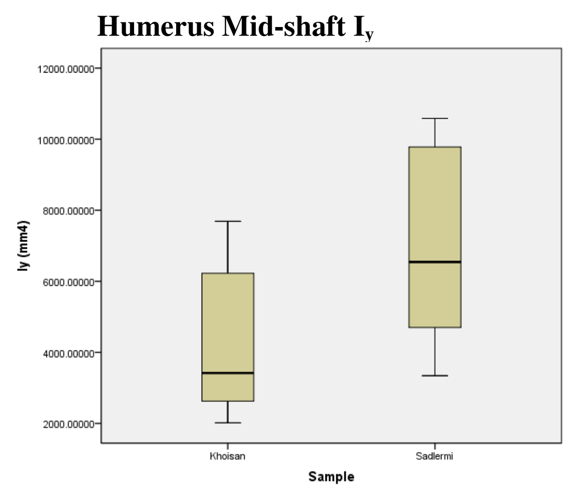

Figure 14. Humeral mid-shaft I_y box plots of Khoisan and Sadlermiut adults.

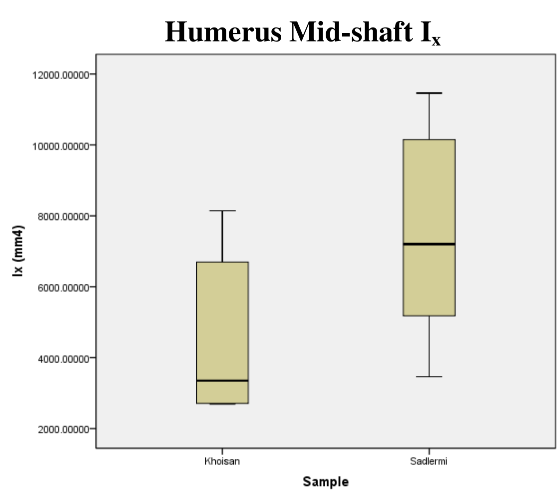

Figure 15. Humeral mid-shaft I_x box plots of Khoisan and Sadlermiut adults.

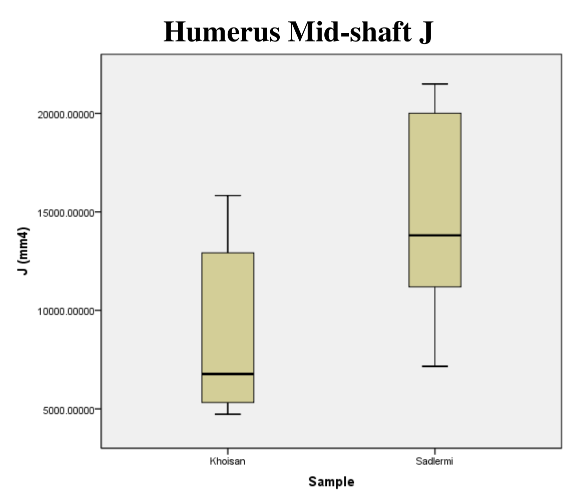

Figure 16. Humeral mid-shaft J box plots of Khoisan and Sadlermiut adults.

5.1.2 *Lower Limb*

This section will describe the results obtained from the tibial and femoral mid-shafts for the Khoisan and Sadlermiut adults with respect to the expectations outlined in section 3.4 for the first research question. It was hypothesized that both tibial and femoral compressive strength and AP bending strength would be greater in the Khoisan individuals compared to the Sadlermiut. It was also hypothesized that tibial and femoral ML and torsional bending strength would be greater in the Sadlermiut individuals compared to the Khoisan. Similar to the humerus results, the cross-sectional variables needed to analyze these strength properties are CA, TA, CA/TA, I_y, I_x and J.

Cross-Sectional Property	**Statistic**	**Khoisan N = 4**	**Sadlermiut N = 10**	**Mann-Whitney U Test**	**Hypothesized Comparison**
CA mm^2	mean sd MW U rank	311.34 87.20 7.00	311.62 69.44 7.70	U = 18.00 p = 0.77	K > S
TA mm^2	mean sd MW U rank	409.79 86.30 6.50	446.08 107.66 7.90	U = 16.00 p = 0.57	K > S
CA/TA	mean sd MW U rank	0.76 0.08 9.50	0.70 0.04 6.70	U = 12.00 p = 0.26	K > S
I_x mm^4	mean sd MW U rank	17079.35 6873.21 7.25	18671.94 7791.56 7.60	U = 19.00 p = 0.89	S > K
I_y mm^4	mean sd MW U rank	9587.27 4402.54 6.75	11473.39 6658.07 7.80	U = 17.00 p = 0.67	K > S
J mm^4	mean sd MW U rank	26666.62 11166.90 7.00	30145.33 14323.98 7.70	U = 18.00 p = 0.77	S > K

Table 9. Tibial mid-shaft cross-sectional properties of Khoisan and Sadlermiut adults with Mann-Whitney U test results (significant at $p < 0.05$).

Cross-Sectional Property	Statistic	Khoisan N = 5	Sadlermiut N = 9	Mann-Whitney U Test	Hypothesized Comparison
CA **mm^2**	mean sd MW U rank	415.19 69.58 7.20	420.35 79.10 7.67	U = 21.00 p = 0.84	K > S
TA **mm^2**	mean sd MW U rank	551.48 77.36 6.80	630.90 151.43 7.89	U = 19.00 p = 0.64	K > S
CA/TA	mean sd MW U rank	0.75 0.09 10.20	0.68 0.07 6.00	U = 9.00 p = 0.07	K > S
I_x **mm^4**	mean sd MW U rank	25154.29 8403.01 6.20	31158.37 13893.83 8.22	U = 16.00 p = 0.39	S > K
I_y **mm^4**	mean sd MW U rank	20961.27 7041.17 6.00	26313.93 11180.17 8.33	U = 15.00 p = 0.32	K > S
J **mm^4**	mean sd MW U rank	46115.56 11586.86 7.00	57472.30 24784.65 7.78	U = 20.00 p = 0.74	S > K

Table 10. Femoral mid-shaft cross-sectional properties of Khoisan and Sadlermiut adults with Mann-Whitney U test results (significant at p < 0.05).

Hypothesis #2 – *Tibial and femoral compressive strength and AP bending strength will be greater in the Khoisan compared to the Sadlermiut due to a higher level of mobility in a more mountainous and rugged terrain.* Cortical area, total area and percent cortical area will be used to examine tibial and femoral compressive strength. I_y will be necessary to view AP bending strength.

The calculated means and standard deviations of these variables for the tibia can be found in Table 9; for the femur, see Table 10. The Khoisan and Sadlermiut means for cortical area at the tibia mid-shaft are almost identical. The difference was not found to be significant according to the MWU test. The box plot (Figure 17) shows a slightly greater range of values for the Sadlermiut. The mean for total area at the tibia mid-shaft is greater in the Sadlermiut compared to the Khoisan. The difference in these means was not found to be significant. The box plot for tibia mid-shaft total area (Figure 18) shows the Sadlermiut as having a greater range of values than the Khoisan. However, the Sadlermiut sample appears to contain an outlier of greater total cross-sectional area which may have contributed to the higher mean exhibited by the Sadlermiut. The measurements for this individual were double-checked for possible error. Without this individual, the Sadlermiut mean is slightly lower ($\bar{x}$ = 421.07) yet still higher than the Khoisan mean.

The Khoisan mean for percent cortical area at the tibia mid-shaft is greater than the Sadlermiut mean. However, the difference between these means was not found to be significant. Both the Khoisan and the Sadlermiut box plots for this property (Figure 19) show a small range of values. The Sadlermiut mean was greater for I_y, yet this difference was not found to be significant. The I_y box plot (Figure 20) shows the Khoisan and Sadlermiut as having a similar range of values.

Figure 20 contains an outlier of significantly greater tibial AP bending strength. This individual is XIV-C:181 who was identified as being an outlier for humeral total area. The measurements for this individual have been double-checked for possible error and none was found. The other measurements this individual were relatively high meaning that XIV-C:181 was likely a very robust male.

The means obtained for cortical area, total area, percent cortical and I_y at the tibia mid-shaft are not in agreement with Hypothesis 2. The differences between the Sadlermiut and Khoisan means for all variables were not found to be significant and therefore the Khoisan do not demonstrate a greater ability to resist tibial compressive and AP bending forces than the Sadlermiut. Based on these results, the Sadlermiut and Khoisan are similarly adapted to withstand compressive and AP bending forces placed upon their tibiae.

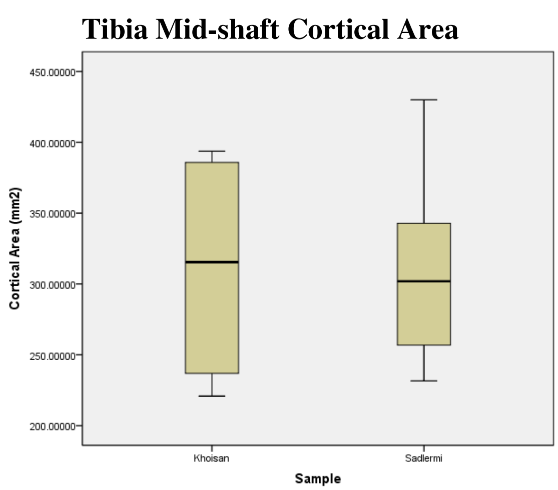

Figure 17. Tibial mid-shaft cortical area box plots of Khoisan and Sadlermiut adults.

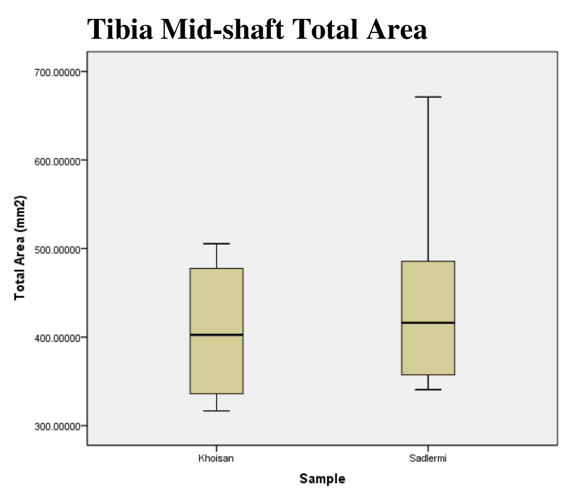

Figure 18. Tibial mid-shaft total area box plots of Khoisan and Sadlermiut adults.

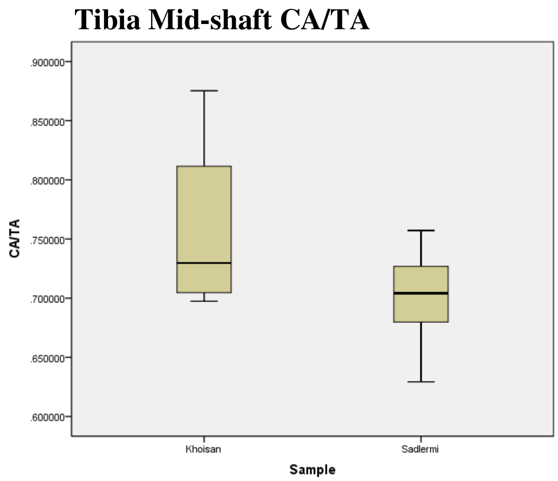

Figure 19. Tibial mid-shaft percent cortical area box plots of Khoisan and Sadlermiut adults.

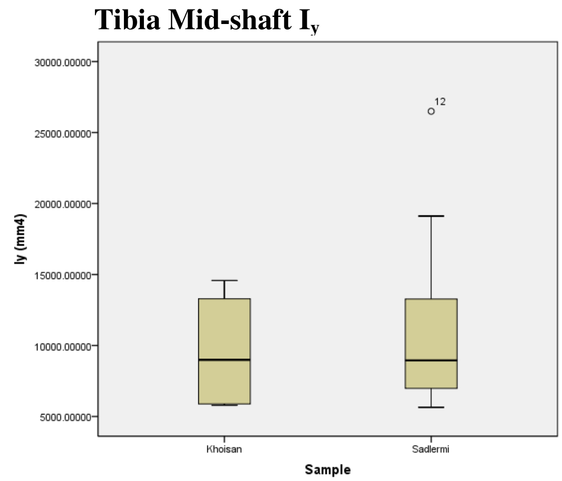

Figure 20. Tibial mid-shaft I_y box plots of Khoisan and Sadlermiut adults.

The Khoisan and Sadlermiut means for cortical area at the femur mid-shaft are almost identical yet the Sadlermiut mean is slightly larger. The difference in means for this property was not found to be significant. The box plot (Figure 21) shows a similar range of values for cortical area between the two samples. The Sadlermiut mean for total area at the femur mid-shaft is greater than the Khoisan mean. The difference was not found to be significant. The range of values for the Sadlermiut adults is much greater than the range for the Khoisan adults. The Sadlermiut sample contains an outlier of larger total cross-sectional area at the femur mid-shaft; without this outlier the Sadlermiut mean is lower ($\bar{x}$ = 592.35) yet still greater than the Khoisan mean. This individual showed no known pathology and was double checked for error. The MWU test with this alternate mean maintains a non-significant result. The Khoisan mean for percent cortical area is larger than the Sadlermiut mean but this difference was not found to be significant. The box plots (Figure 23) show a very small range of values for both the Khoisan and Sadlermiut. The Sadlermiut mean for I_y at the femur mid-shaft is greater than the Khoisan mean, however, the difference was not found to be significant. The I_y box plot (Figure 24) shows the Khoisan and Sadlermiut as having a similar range of values.

The means obtained for cortical area, total area, percent cortical area and AP bending at the femur mid-shaft are not in agreement with Hypothesis 2. The Sadlermiut and Khoisan means are almost identical for CA, TA and CA/TA and the MWU test shows that the difference between them is not significant. While the Sadlermiut mean for I_y was greater than the Khoisan mean, the MWU test did not find this difference to be significant. Therefore, the Sadlermiut and the Khoisan are similarly adapted to resisting femoral compressive and AP bending forces.

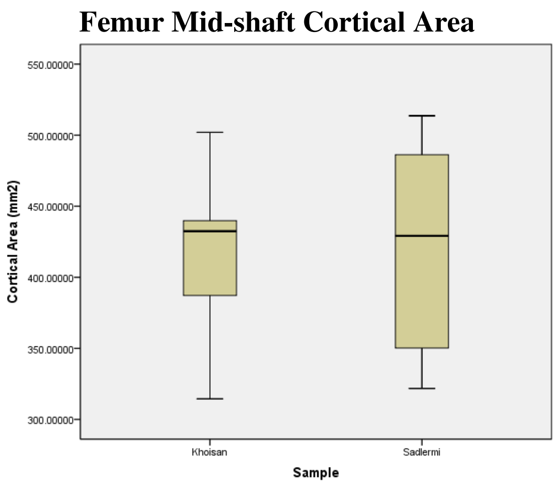

Figure 21. Femoral mid-shaft cortical area box plots of Khoisan and Sadlermiut adults.

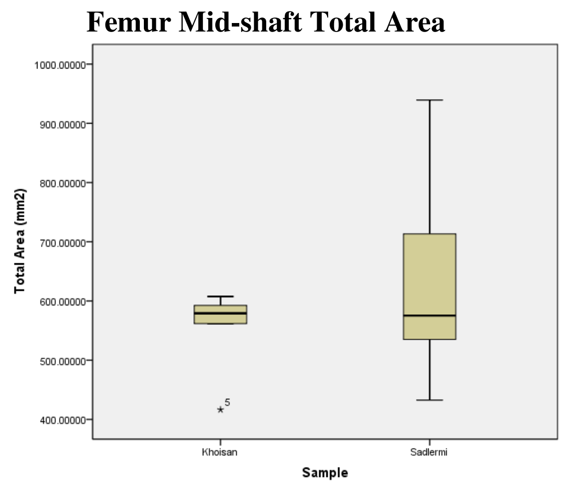

Figure 22. Femoral mid-shaft total area box plots of Khoisan and Sadlermiut adults.

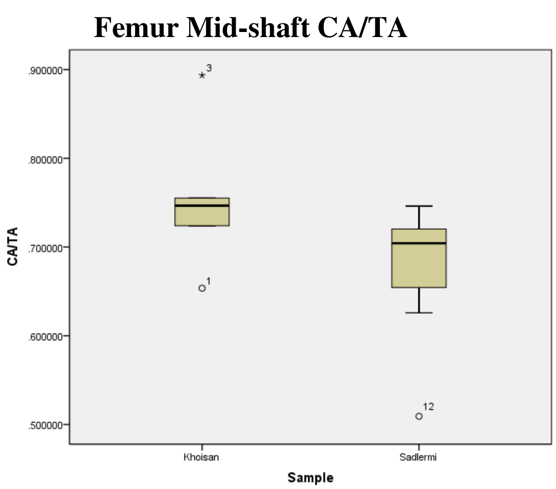

Figure 23. Femoral mid-shaft percent cortical area box plots of Khoisan and Sadlermiut adults.

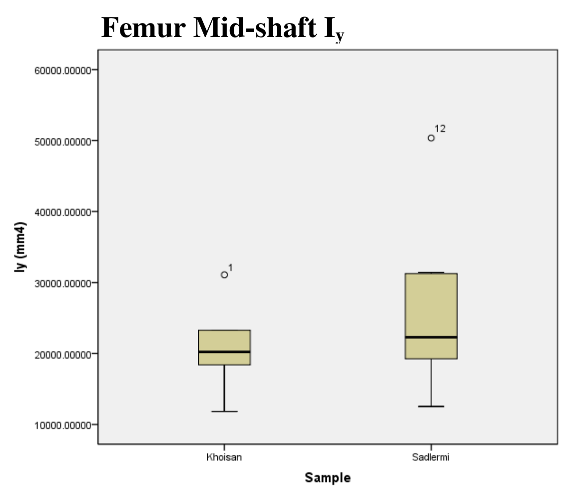

Figure 24. Femoral mid-shaft I_y box plots of Khoisan and Sadlermiut adults.

Hypothesis #3 – *Tibial and femoral ML bending strength and torsional bending strength is likely to be greater in the Sadlermiut compared to the Khoisan because of the strenuous lower limb involvement in sledging activities.* In order to examine tibial and femoral AP and torsional bending strength, the variables I_x and J are required. The calculated means and standard deviations of I_x and J for the tibia can be found in Table 7;

for the femur, see Table 8. The Sadlermiut means for I_x and J at the tibia mid-shaft are greater than the Khoisan means yet the MWU test did not find this difference to be significant. The I_x box plot (Figure 25) shows the Sadlermiut as having a much greater range of values than the Khoisan sample. The samples show a similar range in values on the J box plot (Figure 26).

The means and resulting MWU tests obtained for I_x and J at the tibia mid-shaft are not in agreement with Hypothesis 3. The Sadlermiut mean for I_x and J was found to be larger than the Khoisan mean yet the difference in these means was not found to be significant and therefore it cannot be said that the Sadlermiut were better able to resist tibial ML and torsional bending forces than the Khoisan.

Tibia Mid-shaft I_x

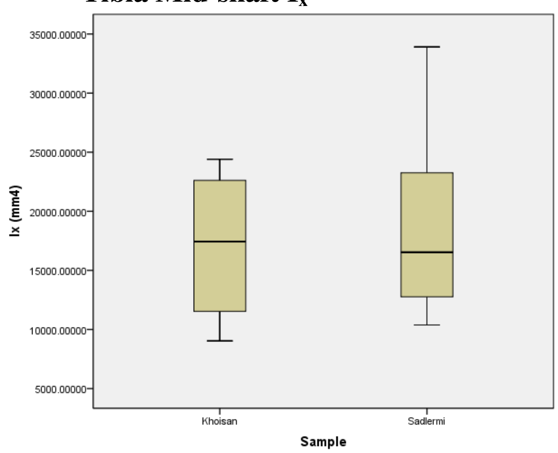

Figure 25. Tibial mid-shaft I_x box plots of Khoisan and Sadlermiut adults.

Tibia Mid-shaft J

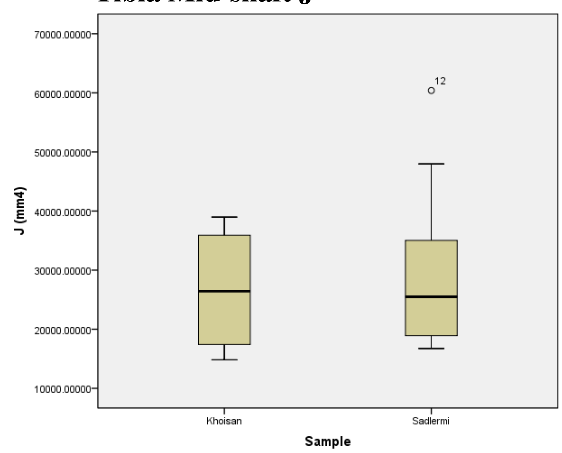

Figure 26. Tibial mid-shaft J box plots of Khoisan and Sadlermiut adults.

The Sadlermiut means at the femur mid-shaft are greater than the Khoisan means for I_x and J. However, the difference in means was not found to be significant for either variable. The I_x box plot (Figure 27) shows the Sadlermiut as having a much greater range of values than the Khoisan. The J box plot (Figure 28) shows the Sadlermiut as having a large range of values while the Khoisan range is very small.

The means obtained for I_x and J at the femur mid-shaft are not in agreement with Hypothesis 3. The difference between the Sadlermiut and Khoisan means for each property were not found to be significant. Therefore, the Sadlermiut and the Khoisan are similarly adapted to resisting femoral ML and torsional bending forces.

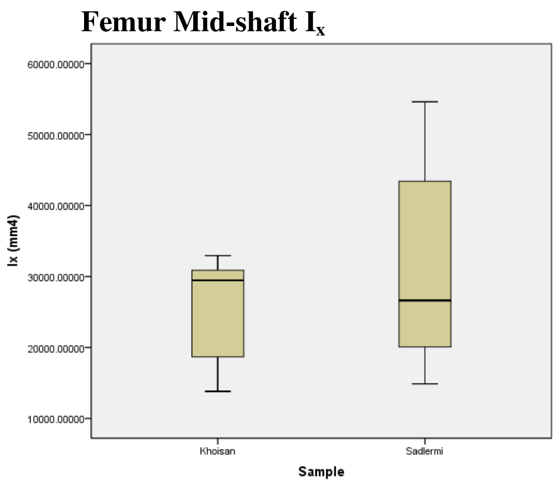

Figure 27. Femoral mid-shaft I_x box plots of Khoisan and Sadlermiut adults.

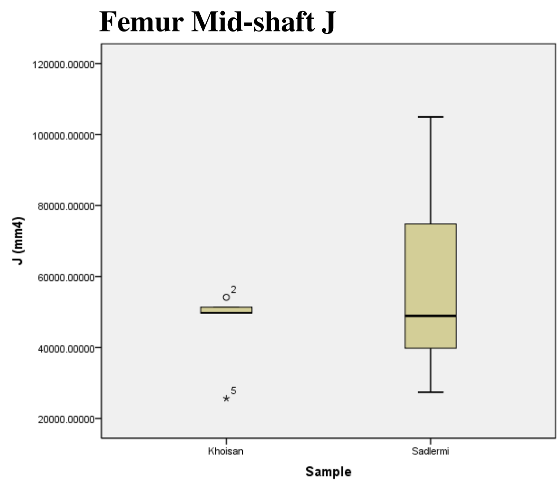

Figure 28. Femoral mid-shaft J box plots of Khoisan and Sadlermiut adults.

5.2 Ontogenetic results

The following results include data from the Khoisan and Sadlermiut individuals aged from neonate to 18 years. The purpose of presenting ontogenetic results is to reveal the process by which the adult end-point seen above is reached for each sample.

The following graphs display the Khoisan and Sadlermiut juvenile results for total area, cortical area, percent cortical area, second moments of area and polar moment of area of the available humeri, tibiae and femora. Medullary area is not presented here because it is a property that is only necessary for calculating cortical area. Biomechanical shape (I_x/I_y) is also not included because of the results of the Stirrup Court LCM vs EEM test which showed that biomechanical shape was not properly calculated by the EEM method alone (see section 4.5).

The ontogenetic graphs were created by plotting a given biomechanical property against age. Using age as the independent variable allows for a visualization of how each property changes throughout the growth period. This change is depicted in each graph by a LOESS growth curve for both sample populations, following Cowgill (2008). Unlike the adult results, a significance test could not be done for the juvenile results because no such test exists for LOESS curves.

5.2.1 *Upper limb*

This section will present the ontogenetic results for the humerus. The results will be given with consideration to the expectations outlined in section 3.4 for the second research question. It was hypothesized that overall humeral strength would be consistently greater in the Sadlermiut juveniles compared to the Khoisan juveniles. In order to test this, the four strength measurements will be looked at: compressive strength (as represented by cortical area, total area and percent cortical area), anterioposterior bending strength (second moment of area about the y-axis – I_y), mediolateral bending strength (second moment of area about the x-axis – I_x) and torsional bending strength (polar moment of area – J).

Hypothesis #4 – *Overall humeral strength (compressive, bending and torsional) will be greater in the Sadlermiut compared to the Khoisan throughout ontogeny. The difference between Khoisan and Sadlermiut humeral strength will become more pronounced as individuals begin to take part in the activities of adults.* To examine this hypothesis, each strength property (i.e. CA, TA, CA/TA, I_y, I_x, J) will be plotted against age in order to view how a given property develops throughout ontogeny.

The Khoisan and Sadlermiut LOESS curves for cortical area at the humerus mid-shaft are in agreement with Hypothesis 4. The Sadlermiut curve is above the Khoisan curve suggesting that the Sadlermiut juveniles were better able to resist compressive forces acting upon their humeri (see Figure 29). However, the Khoisan adults had a greater mean for humeral cortical area than the Sadlermiut in the results from Hypothesis 1. While there is not a great difference between the Sadlermiut and Khoisan juvenile curves, the Khoisan curve should be located above the Sadlermiut according to the results of Hypothesis 1.

The results for total cross-sectional area at the humerus mid-shaft are in agreement with Hypothesis 4 (Figure 30). The Sadlermiut curve lies above the Khoisan curve which suggests the Sadlermiut juvenile humeri were better able to resist compressive forces than the Khoisan juvenile humeri. This also corresponds with the adult results for humeral total area. The Sadlermiut LOESS curve for total area also displays the hypothesized incline which begins at 11 to 12 years and continues until adulthood.

The results for percent cortical area at the humerus mid-shaft were not as expected according to Hypothesis 4. The Khoisan curve was found to be higher than the Sadlermiut curve. However, this result corresponds to what was found for the adult humeri.

The Khoisan and Sadlermiut LOESS curves for I_y and I_x at the humerus mid-shaft are in agreement with Hypothesis 4 (Figures 32 and 33). Both samples show a steady increase in AP and ML bending strength until approximately age 8, with the Sadlermiut curve lying above the Khoisan curve. After 12 years, both populations exhibit a greater increase in AP and ML bending strength which persists throughout adolescence. However, the Khoisan increase begins earlier at about age 7.5 As hypothesized, this increase after adolescence is much greater in the Sadlermiut. This is in agreement with the adult humerus results for I_y and I_x.

The LOESS curves for torsional bending are also in agreement with Hypothesis 4 and the adult results for humeral torsional strength (Figure 34). The Sadlermiut curve is above the Khoisan curve which suggests that the Sadlermiut juvenile humeri were better adapted to resisting torsional bending forces than the Khoisan juvenile humeri. As hypothesized, the Sadlermiut also exhibit a greater increase in torsional bending strength after approximately age 12 compared to the Khoisan. This result matches the adult findings in which the Sadlermiut had significantly greater humeral torsional bending strength than the Khoisan.

Humerus Mid-shaft Cortical Area (Juveniles)

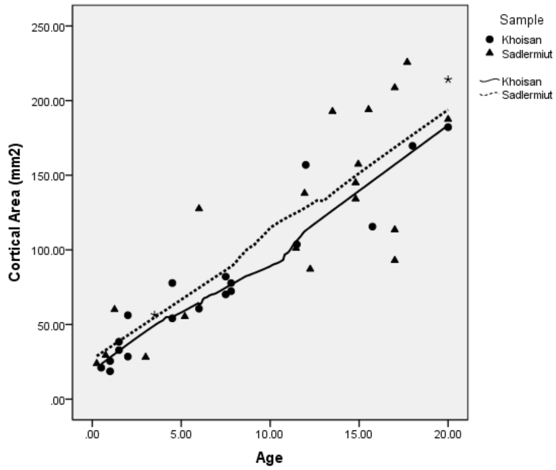

Figure 29. LOESS growth curves for humerus mid-shaft cortical area against age for Khoisan and Sadlermiut juveniles.

Humerus Mid-shaft Total Area (Juveniles)

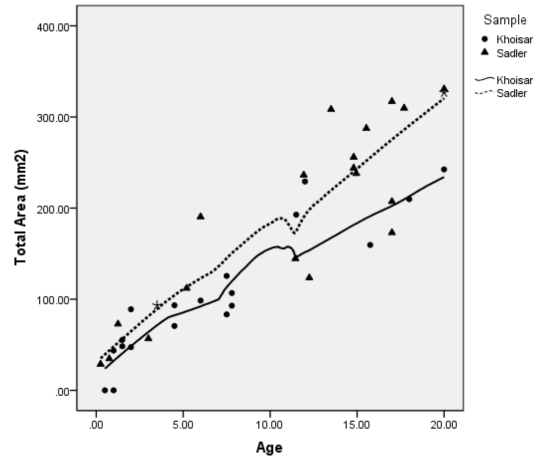

Figure 30. LOESS growth curves for humerus mid-shaft total area against age for Khoisan and Sadlermiut juveniles.

Humerus Mid-shaft Percent Cortical Area (Juveniles)

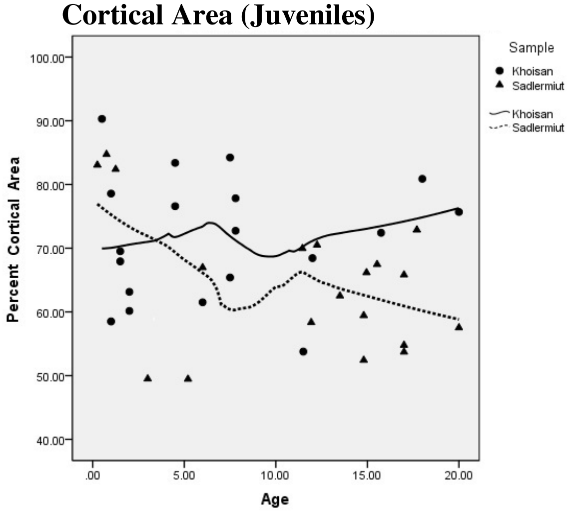

Figure 31. LOESS growth curves for humerus mid-shaft percent cortical area against age for Khoisan and Sadlermiut juveniles.

Humerus Mid-shaft I_y (Juveniles)

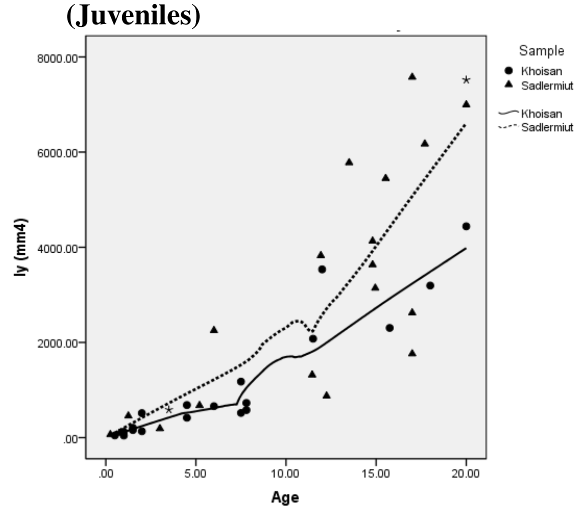

Figure 32. LOESS growth curves for humerus mid-shaft I_y against age for Khoisan and Sadlermiut juveniles.

Humerus Mid-shaft I_x (Juveniles)

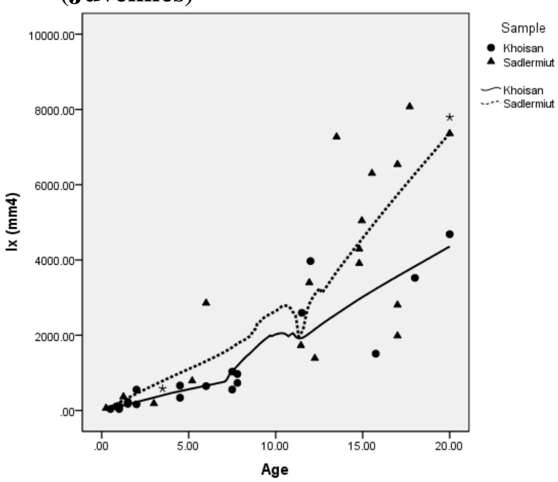

Figure 33. LOESS growth curves for humerus mid-shaft I_x against age for Khoisan and Sadlermiut juveniles.

Humerus Mid-shaft J (Juveniles)

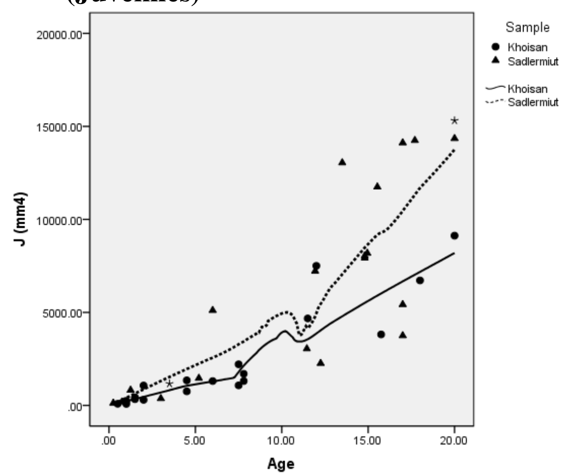

Figure 34. LOESS growth curves for humerus mid-shaft J against age for Khoisan and Sadlermiut juveniles.

5.2.2 *Lower limb*

This section will present the ontogenetic results for the tibia and femur. The results will be given with consideration to the expectations outlined in section 3.4 for the second research question. In order to test the hypotheses, four strength measurements will be looked at: compressive strength (as represented by cortical area and total area), anterioposterior bending strength (second moment of area about the y-axis – I_y), mediolateral bending strength (second moment of area about the x-axis – I_x) and torsional bending strength (polar moment of area – J).

Hypothesis #5 – *Tibial and femoral compressive strength and AP bending strength will be greater in the Khoisan compared to the Sadlermiut once Khoisan juveniles begin to take part in the activities of adults such as trekking over mountainous terrain.* To test this hypothesis, tibial and femoral CA, TA, CA/TA and I_y will be plotted against age for the mid-shaft locations.

Based on the cortical and total area results, Hypothesis 5 is incorrect. The samples display a similar growth trajectory for cortical area and total area at both the tibia and femur mid-shaft locations (Figures 35, 36, 39, 40). The Sadlermiut may have been better adapted to resisting compressive forces acting upon their femora than the Khoisan from about 15 years of age until adulthood. This is suggested by the greater incline in the Sadlermiut femur curves after age 15. From the cortical and total area results it appears that the Khoisan and Sadlermiut were similarly adapted to resisting compressive forces placed upon their lower limb. This result is in agreement with the adult results which found no difference in tibial and femoral CA and TA between the two samples.

The percent cortical area results, however, are in agreement with Hypothesis 5 (Figures 37 and 41). The Khoisan curve for this property is above the Sadlermiut curve throughout most of ontogeny. This result does not agree with the adult results which found no difference in tibial and femoral percent cortical area between the two samples.

It was also hypothesized that the Khoisan juveniles were better adapted to resisting AP bending forces acting upon their tibiae and femora than the Sadlermiut. The results show the reverse (Figures 38 and 42). The curves for I_y are similar at both the tibia and femur mid-shafts until approximately age 12 at which point both samples show an increase in slope which is more pronounced in the Sadlermiut. This result is not in agreement with the adult results which found no difference in tibial and femoral I_y between the two samples.

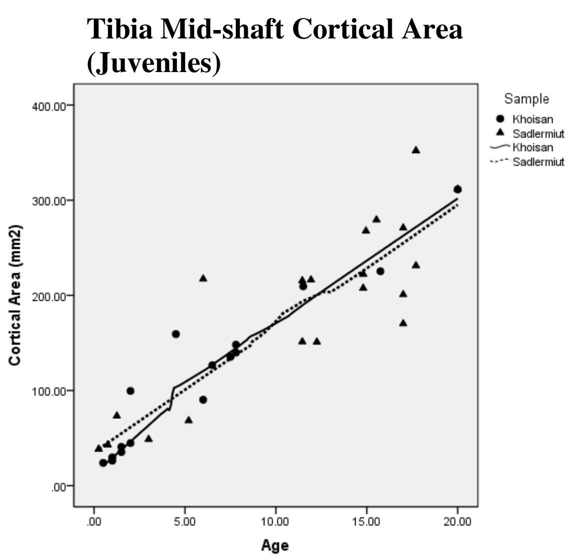

Figure 35. LOESS growth curves for tibia mid-shaft cortical area against age for Khoisan and Sadlermiut juveniles.

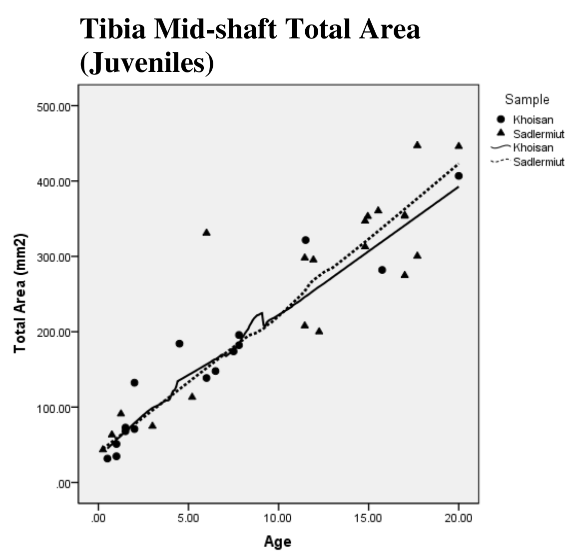

Figure 36. LOESS growth curves for tibia mid-shaft total area against age for Khoisan and Sadlermiut juveniles.

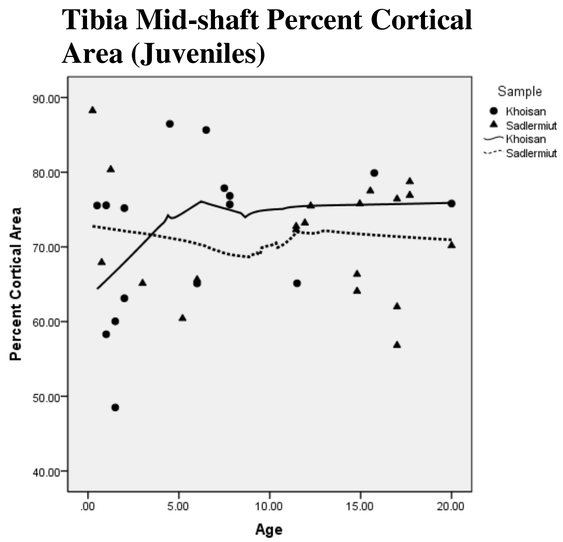

Figure 37. LOESS growth curves for tibia mid-shaft percent cortical area against age for Khoisan and Sadlermiut juveniles.

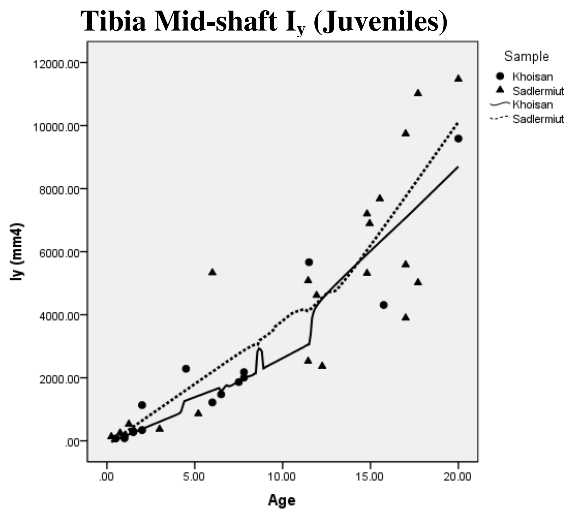

Figure 38. LOESS growth curves for tibia mid-shaft I_y against age for Khoisan and Sadlermiut juveniles.

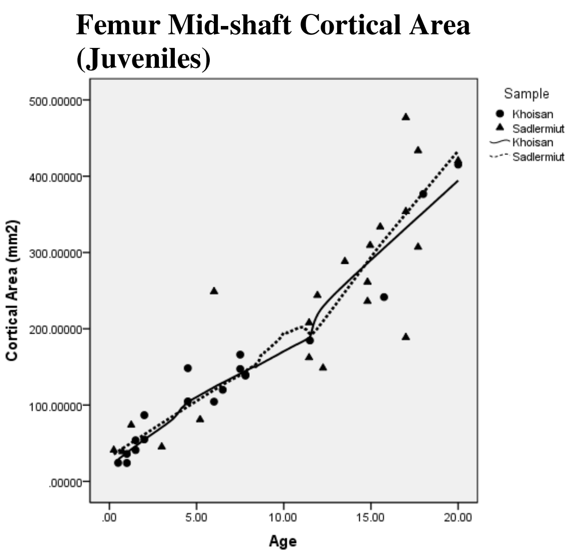

Figure 39. LOESS growth curves for femur mid-shaft cortical area against age for Khoisan and Sadlermiut juveniles.

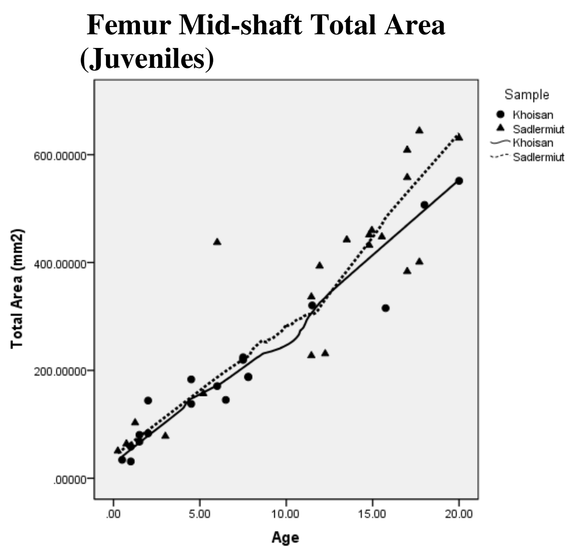

Figure 40. LOESS growth curves for femur mid-shaft total area against age for Khoisan and Sadlermiut juveniles.

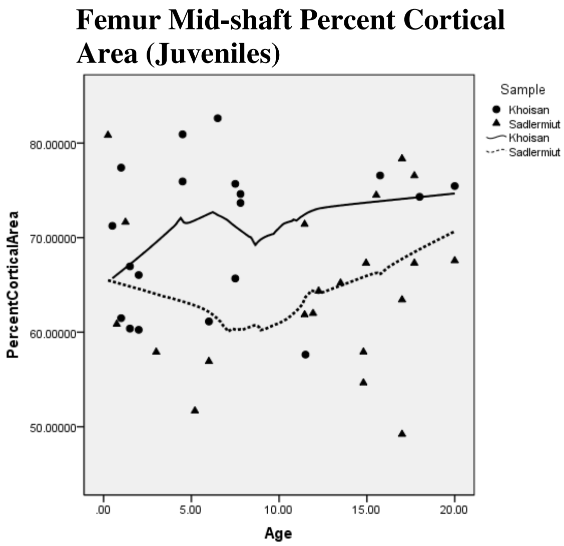

Figure 41. LOESS growth curves for femur mid-shaft percent cortical area against age for Khoisan and Sadlermiut juveniles.

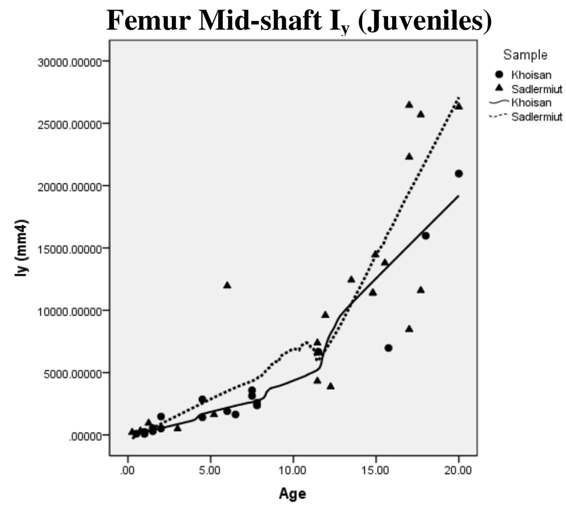

Figure 42. LOESS growth curves for femur mid-shaft I_y against age for Khoisan and Sadlermiut juveniles.

Hypothesis #6 – *Tibial and femoral ML bending strength and torsional bending strength will be greater in the Sadlermiut compared to the Khoisan once Sadlermiut juveniles begin to take part in the activities of adults, particularly sledging.* The properties I_x and J will be plotted against age for the tibia and femur mid-shafts in order to address this hypothesis.

At the tibia mid-shaft, the Khoisan and Sadlermiut I_x LOESS curves follow a similar pattern (Figure 43). At 11 years, the Khoisan curve increases in slope while the Sadlermiut slope does not increase until age 14. The Sadlermiut curve for J lies above the Khoisan curve throughout ontogeny, but the difference is minimal (Figure 44). At approximately age 14, the Sadlermiut curve becomes slightly steeper and maintains this rate until adulthood. The Khoisan curve does not exhibit any change in rate.

At the femur mid-shaft, the Sadlermiut LOESS curve for I_x lies above the Khoisan curve for the majority of ontogeny (Figure 45). At approximately age 12, both curves experience an increase in slope which persists until adulthood – this increase is greater in the Sadlermiut. The Sadlermiut curve for J lies above the Khoisan curve throughout ontogeny (Figure 46). At age 12, both samples exhibit an increase in slope which continues to adulthood. The increase is greater in the Sadlermiut sample.

To conclude, the tibial and femoral results for ML and torsional bending only somewhat agree with Hypothesis 6. The Sadlermiut juveniles demonstrated a greater ability to resist ML and torsional bending forces acting upon the lower limb compared to the Khoisan juveniles. However, the curves were very similar in all graphs, particularly the tibia graphs. Therefore, the overall difference between the two populations may not have been significant. If the differences were not significant, this would correspond to the adult results which found no difference in tibial and femoral ML and torsional bending strength between the Khoisan and the Sadlermiut.

Tibia Mid-shaft I_x (Juveniles)

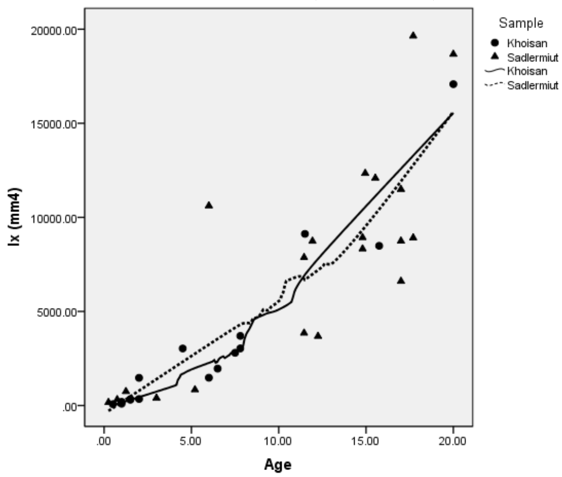

Figure 43. LOESS growth curves for tibia mid-shaft I_x against age for Khoisan and Sadlermiut juveniles.

Tibia Mid-shaft J (Juveniles)

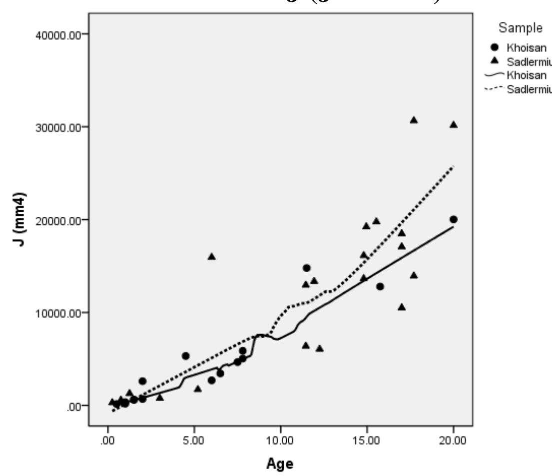

Figure 44. LOESS growth curves for tibia mid-shaft J against age for Khoisan and Sadlermiut juveniles.

Femur Mid-shaft I_x (Juveniles)

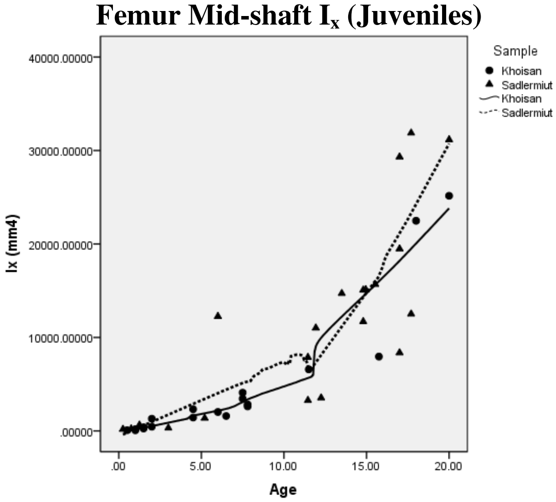

Figure 45. LOESS growth curves for femur mid-shaft I_x against age for Khoisan and Sadlermiut juveniles.

Femur Mid-shaft J (Juveniles)

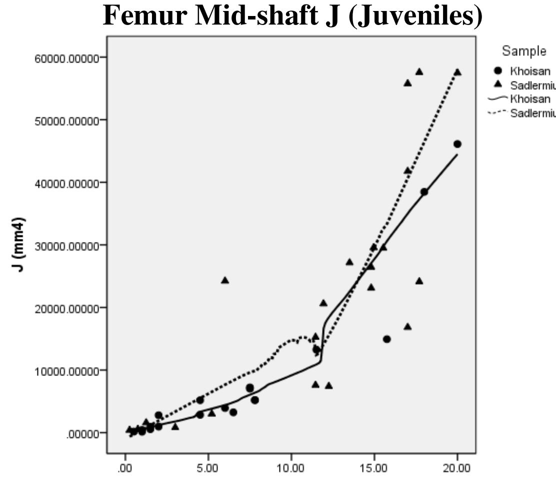

Figure 46. LOESS growth curves for femur mid-shaft J against age for Khoisan and Sadlermiut juveniles.

Table 11 is a summary of the ages at which the LOESS curves for each cross-sectional variable increase. Overall, the Sadlermiut juvenile increases in strength appear to occur later than the Khoisan increases in the humerus and tibia. The femora of both groups show an increase in all strength variables at age 12. Whether these increases can be attributed to the adoption of adult activity patterns or are a result of normal growth and development will be discussed further in the conclusion of Chapter 6.

Variable	*Sadlermiut*			*Khoisan*		
	Humerus	**Tibia**	**Femur**	**Humerus**	**Tibia**	**Femur**
CA	No inc.	No inc.	12	No inc.	No inc.	12
TA	11-12	No inc.	12	11-12	No inc.	12
%CA	No inc.	No inc.	No inc.	No inc.	No inc.	No inc.
Ix	12	14	12	12	11	12
Iy	12	12	12	7.5	12	12
J	12	14	12	12	No inc.	12

Table 11. Summary of LOESS curve age of increases (in years) for juvenile Khoisan and Sadlermiut results.

Chapter 6

6 Discussion

This chapter is a discussion of the results presented in Chapter 5. The organization of this chapter will follow the hypotheses and expectations from section 3.4 starting with the adult results and ending with the ontogenetic results. The discussion of each hypothesis will include the reason why the hypothesis was made, the result obtained and how the actual outcome compares to the expected outcome. When the actual and expected outcomes re not concordant, a discussion will be presented as to why a discrepancy occurred.

6.1 Adults

Hypothesis #1 – *Overall humeral strength (compressive, bending and torsional) will be greater in the Sadlermiut individuals compared to the Khoisan due to a greater involvement in strenuous upper body activities such as paddling and harpoon throwing.* This hypothesis is based on the ethnographic evidence showing that the upper body activities of the Sadlermiut were more strenuous than those of the Khoisan. The Sadlermiut relied on their upper body for transportation, particularly sledge use and umiak paddling (Merbs, 1983). Both Sadlermiut males and females took part in paddling – although males paddled more often than females – meaning that all Sadlermiut adults would have experienced significant torsional stresses being placed upon their humeri (Merbs, 1983). Harpoons were generally used for hunting large game such as whale, walrus, seal and polar bear (Mathiassen, 1927). Harpoon use was expected to have had a significant impact on Sadlermiut upper body strength (Merbs, 1983). The other Sadlermiut tools, such as scrapers, scraper blades and bone needles would have been used for clothing preparation – which was likely a female task (Merbs, 1983; Hawkey and Merbs, 1995). Preparing clothing would have been a strenuous activity, involving heavy lifting and continuous upper limb movement (Hawkey and Merbs, 1995). This activity is likely to have manifested in the humeri of female Sadlermiut.

The Khoisan ethnographic and archaeological evidence suggests a reduced mechanical level of upper body involvement relative to the Sadlermiut. The tools associated with the Khoisan suggest that the main upper body activities of the Khoisan were shellfish and root digging, spear use and bow use (Deacon, 1969; Deacon, 1972). Shellfish and root digging were almost exclusively a female activity while bow and spear use were restricted to males (Deacon, 1969; Deacon, 1972; Klein, 1974; Churchill and Morris, 1998; Sealy and Pfeiffer, 2000). Archaeological evidence suggests that small game was hunted and that traps may have been used at some sites (Klein, 1974). It was assumed that the hunting of small game and the use of traps in hunting would not place significant amounts of stress on the Khoisan humeri. Shellfish digging was also assumed to not be a particularly strenuous upper body activity.

The results showed that total cross-sectional area, AP bending strength and torsional bending strength were significantly greater in the Sadlermiut at the humeral mid-shaft. No significant difference was found for cortical area and I_x. The Khoisan mean for percent cortical area was found to be significantly greater than the Sadlermiut mean. Therefore, the actual humeral mid-shaft results matched the expected results for the variables TA, I_y and J, but not for CA, %CA and I_x.

While the results for total area, I_y and J follow what was expected, the cortical area, percent cortical area and I_x results do not. One possible explanation for this result is that the Sadlermiut experienced lower than expected compressive and ML bending forces acting upon their humeri. Because the Sadlermiut engaged in much more strenuous upper body activities than the Khoisan (e.g. paddling and harpooning vs. bow and arrow use and digging) the original assumption that the Sadlermiut activities would have placed compressive and ML bending strain upon their humeri is not supported. Paddling and harpoon use seem to have placed mainly AP and torsional bending forces upon the Sadlermiut humeri rather than compressive and ML bending forces.

It is also possible that the Khoisan displayed greater than expected humeral strength because three of the six Khoisan humeri used were of the right side whereas all Sadlermiut humeri were of the left side. A study by Stock and Pfeiffer (2004) showed that Khoisan had high bilateral asymmetry in the humeri with right side dominance, particularly with respect to J and TA. Therefore, the greater than expected cortical area and percent cortical area means exhibited by the Khoisan individuals in this study are likely to be a result of right hand dominance.

Despite the inclusion of three right humeri, the Khoisan data were found to have lower means for TA, I_y and J compared to the Sadlermiut. The Sadlermiut, like the Khoisan, are expected to have been right hand dominant (Merbs, 1983; Hawkey and Merbs, 1995). The Sadlermiut left humeri were probably found to be stronger in the aforementioned variables due to the fact that some of the Sadlermiut upper body activities would not have resulted in a side preference, such as paddling and sledging. Therefore, even the non-dominant side would have developed a resistance to bending and torsional forces among the Sadlermiut, as the results seem to suggest.

Hypothesis #2 – *Tibial and femoral compressive strength and AP bending strength will be greater in the Khoisan compared to the Sadlermiut due to a higher level of mobility in a more mountainous and rugged terrain.*. This hypothesis was proposed because the South African landscape is more rugged and varied than that of Southampton Island. In addition, the means of mobility used by the Sadlermiut mainly involved upper body use rather than lower body (i.e. sledging and paddling). It has been suggested that the level of mobility among both the Khoisan (Sealy and Pfeiffer, 2000) and the Sadlermiut (Comer, 1910; Mathiassen, 1927) was relatively low for hunter-gatherers. However, as Ruff (1999) has demonstrated in his study on Great Basin Amerinds, terrain has a greater effect on bone strength compared to distance travelled. For this reason, it has been hypothesized that the mountainous terrain of South Africa would have placed a higher level of compressive and AP bending stress upon the Khoisan lower limbs than the limestone plains of Southampton Island would have placed upon the lower limbs of the Sadlermiut.

The adult results for tibial and femoral compressive strength were not as expected according to Hypothesis 2. The difference between the Khoisan and Sadlermiut means was not found to be significant for CA, TA, CA/TA or I_y at both the tibial and femoral mid-shafts.

There are several possible reasons for why the actual outcome did not agree with the expected outcome. The most likely explanation pertains to the above statement that both groups had relatively low levels of mobility for hunter-gatherers (Comer, 1910; Mathiassen, 1927; Sealy and Pfeiffer, 2000). While terrain does effect the strain placed upon the lower limb, that strain may not be visible if mobility levels were not high enough. Therefore, the Khoisan and Sadlermiut may not have been participating in lower body activities with sufficient intensity to produce an osteogenic response which would explain the lack of difference seen in their lower limb strength.

Compressive and AP bending strength in the lower limb was hypothesized to be lower in the Sadlermiut compared to the Khoisan. It is possible that the lower body activities of the Sadlermiut may have been more strenuous than previously thought. It was assumed that paddling and sledging were the primary modes of transportation used by the Sadlermiut yet they may have also done a considerable amount of trekking, particularly when hunting. In order for trekking to have an effect on the compressive strength of the lower limb, the terrain would have to have been fairly rugged (Ruff, 1999). It is possible that the snow covered limestone planes of Southampton Island provided a great deal of resistance when walking. Also, interspersed through the plains are shed-like hills which are similar to plateaus yet smaller and with steeper sides (Manning, 1936). The Sadlermiut may have climbed these sheds to have a better view of the landscape and where possible game might be located. Climbing steep sheds and trekking through deep snow would place increase compressive and AP bending forces upon the Sadlermiut tibiae and femora.

A study by Stock and Pfeiffer (2001) on femoral and tibial robusticity showed the Khoisan as having greater lower limb robusticity than the Andaman Islanders. They concluded that this was because the Khoisan were terrestrially mobility with no marine mobility while the Andaman Islanders had low levels of terrestrial mobility and high levels of marine mobility. The Sadlermiut, as mentioned above, had high levels of marine mobility. Because the results show them as having comparable tibial and femoral strength to the Khoisan, this supports the hypothesis that the Sadlermiut also engaged in terrestrial mobility in higher than expected levels.

It is also possible that the Khoisan means were lower than expected because three of the four Khoisan tibiae and four of the six Khoisan femora were from female individuals. The Sadlermiut tibiae were divided evenly between males and females and the femora included four males and five females. It has been shown that in both groups males were much more mobile than females (Merbs, 1983; Stock and Pfeiffer, 2004). This is primarily due to male involvement in hunting activities which required travelling to find game. The greater ratio of females studied in the Khoisan adult sample compared to the Sadlermiut adult sample could have skewed the results into showing lower than expected values for lower limb strength in the Khoisan.

The final possible explanation for why the expected results were not achieved concerns adult body size. On average, the Sadlermiut were larger in body mass than the Khoisan. A larger body size would have placed greater compressive stress upon both the tibia and femur. The differences between the Sadlermiut and Khoisan means for CA, TA, and CA/TA were not found to be significant and the Sadlermiut were almost certainly experiencing a greater amount of compressive forces placed upon their lower limb due to their greater body mass when compared to the Khoisan. However, as previously noted, body mass would not have an effect on the variable I_y since this is a normalized variable.

Hypothesis #3 – *Tibial and femoral ML bending strength and torsional bending strength is likely to be greater in the Sadlermiut compared to the Khoisan because of the strenuous lower limb involvement in sledging activities.* This hypothesis was made because of sledge use among the Sadlermiut. While sledging requires upper body strength it is also necessary to maintain control of the lower limbs when sledging over uneven ground (Munn, 1919; Manning, 1936; Merbs, 1983). For the sledge driver to maintain their balance, their lower limbs would need to be locked in place and move side to side or rotate as the sledge bounces and turns. This motion would place ML bending and torsional bending stress upon the lower limb bones.

The adult results for tibial and femoral ML bending and torsional strength were not as expected according to Hypothesis 3. The difference between the Khoisan, Sadlermiut and Stirrup Court means was not found to be significant for I_x or J at the tibia and femur mid-shafts.

There are three possible explanations for why the actual results deviate from what was hypothesized. The first is that neither the Khoisan nor the Sadlermiut engaged in lower body activities with sufficient intensity to result in bone remodeling. The second is that mediolateral and torsional bending forces placed upon the Sadlermiut lower limb were not as great as previously thought. And third, mediolateral and torsional bending forces placed upon the Khoisan lower limb were greater than expected.

As stated above, the most likely explanation is that mobility levels were not high enough among the Khoisan and Sadlermiut to produce significant differences in their tibial and femoral diaphyseal structure. This is supported by ethnographic evidence which states that both groups were relatively sedentary for hunter-gatherers (Comer, 1910; Mathiassen, 1927; Sealy and Pfeiffer, 2000).

The second explanation for the lack of difference is that sledging may not have placed as much stress on the lower limb as was originally predicted. The other option is that the Khoisan were engaging in activities that placed greater than expected ML and torsional bending stress upon their lower limbs. However, the only activity from the ethnographic and archaeological records that seems likely to have placed ML and torsional bending forces upon the Khoisan lower limb is climbing over mountainous or rocky terrain. This is a possibility since Stock and Pfeiffer (2004) have previously claimed that the Khoisan would have regularly encountered rugged terrain in the coastal cape landscape.

6.2 Juveniles

Hypothesis #4 – *Overall humeral strength (compressive, bending and torsional) will be greater in the Sadlermiut compared to the Khoisan throughout ontogeny. The difference between Khoisan and Sadlermiut humeral strength will become more pronounced as* *individuals begin to take part in the activities of adults.* This hypothesis was generated from ethnographic and archaeological evidence which suggests that Sadlermiut upper body activities were more strenuous than Khoisan upper body activities. The Sadlermiut relied heavily upon upper body movement for transportation (i.e. sledging and paddling) and made use of harpoons which also would have put a high amount of strain on their humeri. With respect to Sadlermiut women, clothing preparation was a strenuous upper-body activity which required heavy animal skins to be held up while the skin was softened by biting. The main Khoisan upper body activities – bow and spear use and shellfish digging – would not have been as strenuous as the Sadlermiut activities.

The adult humerus results only partially agreed with Hypothesis 1. Total area, AP bending strength and torsional bending strength were found to be significantly greater in the Sadlermiut humeri but the mean differences in cortical area and ML bending strength were not found to be significant. Percent cortical area was found to be significantly greater for the Khoisan. It was concluded that these results suggested that the activities that the Sadlermiut engaged in did not produce the expected compressive or ML bending forces. This could be because activities, such as paddling, were largely uniplanar, involving bending in the AP plane.

To analyze the ontogenetic humerus results, the normal rate of growth needs to be known for the Khoisan and Sadlermiut (see section 3.1.3 and 3.2.4). A study by Thompson and Nelson (2000) showed that the Sadlermiut and the modern Euroamericans exhibited a similar trajectory for proportional femoral growth despite the fact that the Sadlermiut exhibit a much lower adult stature (Thompson and Nelson, 2000). This suggests that the rate of relative growth among the Sadlermiut was neither retarded nor accelerated when compared to modern Euroamerican groups. Both male and female Sadlermiut juveniles showed a lower rate of absolute growth when compared to modern Euroamerican children (Thompson and Nelson, 2000). Singer and Kimura (1981) found that the modern Khoi rate of absolute growth was lower than the growth rate for two sample populations: modern Americans and Namibians. Therefore, the rates of absolute growth for both the Khoisan and Sadlermiut are expected to be slower than Euroamerican rates of growth. Furthermore, because the Sadlermiut were slightly larger than the

Khoisan in their adult "end-product" it can be assumed that the Sadlermiut rate of growth would have been slightly faster than the Khoisan rate of growth.

The Khoisan and Sadlermiut exhibited almost identical rates of growth for cortical area at the humerus mid-shaft. The Sadlermiut curve was above the Khoisan curve throughout ontogeny but this may be due to the naturally larger body size of the Sadlermiut compared to the Khoisan. The similar rate of cortical area growth suggests that the Khoisan and Sadlermiut adult end-products would have been similar. This is in agreement with the adult cortical area results which showed no significant difference between the cortical area means of the Khoisan and Sadlermiut humeri.

The Khoisan and Sadlermiut juveniles showed similar values for total cross-sectional area at the humerus mid-shaft from birth to about 12 years. After 12 years, both samples exhibited a steady increase which was more pronounced in the Sadlermiut sample. The Sadlermiut slope after age 12 was greater than the Khoisan slope. It is possible that this increase was due to a normal increase in growth. As stated above, it is likely that the Sadlermiut rate of growth was slightly higher than the Khoisan rate and so a greater increase in Sadlermiut TA is not unexpected. In addition to this, a study by Y'edynak (1976) found that in a sample of Eskimo and Aleut juveniles, the females demonstrated a slight increase in humeral growth at about age 10 whereas the males experienced no significant increase in humeral growth. The increase in total area seen above in the Sadlermiut at age 12 does not coincide with Y'edynak's results for normal juvenile humeral growth increases. Therefore, it is possible that the Sadlermiut and Khoisan juveniles began engaging in more strenuous upper body activities at the age of 12. The result could also have been caused by a combination of activity and normal growth.

With respect to I_y, the Khoisan curve increased slowly until about seven and a half years at which point the slope increased slightly and continued in this manner until adulthood. The Sadlermiut curve was above the Khoisan curve and from birth to age 12 showed a greater increase than the Khoisan curve. This increase was further augmented in the Sadlermiut after age 12, as expected from their hypothesized higher rate of growth.

The Khoisan and Sadlermiut LOESS curves for I_x at the mid-shaft followed a similar trajectory from birth to 11 to 12 years with the Sadlermiut curve above the Khoisan curve. Both curves showed a steep incline after about 11 to 12 years which was more pronounced in the Sadlermiut sample, likely due to their higher rate of growth compared to the Khoisan. The torsional bending strength curves started similarly at birth yet the Sadlermiut curve increased at a more rapid rate than the Khoisan curve. The Khoisan showed a greater increase in torsional strength beginning at age nine whereas the Sadlermiut did not exhibit an increase for this variable until age 11.

The Sadlermiut curves for bending and torsional strength all increased after approximately 11 to 12 years. This increase could be due to the onset of puberty, but this does not seem to coincide with growth data (Y'edynak, 1976). Therefore, this increase was probably caused by juvenile participation in the activities of adults at around ages 11 and 12. Such activities would have included harpoon use, paddling and even some bow use among juvenile males, and clothing preparation, sewing and paddling for juvenile females.

The Khoisan curves for bending and torsional strength were more varied in their increases compared to the Sadlermiut curves. For I_y, the curve increased at seven and a half years yet for I_x the curve did not show an increase until about 11.5 years. The Khoisan curve for J experienced a great increase in slope at age nine followed by a steady increase after age 12. The relatively early increase in AP and torsional bending strength are not likely attributable to a normal growth spurt and could mean that Khoisan juveniles were attempting to copy the activities of adults earlier than the Sadlermiut children. The early emphasis on humeral AP and torsional bending strength corresponds to the findings of Stock and Pfeiffer (2004) who noted a high level of humeral AP strengthening in Khoisan females (from shellfish digging) and a high level of humeral torsional strengthening in Khoisan males (likely from spear throwing). The increase in ML bending strength at about 11.5 years likely represents the onset of puberty in some individuals in addition to increased participation in adult activities.

Hypothesis #5 – *Tibial and femoral compressive strength and AP bending strength will be greater in the Khoisan compared to the Sadlermiut once Khoisan juveniles begin to take part in the activities of adults such as trekking over mountainous terrain.* This hypothesis was made based on the landscape in which the Khoisan and Sadlermiut lived and the activities shaped by those environments. The South African Cape landscape is rugged at the escarpment and coast yet flat and covered in forest in the stretch of land between the escarpment and the coast. The karoo and grassland biomes, from which there are at least four Khoisan juveniles in this study, are fairly flat. Even so, it was assumed that the escarpment terrain would be much more rugged than any terrain experienced by the Sadlermiut on Southampton Island. Trekking would have been the most common activity – one that predominately involves compressive and AP bending forces acting upon the lower limb. Based on this information, it was hypothesized that the Khoisan children would display a greater resistance in the tibia and femur to compressive and AP bending forces compared to the Sadlermiut children.

The adult results for tibial and femoral compressive and AP bending strength were not as expected according to Hypothesis 2 – the adult counterpart hypothesis to Hypothesis 5. The difference between the Khoisan and Sadlermiut means was not found to be significant for any cross-sectional variable at both the tibial and femoral mid-shaft. The most likely explanation for why the expected results were not achieved is that both groups were more sedentary than previously thought. The Khoisan and Sadlermiut may not have been participating in lower limb activities with enough intensity to stimulate bone remodeling which would explain the lack of difference between the two groups. However, Stock and Pfeiffer (2001, 2004) have previously found the Khoisan lower limb to have been strengthened by movement across rugged terrain. If the Khoisan tibiae and femora were strengthened from trekking then there are two possible explanations for why the Sadlermiut have strength values for their lower limb that are comparable to the Khoisan: Either the Sadlermiut were more terrestrially mobile than previously thought or the larger average body mass of the Sadlermiut was the cause of their greater resistance to compressive forces acting upon their lower limbs (but not AP bending forces as the variable I_y is normalized).

The juvenile results for tibial and femoral compressive strength generally reflected the adult results for this property. The Khoisan and Sadlermiut LOESS curves for cortical area at the tibia mid-shaft were almost identical, both increased at a steady, unchanging rate throughout ontogeny. The Khoisan and Sadlermiut curves for total cross-sectional area at the tibia mid-shaft were also almost identical. It is likely that the larger body size of the Sadlermiut caused greater compressive forces to be placed upon their tibiae. However, there was no sudden increase in the Sadlermiut curve which would indicate the onset of puberty and the development of the stocky adult form. The fact that neither curve showed a change in the cortical or total area slope indicates that the onset of puberty did not result in a sudden increase in cortical and total area in the lower limb. It further indicates that when the juveniles of both populations began taking part in the activities of adults, the compressive forces acting upon their tibiae were not significant enough to incite a biomechanical response.

For percent cortical area at the tibia mid-shaft, the Sadlermiut curve began higher than the Khoisan curve yet the Khoisan curve surpassed the Sadlermiut curve at about age four. After this point, both curves remained fairly horizontal and experienced little change throughout ontogeny. The Khoisan showed greater values for percent cortical area than the Sadlermiut most likely because of their lower adult total area values – presumably a result of their smaller body size. The fact that both curves showed little change throughout ontogeny again indicates that puberty did not produce a sudden increase in this property and that participation in the activities of adults did not incite increased development of compressive strength in the tibiae of both populations.

The Khoisan and Sadlermiut LOESS curves for cortical area and total area at the femur mid-shaft followed the same pattern: a steady increase from birth until approximately age 11 at which point the slope increased and continued in this manner until adulthood. The Sadlermiut increase was slightly greater than the Khoisan increase which corresponds to the above assumption that the Sadlermiut rate of growth was greater than the Khoisan rate of growth. This increase in compressive strength was not seen in the tibia. It was concluded from the juvenile tibia results that both the onset of puberty and participation in the activities of adults did not cause significant change to occur with regards to the development of compressive strength. Yet, this conclusion does not appear to extend to the femur. It is possible that the increase at age 11in femoral compressive strength is attributable to the onset of puberty; Y'edynak (1976) found that the femur of Eskimo and Aleut children experienced an increase in growth at about age 10 for both males and females.

The Sadlermiut curves for I_y at the tibia and femur mid-shaft were above the Khoisan curves throughout ontogeny. Both sample curves increased steadily from birth to age 12 at which point a greater increase occurred; the Sadlermiut increase in AP bending strength was greater than the Khoisan increase. Because the Sadlermiut curve was above the Khoisan curve for both the tibia and the femur, this means that the Sadlermiut juveniles were better adapted to resisting AP bending forces than the Khoisan juveniles throughout ontogeny. The greater Sadlermiut increase could be a result of their higher rate of growth when compared to the Khoisan. Another explanation is that the Sadlermiut engaged in terrestrial mobility in higher levels than was previously thought which would have caused their lower limbs to experience greater AP bending. It is also possible that sledging contributed to this AP bending strain.

In both the tibia and the femur, the Sadlermiut and Khoisan curves for AP bending strength show an increase at about 12 years. This increase could either be from the onset of puberty or participation in the activities of adults. According to Y'edynak's (1976) findings, the age of 12 would be slightly later than expected to see an increase in Sadlermiut femur growth. Therefore, the increase at around age 12 in Sadlermiut and Khoisan femoral AP bending strength is more likely caused by juvenile adoption of adult activities. However, the increase in growth at the tibia was found to occur at about age 14 for males and around 12 for females (Y'edynak, 1976). Therefore, it is possible that the increase in tibial strength at 12 years was caused by normal growth patterns.

Another point of note for AP bending strength in the Khoisan and Sadlermiut is that the femur showed a greater increase for both samples around the age of 12 compared to the tibia. This implies that the femur experienced greater AP bending forces than the tibia and therefore exhibited a greater adaptation to resisting those forces. The femur also demonstrated a greater resistance to compressive forces compared to the tibia for both samples. The explanation could be that terrestrial mobility caused the femur to experience higher levels of compressive and AP bending strain than the tibia. This idea is supported by a paper by Stock and Pfeiffer (2001) in which they state that the proximal elements of the limb appear to be more responsive to habitual loading than their distal counterparts. In the case of the lower limb, this would mean that the femur is more responsive than the tibia – an idea that is supported by the results of this thesis.

Hypothesis #6 – *Tibial and femoral ML bending strength and torsional bending strength will be greater in the Sadlermiut compared to the Khoisan once Sadlermiut juveniles begin to take part in the activities of adults, particularly sledging.* This hypothesis was made based on the geography of Southampton Island. This arctic landscape is mainly composed of limestone plains which are usually snow covered. Smooth, rolling hills make the landscape ideal for sledging which would have caused their lower limbs to experience ML and torsional bending forces. The lower-body activities of the Khoisan were not expected to have placed great ML and torsional bending strains upon their tibiae and femora given the nature of the South African cape environment. Based on this information, it was hypothesized that the Sadlermiut children would display a greater resistance in their tibiae and femora to ML and torsional bending forces relative to the Khoisan children.

The adult results for tibial and femoral ML and torsional bending strength were not as hypothesized. The Sadlermiut means for I_x and J at both the tibial and femoral mid-shafts were found to be larger than their respective Khoisan means yet the means were not significantly different. Based on these results, the Sadlermiut and the Khoisan adults were similarly adapted to resisting femoral ML and torsional bending forces.

The juvenile results for tibial and femoral ML and torsional bending strength generally followed the pattern seen in the adults but provided some additional insights into the timing of such developments. At the tibia mid-shaft, the Sadlermiut curve for I_x was above the Khoisan curve from birth to approximately age 11 at which point the Khoisan curve showed a greater increase and surpassed the Sadlermiut curve. The

Sadlermiut sample did not show an increase in tibial ML bending strength until about age 14. The two curves were similar and differed only in timing for I_x. The Khoisan may have taken part in adult activities which caused ML bending forces at an earlier age than the Sadlermiut – approximately 11 years for the Khoisan and 14 years for the Sadlermiut. These results suggest that the Khoisan may have experienced greater ML bending forces acting on the lower limb than was previously thought. It is possible that the rugged terrain in which the Khoisan lived placed high ML bending forces on their tibia. Alternately, sledging may not have caused ML bending to occur in levels that would stimulate bone production in the Sadlermiut tibiae.

For torsional bending strength (J) at the tibia mid-shaft, the Sadlermiut curve was above the Khoisan curve throughout ontogeny. Once again around age 14 the Sadlermiut curve became slightly steeper and maintained this rate until adulthood, yet the Khoisan slope for J did not exhibit any change. These results show that the Sadlermiut experienced greater levels of torsional strain on their tibiae than the Khoisan. Therefore, sledging may have placed torsional strain upon the tibia rather than ML bending strain. The results for J also suggest that the both the onset of puberty and the adoption of adult activities did not lead to a sudden increase in tibial torsional strength in the Khoisan juveniles.

As noted, the increase in ML and torsional bending strength in the Sadlermiut occurred at about age 14 for both variables. This age is too late to be the female Sadlermiut growth spurt yet the Aleut and Eskimo males showed a slight increase in tibial growth at age 14 in the study by Y'edynak (1976). Either the Sadlermiut male growth spurt is the cause of the observed increase or activities which placed ML and torsional bending forces upon the tibia were introduced to Sadlermiut juveniles at age 14. An increase due to activity is in agreement with vertebral compression studies done by Merbs (1974, 2002a,b, 2004). Merbs has found that Sadlermiut juveniles possess vertebral compression fractures that have been linked to sledging activity at adolescence (i.e.13 to 17 years) (Merbs, 2002). These fractures occur in both males and females suggesting that both sledge driving and riding caused vertebral stress to occur. Therefore, it is reasonable to assume from the results of this study that both juvenile males and females took part in sledge driving and riding around the age of 14.

At the femur mid-shaft, the Sadlermiut LOESS curve for I_x was above the Khoisan curve for the majority of ontogeny. At approximately age 12, the Sadlermiut slope increased until adulthood. The Khoisan curve showed a similar, less steep slope incline which began at the same age. The Sadlermiut increase in slope was likely greater because of their higher rate of growth. The Sadlermiut curve for torsional strength was above the Khoisan curve at the femur mid-shaft. From birth to about age 12 both samples showed a slow rate of increase, the Sadlermiut rate was slightly greater than the Khoisan rate. After age 12, both samples exhibited an increase which continued to adulthood. The increase was greater in the Sadlermiut sample. There are two main points to address from the femur results: the differences between the two samples and the differences within each sample when compared to the tibial results for the same properties.

The differences between the Khoisan and Sadlermiut femoral ML and torsional bending strength were similar to what was seen in the tibia. There was not an apparent difference between the curves for ML bending strength which suggests that the Khoisan were experiencing greater than anticipated femoral ML bending forces, possibly from trekking. The Sadlermiut femora were better adapted to resisting torsional forces when compared to the Khoisan – this matches the tibial results for torsional strength.

There are several factors to consider for each sample when comparing femoral and tibial ML and torsional bending strength. First, it was discussed above that there was a clear difference in the compressive and AP bending forces experienced by the tibia and the femur; the same appears to be true of ML and torsional bending forces. The femur exhibited a greater ability to resist ML and torsional bending forces than the tibia in both sample populations. This difference was most notable after the samples underwent their respective increases in bending strength; these increases have so far been assumed to represent either the adoption of adult activities or normal growth spurt patterns. The point at which the slope increased was better defined in the femur and the incline itself was greater for both ML and torsional bending strength in both populations when compared to their respective tibia results. This would mean that the femur was more affected than the tibia by activities that caused ML and torsional bending forces to be placed upon the lower limb. In addition to this, the Sadlermiut femora experienced an increase in ML and torsional bending strength earlier than the tibiae. The increase in femoral strength occurred at about age 12 whereas the increase in tibial strength occurred at around age 14. It is possible that adult activities which caused ML and torsional bending forces (e.g. sledging) were introduced to children at a younger age than previously thought (i.e. 12 years). Perhaps the tibia was not experiencing as much strain as the femur in these activities and the subsequent bone strengthening was delayed in this element. It could also be that the greater muscle mass of the femur placed a greater strain upon this element when compared to the tibia. This corresponds to the suggestion made by Stock and Pfeiffer (2001) that proximal limb elements are more responsive to mechanical loading than their distal counterparts.

The Khoisan results also suggested that activities which caused ML and torsional bending forces had a greater effect on the femur when compared to the tibia. The curve for Khoisan ML bending strength showed a greater increase in the femur when compared to the tibia. In addition to this, the Khoisan curve for tibial torsional strength showed no increase at all whereas the femur curve showed a clear increase in slope at about age 12. This information coincides with the Sadlermiut tibia and femur results.

To conclude, the following interpretations were made regarding which increases in juvenile strength can be attributed to the adoption of adult activities and which cannot (refer back to Table 11 if needed). The increases in Sadlermiut humeral strength all took place around age 12. Growth data suggest that the Sadlermiut experienced a humeral growth spurt at age 10 for females and no growth spurt for males. Therefore, the increase in humeral strength at 12 seen in this study is hypothesized to be too late to represent the expected growth spurt and may be attributable to the onset of adult activities. The Khoisan showed similar results in the timing with the exception of AP bending strength which increased at age 7.5. This increase is very likely attributable to the onset of adult activities such as shellfish digging.

The Sadlermiut juvenile tibiae were found to increase in strength between the ages of 12 and 14. This is concordant with growth data which indicates that a Sadlermiut increase in tibial growth would have occurred at about age 14 for males and 10-12 for females. The Khoisan showed an increase in humeral strength between ages 11 and 12.These times of increase match what would be expected of normal growth patterns and, therefore, it cannot be concluded that these increases were a result of activity.

Both the Sadlermiut and Khoisan juvenile femora were found to increase in strength at around age 12. This age of increase is slightly later than expected of normal femora growth patterns and may be attributed to activity yet this cannot be concluded with certainty.

Chapter 7

7 Conclusion

The goal of this research was to examine and compare the biomechanical adaptations of two different climate-adapted populations and how and when those adaptations came about during growth. The populations studied were the Later Stone Age foragers from South Africa known as the Khoisan and the now extinct Sadlermiut Inuit from Southampton Island, Canada. The Khoisan were adapted to a temperate-climate environment while the Sadlermiut were adapted to a cold-climate environment. The different landscapes produced by these climates were assumed to result in different behavioural patterns adopted by the people living in those environments. These behavioural patterns would likely have stimulated morphological changes in the long bones via stress caused by mechanical loading.

In order to examine the relationship between behavioural patterns and long bone morphology in the two sample populations, cortical bone measurements were recorded at three diaphyseal locations on the Sadlermiut and Khoisan humeri, tibiae and femora using biplanar radiographs. The result was a reconstruction of a cross-section from which biomechanical strength properties could be calculated. The accuracy of this method was tested using biplanar radiographs and diaphyseal moulds from a sample of 19th century peri-urban residents of London, Ontario, Canada excavated from the Stirrup Court Cemetery. The radiograph method (EEM) and the mould method (LCM) were found to produce similar results for all cross-sectional geometric properties except biomechanical shape. Therefore, biomechanical shape (I_x/I_y) was not included in the Khoisan and Sadlermiut analysis.

Ethnographic and archaeological data on the Sadlermiut and Khoisan were used to make predictions about how their respective activities affected their long bone diaphyseal structure. These predictions were tested using geometric calculations from mid-shaft cross-sectional data. This analysis was done for both adults and juveniles of the two samples. The juveniles were relied upon to provide insight into the timing of biomechanical adaptation to activity and the process by which the adult end-product was reached, particularly the timing of the onset of adult activities. A summary of the main discussion points will be provided within this conclusion, following the hypotheses outlined in section 3.4.

7.1 Biomechanical analysis

The results for the Khoisan and Sadlermiut adult humeri only partially corresponded to expectations based on their known activity patterns. Ethnographic and archaeological evidence suggests that the Sadlermiut engaged in much more strenuous upper body activities than the Khoisan. The Sadlermiut humeri were significantly stronger than the Khoisan humeri for the variables TA, I_y and J. No significant difference was found for the variables CA and I_x. Percent cortical area was significantly greater in the Khoisan humeri. These results suggest that the upper-body activities of the Sadlermiut, specifically paddling, caused greater AP and torsional bending than compressive and ML bending than the Khoisan experienced.

The tibia and femur results for the Khoisan and Sadlermiut adults indicated that there was no difference in compressive and AP bending strength between the two populations. Stock and Pfeiffer (2001) found that the Khoisan, who were terrestrially mobile, had significantly greater lower limb strength than the Andaman Islanders, a highly marine mobile group. It was expected that when compared to the Sadlermiut, a group that engaged in marine mobility, the Khoisan lower limbs would be significantly stronger in the variables most affected by walking and running: compressive and AP bending strength. Four possible explanations were discussed to address the actual outcome of the biomechanical analysis: (1) The Khoisan and Sadlermiut may not have been participating in lower body activities with sufficient intensity to produce an osteogenic response. (2) The higher percentage of adult females used in the Khoisan sample lowered the Khoisan means for TA, CA and I_y since females of both populations were known to be less mobile than the males. (3) The Sadlermiut were more terrestrially mobile than was previously assumed. (4) The greater average body mass of the Sadlermiut contributed to the compressive forces experienced by their lower limbs. It is possible that the outcome can be attributed to a combination of the above explanations.

These results could have been improved by separating the male and female values and by standardizing for body size. However, it was not possible to separate males and females in this study due to the small sample size. Furthermore, body size was not standardized for because the necessary measurements were not available for all individuals; this would have caused individuals for whom body size could not be estimated to be excluded from the study – an act that would further reduce an already small sample size. Additionally, the only variables studied that would be affected by body size are total area and cortical area. Second moments of area and polar moments of area and normalized and, therefore, unaffected by body mass.

The adult tibia and femur results for ML and torsional bending strength produced no significant difference between the Khoisan and Sadlermiut for these variables. It was expected that sledge use would have caused the Sadlermiut lower limb to be better adapted to resisting ML and torsional bending forces than the Khoisan lower limb. There are two possible explanations for why the expected result was not achieved: (1) Khoisan trekking placed higher than expected ML and torsional bending forces upon their lower limbs. (2) Sledging did not cause significant ML and torsional bending forces to be placed upon the Sadlermiut lower limb. Therefore, either the activity patterns of both populations were not causing strain to occur in the expected directions or the results are not attributable to activity but to some other factor (see section 2.2).

The Sadlermiut and Khoisan juvenile humerus results generally provided the expected ontogenetic trajectory that led to the patterns seen in the adults. The samples displayed almost no difference in their LOESS curves for cortical area and the curves for I_x were similar until around 12 years at which point the slope increased for both samples yet the Sadlermiut slope was greater. The curves for total area were the same until age 12 when both samples showed an increase which was of greater magnitude in the Sadlermiut. The greater increase in Sadlermiut TA may be attributed to the adoption of adult activities yet there is no corresponding increase seen in CA. For I_y, the sample curves were similar until about age 7.5 at which point the Khoisan showed an increase in slope. The Sadlermiut slope did not increase until around age 12. The Khoisan increase in I_y occurred at an age hypothesized to be too young to be attributed to a humeral growth spurt and could have been a result of strenuous activity – most likely digging. The Khoisan curve for J increased greatly in slope at age nine while the Sadlermiut curve experienced a decline at age 10 followed by a steep incline at about age 11. The Khoisan increase in J, which occurs at a younger age than the Sadlermiut, could potentially be explained by the adoption of adult activities – spear throwing is known to have placed torsional bending forces upon the Khoisan humeri (Stock and Pfeiffer, 2004). The Sadlermiut increase in J occurs earlier than the expected humeral growth spurt (Y'edynak, 1976). Therefore, it is possible that the increase in torsional humeral strength is attributable to the adoption of adult activity.

The juvenile results for tibial compressive and AP bending strength showed almost no difference between the Khoisan and Sadlermiut. The curves for CA and TA maintained a similar steady slope until adulthood. The curves for I_y were similar and both showed an increase at about age 12. The juvenile results for femoral compressive strength showed almost no difference between the Khoisan and Sadlermiut. Both curves experienced an increase at about age 12 which was slightly greater in the Sadlermiut. The increase in femoral AP bending strength also occurred at approximately age 12 in both samples yet this increase was much greater in the Sadlermiut juveniles. Based on previous studies by Stock and Pfeiffer (2001, 2004) it was expected that the Khoisan would have much greater compressive and AP bending strength in their lower limbs than the Sadlermiut. Three possible explanations were proposed to address the similarities seen between the samples: (1) The Khoisan and Sadlermiut may not have been participating in lower body activities with sufficient intensity to produce an osteogenic response. (2) The Sadlermiut were more terrestrially mobile than was previously assumed. (3) The greater average body mass of the Sadlermiut contributed to the compressive forces experienced by their lower limbs. In addition to this, the slope increases for all variables occurred at the same age for both populations. Either terrestrial mobility increased at around age 12 for both populations or normal tibial and femoral growth spurts occurred at this time.

The juvenile trajectories for tibial and femoral ML and torsional bending strength led to what was seen in the adult results. The Sadlermiut and Khoisan ML and torsional bending strength differed only in the timing of their respective increases. The Sadlermiut showed an increase in I_x and J at approximately age 14 for the tibia and age 12 for the femur. The Khoisan experienced an increase in I_x at age 11 in the tibia and age 12 in the femur while J exhibited no increase in the tibia and an increase at age 12 in the femur. It was concluded that sledging did not generate ML bending forces in amounts that would have stimulated bone production. However, the Khoisan showed very minimal slope increases for J compared to the Sadlermiut which may indicate that the adoption of sledging caused significant torsional forces to be experienced by the Sadlermiut lower limb. The timing of the Sadlermiut increases in J coincide with osteological studies done by Merbs (1974, 2002a,b, 2004) in which he found that Sadlermiut juveniles were taking part in sledging at adolescence.

The conclusions made from Hypotheses 1 through 6 can now be used to address Hypothesis 7: *There are differences in the biomechanical adaptations of the Khoisan and Sadlermiut samples which correspond appropriately to what is known about their respective activity patterns from archaeological records.* Overall, the results of this study were not as predicted yet some of the results can still be linked to activity patterns. The adult humeral results showed no difference between the samples for CA and I_x, which were both predicted to be greater in the Sadlermiut. However, it was later suggested that paddling would not have caused significant compressive and ML bending forces to be experience by the Sadlermiut humeri. Paddling was likely to have primarily caused AP and torsional bending which were found to be significantly greater in the Sadlermiut humeri. The adults displayed no significant difference in all strength properties for both the tibia and the femur. However, this may not have been because activity did not cause bone remodeling but rather because the level of activity was not intense enough to produce an osteogenic response.

The Khoisan and Sadlermiut juvenile humeral curves were similar for every variable and all increases in strength occurred at times which could not be distinguished from normal growth and development. The only increase in humeral strength that could have been attributed to the adoption of adult activities was I_y which increased in the Khoisan sample at about 7.5 years. The Khoisan and Sadlermiut juvenile tibial and femoral curves were also very similar which was not expected in a comparison of a terrestrially mobile group and a marine mobile group. However, as stated above, it is possible bone remodeling would have occurred in the juvenile lower limb if the lower limb activities were more intense.

Although the results of this biomechanical analysis did not correspond with known activity patterns this does not mean that activity had no effect on Khoisan and Sadlermiut long bone structure. There are several possible reasons why the majority of the results showed no significant difference between the Khoisan and the Sadlermiut: (1) The intensity level and duration of activities differed from what was expected. (2) The assumptions made about how strain occurred in the activities were incorrect. (3) A small sample size led to erroneous results. (4) The unknown genders and sexes of the juveniles led to a more generalized result which did not accurately represent the populations. (5) The larger Sadlermiut body size and the inability to standardize for body mass in this study influenced the lower limb results for total and cortical area.

7.2 Future research

While this study did not find the expected correlations between activity and long bone structure, this is not to say that such a relationship does not exist. There are many obstacles to overcome in future studies of ontogenetic biomechanics. For instance, in this study it was assumed that the juvenile activities would mimic the activities of the adults once children were able to begin to participate in such behaviours. A further investigation into the behaviours of hunter-gatherer children may be helpful in reconstructing a more accurate picture of juvenile activity patterns. Furthermore, interpretations of bone structure could be made more accurate with additional lines of evidence such as isotopic data or musculoskeletal markers of stress.

In this thesis, the juveniles were not separated by sex as several individuals could not be assigned as male or female. However, this made interpreting the results difficult because growth spurts occur at different times for males and females. It was impossible to tell from these results which increases in diaphyseal strength could be attributed to activity and which were normal growth spurts. Future ontogenetic biomechanical studies would benefit from separating males and females in the analysis of strength properties. The nature of sub-adult remains would not always allow for the determination of sex in archaeological populations, therefore, ontogenetic biomechanical research in anthropology should extend to modern populations for whom the sex of sub-adults is known. With this information, increases in diaphyseal strength could be more accurately attributed to their actual cause.

A similar study would also benefit from a test of bilaterality. This test would reveal the degree of handedness in the population of interest and, therefore, lead to a better understanding of how hand dominance would affect the results.

It was noted that a significance test could not be performed for the juvenile results. However, it is possible to improve a similar study which uses LOESS curves with a sensitivity analysis and a power calculation. This calculation would indicate how many specimens were required to produce confidence and the sensitivity analysis would reveal the percentage difference between the samples studied. This thesis project represents a pilot study in which the usefulness of a LOESS curve in a biomechanical analysis was tested. Future studies of this type can be expanded to include a sensitivity analysis which will test the significance of juvenile growth curve results.

An interesting result of this thesis that could be researched further was the greater increase in strength seen in the femur when compared to the tibia in the ontogenetic results. The femur LOESS curve showed a greater increase for all geometric variables and the point at which the increase occurred was much more defined in the femur curve when compared to the tibia curve. This was seen in the lower limb of both populations. These increases could be attributed to normal growth yet Stock and Pfeiffer (2001) have noted that the femur appears to be more responsive to mechanical loading. The results of this thesis would support the idea that the femur is more responsive to mechanical loading than the tibia, particularly during growth. However, it was unclear as to why this may have been the case. Future research would be helpful in confirming the validity of this claim and to understand why this difference would occur between the lower limb bones.

In conclusion, this thesis has provided a biomechanical analysis of the adults and juveniles from two sample populations: the South African Khoisan and the Sadlermiut Inuit. The results of the biomechanical analysis were interpreted using ethnographic, archaeological and osteological data on the two groups as well as growth data from possible related groups. The results generally did not show a strong correlation between expected activity and long bone structure except for humeral AP bending strength, which was high in both samples and started to increase at an early age (7.5 years). It could not be concluded with confidence that the sample differences and increases in strength were a result of activity and not one of several other possible influencing factors.

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Appendix A: Skeletal Samples

A-1: List of Khoisan individuals studied

Specimen ID	Age (years)	Sex	Date (years BP)	Biome	Elements Present		
					Hum.	Tib.	Fem.
UCT 216O	0.50	?	NDA	Forest	Left	Left	Left
UCT 213	1.00	?	NDA	Forest	Left	Left	Left
UCT 189/217L	1.00	?	NDA	Forest	Left	Left	Left
UCT 190/217K	1.50	?	NDA	Forest	?	?	?
UCT 195/215I	1.50	?	NDA	Forest	Left	Left	Left
UCT 216J	2.00	?	NDA	Forest	?	?	?
UCT 346	2.00	?	NDA	Forest	Left	Left	Right
UCT 210	4.50	?	4995 ± 215	Forest	Left	None	Left
UCT 205	4.50	?	4880 ± 70	Forest	Left	Left	Left
UCT 468	6.00	?	NDA	Nama-Karoo	?	Right	Left
UCT 388	6.50	?	NDA	NDA	None	Left	Left
UCT 173	7.50	?	NDA	NDA	Left	None	Left
UCT 208/215B	7.50	?	NDA	Forest	Left	Left	Right
UCT 330	7.80	M	NDA	Grassland	Left	?	?
UCT 51	7.80	F	NDA	NDA	Left	Left	Left
UCT 328	11.50	M	NDA	Grassland	Left	Left	Left
UCT 355	12.00	M	NDA	NDA	Left	None	None
UCT 334	15.75	F	3850 ± 80	Succulent Karoo	Right	Left	Left
UCT 162	18.00	M	2880 ± 50	Fynbos	Left	None	Left
UCT 412	30.00	F	NDA	NDA	Left	Left	Left
UCT 451	30.00	F	NDA	NDA	Right	None	Right
UCT 450	30.00	M	NDA	NDA	Right	None	None
UCT 390	30.00	M	NDA	Fynbos	Right	Right	Right
UCT 185/202	30.00	F	9100 ± 90	Forest	None	Left	Left
UCT 399	50.00	F	NDA	NDA	?	?	Left

Legend:
M = male
F = female
? = unknown
NDA = no data available

B-2: List of Sadlermiut individuals studied

Specimen ID	Age	Sex	Elements Present

	(years)		Hum.	Tib.	Fem.
XIV-C:123	0.25	?	Left	Left	Left
XIV-C:119	0.75	?	Left	Left	Left
XIV-C:77	1.25	?	Left	Left	Left
XIV-C:84	3.00	?	Right	Left	Right
XIV-C:118	5.20	?	Left	Left	Left
XIV-C:301	6.00	?	Left	Left	Left
XIV-C:46	11.45	F	None	Left	Left
XIV-C:327	11.45	M	Left	Left	Left
XIV-C:2	11.93	M	Left	Left	Left
XIV-C:220	12.25	F	Left	Left	Left
XIV-C:22	13.50	F	Left	None	Right
XIV-C:198	14.80	M	Left	Left	Left
XIV-C:316	14.80	M	Left	Left	Left
XIV-C:709	14.95	F	Left	Left	Left
XIV-C:307	15.53	F	Left	Left	Left
XIV-C:146	17.00	M	Left	Left	Right
XIV-C:158	17.00	F	Left	Left	Left
XIV-C:239	17.00	M	Left	Left	Left
XIV-C:193	17.70	F	Right	Left	Left
XIV-C:400	17.70	F	None	Left	Left
XIV-C:126	30.00	M	Left	Left	Left
XIV-C:149	30.00	F	Left	Left	Left
XIV-C:117	40.00	M	Left	Left	None
XIV-C:175	40.00	F	Left	Left	?
XIV-C:179	40.00	M	Left	Left	Left
XIV-C:98	50.00	F	Left	Left	Left
XIV-C:103	50.00	F	Left	Left	Left
XIV-C:181	50.00	M	Left	Left	Left
XIV-C:217	50.00	M	Left	Left	Left
XIV-C:221	50.00	F	Left	Left	Left

Legend:
M = male
F = female
? = unknown

C-3: List of Stirrup Court individuals studied

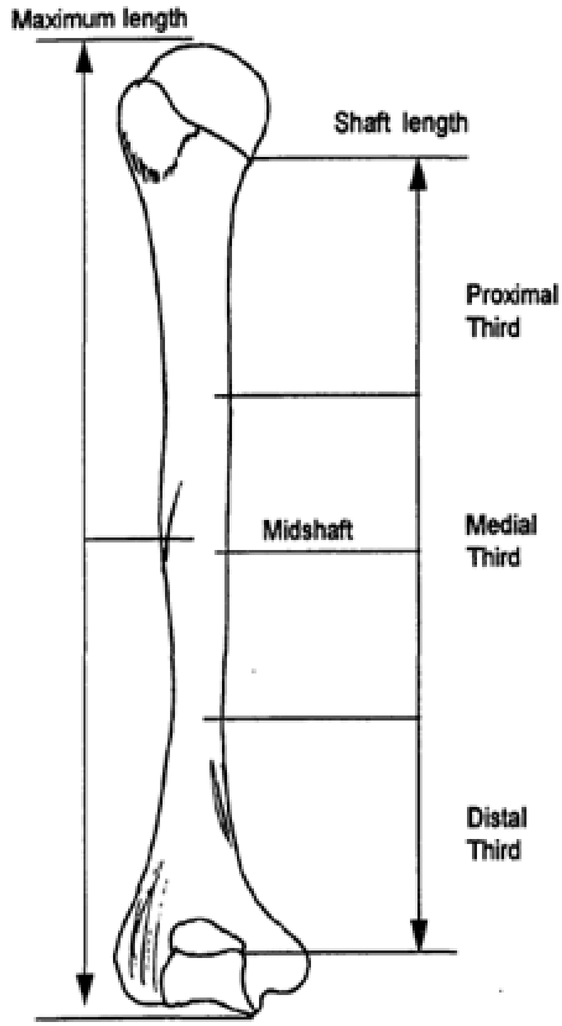
Specimen ID	Age	Sex	Elements Present

	(years)		Hum.	Tib.	Fem.
SC J	3.50	?	Right	None	None
SC 14	27.00	M	Both	Both	Both
SC 20	30.00	M	Both	None	Both
SC X1	30.00	F	Right	Left	Both
SC X2	30.00	M	Left	Right	Both
SC X4	35.00	M	None	Right	None
SC 11	37.50	M	Both	Both	Right
SC 17	40.00	M	Both	Both	Both
SC B	40.00	M	Both	None	Right
SC 21	44.50	M	Both	Both	Both
SC 10	45.00	M	Both	Both	Both
SC 5	50.00	F	Left	Both	Left
SC X3	55.50	F	Left	Right	Right
SC 19	60.00	M	Both	Both	Left
SC 6	61.00	M	Both	None	Both
SC A	63.00	F	Both	None	None
SC 4	76.00	M	Both	Both	Both
SC 7	81.00	F	Both	None	Both
SC 18	84.00	F	Both	Both	Both

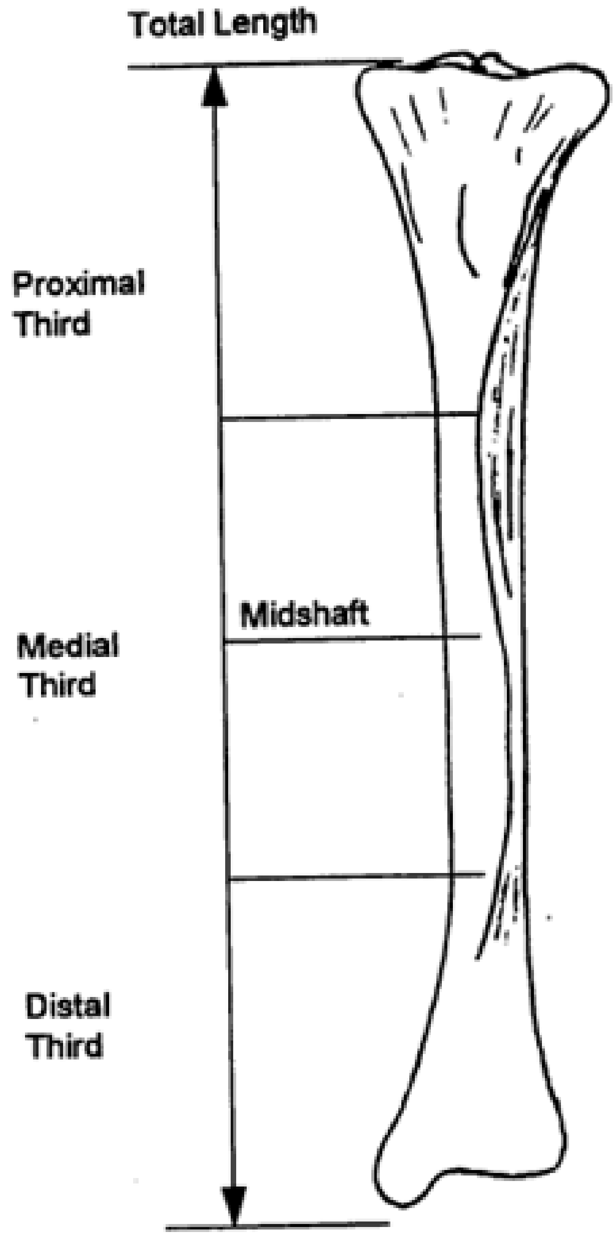
Legend:
M = male
F = female
? = unknown

Appendix B: Long Bone Cross-Sectional Measurements and Calculations

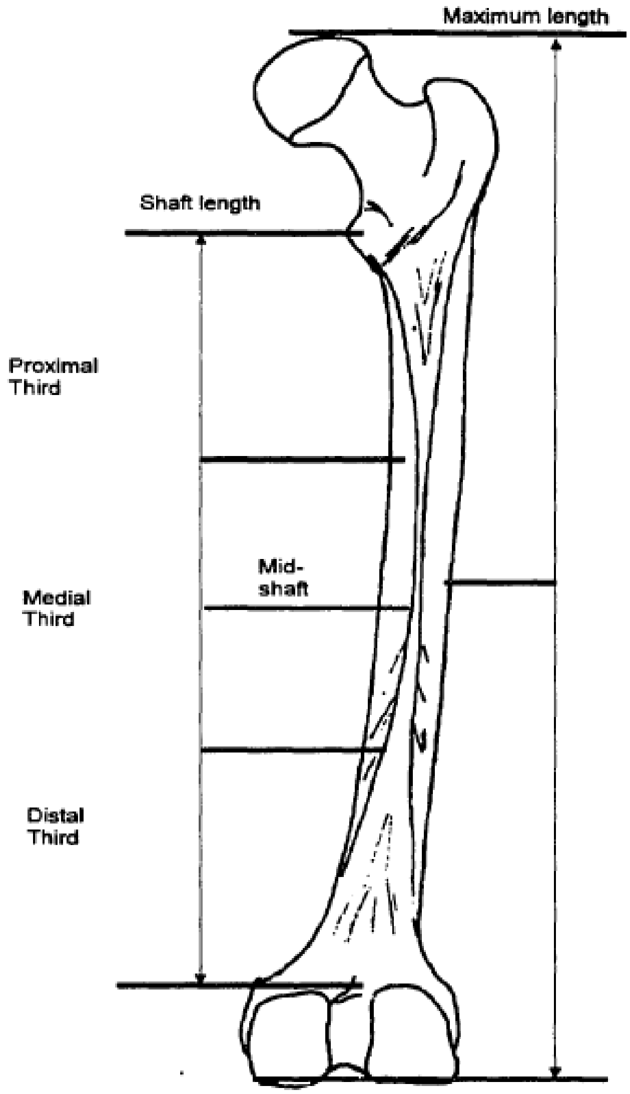
B-1: Method of humeral shaft length measurement (Nelson, 1995)



B-2: Method of tibial shaft length measurement (Nelson, 1995)



B-3: Method of femoral shaft length measurement (Nelson, 1995)



B-4: Cross-sectional measurement key.
Applicable to humerus, tibia and femur tables in Appendix D and E.

Radiograph measurements

1. Maximum length
2. Shaft length

Mid-shaft cross-section

3. Anterior-posterior diameter
4. Medial-lateral diameter
5. Anterior cortical thickness
6. Posterior cortical thickness
7. Medial cortical thickness
8. Lateral cortical thickness

Proximal third cross-section

9. Anterior-posterior diameter
10. Medial-lateral diameter
11. Anterior cortical thickness
12. Posterior cortical thickness
13. Medial cortical thickness
14. Lateral cortical thickness

Distal third cross-section

15. Anterior-posterior diameter
16. Medial-lateral diameter
17. Anterior cortical thickness
18. Posterior cortical thickness
19. Medial cortical thickness
20. Lateral cortical thickness

Radiograph cross-sectional geometry

Mid-shaft

21. Total cross-section area
22. Medullary area
23. Cortical area
24. Second moment of area about the ML axis (I_x)
25. Second moment of area about the AP axis (I_y)
26. Polar moment of area (J)
27. Biomechanical shape (I_x/I_y)
28. Percent cortical area

Proximal Third

29. Total cross-section area
30. Medullary area
31. Cortical area
32. Second moment of area about the ML axis (I_x)
33. Second moment of area about the AP axis (I_y)
34. Polar moment of area (J)
35. Biomechanical shape (I_x/I_y)
36. Percent cortical area

Distal Third

37. Total cross-section area
38. Medullary area
39. Cortical area
40. Second moment of area about the ML axis (I_x)
41. Second moment of area about the AP axis (I_y)
42. Polar moment of area (J)
43. Biomechanical shape (I_x/I_y)
44. Percent cortical area

B-5: Cross-sectional measurement key.
Applicable only to Stirrup Court humerus, tibia and femur tables in Appendix F.

External measurements

Radiograph cross-sectional geometry

1. Maximum length
2. Shaft length

Mid-shaft

3. Anterior-posterior diameter
4. Medial-lateral diameter
5. Maximum diameter
6. Minimum diameter

Proximal third

7. Anterior-posterior diameter
8. Medial-lateral diameter
9. Maximum diameter
10. Minimum diameter

Distal third

11. Anterior-posterior diameter
12. Medial-lateral diameter
13. Maximum diameter
14. Minimum diameter

Radiograph measurements

Mid-shaft cross-section

15. Anterior-posterior diameter
16. Medial-lateral diameter
17. Anterior cortical thickness
18. Posterior cortical thickness
19. Medial cortical thickness
20. Lateral cortical thickness

Proximal third cross-section

21. Anterior-posterior diameter
22. Medial-lateral diameter
23. Anterior cortical thickness
24. Posterior cortical thickness
25. Medial cortical thickness
26. Lateral cortical thickness

Distal third cross-section

27. Anterior-posterior diameter
28. Medial-lateral diameter
29. Anterior cortical thickness
30. Posterior cortical thickness
31. Medial cortical thickness
32. Lateral cortical thickness

ImageJ cross-sectional geometry

Mid-shaft

57. Total cross-section area
58. Medullary area
59. Cortical area
60. Second moment of area about the ML axis (I_x)

Mid-shaft

33. Total cross-section area
34. Medullary area
35. Cortical area
36. Second moment of area about the ML axis (I_x)
37. Second moment of area about the AP axis (I_y)
38. Polar moment of area (J)
39. Biomechanical shape (I_x/I_y)
40. Percent cortical area

Proximal Third

41. Total cross-section area
42. Medullary area
43. Cortical area
44. Second moment of area about the ML axis (I_x)
45. Second moment of area about the AP axis (I_y)
46. Polar moment of area (J)
47. Biomechanical shape (I_x/I_y)
48. Percent cortical area

Distal Third

49. Total cross-section area
50. Medullary area
51. Cortical area
52. Second moment of area about the ML axis (I_x)
53. Second moment of area about the AP axis (I_y)
54. Polar moment of area (J)
55. Biomechanical shape (I_x/I_y)
56. Percent cortical area

61. Second moment of area about the AP axis (I_y)
62. Maximum moment of area (I_{max})
63. Minimum moment of area (I_{min})
64. Polar moment of area (J)
65. Biomechanical shape (I_x/I_y)
66. Theta
67. Percent cortical area

Appendix C: Skeletal Recording Forms

C-1: Long bone radiograph measurement recording form.
Used for Khoisan, Sadlermiut and Stirrup Court samples

___________ CROSS-SECTIONAL X-RAY MEASUREMENTS RECORDING FORM

Specimen: ______________________________ Observer: _____________
Sex: ___________________ Date: ________________
Age: ___________________
Location/Site: ____
Comments:____
____
____

Side: R or L Additional Notes:

Maximum Length: __________
Shaft Length: __________
Proximal Third to Mid-shaft Length: ____

Mid-shaft
Location: __________
Ant.-Post. Diameter: __________
Med.-Lat. Diameter: __________
Ant. Cortical Thickness: __________
Post. Cortical Thickness: __________
Med. Cortical Thickness: __________
Lat. Cortical Thickness: __________

Proximal Third
Location: __________
Ant.-Post. Diameter: __________
Med.-Lat. Diameter: __________
Ant. Cortical Thickness: __________
Post. Cortical Thickness: __________
Med. Cortical Thickness: __________
Lat. Cortical Thickness: __________

Distal Third
Location: __________
Ant.-Post. Diameter: __________
Med.-Lat. Diameter: __________
Ant. Cortical Thickness: __________
Post. Cortical Thickness: __________
Med. Cortical Thickness: __________
Lat. Cortical Thickness: __________

C-2: Long bone external measurements recording forms
Used for Stirrup Court sample only

STIRRUP COURT HUMERAL EXTERNAL MEASUREMENTS

Specimen: ______________________________ Observer: ______________
Recorded Sex: ____________________ Date: _________________
Recorded Age: ____________________
Comments:____
____
____
____

Humerus (mm)	Right	Left	Notes:
Maximum length	_____	_____	
Longitudinal head length	_____	_____	
Articular width	_____	_____	
Epicondylar breadth	_____	_____	
Shaft length	_____	_____	
Mid-shaft	_____	_____	
AP diameter	_____	_____	
ML diameter	_____	_____	
Circumference	_____	_____	
Maximum Diameter	_____	_____	
Minimum Diameter	_____	_____	
Least Circumference	_____	_____	
Proximal Third	_____	_____	
AP diameter	_____	_____	
ML diameter	_____	_____	
Circumference	_____	_____	
Maximum Diameter	_____	_____	
Minimum Diameter	_____	_____	
Least Circumference	_____	_____	
Distal Third	_____	_____	
AP diameter	_____	_____	
ML diameter	_____	_____	
Circumference	_____	_____	
Maximum Diameter	_____	_____	
Minimum Diameter	_____	_____	
Least Circumference	_____	_____	

STIRRUP COURT FEMORAL EXTERNAL MEASUREMENTS

Specimen: ______________________________ Observer: _____________

Recorded Sex: ___________________ Date: ________________

Recorded Age: ___________________

Comments:____

____

____

____

Femur (mm)	Right	Left	Notes:
Maximum Length	_____	_____	
Oblique Length	_____	_____	
Longitudinal Head Length	_____	_____	
Distal Articular breadth	_____	_____	
Biepicondylar Breadth	_____	_____	
Subtrochanteric AP Diameter	_____	_____	
Subtrochanteric ML diameter	_____	_____	
Subtrochanteric circumference	_____	_____	
Shaft Length	_____	_____	
Mid-shaft	_____	_____	
AP diameter	_____	_____	
ML diameter	_____	_____	
Circumference	_____	_____	
Maximum Diameter	_____	_____	
Minimum Diameter	_____	_____	
Least Circumference	_____	_____	
Proximal Third	_____	_____	
AP diameter	_____	_____	
ML diameter	_____	_____	
Circumference	_____	_____	
Maximum Diameter	_____	_____	
Minimum Diameter	_____	_____	
Least Circumference	_____	_____	
Distal Third	_____	_____	
AP diameter	_____	_____	
ML diameter	_____	_____	
Circumference	_____	_____	
Maximum Diameter	_____	_____	
Minimum Diameter	_____	_____	
Least Circumference	_____	_____	

STIRRUP COURT TIBIAL EXTERNAL MEASUREMENTS

Specimen: ______________________________ Observer: ______________

Recorded Sex: ____________________ Date: _________________

Recorded Age: ____________________

Comments:____

____

____

____

Tibia(mm)	Right	Left	Notes:
Maximum length	______	______	
Total length	______	______	
Condylo-astragalar length	______	______	
Proximal articular breadth	______	______	
Distal AP	______	______	
AP diameter at nut. foramen	______	______	
ML diameter at nut. foramen	______	______	
Circumference at nut. foramen	______	______	
Shaft Length	______	______	
Mid-shaft	______	______	
AP diameter	______	______	
ML diameter	______	______	
Circumference	______	______	
Maximum Diameter	______	______	
Minimum Diameter	______	______	
Least Circumference	______	______	
Proximal Third	______	______	
AP diameter	______	______	
ML diameter	______	______	
Circumference	______	______	
Maximum Diameter	______	______	
Minimum Diameter	______	______	
Least Circumference	______	______	
Distal Third	______	______	
AP diameter	______	______	
ML diameter	______	______	
Circumference	______	______	
Maximum Diameter	______	______	
Minimum Diameter	______	______	
Least Circumference	______	______	

Appendix D: Cross-sectional measurements taken from Khoisan and Sadlermiut long bone radiographs

D-1: Khoisan humerus cross-sectional measurements. See B-4 for key.

Specimen ID	Side	1	2	3	4	5	6	7	8	9	10
UCT 216O	Left	64.6	60.2	5.3	5.6	1.5	2.0	2.0	2.0	6.0	6.0
UCT 213	Left	62.6	57.7	5.4	5.6	1.2	1.8	1.7	1.2	5.2	5.9
UCT 189/217L	Left	77.6	71.2	7.5	7.4	1.9	0.9	1.3	1.2	7.3	7.3
UCT 190/217K	None	96.8	90.8	8.8	8.0	1.0	2.0	2.3	2.0	8.2	7.9
UCT 195/215I	Left	109.0	95.9	8.1	7.6	1.7	1.7	1.7	1.7	8.5	7.1
UCT 216J	None	101.9	97.5	8.5	7.1	1.0	1.0	1.7	1.7	8.4	7.5
UCT 346	Left	126.0	111.0	11.0	10.3	2.4	1.4	2.6	1.9	10.5	10.7
UCT 210	Left	155.0	141.5	9.0	10.0	2.4	2.3	2.7	2.4	8.7	10.0
UCT 205	Left	160.2	152.4	10.8	11.0	3.3	3.3	3.3	3.0	11.6	11.6
UCT 468	None	161.0	140.7	11.2	11.2	2.3	1.8	2.4	2.0	11.6	12.5
UCT 388	None										
UCT 173	Left	175.5	164.5	12.2	13.1	2.6	2.6	2.6	2.6	11.9	12.8
UCT 208/215B	Left	192.0	173.0	10.5	10.1	3.2	2.9	3.3	3.0	10.5	11.3
UCT 330	Left	181.0	163.0	12.6	10.8	2.8	2.8	2.8	2.7	12.0	11.5
UCT 51	Left	182.0	164.0	11.6	10.2	2.9	2.6	3.2	2.7	12.3	10.3
UCT 328	Left	216.0	195.0	16.7	14.7	2.4	2.6	2.6	2.4	17.0	15.0
UCT 355	Left		241.0	17.8	16.4	3.0	3.7	4.3	3.8	18.1	15.7
UCT 334	Right	274.0	233.0	12.7	16.0	3.6	3.2	3.2	3.3	13.2	14.2
UCT 162	Left	255.0	203.0	16.8	15.9	3.8	5.6	4.6	4.4	15.5	16.8
UCT 412	Left	291.0	238.8	16.2	13.9	4.0	3.8	3.4	4.0	14.4	15.5
UCT 451	Right	281.5	224.0	21.2	20.4	3.7	4.2	4.5	3.9	24.3	22.6
UCT 450	Right	324.4	260.0	19.5	18.8	5.9	5.8	7.2	5.3	20.0	18.9
UCT 390	Right	297.0	244.0	15.7	16.8	6.2	5.7	6.7	6.2	16.0	17.8
UCT 185/202	None										
UCT 399	None	255.0	204.0	16.0	16.0	3.1	2.9	2.5	2.9	15.6	19.6

Specimen ID	11	12	13	14	15	16	17	18	19	20
UCT 216O	1.6	1.2	0.8	1.1	5.3	7.0	1.7	1.1	1.6	1.6
UCT 213	1.4	1.7	1.4	1.0	6.8	7.0	0.8	0.8	1.8	1.2
UCT 189/217L	0.7	0.8	1.1	0.9	9.1	9.1	0.8	0.9	0.9	0.8
UCT 190/217K	1.4	0.9	1.8	1.4	10.2	9.4	1.2		1.1	
UCT 195/215I	1.5	1.5	1.4	1.5	8.3	8.9	1.3	1.3	1.5	1.5
UCT 216J	0.9	1.2	1.6	1.2	8.9	8.9	1.2	1.7	1.4	1.1
UCT 346	2.3	1.9	1.9	1.8	10.5	11.6	1.9	1.9	1.9	1.9
UCT 210	2.8	2.7	2.7	2.3	9.2	10.9	2.4	1.8	2.9	2.4
UCT 205	3.8	3.2	3.3	3.1	9.8	12.2	2.9	2.5	3.4	3.0
UCT 468	2.4	1.3	2.8	1.8	10.9	11.3	1.9	1.9	1.9	1.8
UCT 388										
UCT 173	3.0	2.3	2.4	2.4	12.4	14.0	2.4	2.4	2.4	2.4
UCT 208/215B	2.7	2.7	2.7	2.6	10.0	11.2	2.8	2.2	3.3	3.0
UCT 330	2.9	2.6	2.5	2.4	11.5	11.9	2.6	2.0	2.3	2.3
UCT 51	2.4	2.0	2.3	2.3	10.3	10.8	2.6	2.2	3.4	2.2
UCT 328	2.2	1.8	2.3	2.2	15.1	16.5	1.9	2.5	2.3	1.8
UCT 355	4.3	3.6	4.1	3.6	16.5	17.9	3.9	4.2	3.5	4.0
UCT 334	3.1	2.8	2.8	2.6	12.7	15.6	4.1	3.2	3.1	3.1
UCT 162	3.6	4.1	4.3	4.2	17.4	15.8	3.5	2.8	3.8	4.6
UCT 412	3.3	2.9	3.2	3.0	15.6	14.5	3.5	3.2	4.0	4.0
UCT 451	2.7	3.0	3.4	4.2	19.8	18.7	4.3	3.9	4.8	3.6
UCT 450	6.2	5.1	5.2	4.9	19.7	19.5	6.4	5.4	5.9	5.2
UCT 390	5.7	5.1	5.9	5.7	15.7	15.8	6.1	5.7	6.4	5.7
UCT 185/202										
UCT 399	2.1	2.2	2.2	3.6	15.0	16.0	3.6	2.7	3.3	3.2

D-2: Khoisan tibia cross-sectional measurements. See B-4 for key.

Specimen ID	Side	1	2	3	4	5	6	7	8	9	10
UCT 216O	Left	67.1	67.1	6.3	6.4	2.1	1.3	1.8	1.2	7.0	7.8
UCT 213	Left	64.7	64.7	6.8	6.5	2.0	1.8	1.9	1.0	6.5	7.4
UCT 189/217L	Left	85.3	85.0	8.9	7.3	1.1	1.5	1.5	1.5	8.5	8.8
UCT 190/217K	None	105.6	105.6	10.3	9.0	0.9	1.7	1.6	1.2	9.7	10.7
UCT 195/215I	Left	122.0	122.0	9.2	9.4	2.0	1.8	1.5	1.5	10.6	11.3
UCT 216J	None	110.0	110.0	9.4	9.6	2.3	1.9	1.6	1.6	8.9	11.6
UCT 346	Left	144.3	144.3	13.7	12.3	4.8	3.4	2.4	2.3	15.0	14.3
UCT 210	None										
UCT 205	Left	195.0	195.0	16.4	14.3	6.5	4.7	4.7	3.5	17.9	17.4
UCT 468	Right	186.0	186.0	13.9	12.7	3.2	2.7	2.5	2.5	14.9	14.6
UCT 388	Left	203.4	203.4	14.7	12.8	4.7	5.0	3.5	3.9	15.8	14.5
UCT 173	None										
UCT 208/215B	Left	223.5	223.5	16.4	13.5	5.0	4.4	3.3	3.2	18.0	16.7
UCT 330	None	230.0	230.0	17.8	14.0	5.8	4.7	3.3	2.4	19.5	15.6
UCT 51	Left	240.0	240.0	16.8	13.8	6.0	4.0	3.0	2.9	18.8	16.2
UCT 328	Left	296.0	296.0	22.5	18.2	5.6	4.8	3.5	2.9	25.8	20.0
UCT 355	None										
UCT 334	Left	325.0	325.0	22.3	16.1	6.5	7.0	3.4	4.5	24.5	17.8
UCT 162	None										
UCT 412	Left		378.8	26.0	17.4	6.8	6.9	3.0	3.8	29.3	19.0
UCT 451	None										
UCT 450	None										
UCT 390	Right	353.0	353.0	27.4	20.9	10.1	8.9	5.5	6.9	33.9	20.5
UCT 185/202	Left	357.0	357.0	28.6	22.5	9.3	7.0	4.3	5.0	33.7	25.7
UCT 399	None	305.0	305.0	22.4	18.0	5.9	5.0	3.6	4.5	25.4	21.6

Specimen ID	11	12.0	13	14	15	16	17	18	19	20
UCT 216O	1.3	1.3	1.4	0.9	6.7	6.8	0.9	0.9	1.0	1.3
UCT 213	1.5	1.1	1.5	0.8	8.2	7.0	1.3	1.1	1.4	0.7
UCT 189/217L	0.9	1.1	1.0	0.8	10.4	8.4	0.9	0.9	0.9	0.7
UCT 190/217K	0.7	1.5	1.9	1.0	11.5	9.7		0.7	0.8	1.2
UCT 195/215I	1.3	1.7	1.6	1.3	9.5	9.9	1.3	1.2	1.2	1.6
UCT 216J	1.3	1.4	1.2	1.2	10.9	10.1	1.4	1.4	1.3	1.3
UCT 346	2.9	3.8	1.9	2.1	13.3	14.0	1.7	2.0	1.9	1.5
UCT 210										
UCT 205	7.2	5.6	3.6	3.3	14.0	14.0	5.1	3.9	3.9	3.2
UCT 468	3.0	2.6	2.2	1.7	13.4	12.9	2.3	2.1	2.4	2.1
UCT 388	4.1	4.2	3.0	3.0	13.2	12.7	3.3	3.2	2.5	2.7
UCT 173										
UCT 208/215B	4.7	4.5	2.7	2.2	14.8	13.6	3.4	3.3	3.0	2.6
UCT 330	5.3	4.0	2.8	2.0	15.8	15.0	3.6	3.3	3.1	2.0
UCT 51	3.8	4.7	2.8	2.4	14.6	14.9	3.3	2.7	2.8	2.4
UCT 328	2.3	4.0	2.5	2.5	20.4	19.7	3.6	3.1	3.0	2.5
UCT 355										
UCT 334	5.8	5.8	2.7	2.7	18.3	15.6	4.7	5.2	3.3	3.8
UCT 162										
UCT 412	7.0	7.3	4.4	2.5	23.3	18.2	5.3	3.6	2.8	3.9
UCT 451										
UCT 450										
UCT 390	10.3	10.1	4.9	4.9	23.0	20.6	8.2	6.2	5.1	5.2
UCT 185/202	9.5	5.3	4.0	4.6	23.8	21.8	5.6	3.6	4.5	3.3
UCT 399	5.1	3.2	1.9	3.3	19.2	18.4	4.2	2.6	2.6	3.2

D-3: Khoisan femur cross-sectional measurements. See B-4 for key.

Specimen ID	Side	1	2	3	4	5	6	7	8	9	10
UCT 216O	Left	80.7	71.8	6.2	7.0	1.5	1.5	1.6	1.5	7.0	7.0
UCT 213	Left	74.5	66.1	6.1	6.5	1.2	2.1	1.4	1.9	6.5	7.0
UCT 189/217L	Left	101.4	93.8	8.1	9.2	1.1	2.9	1.0	1.2	8.8	9.8
UCT 190/217K	None		106.6	8.9	9.7	1.2	3.2	1.2	0.9	9.7	9.2
UCT 195/215I	Left	142.4	126.7	9.3	11.0	1.8	2.3	2.3	2.2	9.9	10.3
UCT 216J	None		114.2	10.0	10.6	1.6	2.5	2.5	2.0	9.2	10.0
UCT 346	Right	176.0	158.0	13.1	14.0	2.5	2.5	2.5	2.5	12.5	14.2
UCT 210	Left	226.0	190.0	13.3	13.2	3.0	3.9	3.4	3.2	13.1	13.3
UCT 205	Left	242.0	206.2	14.5	16.1	3.9	4.5	4.2	4.6	14.0	16.7
UCT 468	Left	236.0	197.0	14.9	14.6	2.6	3.4	2.5	2.6	15.1	13.4
UCT 388	Left	242.0	210.0	13.5	13.7	3.5	4.9	3.6	3.8	13.2	13.3
UCT 173	Left		241.0	16.8	17.0	2.9	4.0	3.6	3.5	16.2	17.5
UCT 208/215B	Right		235.0	17.8	15.7	4.2	5.7	3.5	3.6	17.0	15.4
UCT 330	None	268.0	241.0	15.5	15.4	3.4	4.8	3.6	3.5	14.7	16.7
UCT 51	Left		230.0	16.3	14.7	2.9	5.1	3.6	3.5	15.6	14.5
UCT 328	Left	338.0	291.0	20.2	20.2	2.8	4.4	3.5	3.4	20.1	20.0
UCT 355	None										
UCT 334	Left		337.0	20.7	19.4	4.7	6.4	4.9	4.7	19.0	19.0
UCT 162	Left		298.0	27.7	23.3	5.7	8.3	6.0	5.2	26.9	25.0
UCT 412	Left		308.0	24.1	31.3	4.1	7.0	5.4	5.8	21.5	23.6
UCT 451	Right		325.0	30.1	25.7	5.1	8.7	6.5	6.1	28.2	26.1
UCT 450	None										
UCT 390	Right		331.6	31.1	23.0	7.1	12.8	8.1	8.1	26.7	24.3
UCT 185/202	Left		320.0	30.1	24.5	5.1	10.4	5.9	5.8	28.1	24.6
UCT 399	Left		296.0	24.1	22.0	4.4	7.9	5.5	5.5	22.0	22.3

Specimen ID	11	12	13	14	15	16	17	18	19	20
UCT 216O	1.3	1.5	1.6	1.5	7.5	9.6	0.8	0.9	0.9	0.9
UCT 213	1.1	1.4	1.6	1.7	7.8	8.9	1.4	0.9	0.8	0.8
UCT 189/217L	0.7	1.3	1.2	0.9	9.7	12.1	0.7	1.2	1.0	0.9
UCT 190/217K	1.2	1.7	1.1	1.0	9.0	13.4	1.0	3.2	1.4	1.0
UCT 195/215I	2.2	2.8	1.8	2.6	10.5	14.4	1.8	1.7	1.2	1.2
UCT 216J	2.1	2.6	2.3	2.7	10.1	13.1	1.7	1.8	1.6	1.3
UCT 346	2.7	3.3	3.3	3.3	16.0	17.9	1.9	2.1	1.8	1.6
UCT 210	3.3	3.3	3.3	3.8	13.7	16.3	2.5	3.4	2.5	2.3
UCT 205	4.3	5.2	3.8	3.1	14.6	18.8	3.4	3.8	3.0	3.3
UCT 468	2.3	3.7	2.7	2.7	15.5	17.7	2.3	2.5	2.2	2.1
UCT 388	3.4	4.8	4.0	3.9	13.5	15.3	2.3	3.1	2.3	2.3
UCT 173	3.5	3.7	3.5	4.8	16.3	19.5	2.5	2.8	2.4	2.0
UCT 208/215B	3.2	5.4	3.5	3.6	17.0	18.4	2.4	3.8	2.7	2.6
UCT 330	3.5	3.7	5.0	4.6	15.8	17.5	2.6	3.6	2.7	2.2
UCT 51	3.3	4.3	3.6	4.2	16.5	16.1	2.4	3.4	2.4	2.3
UCT 328	3.0	4.4	4.7	4.8	21.9	25.5	2.0	2.5	2.5	2.0
UCT 355										
UCT 334	5.0	6.3	5.9	6.0	21.5	23.8	3.5	3.9	3.1	2.9
UCT 162	5.2	7.3	6.0	5.7	28.3	23.8	4.0	7.1	4.0	3.6
UCT 412	4.4	6.4	6.8	6.4	24.9	22.9	3.5	5.7	4.5	4.5
UCT 451	6.1	9.3	7.7	7.6	29.8	30.4	4.0	6.7	3.9	3.3
UCT 450										
UCT 390	7.6	10.3	7.9	9.3	30.4	24.3	6.8	9.4	5.6	5.7
UCT 185/202	6.0	8.9	6.2	6.6	27.8	27.7	3.9	6.5	5.1	3.6
UCT 399	4.7	6.5	5.6	7.4	23.9	26.5	2.2	5.0	3.3	3.3

D-4: Sadlermiut humerus cross-sectional measurements. See B-4 for key.

Specimen ID	Side	1	2	3	4	5	6	7	8	9	10
XIV-C:123	Left	75.3	69.7	6.1	6.0	2.1	0.9	2.1	1.9	6.7	6.6
XIV-C:119	Left	86.0	81.0	6.6	6.7	2.3	1.6	1.8	2.4	7.7	8.7
XIV-C:77	Left	96.6	89.9	9.1	10.2	2.9	2.4	2.7	3.2	10.0	11.3
XIV-C:84	Right	112.0	102.1	8.6	8.4	1.4	0.8	1.1	1.6	8.2	9.7
XIV-C:118	Left			12.4	11.5	1.5	2.0	1.3	2.1		
XIV-C:301	Left	240.0	207.6	16.5	14.7	4.6	2.9	3.2	2.6	14.6	16.0
XIV-C:46	None										
XIV-C:327	Left	182.0	159.0	14.6	12.6	2.9	3.2	3.2	2.9	14.5	15.1
XIV-C:2	Left			17.1	17.6	3.7	2.0	3.5	3.1		
XIV-C:220	Left	207.0	175.0	14.3	11.0	2.8	2.4	3.1	2.8	13.7	11.7
XIV-C:22	Left	285.0	227.8	21.0	18.7	4.6	3.6	3.8	3.4	21.0	20.8
XIV-C:198	Left	267.0	221.0	17.9	18.2	2.5	2.8	3.2	2.7	17.0	18.3
XIV-C:316	Left	263.0	209.0	18.6	16.7	3.0	3.0	3.4	3.3	16.4	18.0
XIV-C:709	Left	257.0	225.0	19.8	15.3	3.7	3.6	3.6	3.5	19.3	16.6
XIV-C:307	Left	258.0	216.0	19.9	18.4	4.0	4.1	4.7	3.6	19.3	19.7
XIV-C:146	Left			19.5	20.7	3.6	3.8	4.2	5.1		
XIV-C:158	Left	269.0	232.0	16.7	15.8	2.7	2.3	2.8	2.8	15.7	17.5
XIV-C:239	Left	234.0	197.0	15.2	14.5	2.7	2.4	2.2	2.2	13.2	15.3
XIV-C:193	Right			21.2	18.6	4.8	5.7	4.3	4.3		
XIV-C:400	None										
XIV-C:126	Left			23.2	21.6	4.8	4.1	5.6	3.8		
XIV-C:149	Left			18.5	16.1	3.2	3.0	3.3	3.8		
XIV-C:117	Left			22.0	19.7	4.1	2.8	3.2	3.6		
XIV-C:175	Left			16.7	17.4	3.3	3.4	2.8	4.1		
XIV-C:179	Left			22.3	22.9	4.2	3.6	3.6	4.0		
XIV-C:98	Left	284.0	230.0	19.6	19.5	5.8	3.8	4.4	3.9	17.4	19.5
XIV-C:103	Left			21.2	17.6	3.8	3.1	3.0	3.5		
XIV-C:181	Left			24.1	23.1	2.6	2.7	2.7	3.1		
XIV-C:217	Left			20.7	22.4	4.3	3.1	3.6	2.8		
XIV-C:221	Left			20.3	19.9	1.7	1.6	4.6	2.9		

Specimen ID	11	12	13	14	15	16	17	18	19	20
XIV-C:123	2.5	1.5	1.6	1.6	6.9	7.5	1.9	2.2	2.0	1.6
XIV-C:119	1.7	1.2	1.2	1.4	7.0	8.0	1.1	1.0	1.0	1.5
XIV-C:77	2.1	1.6	1.6	1.6	9.5	11.0	1.8	1.3	2.2	1.9
XIV-C:84	1.2	1.2	1.5	1.3	9.2	9.8	1.3	1.2	1.2	1.1
XIV-C:118										
XIV-C:301	2.9	2.4	1.9	2.1	16.3	15.5	2.8	2.0	2.1	3.1
XIV-C:46										
XIV-C:327	3.4	2.5	3.2	3.0	12.7	12.5	2.6	2.5	3.3	2.9
XIV-C:2										
XIV-C:220	3.9	2.3	3.2	2.1	13.2	12.5	2.4	1.8	2.5	2.2
XIV-C:22	5.5	2.2	3.5	4.4	18.9	17.8	2.8	3.0	4.3	4.3
XIV-C:198	2.8	2.9	3.4	2.2	16.9	16.6	3.2	2.7	2.8	3.3
XIV-C:316	3.0	2.7	3.3	3.2	18.7	16.4	3.1	2.6	3.5	3.7
XIV-C:709	3.9	2.5	3.4	3.4	16.4	17.2	3.8	2.6	3.7	4.0
XIV-C:307	4.4	3.8	3.5	2.5	17.1	17.7	3.5	3.5	4.0	3.8
XIV-C:146										
XIV-C:158	2.6	2.1	2.1	4.0	16.7	14.9	2.4	1.8	2.4	3.1
XIV-C:239	3.1	2.5	2.3	2.6	15.0	14.6	2.2	2.1	1.9	2.1
XIV-C:193										
XIV-C:400										
XIV-C:126										
XIV-C:149										
XIV-C:117										
XIV-C:175										
XIV-C:179										
XIV-C:98	4.5	3.4	4.1	3.0	17.9	18.1	3.8	2.8	3.2	4.0
XIV-C:103										
XIV-C:181										
XIV-C:217										
XIV-C:221										

D-5: Sadlermiut tibia cross-sectional measurements. See B-4 for key.

Specimen ID	Side	1	2	3	4	5	6	7	8	9	10
XIV-C:123	Left	73.8	73.8	7.8	7.1	3.3	2.4	2.7	1.3	8.9	8.2
XIV-C:119	Left	88.2	88.2	9.7	8.3	2.2	1.2	2.3	1.9	11.4	9.7
XIV-C:77	Left	100.8	100.8	11.6	10.0	3.6	3.7	3.0	1.7	13.7	11.5
XIV-C:84	Left	103.9	103.9	9.8	9.7	2.7	2.0	1.6	1.6	10.9	11.4
XIV-C:118	Left			12.0	12.0	2.5	1.8	2.5	2.1		
XIV-C:301	Left	262.0	262.0	23.8	17.7	7.2	5.2	2.4	2.6	27.5	20.5
XIV-C:46	Left			21.8	17.4	7.7	3.8	3.2	4.0		
XIV-C:327	Left	208.0	208.0	18.0	14.7	6.2	3.7	3.0	2.8	19.2	17.5
XIV-C:2	Left			22.8	16.5	7.3	4.3	3.4	4.1		
XIV-C:220	Left	225.0	225.0	17.8	14.3	6.0	3.8	3.4	3.1	20.3	17.5
XIV-C:22	None										
XIV-C:198	Left	293.3	293.3	22.5	17.7	7.0	3.2	3.0	3.8	27.4	22.8
XIV-C:316	Left	323.0	323.0	22.2	19.9	6.6	3.2	4.3	2.8	26.3	24.5
XIV-C:709	Left	282.0	282.0	24.3	18.5	8.4	6.0	3.4	4.1	27.5	21.8
XIV-C:307	Left	287.0	287.0	23.9	19.2	9.1	5.5	4.0	4.1	27.4	20.6
XIV-C:146	Left			20.7	21.8	7.2	4.0	6.4	4.2		
XIV-C:158	Left	324.0	324.0	25.0	18.0	5.4	4.3	2.3	3.0	28.4	23.1
XIV-C:239	Left	263.1	263.1	21.2	16.5	5.4	3.6	2.9	2.7	25.1	19.2
XIV-C:193	Left			27.9	20.4	11.1	4.7	4.8	5.6		
XIV-C:400	Left	324.0	324.0	22.5	17.0	8.3	5.1	3.8	3.5	27.0	28.0
XIV-C:126	Left			30.0	24.1	11.2	5.4	5.8	5.2		
XIV-C:149	Left			23.7	18.3	6.9	3.7	3.7	4.0		
XIV-C:117	Left			24.2	18.8	8.4	4.4	3.8	4.1		
XIV-C:175	Left			25.9	17.0	9.3	4.3	3.9	3.2		
XIV-C:179	Left			27.6	22.4	8.2	3.8	4.1	4.7		
XIV-C:98	Left	318.0	318.0	26.6	19.5	9.8	4.9	4.0	4.7	30.8	22.6
XIV-C:103	Left			27.6	19.6	9.7	3.4	3.1	5.3		
XIV-C:181	Left			31.3	27.3	8.9	4.3	5.0	4.8		
XIV-C:217	Left			29.2	21.1	10.0	5.7	3.1	4.7		
XIV-C:221	Left			25.9	18.5	9.0	3.9	3.9	2.9		

Specimen ID	11	12	13	14	15	16	17	18	19	20
XIV-C:123	2.3	1.6	2.6	1.6	7.9	8.6	2.5	1.7	2.1	1.2
XIV-C:119	2.2	2.3	1.3	1.3	10.1	10.4	1.1	1.2	1.8	0.9
XIV-C:77	2.1	3.6	1.9	1.6	11.4	11.0	1.4	1.6	1.7	1.3
XIV-C:84	1.8	1.3	1.3	1.4	9.2	9.9	1.3	1.4	1.2	1.3
XIV-C:118										
XIV-C:301	4.8	4.8	1.8	2.1	21.4	19.4	4.6	2.4	2.4	3.2
XIV-C:46										
XIV-C:327	4.5	3.5	2.6	2.5	16.4	16.8	4.7	2.2	3.1	3.4
XIV-C:2										
XIV-C:220	5.4	2.7	3.2	2.0	16.9	15.5	3.6	2.6	1.8	2.6
XIV-C:22										
XIV-C:198	6.7	3.2	2.6	2.3	21.0	18.8	5.7	2.7	2.7	2.9
XIV-C:316	2.7	2.9	3.5	3.0	20.3	21.2	4.2	3.3	3.2	3.0
XIV-C:709	7.3	5.7	2.7	3.6	22.1	19.6	6.3	3.9	2.8	3.4
XIV-C:307	7.5	5.3	2.8	3.5	21.2	19.3	4.7	4.3	3.2	3.4
XIV-C:146										
XIV-C:158	5.2	3.0	2.2	3.0	22.6	20.4	1.9	2.5	2.3	3.3
XIV-C:239	5.6	2.8	2.2	2.6	19.4	18.5	3.1	2.6	2.9	2.1
XIV-C:193										
XIV-C:400	7.8	5.9	3.8	3.0	24.8	24.9	2.7	4.8	3.3	3.4
XIV-C:126										
XIV-C:149										
XIV-C:117										
XIV-C:175										
XIV-C:179										
XIV-C:98	8.5	5.2	3.2	3.2	22.8	21.0	4.8	3.5	3.1	4.1
XIV-C:103										
XIV-C:181										
XIV-C:217										
XIV-C:221										

D-6: Sadlermiut femur cross-sectional measurements. See B-4 for key.

Specimen ID	Side	1	2	3	4	5	6	7	8	9	10
XIV-C:123	Left	89.4	72.3	7.7	8.4	2.7	1.9	1.8	2.6	8.0	7.4
XIV-C:119	Left	108.0	89.5	8.4	9.7	0.9	2.0	1.8	2.1	8.3	8.9
XIV-C:77	Left	122.9	106.0	10.4	12.6	2.0	2.5	3.3	3.0	10.7	11.6
XIV-C:84	Right		115.7	8.8	11.3	1.8	1.7	1.7	1.7	9.2	10.4
XIV-C:118	Left			13.4	14.9	2.2	2.1	2.4	1.9		
XIV-C:301	Left		281.6	24.1	23.1	2.7	5.3	4.3	3.9	23.0	23.1
XIV-C:46	Left			21.2	20.2	3.1	4.6	3.7	4.4		
XIV-C:327	Left	261.0	228.0	15.9	18.2	3.3	3.8	5.0	3.8	15.5	18.9
XIV-C:2	Left			23.5	21.5	3.2	6.1	3.5	4.4		
XIV-C:220	Left	285.0	246.0	16.7	17.6	3.3	3.7	3.2	3.6	16.8	19.3
XIV-C:22	Right		268.1	24.8	22.7	4.1	6.4	4.7	4.3	25.9	23.2
XIV-C:198	Left		318.0	26.0	22.1	3.2	5.4	3.5	4.7	25.2	20.2
XIV-C:316	Left		301.2	23.6	23.3	3.0	5.3	3.5	3.5	23.0	23.9
XIV-C:709	Left		291.0	24.7	23.7	3.7	6.5	4.8	5.7	24.1	23.8
XIV-C:307	Left		301.6	24.9	22.9	4.2	7.6	5.9	5.9	24.4	23.9
XIV-C:146	Right			28.7	27.0	5.8	8.8	6.7	8.4		
XIV-C:158	Left		310.0	26.7	26.6	2.3	5.3	6.8	6.2	24.9	26.2
XIV-C:239	Left			22.3	21.9	2.1	4.4	2.8	3.4		
XIV-C:193	Left			30.6	26.8	4.2	9.1	5.2	6.1		
XIV-C:400	Left		290.3	23.1	22.1	5.0	6.7	5.8	5.8	22.2	24.2
XIV-C:126	Left			31.3	27.9	4.8	8.6	6.4	7.3		
XIV-C:149	Left			26.4	26.4	4.0	6.1	4.5	5.9		
XIV-C:117	Left				27.5		6.4	7.6			
XIV-C:175	None			24.7	22.3	4.2	7.9	5.0	6.1		
XIV-C:179	Left			32.9	27.6	6.0	9.5	6.1	6.9		
XIV-C:98	Left		336.0	28.5	25.7	5.1	7.9	6.0	7.7	27.7	26.2
XIV-C:103	Left			25.8	25.9	4.1	6.0	4.4	7.4		
XIV-C:181	Left			35.7	33.5	3.8	6.6	5.0	5.3		
XIV-C:217	Left			33.3	27.7	4.9	10.8	5.5	6.7		
XIV-C:221	Left			27.7	24.6	3.7	4.7	6.2	6.2		

Specimen ID	11	12	13	14	15	16	17	18	19	20
XIV-C:123	3.1	2.0	2.2	2.9	9.1	11.6	1.8	1.7	0.9	1.5
XIV-C:119	1.3	2.9	2.7	2.9	11.1	14.5	0.6	1.1	0.6	0.8
XIV-C:77	2.2	3.4	3.2	3.5	12.5	16.2	1.5	1.2	1.2	1.2
XIV-C:84	1.8	1.3	1.9	1.6	10.0	14.8	1.7	1.4	1.4	1.4
XIV-C:118										
XIV-C:301	3.3	5.1	5.1	4.3	24.3	27.5	1.8	3.5	2.4	2.4
XIV-C:46										
XIV-C:327	3.1	4.0	5.4	4.9	18.0	22.9	2.7	3.5	2.2	2.5
XIV-C:2										
XIV-C:220	3.3	3.8	3.7	3.9	19.0	22.5	1.8	2.5	2.1	2.1
XIV-C:22	4.4	5.8	6.6	6.0	25.8	26.9	4.0	2.9	3.2	3.2
XIV-C:198	4.1	5.3	4.7	5.4	26.4	31.2	2.6	4.1	1.8	2.2
XIV-C:316	3.4	5.9	3.9	4.0	25.4	29.1	2.6	3.2	2.6	2.5
XIV-C:709	5.3	6.7	6.7	6.0	25.7	31.6	3.8	4.3	3.3	2.8
XIV-C:307	4.5	7.2	7.7	6.3	26.1	27.4	3.0	4.6	2.7	3.2
XIV-C:146										
XIV-C:158	2.9	4.5	7.0	5.8	26.6	27.8	3.3	3.4	3.3	3.0
XIV-C:239										
XIV-C:193										
XIV-C:400	5.5	6.2	6.4	7.3	24.8	24.9	3.0	4.7	3.2	3.6
XIV-C:126										
XIV-C:149										
XIV-C:117										
XIV-C:175										
XIV-C:179										
XIV-C:98	6.1	8.0	6.6	9.6	28.1	31.6	4.9	5.7	3.5	3.5
XIV-C:103										
XIV-C:181										
XIV-C:217										
XIV-C:221										

Appendix E: Cross-sectional geometry calculated from Khoisan and Sadlermiut long bone radiographs

E-1: Khoisan humerus cross-sectional geometry calculated from radiograph measurements. See B-4 for key.

Specimen ID	21	22	23	24	25	26	27	28	29	30
UCT 216O	23.3106	2.2619	21.0487	40.3101	45.3269	85.6370	0.8893	90.2965	28.2743	10.3044
UCT 213	23.7504	5.0893	18.6611	40.8700	43.8272	84.6972	0.9325	78.5714	24.0960	5.7727
UCT 189/217L	43.5896	18.0877	25.5019	120.5431	121.9652	242.5083	0.9883	58.5045	41.8539	24.1431
UCT 190/217K	55.2920	16.8546	38.4374	226.1152	206.2013	432.3166	1.0966	69.5170	50.8781	21.7791
UCT 195/215I	48.3491	15.5038	32.8454	176.8567	157.4474	334.3041	1.1233	67.9337	47.3988	18.1427
UCT 216J	47.3988	18.8889	28.5100	164.1568	133.1740	297.3308	1.2326	60.1491	49.4801	23.2556
UCT 346	88.9856	32.7982	56.1874	553.7016	514.7089	1068.4104	1.0758	63.1421	88.2395	34.6361
UCT 210	70.6858	16.5483	54.1375	338.6693	416.4675	755.1368	0.8132	76.5889	68.3296	12.5664
UCT 205	93.3053	15.5038	77.8015	663.1028	683.7981	1346.9009	0.9697	83.3838	105.6832	18.7867
UCT 468	98.5203	37.9190	60.6013	649.0780	660.3477	1309.4258	0.9829	61.5115	113.8827	49.0167
UCT 388										
UCT 173	125.5223	43.4325	82.0898	1034.6594	1176.8915	2211.5510	0.8791	65.3986	119.6319	41.4690
UCT 208/215B	83.2915	13.1319	70.1596	557.6900	518.8329	1076.5229	1.0749	84.2339	93.1875	24.0332
UCT 330	106.8770	29.1383	77.7387	971.2509	727.8771	1699.1281	1.3344	72.7366	108.3849	33.6936
UCT 51	92.9283	20.6010	72.3273	733.0214	578.8050	1311.8264	1.2664	77.8313	99.5021	35.3665
UCT 328	192.8074	89.1348	103.6726	2596.4914	2078.1581	4674.6496	1.2494	53.7700	200.2765	107.2068
UCT 355	229.2734	72.3587	156.9145	3970.0282	3535.9290	7505.9572	1.1228	68.4400	223.1866	64.0885
UCT 334	159.5929	44.0216	115.5713	1510.5902	2305.0254	3815.6156	0.6553	72.4163	147.2150	50.4540
UCT 162	209.7956	40.1024	169.6931	3523.3836	3195.0753	6718.4590	1.1028	80.8850	204.5177	50.8467
UCT 412	176.8560	42.8827	133.9732	2711.2009	2017.3142	4728.5151	1.3440	75.7527	175.3009	59.8945
UCT 451	339.6690	125.3495	214.3195	8143.0681	7688.7650	15831.8332	1.0591	63.0966	431.3250	219.1261
UCT 450	287.9270	38.5945	249.3325	6695.8974	6224.3452	12920.2426	1.0758	86.5957	296.8805	60.1301
UCT 390	207.1566	11.6396	195.5170	3180.1017	3642.4071	6822.5088	0.8731	94.3813	223.6814	25.3212
UCT 185/202										
UCT 399	201.0619	83.2522	117.8097	2695.2438	2626.6689	5321.9127	1.0261	58.5938	240.1433	122.4750

Specimen ID	31	32	33	34	35	36	37	38	39	40
UCT 216O	17.9699	56.3739	52.4264	108.8002	1.0753	63.5556	29.1382	7.4613	21.6770	47.3387
UCT 213	18.3233	38.9604	47.7005	86.6609	0.8168	76.0430	37.3850	16.3363	21.0487	80.4342
UCT 189/217L	17.7107	88.4960	96.4427	184.9386	0.9176	42.3156	65.0388	43.0084	22.0304	189.1029
UCT 190/217K	29.0990	164.0521	166.8644	330.9165	0.9831	57.1936	75.3040	58.6692	16.6347	97.0385
UCT 195/215I	29.2561	179.7341	129.2600	308.9940	1.3905	61.7233	58.0174	26.4129	31.6044	196.1663
UCT 216J	26.2244	159.5314	140.0910	299.6223	1.1388	53	62.2114	30.1593	32.0521	236.4683
UCT 346	53.6034	519.8255	525.1932	1045.0187	0.9900	60.7477	95.6615	41.0449	54.6166	544.0109
UCT 210	55.7633	315.1609	406.8094	721.9703	0.7747	81.6092	78.7597	21.9911	56.7686	379.5319
UCT 205	86.8964	861.8937	856.8175	1718.7112	1.0060	82.2235	93.9022	20.0434	73.8588	538.3762
UCT 468	64.8660	740.5259	899.4261	1639.9520	0.8233	56.9586	96.7375	42.3801	54.3574	584.8126
UCT 388										
UCT 173	78.1629	938.1421	1059.1540	1997.2961	0.8857	65.3361	136.3451	54.9150	81.4300	1112.0333
UCT 208/215B	69.1543	603.0511	689.5388	1292.5899	0.8746	74.2099	87.9646	19.2422	68.7223	517.4960
UCT 330	74.6914	885.3923	804.0163	1689.4086	1.1012	68.9130	107.4817	39.5605	67.9212	765.0523
UCT 51	64.1356	800.7084	587.9450	1388.6534	1.3619	64.4565	87.3677	22.4624	64.9053	535.6250
UCT 328	93.0697	2475.8946	2077.0898	4552.9844	1.1920	46.4706	195.6820	104.2066	91.4753	2022.8641
UCT 355	159.0981	4142.1363	3176.3560	7318.4923	1.3041	71.2848	231.9673	68.6124	163.35	3642.0000
UCT 334	96.7611	1433.4013	1610.3126	3043.7138	0.8901	65.7277	155.6031	39.8668	155.7363	1485.0652
UCT 162	153.6710	2873.3869	3388.5960	6261.9829	0.8480	75.1382	215.9217	64.5126	151.4090	3577.7203
UCT 412	115.4064	2016.5536	2307.5753	4324.1290	0.8739	65.8333	177.6571	45.4353	132.2218	2475.8573
UCT 451	212.1989	11170.2419	10616.4876	21786.4876	1.0522	49.1970	290.8015	93.8694	196.9622	6330.6333
UCT 450	236.7504	7114.7507	6335.3167	13450.0674	1.1230	79.7460	301.7107	52.1190	249.5917	7099.1343
UCT 390	198.3602	3533.5396	4368.3311	7901.8707	0.8089	55.2822	194.8259	11.3333	183.4926	2990.1592
UCT 185/202										
UCT 399	117.6683	2674.5284	4185.6061	6860.1345	0.6390	48.9992	188.4956	64.9132	123.5824	2323.5896

Specimen ID	41	42	43	44
UCT 216O	82.5022	129.8408	0.5738	74.3935
UCT 213	95.5438	175.9780	0.8419	56.3025
UCT 189/217L	189.1029	378.2057	1.0000	33.8727
UCT 190/217K	82.9173	179.9558	1.1703	22.091
UCT 195/215I	229.7576	425.9238	0.8538	54.4741
UCT 216J	229.4604	465.9286	1.0305	51.5213
UCT 346	648.4399	1192.4508	0.8390	57.0936
UCT 210	539.8307	919.3625	0.7031	72.0782
UCT 205	830.3645	1368.7410	0.6484	78.6551
UCT 468	618.8450	1203.6576	0.9450	56.1906
UCT 388				
UCT 173	1379.7272	2491.7605	0.8060	59.7235
UCT 208/215B	660.2128	1177.7088	0.7838	78.125
UCT 330	819.5194	1584.5717	0.9335	63.1933
UCT 51	588.0640	1123.6890	0.9108	74.2898
UCT 328	2314.2927	4337.1568	0.8741	46.7469
UCT 355	4175.0000	7818.0000	0.8723	70.4194
UCT 334	2146.5584	3631.6236	0.6918	74.3792
UCT 162	3133.4033	6711.1236	1.1418	70.1222
UCT 412	2214.5473	4690.4046	1.1180	74.4253
UCT 451	5683.5582	12014.1916	1.1139	67.7308
UCT 450	6932.7808	14031.9151	1.0240	82.7255
UCT 390	3028.5995	6018.7587	0.9873	94.1829
UCT 185/202				
UCT 399	2649.5306	4973.1202	0.8770	65.5625

E-2: Khoisan tibia cross-sectional geometry calculated from radiograph measurements. See B-4 for key.

Specimen ID	21	22	23	24	25	26	27	28	29	30
UCT 216O	31.6673	7.7440	23.9232	72.8440	74.5505	147.3945	0.9771	75.5456	42.8827	19.0066
UCT 213	34.7146	8.4823	26.2323	95.4416	82.5245	177.9661	1.1565	75.5656	37.7777	15.6216
UCT 189/217L	51.0273	21.2764	29.7509	198.3786	145.3653	343.7438	1.3647	58.3038	58.7478	35.7356
UCT 190/217K	72.8064	37.4949	35.3115	331.4406	275.4086	606.8492	1.2035	48.5005	81.5165	45.9458
UCT 195/215I	67.9212	27.1434	40.7779	309.3824	305.6080	614.9905	1.0123	60.0370	94.0750	50.1398
UCT 216J	70.8743	26.1381	44.7363	345.5737	341.3227	686.8965	1.0125	63.1206	81.0845	44.79911
UCT 346	132.3474	32.8296	99.5178	1469.0564	1132.8036	2601.8601	1.2968	75.1944	168.4679	67.1437
UCT 210										
UCT 205	184.1916	24.9128	159.2787	3030.8220	2285.7742	5316.5963	1.3259	86.4745	244.6201	42.0581
UCT 468	138.6463	48.3805	90.2658	1476.0746	1218.3616	2694.4363	1.2115	65.1051	170.8555	78.1550
UCT 388	147.7805	21.2058	126.5748	1962.1772	1473.6347	3435.8119	1.3315	85.6505	179.9347	50.0691
UCT 173										
UCT 208/215B	173.8872	38.4845	135.4026	2800.7362	1862.7010	4663.4372	1.50356	77.8681	236.0907	81.5557
UCT 330	195.7212	47.5872	148.1339	3698.2546	2179.9599	5878.2146	1.6965	75.6862	238.9181	86.5195
UCT 51	182.0867	42.1916	139.8951	3035.1595	2002.5762	5037.7357	1.5156	76.8289	239.2009	88.9856
UCT 328	321.6205	112.1391	209.4814	9122.5848	5666.9632	14789.5480	1.6098	65.1331	405.2655	229.7290
UCT 355										
UCT 334	281.9815	56.6743	225.3072	8485.4244	4308.6463	12794.0707	1.9694	79.9014	342.5121	125.6323
UCT 162										
UCT 412	355.3141	102.4002	252.9139	14043.4043	5981.3084	20024.7128	2.3479	71.1804	437.2312	142.5498
UCT 451										
UCT 450										
UCT 390	449.7661	56.0774	393.6887	20833.7854	11994.2794	32828.0649	1.7370	87.5319	545.8125	113.4508
UCT 185/202	505.4037	127.5172	377.8865	24406.1969	14581.7345	38987.9315	1.6738	74.7692	680.2255	253.8328
UCT 399	316.6725	95.8186	220.8540	9034.0029	5791.7704	14825.7734	1.5598	69.7421	428.9059	222.2834

Specimen ID	31	32	33	34	35	36	37	38	39	40
UCT 216O	23.8761	108.3304	124.9936	233.3240	0.8667	55.6777	35.7827	17.3180	18.4647	74.4051
UCT 213	22.1561	83.8409	100.6363	184.4772	0.8331	58.6486	45.0819	22.3210	22.7608	142.0845
UCT 189/217L	23.0122	170.0063	173.9866	343.9929	0.9771	39.1711	68.6124	45.9301	22.6823	251.5079
UCT 190/217K	35.5707	300.9928	387.2706	688.2634	0.7772	43.6362	87.6112	65.3137	22.2975	216.5868
UCT 195/215I	43.9352	475.3425	527.2450	1002.5875	0.9016	46.7023	73.8667	39.0343	34.8324	296.9049
UCT 216J	36.2854	293.5388	444.9334	738.4722	0.6597	44.7501	86.4645	47.7129	38.7515	446.4000
UCT 346	101.3242	2057.3778	1706.8041	3764.1820	1.2054	60.1445	146.2411	79.9221	66.3190	1152.4704
UCT 210										
UCT 205	202.5620	4797.7940	4337.8749	9135.6689	1.1060	82.8068	153.9380	27.0962	126.8418	1831.5647
UCT 468	92.7005	1942.4887	1707.9720	3650.4608	1.1373	54.2567	135.7639	59.3761	76.3878	1221.9639
UCT 388	129.8656	2631.2337	2138.3612	4769.5950	1.2305	72.1737	131.6642	39.4663	92.1979	1322.9542
UCT 173										
UCT 208/215B	154.5349	4384.8607	3397.6821	7782.5427	1.2905	65.4558	158.0849	50.8938	107.1911	1955.2988
UCT 330	152.3987	5058.1386	2981.5157	8039.6542	1.6965	63.7870	186.1394	69.2014	116.9379	2559.1706
UCT 51	150.2152	4665.2227	3244.8705	7910.0932	1.4377	62.7988	170.8555	65.5179	105.3376	1963.8019
UCT 328	175.5365	11017.2034	6901.0728	17918.2761	1.5964	43.3140	315.6358	152.7914	162.8445	6398.8400
UCT 355										
UCT 334	216.8800	11542.9026	5575.2703	17118.1730	2.0704	63.3203	224.2155	56.0774	168.1380	4440.9946
UCT 162										
UCT 412	294.6814	21450.5460	8369.7234	29820.2694	2.5629	67.3973	333.0559	130.0619	202.9940	9461.0158
UCT 451										
UCT 450										
UCT 390	432.3617	37909.6133	13524.2941	51433.9074	2.8031	79.2143	372.1216	41.8774	330.2442	12062.5058
UCT 185/202	426.3927	40830.0675	23404.7353	64234.8028	1.7445	62.6840	407.4960	160.5354	246.9606	12022.7534
UCT 399	206.6225	12113.0021	8837.6168	20950.6190	1.37062	48.1743	273.0201	111.1888	161.8313	5055.6398

Specimen ID	41	42	43	44
UCT 216O	80.7389	155.1440	0.9216	51.6023
UCT 213	99.1519	241.2363	1.4330	50.4878
UCT 189/217L	168.4533	419.9612	1.4930	33.0586
UCT 190/217K	262.9151	479.5019	0.8238	25.4505
UCT 195/215I	326.1862	623.0911	0.9102	47.1558
UCT 216J	383.5243	829.9243	1.1639	44.8179
UCT 346	1223.1514	2375.6218	0.9422	45.3491
UCT 210				
UCT 205	1801.0844	3632.6491	1.0169	82.3980
UCT 468	1147.8067	2369.7705	1.0646	56.2652
UCT 388	1187.9447	2510.8989	1.1136	70.0251
UCT 173				
UCT 208/215B	1620.8844	3576.1832	1.2063	67.8060
UCT 330	2160.3614	4719.5320	1.1846	62.8228
UCT 51	1981.1900	3944.9920	0.9912	61.6530
UCT 328	5711.8815	12110.7215	1.1203	51.5925
UCT 355				
UCT 334	3152.4189	7593.4135	1.4088	74.9895
UCT 162				
UCT 412	5755.4955	15216.5114	1.6438	60.9489
UCT 451				
UCT 450				
UCT 390	9721.7981	21784.3040	1.2408	88.7463
UCT 185/202	10041.7304	22064.4837	1.1973	60.6044
UCT 399	4621.6552	9677.2950	1.0939	59.2745

E-3: Khoisan femur cross-sectional geometry calculated from radiograph measurements. See B-4 for key.

Specimen ID	21	22	23	24	25	26	27	28	29	30
UCT 216O	34.0863	9.8018	24.2845	75.6192	95.0370	170.6562	0.7957	71.2442	38.4845	12.8648
UCT 213	31.1410	7.0372	24.1039	67.1331	77.1598	144.2929	0.8701	77.4023	35.7356	11.6239
UCT 189/217L	58.5279	22.5409	35.9869	186.6244	240.2143	426.8386	0.7769	61.4868	67.7327	41.1234
UCT 190/217K	67.8034	26.8606	40.9428	257.1913	300.7588	557.9501	0.8551	60.3846	70.0889	37.9190
UCT 195/215I	80.3462	26.5465	53.7998	386.9803	537.4200	924.4003	0.7201	66.9599	80.0871	22.7059
UCT 216J	83.2522	28.2665	54.9857	450.1625	516.2265	966.3891	0.8720	66.0472	72.2566	17.6715
UCT 346	144.0420	57.2555	86.7865	1310.1573	1474.6587	2784.8160	0.8884	60.2508	139.4082	38.7987
UCT 210	137.8845	33.1752	104.7093	1430.6243	1410.8058	2841.4302	1.0140	75.9398	136.8399	31.6515
UCT 205	183.3512	34.9738	148.3774	2324.1239	2852.1908	5176.3147	0.8149	80.9253	183.6261	34.6361
UCT 468	170.8555	66.4054	104.4501	2024.5990	1901.3830	3925.9820	1.0648	61.1336	158.9175	57.1770
UCT 388	145.2594	25.2348	120.0245	1598.6081	1641.0798	3239.6879	0.9741	82.6277	137.8845	21.2058
UCT 173	224.3097	76.9769	147.3328	3449.8405	3579.7698	7029.6102	0.9637	65.6828	222.6604	65.0310
UCT 208/215B	219.4874	53.3600	166.1274	4098.6057	3134.5075	7233.1132	1.3076	75.6888	205.6172	54.7580
UCT 330	187.4745	47.5873	139.8872	2625.3020	2573.7890	5199.0910	1.0200	74.6167	192.8074	41.8225
UCT 51	188.1893	49.5429	138.6463	2830.3190	2362.5955	5192.9145	1.19797	73.6739	177.6571	42.0973
UCT 328	320.4739	135.7953	184.6785	6587.7327	6670.9933	13258.7260	0.9875	57.6267	315.7301	104.7328
UCT 355										
UCT 334	315.4002	73.8903	241.5099	7951.2873	6974.5098	14925.7971	1.1401	76.5725	283.5287	42.9377
UCT 162	506.9038	130.1955	376.7084	22485.5401	15980.1631	38465.7033	1.4071	74.3156	528.1803	150.4195
UCT 412	592.4494	205.2245	387.2249	18678.4329	31081.4393	49759.8722	0.6010	65.3600	398.5110	87.3991
UCT 451	607.5605	167.7061	439.8544	30868.0856	23272.4571	54140.5427	1.3264	72.3968	578.0688	108.5734
UCT 450										
UCT 390	561.7953	59.8159	501.9794	32948.1712	18401.4893	51349.6605	1.7905	89.3527	509.5742	49.0717
UCT 185/202	579.1919	146.7752	432.4167	29461.1000	20225.2756	49686.3756	1.4566	74.6586	542.9143	122.3336
UCT 399	416.4181	101.9447	314.4734	13815.6488	11825.6911	25641.3399	1.1683	75.5187	385.3163	78.8854

Specimen ID	31	32	33	34	35	36	37	38	39	40
UCT 216O	25.6197	103.4821	105.5809	209.0630	0.9801	66.5714	56.5487	35.5314	21.0173	123.8601
UCT 213	24.1117	82.3528	99.4516	181.8044	0.8281	67.47252747	54.5223	31.5337	22.9886	143.0284
UCT 189/217L	26.6093	199.5587	251.8224	451.3811	0.7925	39.2857	92.1822	62.4863	29.6959	292.3616
UCT 190/217K	32.1699	297.4173	251.0953	548.5126	1.1845	45.8987	94.7190	41.4690	53.2500	330.5458
UCT 195/215I	57.3812	453.6581	476.5573	930.2154	0.9519	71.6485	118.7522	65.9734	52.7788	615.8621
UCT 216J	54.5852	358.4101	423.0566	781.4667	0.8472	75.5435	103.9160	52.8730	51.0430	518.3138
UCT 346	100.6095	1254.1167	1616.8283	2870.9451	0.7757	72.1690	224.9380	136.6593	88.2788	2365.5929
UCT 210	105.1884	1384.1138	1434.2345	2818.3483	0.9651	76.8697	175.3873	70.4502	104.9370	1765.6714
UCT 205	148.9900	2196.9390	2987.5853	5184.5243	0.7354	81.1377	215.5761	72.6493	142.9268	2618.9870
UCT 468	101.7405	1924.9847	1554.7433	3479.7280	1.2381	64.0210	215.4740	112.6104	102.8636	2427.3199
UCT 388	116.6788	1456.1489	1485.6892	2941.8382	0.9801	84.6206	162.2240	68.0705	94.1535	1549.9358
UCT 173	157.6294	3322.0490	3879.0342	7201.0832	0.8564	70.7937	249.6388	130.4546	119.1842	3152.6972
UCT 208/215B	150.8593	3382.1720	2811.8077	6193.9798	1.2028	73.3690	245.6725	111.1181	134.5544	3527.9970
UCT 330	150.9849	2456.4182	3226.8503	5683.2685	0.7612	78.3087	217.1626	95.0018	122.1608	2798.8486
UCT 51	135.5597	2519.9820	2211.4502	4731.4321	1.1395	76.3042	208.6410	95.8029	112.8382	2820.3424
UCT 328	210.9972	6839.8165	7171.1850	14011.0014	0.9538	66.8284	438.6056	286.9845	151.6211	7665.1268
UCT 355										
UCT 334	240.5910	6216.6272	6261.7100	12478.3372	0.9928	84.8560	401.8882	197.1192	204.7690	9145.9978
UCT 162	377.7608	21705.9747	18964.3284	40670.3031	1.1446	71.5212	528.9971	218.8433	310.1537	21536.1127
UCT 412	311.1119	10775.8857	13276.8729	24052.7586	0.8116	78.0686	447.8419	171.3974	276.4444	14377.6936
UCT 451	469.4953	27277.4453	23819.8040	51097.2492	1.1452	81.2179	711.5079	348.0256	363.4823	30313.6839
UCT 450										
UCT 390	460.5025	22367.9260	18624.9398	40992.8659	1.2010	90.3701	580.1893	144.9845	435.2048	31357.9174
UCT 185/202	420.5807	25128.9290	19463.4524	44592.3814	1.2911	77.4672	604.8037	259.6526	345.1511	23531.3281
UCT 399	306.4309	11000.3984	11469.1014	22469.4998	0.9591	79.5271	497.4319	261.0114	236.4206	12132.6635

Specimen ID	41	42	43	44
UCT 216O	190.6121	314.4722	0.6498	37.1667
UCT 213	164.8926	307.9210	0.8674	42.1636
UCT 189/217L	436.7226	729.0843	0.6694	32.2144
UCT 190/217K	746.4242	1076.9700	0.4428	56.2189
UCT 195/215I	945.2675	1561.1296	0.6515	44.4444
UCT 216J	768.3357	1286.6495	0.6746	49.1195
UCT 346	2705.2542	5070.8471	0.8744	39.2458
UCT 210	2328.9226	4094.5940	0.7581	59.8316
UCT 205	4050.1442	6669.1312	0.6466	66.2999
UCT 468	2954.7555	5382.0755	0.8215	47.7383
UCT 388	1886.3517	3436.2875	0.8217	58.0392
UCT 173	4062.8324	7215.5296	0.7760	47.74265
UCT 208/215B	4006.1124	7534.1094	0.8807	54.7698
UCT 330	3203.4176	6002.2662	0.8737	56.2532
UCT 51	2601.5133	5421.8557	1.0841	54.0824
UCT 328	9863.3096	17528.4364	0.7771	34.5689
UCT 355				
UCT 334	10320.5261	19466.5239	0.8862	50.9517
UCT 162	15123.3108	36659.4234	1.4240	58.6305
UCT 412	12608.5665	26986.2601	1.1403	61.7281
UCT 451	29327.8015	59641.4854	1.0336	51.0862
UCT 450				
UCT 390	19880.3679	51238.2852	1.5773	75.0108
UCT 185/202	22889.3978	46420.7259	1.0280	57.0683
UCT 399	15372.4036	27505.0671	0.7892	47.5282

E-4: Sadlermiut humerus cross-sectional geometry calculated from radiograph measurements. See B-4 for key.

Specimen ID	21	22	23	24	25	26	27	28	29	30
XIV-C:123	28.7456	4.8695	23.8761	61.8162	63.4015	125.2177	0.9750	83.0601	34.7303	7.2100
XIV-C:119	34.7303	5.3014	29.4289	91.3714	94.8063	186.1776	0.9638	84.7354	52.6138	22.9965
XIV-C:77	72.9007	12.8334	60.0673	364.7509	458.2325	822.9833	0.7960	82.3960	88.7500	40.0789
XIV-C:84	56.7372	28.6513	28.0858	183.7110	188.4133	372.1243	0.9750	49.5017	62.4706	31.4316
XIV-C:118	111.9978	56.6194	55.3784	788.8407	675.2357	1464.0765	1.1682	49.4460		
XIV-C:301	190.4983	62.9104	127.5879	2855.0998	2252.8995	5107.9993	1.2673	66.9759	183.4690	87.6504
XIV-C:46										
XIV-C:327	144.4818	43.3932	101.0886	1727.5163	1317.6403	3045.1567	1.3111	69.9663	171.9629	60.1144
XIV-C:2	236.3734	98.4889	137.8845	3397.9103	3824.6136	7222.5239	0.8884	58.3333		
XIV-C:220	123.5431	36.4503	87.0928	1388.2370	873.8770	2262.1140	1.5886	70.4959	125.8915	37.6991
XIV-C:22	308.4259	115.6106	192.8152	7270.9026	5777.8488	13048.7514	1.2584	62.5159	343.0619	134.7508
XIV-C:198	255.8670	121.7210	134.1460	3910.8964	4131.6282	8042.5246	0.9466	52.4280	244.3374	112.7125
XIV-C:316	243.9604	98.9602	145.0002	4293.1010	3633.4646	7926.5656	1.1815	59.4360	231.8495	96.6432
XIV-C:709	237.9285	80.5033	157.4252	5043.3742	3142.4236	8185.7978	1.6049	66.1649	251.6259	99.2900
XIV-C:307	287.5814	93.6038	193.9776	6302.8856	5446.4612	11749.3468	1.1572	67.4514	298.6162	119.4355
XIV-C:146	317.0260	108.3378	208.6881	6541.3157	7576.8522	14118.1679	0.8633	65.8268		
XIV-C:158	207.2352	93.7294	113.5057	2803.4795	2623.9110	5427.3905	1.0684	54.7715	215.7881	98.4889
XIV-C:239	173.1018	80.1185	92.9833	1985.4281	1763.8600	3749.2881	1.1256	53.7160	158.6190	62.0779
XIV-C:193	309.6982	84.0376	225.6606	8074.7259	6171.2144	14245.9403	1.3085	72.8647		
XIV-C:400										
XIV-C:126	393.5787	137.0206	256.5582	11463.0305	10031.8604	21494.8909	1.1427	65.1860		
XIV-C:149	233.9308	86.9436	146.9873	4180.4374	3341.0258	7521.4632	1.2512	62.8336		
XIV-C:117	340.3916	152.9877	187.4039	7999.2702	6654.1272	14653.3973	1.2022	55.0554		
XIV-C:175	228.2210	82.4668	145.7542	3462.2943	3695.7083	7158.0025	0.9368	63.8654		
XIV-C:179	401.0793	174.2406	226.8387	10148.4374	10584.0523	20732.4897	0.9588	56.5571		
XIV-C:98	300.1792	87.9646	212.2146	6533.0967	6436.5267	12969.6234	1.0150	70.6960	266.4856	92.5199
XIV-C:103	293.0478	124.6663	168.3815	6611.8206	4699.8362	11311.6569	1.4068	57.4587		
XIV-C:181	437.2390	255.4429	181.79611	10227.7798	9779.4005	20007.1804	1.0458	41.5782		
XIV-C:217	364.1734	167.1327	197.0407	7793.8321	8696.9313	16490.7633	0.8962	54.1063		
XIV-C:221	317.2774	165.5619	151.7154	5180.3471	6011.6070	11191.9541	0.8617	47.8179		

Specimen ID	31	32	33	34	35	36	37	38	39	40
XIV-C:123	27.5204	91.8805	89.3441	181.2245	1.0284	79.2402	40.6444	8.5765	32.0678	116.4953
XIV-C:119	29.6174	159.2989	195.0066	354.3055	0.8169	56.2920	43.9823	21.1665	22.8158	102.8308
XIV-C:77	48.6711	450.6992	543.9320	994.6312	0.8286	54.8407	82.0741	34.6832	47.3909	370.4062
XIV-C:84	31.0389	196.4476	273.2046	469.6522	0.7190	49.6857	70.8115	39.4663	31.3452	263.6424
XIV-C:118										
XIV-C:301	95.8186	1959.9712	2144.9720	4104.9432	0.9138	52.2260	198.4308	93.0304	105.4004	2498.0909
XIV-C:46										
XIV-C:327	111.8486	1963.1059	2152.0512	4115.1571	0.9122	65.0422	124.6820	37.6049	87.0771	1120.9839
XIV-C:2										
XIV-C:220	88.1924	1309.8087	964.2917	2274.1004	1.3583	70.0543	129.5907	55.1350	74.4557	1123.4854
XIV-C:22	208.3112	7361.7203	7829.9638	15191.6841	0.9402	60.7212	264.2237	94.6562	169.5675	4882.2364
XIV-C:198	131.6249	3513.3045	3902.5987	7415.9032	0.9002	53.8701	220.3356	90.7135	129.6221	3237.4701
XIV-C:316	135.2063	3202.1192	3895.7220	7097.8412	0.8220	58.3164	240.8659	93.9336	146.9323	4262.4770
XIV-C:709	152.3358	4744.9662	3737.6380	8482.6042	1.2695	60.5406	221.5451	74.6128	146.9323	3217.3427
XIV-C:307	179.1807	6014.3304	5792.3086	11806.6390	1.0383	60.0037	237.7165	78.5320	159.1845	3843.7266
XIV-C:146										
XIV-C:158	117.2992	2568.2047	3166.8251	5735.0298	0.8110	54.3585	195.4306	92.2843	103.1463	2489.5277
XIV-C:239	96.5411	1494.0804	1898.7540	3392.8344			172.0022	89.0799	82.9223	1780.8969
XIV-C:193										
XIV-C:400										
XIV-C:126										
XIV-C:149										
XIV-C:117										
XIV-C:175										
XIV-C:179										
XIV-C:98	173.9657	4477.8319	5401.2088	9879.0407	0.8290	65.2815	254.4612	96.7375	157.7237	4284.7004
XIV-C:103										
XIV-C:181										
XIV-C:217										
XIV-C:221										

Specimen ID	41	42	43	44
XIV-C:123	134.3024	250.7977	0.8674	78.8986
XIV-C:119	133.3611	236.1920	0.7711	51.8750
XIV-C:77	516.1298	886.5360	0.7177	57.7416
XIV-C:84	286.0746	549.7170	0.9216	44.2657
XIV-C:118				
XIV-C:301	2318.9277	4817.0187	1.0773	53.1170
XIV-C:46				
XIV-C:327	1122.1599	2243.1438	0.9990	69.8394
XIV-C:2				
XIV-C:220	1053.7243	2177.2097	1.0662	57.4545
XIV-C:22	4731.5576	9613.7940	1.0318	64.1757
XIV-C:198	3160.0199	6397.4900	1.0245	58.8294
XIV-C:316	3550.5072	7812.9843	1.2005	61.0017
XIV-C:709	3672.9749	6890.3176	0.8760	66.3216
XIV-C:307	4172.4068	8016.1334	0.9212	66.9640
XIV-C:146				
XIV-C:158	2180.6629	4670.1906	1.1416	52.7790
XIV-C:239	1664.0882	3444.9851	1.0702	48.2100
XIV-C:193				
XIV-C:400				
XIV-C:126				
XIV-C:149				
XIV-C:117				
XIV-C:175				
XIV-C:179				
XIV-C:98	4466.9436	8751.6440	0.9592	61.9834
XIV-C:103				
XIV-C:181				
XIV-C:217				
XIV-C:221				

E-5: Sadlermiut tibia cross-sectional geometry calculated from radiograph measurements. See B-4 for key.

Specimen ID	21	22	23	24	25	26	27	28	29	30
XIV-C:123	43.4954	5.1129	38.3824	162.8085	131.1275	293.9360	1.2416	88.2449	57.3184	15.7080
XIV-C:119	63.2324	20.2868	42.9456	314.0545	249.7464	563.8009	1.2575	67.9170	86.8493	38.4767
XIV-C:77	91.1062	17.8992	73.2070	745.4626	528.5779	1274.0404	1.4103	80.3534	123.7395	50.2655
XIV-C:84	74.6599	26.0359	48.6240	400.9245	370.2960	771.2205	1.0827	65.1273	97.5936	53.2971
XIV-C:118	113.0973	44.7520	68.3453	842.9702	861.7501	1704.7203	0.9782	60.4306		
XIV-C:301	330.8568	113.7099	217.1469	10616.2952	5330.3837	15946.6789	1.9917	65.6317	442.7682	233.3732
XIV-C:46	297.9172	82.5139	215.4033	7867.8176	5082.5324	12950.3500	1.5480	72.3031		
XIV-C:327	207.8164	56.6194	151.1970	3854.5098	2525.6103	6380.1202	1.5262	72.7551	263.8938	109.0761
XIV-C:2	295.4668	79.1681	216.2987	8735.7122	4613.5157	13349.2279	1.8935	73.2057		
XIV-C:220	199.9152	49.0088	150.9064	3684.2269	2367.2249	6051.4518	1.5563	75.4852	279.0127	117.8568
XIV-C:22										
XIV-C:198	312.7848	105.2983	207.4865	8328.0061	5317.2184	13645.2246	1.5662	66.3352	490.6539	246.0260
XIV-C:316	346.9732	124.6584	222.3148	8927.4022	7201.8627	16129.2649	1.2396	64.0726	506.0713	292.6394
XIV-C:709	353.0757	85.5299	267.5459	12344.0210	6891.8644	19235.8855	1.7911	75.7758	470.8462	176.5182
XIV-C:307	360.4035	81.0767	279.3269	12089.4250	7679.0944	19768.5194	1.5743	77.5039	443.3101	163.9754
XIV-C:146	354.4188	83.5664	270.8524	8740.2559	9739.6509	18479.9068	0.8974	76.4216		
XIV-C:158	353.4292	152.6107	200.8185	11491.7896	5585.6275	17077.4171	2.0574	56.8200	515.2526	283.9843
XIV-C:239	274.7323	104.4422	170.2900	6609.1717	3897.5075	10506.6791	1.6957	61.9840	378.4991	188.8726
XIV-C:193	447.0172	95.0332	351.9840	19642.1736	11013.6499	30655.8234	1.7834	78.7406		
XIV-C:400	300.4148	69.3271	231.0877	8915.7797	5016.5278	13932.3075	1.7773	76.9229	593.7610	221.4509
XIV-C:126	567.8429	137.8688	429.9741	28862.6728	19117.9354	47980.6081	1.5097	75.7206		
XIV-C:149	340.6350	109.0604	231.5746	10377.7834	6360.2181	16738.0015	1.6317	67.9832		
XIV-C:117	357.3247	97.5936	259.7312	11749.2185	7165.5895	18914.8079	1.6397	72.6877		
XIV-C:175	345.8108	95.6379	250.1729	12767.7735	5644.1713	18411.9448	2.2621	72.3439		
XIV-C:179	485.5646	166.6301	318.9345	19355.4383	13278.2291	32633.6674	1.4577	65.6832		
XIV-C:98	407.3860	100.9394	306.4467	16316.7920	8929.4976	25246.2896	1.8273	75.2227	546.7000	217.5710
XIV-C:103	424.8690	127.5487	297.3203	16743.4063	8980.5808	25723.9871	1.8644	69.9793		
XIV-C:181	671.1149	248.7749	422.3400	33907.7564	26495.2908	60403.0472	1.2798	62.9311		
XIV-C:217	483.8995	141.0182	342.8813	23260.7706	11778.3918	35039.1624	1.9749	70.8579		
XIV-C:221	376.3235	119.4591	256.8645	13377.7748	6983.9947	20361.7695	1.9155	68.2563		

Specimen ID	31	32	33	34	35	36	37	38	39	40
XIV-C:123	41.6104	256.5674	219.7630	476.3304	1.1675	72.5952	53.3600	15.4017	37.9583	191.4950
XIV-C:119	48.3727	590.7689	389.5028	980.2717	1.5167	55.6972	82.4982	47.1710	35.3272	346.3346
XIV-C:77	73.4740	1202.8620	819.8175	2022.6795	1.4672	59.3780	98.4889	52.7788	45.7102	566.0848
XIV-C:84	44.2965	514.6920	540.2816	1054.9736			71.5341	37.7777	33.7564	278.4585
XIV-C:118										
XIV-C:301	209.3950	16254.2720	7599.2107	23853.4827	2.1389	47.2922	326.0659	156.0743	169.9916	6947.8594
XIV-C:46										
XIV-C:327	154.8177	5178.4749	4002.4058	9180.8807	1.2938	58.6667	216.3929	76.8512	139.5417	3017.8629
XIV-C:2										
XIV-C:220	161.1558	5717.9053	4152.6099	9870.5152	1.3769	57.7593	205.7350	93.2817	112.4533	2962.3450
XIV-C:22										
XIV-C:198	244.6280	16802.4036	11003.4198	27805.8235	1.5270	49.8575	310.0752	130.6274	179.4478	6742.4348
XIV-C:316	213.4320	14033.7752	13016.2668	27050.0421	1.0782	42.1743	338.0040	150.7964	187.2075	7106.2141
XIV-C:709	294.3280	19754.5554	11277.5952	31032.1506	1.7517	62.5104	340.2031	125.2396	214.9635	8991.0471
XIV-C:307	279.3347	18301.7760	9630.1062	27931.8823	1.9005	63.0111	321.3535	121.6896	199.6639	7886.9685
XIV-C:146										
XIV-C:158	231.2683	17966.0075	11395.8021	29361.8096	1.5765	44.8845	362.1000	211.5548	150.5451	7133.6260
XIV-C:239	189.6265	10872.5629	6257.7509	17130.3137			281.8794	145.2594	136.6200	4907.7932
XIV-C:193										
XIV-C:400	372.3101	24286.2222	22817.2275	47103.4496	1.0644	62.7037	484.9991	247.2905	237.7086	13461.3764
XIV-C:126										
XIV-C:149										
XIV-C:117										
XIV-C:175										
XIV-C:179										
XIV-C:98	329.1290	27453.6923	13883.3210	41337.0132	1.9775	60.2029	376.0486	157.1582	218.8905	10038.5913
XIV-C:103										
XIV-C:181										
XIV-C:217										
XIV-C:221										

Specimen ID	41	42	43	44
XIV-C:123	215.2325	406.7275	0.8897	71.1363
XIV-C:119	360.5832	706.9178	0.9605	42.8218
XIV-C:77	529.1587	1095.2436	1.0698	46.4115
XIV-C:84	308.6967	587.1552	0.9020	47.1893
XIV-C:118				
XIV-C:301	5764.3112	12712.1706	1.2053	52.1341
XIV-C:46				
XIV-C:327	3304.9178	6322.7807	0.9131	64.4853
XIV-C:2				
XIV-C:220	2343.6070	5305.9520	1.2640	54.6593
XIV-C:22				
XIV-C:198	5424.7713	12167.2061	1.2429	57.8723
XIV-C:316	7371.2334	14477.4475	0.9640	55.3862
XIV-C:709	6744.9359	15735.9829	1.3330	63.1868
XIV-C:307	6252.6449	14139.6134	1.2614	62.1322
XIV-C:146				
XIV-C:158	6394.8233	13528.4493	1.1155	41.5756
XIV-C:239	4327.0286	9234.8218	1.1342	48.4675
XIV-C:193				
XIV-C:400	13673.2250	27134.6014	0.9845	49.0122
XIV-C:126				
XIV-C:149				
XIV-C:117				
XIV-C:175				
XIV-C:179				
XIV-C:98	8426.7670	18465.3583	1.1913	58.2080
XIV-C:103				
XIV-C:181				
XIV-C:217				
XIV-C:221				

E-6: Sadlermiut femur cross-sectional geometry calculated from radiograph measurements. See B-4 for key.

Specimen ID	21	22	23	24	25	26	27	28	29	30
XIV-C:123	50.7996	9.7389	41.0606	180.4668	212.3593	392.8261	0.8498	80.8287	46.4956	5.2386
XIV-C:119	63.9942	25.0542	38.9400	222.3913	322.7233	545.1146	0.6891	60.8493	58.0174	10.6264
XIV-C:77	102.9186	29.1932	73.7253	629.6689	947.8751	1577.5441	0.6643	71.6346	97.4836	19.6271
XIV-C:84	78.1000	32.8846	45.2154	320.1289	495.0162	815.1451	0.6467	57.8942	75.1469	33.0574
XIV-C:118	156.8126	75.7595	81.0531	1367.3601	1634.6910	3002.0511	0.8365	51.6879		
XIV-C:301	437.2390	188.4092	248.8298	12260.1966	11954.6566	24214.8533	1.0256	56.9093	417.2820	157.0953
XIV-C:46	336.3389	128.2948	208.0441	7869.7337	7378.0977	15247.8315	1.0666	61.8555		
XIV-C:327	227.2785	64.9681	162.3104	3271.0111	4313.6968	7584.7078	0.7583	71.4147	230.0824	56.7372
XIV-C:2	393.4452	149.5398	243.9054	11010.8067	9589.3500	20600.1568	1.1482	61.9922		
XIV-C:220	230.8442	82.2783	148.5659	3534.7975	3864.2215	7399.0190	0.9148	64.3576	254.6575	89.1348
XIV-C:22	442.1478	153.8674	288.2804	14717.5381	12425.2447	27142.7827	1.1845	65.2000	471.9300	130.7060
XIV-C:198	451.2898	189.9564	261.3333	15075.6262	11363.9694	26439.5957	1.3266	57.9081	399.7991	125.3338
XIV-C:316	431.8747	195.8704	236.0043	11693.8263	11401.2287	23095.0551	1.0257	54.6465	431.7334	172.1593
XIV-C:709	459.7642	150.3252	309.4390	15117.9583	14458.0402	29575.9984	1.0456	67.3038	450.4887	105.4868
XIV-C:307	447.8419	114.2047	333.6371	15686.2066	13798.8498	29485.0563	1.1368	74.4989	458.0128	98.7481
XIV-C:146	608.6050	131.7820	476.8231	29315.4373	26441.6875	55757.1248	1.1087	78.3469		
XIV-C:158	557.8055	204.0150	353.7905	19477.9639	22280.1898	41758.1537	0.8742	63.4254	512.3781	184.1759
XIV-C:239	383.5649	194.8259	188.7390	8358.0424	8460.5492	16818.5916	0.9879	49.2065		
XIV-C:193	644.0893	210.6045	433.4848	31875.8977	25687.4441	57563.3418	1.2409	67.3020		
XIV-C:400	400.9536	94.0122	306.9415	12519.7120	11591.5572	24111.2692	1.0801	76.5529	421.9473	86.5901
XIV-C:126	685.8647	199.6325	486.2321	36981.5953	30794.8523	67776.4476	1.2009	70.8933		
XIV-C:149	547.3911	204.8318	342.5593	20082.1363	20406.6651	40488.8014	0.9841	62.5803		
XIV-C:117										
XIV-C:175	432.6052	110.8354	321.7698	14885.7432	12531.6129	27417.3561	1.18786	74.3796		
XIV-C:179	713.1729	199.5225	513.6504	43622.7407	31251.7009	74874.4416	1.3959	72.0233		
XIV-C:98	575.2649	146.0841	429.1808	26626.3543	22291.0662	48917.4205	1.1945	74.6058	569.9949	106.8142
XIV-C:103	524.8188	173.8636	350.9552	18920.6490	19258.0002	38178.6492	0.9825	66.8717		
XIV-C:181	939.2969	460.9973	478.2996	54603.3753	50354.5549	104957.9302	1.0844	50.9210		
XIV-C:217	724.4591	214.2566	510.2025	43413.5010	31415.1692	74828.6701	1.3819	70.4253		
XIV-C:221	535.1860	184.9299	350.2562	21289.2549	18521.7632	39811.0181	1.1494	65.4457		

Specimen ID	31	32	33	34	35	36	37	38	39	40
XIV-C:123	41.2570	181.4429	156.6759	338.1187	1.1581	88.7331	82.9066	40.4637	42.4429	349.5871
XIV-C:119	47.3909	230.3107	279.8595	510.1702	0.8230	81.6840	126.4098	96.7139	29.6959	413.6012
XIV-C:77	77.8565	656.8029	789.8314	1446.6343	0.8316	79.8663	159.0431	106.2172	52.8259	908.3913
XIV-C:84	42.0895	316.9591	408.2986	725.2577	0.7763	56.0096	116.2389	65.0310	51.2080	529.6642
XIV-C:118										
XIV-C:301	260.1867	11499.4085	12033.4791	23532.8875	0.9556	62.3527	524.8423	338.7422	186.1001	11036.5394
XIV-C:46										
XIV-C:327	173.3452	3189.3702	4869.7589	8059.1292	0.6549	75.3405	323.7411	168.6721	155.0690	5031.5462
XIV-C:2										
XIV-C:220	165.5227	3959.4189	5164.6102	9124.02904	0.7666	64.9981	335.7577	211.2800	124.4778	4652.2538
XIV-C:22	341.2241	17683.7765	14941.5747	32625.3511	1.1835	72.3040	545.0820	304.3025	240.7795	15674.6431
XIV-C:198	274.4652	13846.7801	9374.4300	23221.2101	1.4771	68.6508	646.9168	420.8478	226.0690	17294.3536
XIV-C:316	259.5741	11807.2396	12657.8869	24465.1265	0.9328	60.1237	580.5192	369.4513	211.0679	14446.0076
XIV-C:709	345.0019	15320.2575	15119.2378	30439.4953	1.0133	76.5839	637.8376	352.4867	285.3509	19456.9465
XIV-C:307	359.2647	15817.7785	15684.7629	31502.5414	1.0085	78.4399	561.6696	312.3921	249.2775	16780.6910
XIV-C:146										
XIV-C:158	328.2022	16145.7100	19811.8753	35957.5853	0.8150	64.0547	580.7862	336.0326	244.7536	17364.8088
XIV-C:239										
XIV-C:193										
XIV-C:400	335.3572	12387.0256	14825.6042	27212.6298	0.8355	79.4784	484.9991	243.0886	241.9105	13848.6502
XIV-C:126										
XIV-C:149										
XIV-C:117										
XIV-C:175										
XIV-C:179										
XIV-C:98	463.1807	25981.0578	23490.8614	49471.9192	1.1060	81.2605	697.4022	338.1139	359.2882	27840.5124
XIV-C:103										
XIV-C:181										
XIV-C:217										
XIV-C:221										

Specimen ID	41	42	43	44
XIV-C:123	476.0781	825.6652	0.7343	51.1936
XIV-C:119	619.6700	1033.2712	0.6675	23.4918
XIV-C:77	1344.4541	2252.8454	0.6757	33.2148
XIV-C:84	1006.0322	1535.6964	0.5265	44.0541
XIV-C:118				
XIV-C:301	13897.5953	24934.1347	0.7941	35.4583
XIV-C:46				
XIV-C:327	7110.9601	12142.5063	0.7076	47.8991
XIV-C:2				
XIV-C:220	6201.3623	10853.6161	0.7502	37.0737
XIV-C:22	16658.9798	32333.6229	0.9409	44.1731
XIV-C:198	19850.2438	37144.5975	0.8712	34.9456
XIV-C:316	17421.5544	31867.5620	0.8292	36.3585
XIV-C:709	25432.9182	44889.8648	0.7650	44.7372
XIV-C:307	17285.7478	34066.4388	0.9708	44.3815
XIV-C:146				
XIV-C:158	18327.2939	35692.1027	0.9475	42.1418
XIV-C:239				
XIV-C:193				
XIV-C:400	13797.1321	27645.7823	1.0037	49.8785
XIV-C:126				
XIV-C:149				
XIV-C:117				
XIV-C:175				
XIV-C:179				
XIV-C:98	30736.5550	58577.0674	0.9058	51.5181
XIV-C:103				
XIV-C:181				
XIV-C:217				
XIV-C:221				

Appendix F: Stirrup Court Data

F-1: Right humerus external measurements. See B-5 for key.

Specimen ID	1	2	3	4	5	6	7	8	9	10
SC J										
SC 14	333.0	271.0	24.1	23.9	26.3	17.9	26.4	24.6	26.1	24.6
SC 20	355.5	291.0	24.5	22.7	24.5	21.5	24.7	23.2	25.1	21.0
SC X1	319.0	268.0	20.7	16.9	21.4	15.4	19.0	18.3	20.0	16.2
SC X2										
SC X4										
SC 11	356.5	290.0	21.6	22.2	23.3	18.8	22.5	21.5	23.2	21.2
SC 17	345.0	282.0	22.1	22.5	23.9	19.3	22.2	23.8	25.4	21.3
SC B	317.0	275.0	24.5	18.5	24.5	17.1	21.8	18.1	22.4	18.0
SC 21	338.0	284.0	23.0	19.2	22.8	15.4	24.6	21.7	24.9	20.4
SC 10	302.0	245.0	21.1	20.0	22.4	18.4	23.1	20.6	23.3	19.7
SC 5										
SC X3										
SC 19	322.0	258.0	20.2	21.0	21.0	18.3	23.0	21.9	23.7	21.7
SC 6	358.0	296.0	26.3	26.2	26.5	21.7	27.1	25.2	27.5	24.0
SC A	325.0	273.0	19.9	21.9	22.3	16.9	16.8	22.5	22.5	16.5
SC 4	340.5	286.0	24.1	21.5	24.1	20.2	24.4	22.7	25.7	21.9
SC 7	300.0	245.0	21.8	18.9	21.6	18.4	21.9	21.1	22.0	19.8
SC 18	333.5	278.0	17.9	19.5	19.5	16.7	19.3	19.8	19.9	17.4

Specimen ID	11	12	13	14
SC J				
SC 14	22.1	22.0	22.3	20.8
SC 20	21.1	24.7	25.6	20.2
SC X1	18.9	16.2	19.6	15.1
SC X2				
SC X4				
SC 11	21.0	19.9	21.3	18.7
SC 17	20.5	23.2	24.1	19.7
SC B	19.6	21.3	22.7	17.0
SC 21	20.0	19.4	20.0	18.5
SC 10	21.1	16.4	20.6	16.2
SC 5				
SC X3				
SC 19	18.3	23.4	23.7	18.3
SC 6	23.7	23.8	26.1	21.5
SC A	20.0	16.8	20.5	16.3
SC 4	20.8	23.6	23.6	20.3
SC 7	20.7	18.0	21.0	16.9
SC 18	18.3	17.5	19.6	17.3

F-2: Left humerus external measurements. See B-5 for key.

Specimen ID	1	2	3	4	5	6	7	8	9	10
SC J										
SC 14	328.5	271.0	23.5	22.1	25.0	17.4	24.6	24.1	24.5	23.3
SC 20	355.5	295.0	24.2	21.1	24.1	20.0	24.0	21.2	24.0	20.0
SC X1										
SC X2	307.0	254.0	19.6	16.0	20.2	14.7	18.1	17.7	18.7	16.1
SC X4										
SC 11	349.0	282.0	20.7	18.6	21.8	18.5	21.3	21.0	23.1	20.6
SC 17	342.5	282.0	21.0	23.0	23.2	18.7	22.3	23.6	24.1	20.8
SC B	330.5	275.0	22.9	20.0	24.3	17.5	21.9	21.4	21.5	18.0
SC 21	330.0	273.0	22.1	21.4	23.0	15.5	25.4	22.0	25.7	20.9
SC 10	296.0	242.0	21.7	18.7	22.4	16.6	22.5	19.6	22.8	19.4
SC 5	298.0	245.0	20.1	21.3	21.4	15.5	19.9	19.2	20.9	17.4
SC X3	304.0	256.0	20.5	18.5	20.5	18.0	22.1	20.8	23.2	19.2
SC 19	319.0	258.0	19.2	21.4	21.6	18.6	22.5	21.6	23.7	21.8
SC 6	359.0	298.0	24.9	24.7	25.4	20.6	25.2	24.6	26.3	22.4
SC A	311.5	263.0	18.8	18.8	20.5	17.5	16.9	21.9	16.7	22.3
SC 4	336.0	280.0	23.3	22.1	23.5	19.7	24.6	21.2	24.6	20.6
SC 7	292.0	240.0	21.5	19.7	21.5	17.2	22.1	20.0	22.2	18.8
SC 18	316.5	263.0	17.9	18.6	19.3	15.8	18.1	18.6	19.3	16.8

Specimen ID	11	12	13	14
SC J				
SC 14	21.6	20.6	21.6	19.7
SC 20	21.0	20.5	24.2	17.7
SC X1				
SC X2	19.5	14.2	21.0	14.0
SC X4				
SC 11	21.2	19.0	21.0	17.9
SC 17	20.2	20.3	20.9	19.1
SC B	23.8	17.7	23.9	17.7
SC 21	21.0	18.8	21.0	18.2
SC 10	21.2	17.2	21.5	16.0
SC 5	17.8	18.4	19.6	15.8
SC X3	19.6	17.4	20.6	17.1
SC 19	18.0	23.2	24.1	17.1
SC 6	22.7	22.8	25.0	20.2
SC A	17.6	17.6	22.2	15.3
SC 4	20.4	20.9	22.7	18.8
SC 7	20.0	18.3	20.1	16.8
SC 18	18.6	18.1	18.2	16.2

F-3: Right tibia external measurements. See B-5 for key.

Specimen ID	1	2	3	4	5	6	7	8	9	10
SC J										
SC 14	383.0	383.0	29.2	23.1	31.7	23.1	36.3	27.2	38.3	25.8
SC 20										
SC X1										
SC X2	335.5	335.5	28.7	19.9	30.3	19.7	34.6	22.4	36.8	22.2
SC X4	403.5	403.5	29.7	26.0	31.4	24.7	38.1	30.0	40.4	28.4
SC 11	398.0	398.0	30.6	22.2	30.7	21.8	37.5	25.4	37.5	24.7
SC 17	386.5	386.5	28.4	23.2	31.1	22.2	37.0	29.6	38.4	26.9
SC B										
SC 21	379.0	379.0	25.3	19.0	30.4	18.1	29.8	23.3	30.3	23.0
SC 10	341.0	341.0	26.9	24.4	30.2	21.7	32.5	25.9	36.6	25.3
SC 5	354.0	354.0	27.7	19.8	29.8	19.7	30.0	24.4	32.7	22.0
SC X3	375.0	375.0	28.0	24.1	29.7	20.6	33.1	21.2	33.1	21.2
SC 19	364.0	364.0	27.4	22.0	29.6	20.4	30.5	28.6	35.2	24.5
SC 6										
SC A										
SC 4	380.0	380.0	27.7	28.2	34.0	22.6	35.5	29.4	39.6	23.9
SC 7										
SC 18	384.0	384.0	26.5	22.1	27.4	20.3	31.0	27.6	32.6	23.1

Specimen ID	11	12	13	14

SC J				
SC 14	24.9	23.9	27.4	22.4
SC 20				
SC X1				
SC X2	22.5	21.0	26.7	18.6
SC X4	24.2	24.0	28.4	22.6
SC 11	24.6	22.7	25.7	22.3
SC 17	23.6	23.8	26.6	21.6
SC B				
SC 21	22.1	17.8	22.7	17.7
SC 10	22.3	20.4	25.4	19.7
SC 5	23.0	20.4	23.1	20.2
SC X3	23.4	21.9	26.4	19.0
SC 19	22.2	22.9	25.4	20.2
SC 6				
SC A				
SC 4	23.4	24.5	28.0	22.0
SC 7				
SC 18	22.5	20.1	24.3	19.2

F-4: Left tibia external measurements. See B-5 for key.

Specimen ID	1	2	3	4	5	6	7	8	9	10
SC J										
SC 14	384.0	384.0	27.7	24.7	30.5	22.6	34.7	27.9	38.5	25
SC 20										
SC X1	354.0	254.0	27.7	21.2	28.8	21.1	33.7	21.7	34.4	21.8
SC X2										
SC X4	387.0	387.0								
SC 11	395.0	395.0	28.1	21.8	29.6	21.7	35.9	23.9	35.6	23.6
SC 17	385.5	385.5	27.3	25.9	32.2	21.0	37.4	29.6	39.6	24.3
SC B										
SC 21	375.0	375.0	24.6	19.4	25.0	18.1	28.6	23.7	29.3	23.5
SC 10	339.0	339.0	27.8	26.5	30.5	21.3	34.5	26.1	36.8	25.7
SC 5	354.5	354.5	28.8	220	29.9	20.5	31.7	25.2	34.2	20.6
SC X3										
SC 19	366.0	366.0	26.2	23.9	28.8	20.6	37.1	28.4	40.6	25.3
SC 6										
SC A										
SC 4	380.0	380.0	29.7	26.3	33.4	25.0	35.2	30.6	39.9	24.2
SC 7										
SC 18	388.0	388.0	28.3	21.8	28.5	19.9	30.1	22.1	33.4	22.1

Specimen ID	11	12	13	14
SC J				
SC 14	24.6	23.8	26.5	21.1
SC 20				
SC X1	23.9	22.0	25.6	21.1
SC X2				
SC X4				
SC 11	23.0	22.7	25.0	20.9
SC 17	24.8	23.1	27.2	20.0
SC B				
SC 21	21.5	17.3	22.1	17.1
SC 10	23.0	22.0	26.0	20.4
SC 5	22.6	22.1	24.7	20.4
SC X3				
SC 19	22.4	23.1	25.6	20.5
SC 6				
SC A				
SC 4	23.9	26.9	28.9	22.5
SC 7				
SC 18	22.5	20.9	26.4	19.2

F-5: Right femur external measurements. See B-5 for key.

Specimen ID	1	2	3	4	5	6	7	8	9	10
SC J										
SC 14	479.0	340.0	32.2	29.3	32.7	27.9	31.9	30.5	32.1	28.6
SC 20	478.5	357.0	29.1	28.3	30.0	24.4	28.7	30.5	30.5	26.4
SC X1	457.0	354.0	24.3	22.0	25.0	21.6	25.3	23.4	25.3	22.8
SC X2	430.5	324.0	26.2	25.7	26.4	23.1	25.9	27.3	25.9	23.7
SC X4										
SC 11	502.0	364.0	30.5	24.8	30.2	24.4	28.4	24.6	32.1	23.6
SC 17	487.0	347.0	28.9	29.4	29.5	27.4	29.0	29.4	29.4	28.1
SC B	460.0	381.0	25.1	28.5	28.4		25.5	31.1	31.1	24.2
SC 21	415.5	328.0	25.7	21.6	26.0	18.9	26.7	16.6	27.7	15.6
SC 10	426.0	307.0	26.1	26.2	26.3	23.7	26.0	27.0	26.9	23.0
SC 5										
SC X3	426.0	324.0	25.5	26.6	26.6	23.0	25.3	27.5	27.7	24.2
SC 19										
SC 6	488.0	366.0	31.5	31.4	31.5	28.1	32.1	32.6	33.5	27.1
SC A										
SC 4	458.0	339.0	29.7	30.0	30.0	26.3	30.3	30.0	30.5	27.3
SC 7	419.0	308.0	25.5	25.6	25.7	22.1	25.6	24.5	26.5	21.5
SC 18	458.0	345.0	27.8	27.8	23.4	28.1	25.7	27.1	28.1	24.1

Specimen ID	11	12	13	14
SC J				
SC 14	31.1	34.0	34.1	29.5
SC 20	27.9	29.1	29.3	26.7
SC X1	25.3	23.5	25.2	23.3
SC X2	27.9	25.2	27.9	24.6
SC X4				
SC 11	31.2	27.3	31.4	26.2
SC 17	31.2	35.7	36.4	29.8
SC B	27.0	27.1	27.3	25.1
SC 21	24.5	31.1	32.0	22.8
SC 10	25.9	27.0	27.0	25.1
SC 5				
SC X3	26.5	27.4	27.2	24.4
SC 19				
SC 6	30.8	34.7	34.9	29.0
SC A				
SC 4	31.0	31.6	31.6	28.4
SC 7	27.2	27.9	28.8	23.5
SC 18	29.1	33.1	26.3	33.1

F-6: Left femur external measurements. See B-5 for key.

Specimen ID	1	2	3	4	5	6	7	8	9	10
SC J										

SC 14	483.0	341.0	31.7	31.3	31.7	27.6	31.2	32.4	32.5	28.1
SC 20	480.0	360.0	28.1	29.9	31.8	23.8	28.5	32.1	32.1	26.0
SC X1	459.0	354.0	24.4	23.2	25.1	21.8	24.6	24.2	24.5	23.1
SC X2	440.0	325.0	26.5	24.7	25.6	24.1	25.5	26.8	26.8	24.6
SC X4										
SC 11										
SC 17	484.5	342.0	28.2	29.8	29.8	26.6	28.4	29.9	30.0	27.4
SC B										
SC 21	422.5	319.0	25.6	24.3	25.5	21.9				
SC 10	431.0	310.0	26.0	25.3	26.2	24.4	26.1	25.0	26.2	23.5
SC 5	415.0	314.0	29.2	27.7	29.2	24.0	27.6	28.8	28.8	25.4
SC X3										
SC 19	432.5	324.0	27.7	27.9	28.1	24.9	27.8	29.2	29.3	25.5
SC 6	494.0	366.0	31.1	30.5	31.1	28.7	32.3	31.5	33.4	28.3
SC A										
SC 4	465.0	344.0	31.0	28.8	31.0	27.6	30.8	30.4	30.8	28.0
SC 7	412.0	302.5	25.8	26.7	27.0	23.5	24.0	26.1	27.6	22.9
SC 18		345.0	26.6	26.2	22.9	27.2	25.0	27.7	27.9	24.2

Specimen ID	11	12	13	14
SC J				
SC 14	31.4	33.7	34.2	29.7

SC 20	29.0	30.5	30.5	27.5
SC X1	24.7	24.9	25.3	24.1
SC X2	27.6	24.9	27.6	23.8
SC X4				
SC 11				
SC 17	29.9	34.3	34.5	28.7
SC B				
SC 21	23.8	32.8	32.6	23.3
SC 10	25.6	27.2	27.2	24.9
SC 5	28.9	28.7	29.0	26.0
SC X3				
SC 19	27.7	30.4	31.0	27.5
SC 6	30.5	34.1	34.8	29.3
SC A				
SC 4	32.1	31.4	32.2	29.8
SC 7	26.0	30.2	30.2	23.9
SC 18	27.5	30.8	31.3	24.8

F-7: Right humerus radiograph cross-sectional measurements. See B-5 for key.

Specimen ID	15	16	17	18	19	20	21	22	23	24

SC J	10.9	10.9	2.2	1.8	2.0	2.1	10.4	11.9	1.7	1.9
SC 14	23.4	24.3	5.7	4.1	5.1	5.0	26.8	25.1	6.6	4.9
SC 20	24.8	23.9	6.0	5.6	6.0	6.1	24.9	23.0	6.2	4.5
SC X1	19.4	18.1	5.7	5.5	4.8	4.2	18.2	18.8	4.0	3.9
SC X2										
SC X4										
SC 11	22.7	23.0	5.7	4.6	4.2	4.6	23.1	22.6	4.7	3.5
SC 17	20.7	24.2	5.7	5.4	5.8	5.7	22.0	25.2	4.4	4.8
SC B	24.6	21.5	3.4	4.8	3.5	3.5	22.3	21.6	5.5	3.7
SC 21	23.0	21.3	4.8	4.5	4.5	3.8	24.4	22.0	4.1	3.6
SC 10	21.8	19.9	5.3	5.3	4.0	4.6	23.5	20.1	5.2	3.3
SC 5										
SC X3										
SC 19	20.5	21.3	4.3	3.5	4.4	4.1	24.0	22.1	5.4	2.6
SC 6	26.3	27.1	5.6	3.9	3.8	5.8	27.5	25.9	5.7	3.1
SC A	20.5	21.9	1.9	2.3	2.8	1.8	17.2	22.6	2.6	2.0
SC 4	23.5	23.7	5.0	4.5	4.5	5.1	23.7	23.2	5.2	3.3
SC 7	20.9	19.4	3.1	2.3	3.7	2.3	20.8	20.3	3.2	2.3
SC 18	19.2	19.5	3.2	2.5	2.0	3.0	19.6	20.1	2.5	2.1

Specimen ID	25	26	27	28	29	30	31	32
SC J	2.4	2.3	9.1	10.3	1.8	1.7	2.1	1.2

SC 14	4.2	4.0	22.6	21.8	6.3	5.2	5.3	5.3
SC 20	4.9	5.0	21.6	21.6	5.9	6.6	6.7	6.2
SC X1	4.1	3.8	19.7	15.5	4.4	5.3	4.1	4.4
SC X2								
SC X4								
SC 11	3.4	4.3	21.2	19.1	5.9	5.9	4.5	5.5
SC 17	4.2	4.6	22.0	22.0	6.3	7.6	5.4	6.8
SC B	3.9	3.6	18.9	17.2	3.0	3.5	4.1	3.7
SC 21	3.2	3.2	20.3	18.5	4.8	3.7	4.8	3.9
SC 10	3.9	3.8	21.1	16.9	6.3	5.2	5.3	4.8
SC 5								
SC X3								
SC 19	2.9	2.9	19.1	23.5	4.2	4.4	4.5	7.5
SC 6	3.8	3.2	23.7	21.7	4.2	3.8	3.6	3.6
SC A	2.6	1.8	19.5	16.2	2.6	2.4	2.4	2.2
SC 4	3.5	4.7	21.0	21.0	5.4	4.3	5.4	4.8
SC 7	2.6	2.1	21.3	17.0	4.2	2.7	2.9	2.2
SC 18	2.2	1.3	18.2	18.1	2.7	2.1	2.6	2.7

F-8: Left humerus radiograph cross-sectional measurements. See B-5 for key.

Specimen ID	15	16	17	18	19	20	21	22	23	24
SC J										
SC 14	21.3	22.7	5.4	4.5	4.9	5.4	24.1	24.4	5.5	4.5
SC 20	24.5	21.2	5.2	4.9	6.0	5.5	24.4	21.4	5.8	6.1
SC X1										
SC X2	20.0	16.6	4.7	5.7	4.8	4.2	18.1	17.8	4.2	4.2
SC X4										
SC 11	21.2	21.5	5.3	4.0	4.2	4.8	22.3	20.9	4.0	3.7
SC 17	19.8	23.0	5.2	4.3	4.4	5.6	21.2	23.2	4.3	4.3
SC B	22.7	20.3	5.3	4.3	4.1	4.8	20.6	20.2	5.2	4.1
SC 21	21.2	20.4	4.4	3.6	3.7	3.3	24.6	22.3	3.7	3.4
SC 10	19.8	18.7	5.5	5.2	4.8	5.2	21.7	19.9	4.0	3.7
SC 5	20.2	17.7	3.2	4.2	3.2	3.2	19.9	17.9	3.9	2.9
SC X3	19.2	20.1	5.3	5.8	5.9	5.0	21.4	22.2	5.8	5.0
SC 19	19.3	21.3	3.9	3.6	4.5	4.5	22.3	21.8	3.2	2.9
SC 6	23.6	24.1	4.9	3.3	3.8	4.8	23.6	24.1	4.0	3.4
SC A	18.1	18.1	2.3	2.2	2.2	1.7	16.7	21.9	2.6	1.7
SC 4	23.0	22.1	4.6	4.5	5.1	5.6	23.9	20.4	4.3	4.6
SC 7	19.6	18.0	2.8	1.9	3.1	2.6	20.3	19.9	2.9	1.7
SC 18	16.7	17.9	2.7	1.7	2.0	1.1	16.7	18.3	2.6	1.3

Specimen ID	25	26	27	28	29	30	31	32
SC J								
SC 14	4.3	4.7	22.2	20.4	5.7	6.2	4.6	5.4
SC 20	5.0	4.5	21.4	22.6	2.4	6.0	7.2	6.7
SC X1								
SC X2	4.1	3.5	20.2	14.4	4.5	5.4	3.7	3.7
SC X4								
SC 11	3.5	3.4	21.2	18.7	5.4	5.4	4.6	5.1
SC 17	3.9	4.5	21.5	20.2	5.7	6.2	5.4	5.1
SC B	4.1	3.9	24.2	17.5	5.5	5.0	4.0	4.2
SC 21	3.9	2.8	21.0	18.3	4.9	3.2	5.2	3.6
SC 10	4.5	3.0	21.8	17.1	6.6	6.1	4.7	4.7
SC 5	3.4	3.3	17.9	19.6	3.9	3.7	3.7	2.1
SC X3	6.4	3.9	21.1	17.4	5.6	5.6	5.3	4.7
SC 19	2.5	3.1	21.1	24.2	5.0	2.2	4.6	2.8
SC 6	3.4	3.2	24.5	22.9	4.7	5.6	3.2	5.8
SC A	2.4	1.7	20.2	17.7	2.4	1.8	2.2	1.9
SC 4	3.5	4.0	22.5	20.4	5.8	5.8	4.4	5.7
SC 7	2.2	2.2	20.4	18.5	3.0	1.7	2.2	3.0
SC 18	2.4	1.3	18.2	16.4	2.4	1.4	2.1	2.4

F-9: Right tibia radiograph cross-sectional measurements. See B-5 for key.

Specimen ID	15	16	17	18	19	20	21	22	23	24
SC J										
SC 14	29.1	27.3	12.2	7.2	7.8	9.8	37.3	32.9	9.1	6.9
SC 20										
SC X1										
SC X2	26.5	22.2	12.0	5.8	4.9	11.6	32.4	24.2	8.4	4.7
SC X4	29.0	26.7	8.7	4.7	5.2	6.0	35.9	31.3	4.8	4.3
SC 11	30.6	22.1	10.1	7.1	5.1	4.9	38.4	26.6	8.2	7.6
SC 17	29.4	27.7	12.3	6.8	5.8	10.0	39.7	31.4	7.3	7.1
SC B										
SC 21	25.6	18.4	6.5	4.6	4.2	3.4	30.8	24.1	4.9	3.3
SC 10	28.2	25.7	13.0	5.5	5.5	13.2	37.5	26.4	9.6	5.9
SC 5	29.9	23.	6.6	5.6	3.0	6.7	32.1	28.2	4.5	4.5
SC X3	27.7	27.2	6.6	4.0	3.1		32.5	26.9	4.4	3.3
SC 19	28.2	26.8	10.7	6.3	5.8	8.3	32.1	31.1	7.0	5.1
SC 6										
SC A										
SC 4	27.7	27.4	9.5	5.0	4.9	6.2	35.5	30.9	8.2	4.4
SC 7										
SC 18	27.0	22.8	4.7	5.7	4.0	2.2	32.3	25.5	4.0	3.9

Specimen ID	25	26	27	28	29	30	31	32
SC J								
SC 14	3.7	7.8	24.7	25.9	9.3	4.6	6.3	6.0
SC 20								
SC X1								
SC X2	3.2	5.0	20.8	22.9	8.1	3.6	5.4	4.3
SC X4	2.9	4.7	23.2	25.0	5.6	3.6	5.6	3.2
SC 11	4.3	3.8	24.3	22.5	7.2	4.4	4.1	4.8
SC 17	3.6	4.5	24.5	24.7	9.7	4.8	5.0	4.3
SC B								
SC 21	2.6	2.6						
SC 10	5.0	5.0	23.8	21.4	8.9	5.1	4.8	4.6
SC 5	5.7	2.2	22.8	22.0	5.3	3.4	3.9	2.9
SC X3	2.1	1.9	23.0	24.0	6.3	3.8	3.4	3.7
SC 19	4.0	4.7	22.0	24.8	6.2	3.5	6.0	3.6
SC 6								
SC A								
SC 4	4.5	5.4	23.0	25.8	6.7	3.9	6.4	3.5
SC 7								
SC 18	3.1	1.9	21.9	22.6	4.6	2.9	4.4	1.3

F-10: Left tibia radiograph cross-sectional measurements. See B-5 for key.

Specimen ID	15	16	17	18	19	20	21	22	23	24
SC J										
SC 14	27.8	25.9	12.2	6.4	5.5	6.7	35.9	30.1	8.2	4.9
SC 20										
SC X1	29.3	22.7	7.8	3.1	2.8	6.4	35.5	23.5	5.9	3.2
SC X2										
SC X4										
SC 11	26.4	23.2	8.7	4.7	4.1	6.0	33.9	26.7	7.0	4.4
SC 17	24.9	27.1	8.6	6.4	5.6	9.5	33.6	31.4	6.2	5.7
SC B										
SC 21	25.7	18.6	7.7	4.2	4.1	3.9	30.4	24.4	3.4	3.3
SC 10	29.3	22.0	12.2	6.1	5.2	7.5	37.1	26.1	8.8	4.7
SC 5	28.9	21.3	7.9	7.1	3.3	5.9	33.2	22.6	4.7	5.3
SC X3										
SC 19	25.7	21.6	7.9	6.5	4.7	4.9	35.6	29.2	6.1	3.8
SC 6										
SC A										
SC 4	27.3	29.2	8.4	6.1	5.5	9.3		32.6		5.1
SC 7										
SC 18	25.3	21.6	6.5	5.3	2.5	4.5	27.7	23.7	6.4	3.0

Specimen ID	25	26	27	28	29	30	31	32
SC J								
SC 14	3.8	5.6	24.0	24.7	9.2	3.9	6.5	5.2
SC 20								
SC X1	3.0	4.4	25.3	21.8	5.7	3.9	2.0	3.1
SC X2								
SC X4								
SC 11	3.5	5.9	22.4	22.0	6.5	3.5	3.8	3.8
SC 17	3.2	4.7	22.2	23.5	6.9	4.4	4.8	3.7
SC B								
SC 21	2.4	2.9						
SC 10	3.8	5.3	23.6	21.0	9.3	4.0	5.2	3.7
SC 5	2.3	3.9	22.8	21.7	5.6	3.7	3.6	3.2
SC X3								
SC 19	3.5	1.8	22.2	22.9	5.0	4.2	5.4	3.1
SC 6								
SC A								
SC 4	3.8	5.4	23.3	26.8	5.2	4.8	5.9	3.4
SC 7								
SC 18	3.3	1.9	21.8	19.2	3.6	1.8	2.1	1.8

F-11: Right femur radiograph cross-sectional measurements. See B-5 for key.

Specimen ID	15	16	17	18	19	20	21	22	23	24
SC J										
SC 14	33.03	30.22	5.74	10.64	8.44	8.38	31.83	31.50	6.99	8.40
SC 20	29.65	28.72	6.51	10.68	8.62	9.54	29.60	30.92	6.25	8.34
SC X1	24.17	21.72	5.51	6.36	4.89	6.73	24.79	23.38	5.30	7.57
SC X2	26.42	26.07	5.63	7.28	6.05	8.38	26.00	27.78	6.00	8.84
SC X4										
SC 11	29.10	24.17	5.78	8.99	5.63	6.66	31.89	24.46	8.40	8.82
SC 17	29.58	30.17	5.45	7.35	6.66	7.46	29.38	29.91	7.00	7.21
SC B	24.13	28.86	1.93	3.48	3.87	2.78	24.33	30.84	3.11	2.47
SC 21	25.30	21.54	2.99	3.11	3.06	2.33	26.48	16.46	3.98	4.22
SC 10	24.94	26.24	5.58	6.49	7.15	7.70	25.67	26.81	7.26	7.92
SC 5										
SC X3	25.87	26.24	3.38	6.53	5.37	6.42	24.95	26.92	3.87	6.01
SC 19										
SC 6	32.31	32.55	3.85	9.08	6.05	6.36	32.37	33.65	5.04	7.24
SC A										
SC 4	29.49	29.89	4.84	6.03	5.94	6.99	29.98	30.35	5.54	6.18
SC 7	25.47	24.57	3.01	5.90	4.29	4.66	25.61	23.87	3.96	6.07
SC 18	27.43	25.96	1.92	1.83	4.64	4.82	25.65	25.87	1.10	1.74

Specimen ID	25	26	27	28	29	30	31	32
SC J								
SC 14	9.59	9.35	31.12	34.83	4.58	7.28	5.81	6.66
SC 20	9.45	8.80	28.90	29.36	5.33	5.78	6.97	6.51
SC X1	6.86	7.46	24.51	23.36	3.54	3.63	4.77	3.90
SC X2	7.39	8.93	27.30	25.58	4.71	5.06	4.95	6.18
SC X4								
SC 11	6.05	7.33	30.64	26.79	4.49	4.95	3.79	4.09
SC 17	9.06	8.33	31.32	35.72	4.03	3.11	3.54	3.43
SC B	3.98	2.99	26.06	27.78	2.56	4.86	3.85	2.89
SC 21	3.48	3.61	24.00	31.45	1.78	2.75	1.83	1.65
SC 10	8.62	8.80	25.08	26.97	4.29	4.49	4.64	5.39
SC 5								
SC X3	6.29	6.11	25.87	27.60	2.62	4.58	4.64	3.79
SC 19								
SC 6	9.54	7.39	31.14	35.91	3.85	4.71	3.61	3.43
SC A								
SC 4	7.65	8.07	31.32	30.64	3.54	4.40	5.13	4.40
SC 7	5.45	5.50	26.73	27.98	2.51	3.79	3.79	2.07
SC 18	5.37	7.70	28.15	30.61	1.15	2.40	2.80	2.20

F-12: Left femur radiograph cross-sectional measurements. See B-5 for key.

Specimen ID	15	16	17	18	19	20	21	22	23	24
SC J										

SC 14	30.62	32.29	5.59	9.54	9.41	9.22	31.06	32.92	6.60	8.45
SC 20	26.97	30.64	6.97	8.62	8.62	9.63	27.63	32.66	5.89	7.92
SC X1	24.04	23.56	4.71	6.23	5.63	6.73	24.42	24.50	5.39	7.81
SC X2	26.13	25.3	6.29	7.15	6.25	8.47	25.80	27.10	6.51	8.29
SC X4										
SC 11										
SC 17	28.61	30.72	5.33	8.03	7.41	7.65	28.86	30.84	6.82	7.50
SC B										
SC 21	24.64	23.56	4.23	6.80	6.42	3.98	25.69	20.61	4.34	4.03
SC 10	25.36	25.58	6.34	8.01	6.91	8.33	25.74	25.50	6.88	8.80
SC 5	28.81	28.15	3.30	2.29	5.68	6.78	26.13	29.12	4.22	5.45
SC X3										
SC 19	27.47	28.66	3.83	6.86	5.50	6.23	27.85	30.09	4.40	7.54
SC 6	32.04	31.87	3.98	9.24	7.10	6.42	33.10	33.58	5.17	7.65
SC A										
SC 4	29.12	28.73	4.78	6.23	5.50	6.73	29.50	30.46	5.02	4.93
SC 7	24.95	26.31	3.11	5.59	5.26	4.84	24.28	26.18	3.94	5.61
SC 18	26.44	25.56	1.92	0.73	5.78	5.59	24.28	25.41	1.70	1.70

Specimen ID	25	26	27	28	29	30	31	32
SC J								
SC 14	10.22	10.17	31.91	34.37	4.31	6.75	7.02	6.47

SC 20	10.51	9.21	28.09	30.92	5.04	6.60	7.06	7.33
SC X1	6.93	8.14	24.24	25.19	3.67	3.79	3.10	4.23
SC X2	7.59	8.86	27.47	25.39	4.58	6.07	4.11	5.81
SC X4								
SC 11								
SC 17	8.88	8.99	29.74	35.23	3.61	7.33	3.61	3.79
SC B								
SC 21	4.09	4.22	25.34	31.85	2.07	2.75	2.03	2.51
SC 10	8.80	8.67	25.05	27.52	5.04	5.00	7.46	5.68
SC 5	7.83	8.67	27.76	28.99	2.01	4.40	4.36	4.45
SC X3								
SC 19	7.33	8.07	27.17	31.25	3.30	3.85	4.42	3.68
SC 6	9.92	8.12	30.73	35.23	3.50	4.36	3.54	4.16
SC A								
SC 4	7.59	7.57	31.83	31.25	3.17	3.19	5.41	4.16
SC 7	5.56	6.91	26.24	30.24	2.56	3.57	4.60	2.62
SC 18	5.46	7.79	26.39	30.15	1.43	2.29	2.56	2.29

F-13: Right humerus cross-sectional geometry calculated from radiograph measurements. See B-5 for key.

Specimen ID	33	34	35	36	37	38	39	40	41	42
SC J	93.3132	36.8509	56.4623	580.8180	586.2572	1167.0752	0.9907	60.5084	97.2009	38.4531
SC 14	446.5931	151.6761	294.9170	13383.1596	14569.7254	27952.8850	0.9186	66.0371	528.3216	203.0804
SC 20	465.5212	122.3336	343.1876	16555.7842	15554.3746	32110.1589	1.0644	73.7211	449.7975	146.0998
SC X1	275.7847	58.6064	217.1783	6240.1082	5336.8416	11576.9498	1.1693	78.7492	268.7318	88.1767
SC X2										
SC X4										
SC 11	410.0564	138.2929	271.7635	11814.0056	11806.3061	23620.3112	1.0007	66.2747	410.0250	174.3662
SC 17	393.4374	95.7557	297.6816	9982.0977	13435.1967	23417.2943	0.7430	75.6618	435.4247	164.8708
SC B	413.7085	194.7395	218.9690	11928.4329	9393.2982	21321.7312	1.2699	52.9283	378.3106	145.0709
SC 21	384.7666	139.8794	244.8871	11075.5264	9405.8971	20481.4236	1.1775	63.6456	421.6017	204.6119
SC 10	340.7214	99.4000	241.3214	9340.9824	7627.1635	16968.1459	1.2247	70.8266	370.9828	146.0841
SC 5										
SC X3										
SC 19	342.9441	127.6743	215.2698	7688.0609	8412.4330	16100.4939	0.9139	62.7711	416.5752	204.8318
SC 6	559.7768	230.9071	328.8698	19842.3360	20881.3688	40723.7048	0.9502	58.7502	559.3998	277.5833
SC A	350.9944	214.9635	136.0310	5686.6262	6403.9694	12090.5956	0.8880	38.7559	305.3000	180.1075
SC 4	437.4275	155.0376	282.3899	13183.8635	13408.1129	26591.9764	0.9833	64.5570	431.8433	179.0708
SC 7	318.4475	163.1272	155.3203	6190.8474	5496.1050	11686.9524	1.1264	48.7742	331.6265	187.4588
SC 18	294.0531	153.7417	140.3114	4984.2994	4887.5433	9871.8428	1.0198	47.7163	309.4155	195.5641

Specimen ID	43	44	45	46	47	48	49	50	51	52
SC J	58.7478	545.3123	735.5414	1280.8537	0.7414	60.4396	73.6154	30.7876	42.8278	320.5295
SC 14	325.2412	20506.8241	17174.5837	37681.4078	1.19402	61.5612	386.9500	97.6407	289.3093	11561.0112
SC 20	303.6978	15432.3757	13303.8785	28736.2542	1.1600	67.5188	366.4354	62.1800	304.2554	10354.2614
SC X1	180.5552	4978.4264	5278.5666	10256.9930	0.9431	67.1879	239.8213	54.9779	184.8435	5458.9602
SC X2										
SC X4										
SC 11	235.6587	11145.9308	10608.1465	21754.0774	1.0507	57.4742	318.0234	67.1830	250.8405	8562.2601
SC 17	270.5540	11472.7080	14499.9165	25972.6246	0.7912	62.1356	380.1327	62.3449	317.7878	11211.8531
SC B	233.2397	10011.5586	9223.6459	19235.2044	1.0854	61.6530	255.3172	91.5460	163.7712	4811.4397
SC 21	216.9898	12096.4397	9641.3050	21737.7447	1.2546	51.4680	294.9563	90.8234	204.1328	6766.6944
SC 10	224.8988	10532.9182	7963.0779	18495.9961	1.322719472	60.6224	280.0651	51.2708	228.7943	7478.6826
SC 5										
SC X3										
SC 19	211.7433	10929.5608	9314.8572	20244.4180	1.1733	50.8296	352.5260	94.8368	257.6891	7383.0299
SC 6	281.8166	19442.4426	17206.3782	36648.8208	1.1300	50.3784	403.9224	178.7959	225.1265	11412.6548
SC A	125.1925	3818.3501	5946.9878	9765.3380	0.6421	41.0064	248.1073	132.1040	116.0033	4157.6704
SC 4	252.7725	12298.2466	11898.8921	24197.1387	1.0336	58.5334	346.3606	95.8500	250.5106	8741.5324
SC 7	144.1677	6137.2215	5663.0489	11800.2704	1.0837	43.4729	284.3927	134.5858	149.8068	6176.1825
SC 18	113.8513	4657.6849	4337.2041	8994.8890	1.0739	36.7956	258.7259	134.7115	124.0144	3819.1786

Specimen ID	53	54	55	56
SC J	383.1126	703.6421	0.8366	58.1777
SC 14	10727.8783	22288.8895	1.0777	74.7666
SC 20	10386.4247	20740.6861	0.9969	83.0311
SC X1	3431.0925	8890.0527	1.5910	77.0755
SC X2				
SC X4				
SC 11	6882.1249	15444.3850	1.2441	78.8748
SC 17	11088.2470	22300.1001	1.0111	83.5992
SC B	4209.5441	9020.9838	1.1430	64.1442
SC 21	5737.5568	12504.2512	1.1794	69.2078
SC 10	4847.2425	12325.9252	1.5429	81.6933
SC 5				
SC X3				
SC 19	11091.8546	18474.8846	0.6656	73.0979
SC 6	9538.1995	20950.8543	1.1965	55.7351
SC A	2955.7598	7113.4302	1.4066	46.7553
SC 4	8835.8902	17577.4226	0.9893	72.3265
SC 7	3914.3756	10090.5581	1.5778	52.6761
SC 18	3917.4255	7736.6040	0.9749	47.9327

F-14: Left humerus cross-sectional geometry calculated from radiograph measurements. See B-5 for key.

Specimen ID	33	34	35	36	37	38	39	40	41	42
SC J										

SC 14	379.7479	111.0239	268.7240	9834.4256	11153.2720	20987.6976	0.8818	70.7638	461.8455	170.5414
SC 20	407.9358	109.7044	298.2314	13878.8212	10804.4076	24683.2287	1.2846	73.1074	410.1035	116.8280
SC X1										
SC X2	260.7522	57.3027	203.4495	6170.3809	4277.3322	10447.7132	1.4426	78.0241	253.0396	77.7073
SC X4										
SC 11	357.9845	116.8280	241.1565	8948.5114	9185.8890	18134.4004	0.9742	67.3651	366.0505	160.5354
SC 17	357.6703	105.1648	252.5055	8036.3434	10661.0445	18697.3879	0.7538	70.5973	386.2902	146.4610
SC B	361.9193	117.2914	244.6280	10354.4328	8347.5021	18701.9350	1.2404	67.5918	326.8199	108.2750
SC 21	339.6690	138.9212	200.7478	7990.8408	7266.3449	15257.1857	1.0997	59.1010	430.8537	214.4137
SC 10	290.8015	62.1800	228.6216	6801.7646	6058.3353	12860.0998	1.1227	78.6177	339.1585	136.3451
SC 5	280.8113	113.6000	167.2113	5950.4309	4591.8610	10542.2919	1.2959	59.5458	279.7667	115.2336
SC X3	303.1009	58.5279	244.5730	6738.9096	7329.1856	14068.0951	0.9195	80.6903	373.1270	99.0701
SC 19	322.8693	113.9927	208.8766	6520.6139	8077.2896	14597.9034	0.8073	64.6939	381.8135	206.1199
SC 6	446.7031	187.4745	259.2285	12564.1360	13319.7887	25883.9247	0.9433	58.0315	446.7031	222.6604
SC A	257.3043	151.6761	105.6282	3514.1669	3333.8761	6848.0430	1.0541	41.0519	287.2437	173.3531
SC 4	399.2179	124.4542	274.7637	11695.8271	11164.1947	22860.0219	1.0476	68.8255	382.9287	151.9745
SC 7	277.0885	143.9399	133.1486	4594.9798	4231.2780	8826.2578	1.0860	48.0527	317.2773	191.1266
SC 18	234.7791	142.9739	91.8052	2649.0296	2670.2440	5319.2736	0.9921	39.1028	240.0255	146.7752

Specimen ID	43	44	45	46	47	48	49	50	51	52
SC J										
SC 14	291.3042	14578.6029	14646.6078	29225.2107	0.9954	63.0739	355.6911	84.1319	271.5593	10391.4400

SC 20	293.2755	14115.3775	10693.9765	24809.3540	1.3199	71.5126	379.8500	88.8285	291.0214	9558.3530
SC X1										
SC X2	175.3323	4724.1761	4495.4314	9219.6075	1.0509	69.2905	228.4566	42.8749	185.5817	5531.2400
SC X4										
SC 11	205.5151	9231.9128	8026.1347	17258.0475	1.1502	56.1439	311.3632	73.5133	237.8500	8249.2440
SC 17	239.8292	9397.6329	10968.5204	20366.1532	0.8568	62.0852	341.0984	73.1363	267.9621	9427.4630
SC B	218.5449	7754.9980	7325.8768	15080.8748	1.0586	66.8701	332.6161	100.0676	232.5485	10991.7800
SC 21	216.4400	12182.3493	10000.8576	22183.2070	1.2181	50.2352	301.8285	96.2505	205.5780	7215.9830
SC 10	202.8134	8306.2884	6955.8548	15262.1432	1.1941	59.7990	292.7807	55.0329	237.7479	8407.2540
SC 5	164.5331	5639.4627	4698.5812	10338.0439	1.2002	58.8108	275.5491	111.6365	163.9126	4775.9460
SC X3	274.0568	9962.5251	10405.6552	20368.1803	0.9574	73.4487	288.3511	57.5383	230.8128	7671.091
SC 19	175.6936	8476.0410	7919.6187	16395.6596	1.0703	46.0156	401.0400	183.4062	217.6338	8282.0280
SC 6	224.0427	11857.5914	11949.3020	23806.8934	0.9923	50.1547	440.6476	155.0219	285.6258	14529.0800
SC A	113.8906	3252.3777	5123.9254	8376.3031	0.6347	39.6495	280.8113	170.9026	109.9086	4387.6490
SC 4	230.9542	11527.9834	8363.5973	19891.5807	1.3784	60.3126	360.4978	88.1767	272.3211	10751.6100
SC 7	126.1507	5054.1990	4982.9254	10037.1244	1.0143	39.7604	296.4093	163.9990	132.4103	5027.9890
SC 18	93.2503	2521.1972	2954.1878	5475.3850	0.8534	38.8502	234.4256	134.5858	99.8398	3029.9620

Specimen ID	53	54	55	56
SC J				
SC 14	8665.1630	19056.6000	1.1992	76.3469

SC 20	11698.3000	21256.6500	0.8171	76.6148
SC X1				
SC X2	2847.3920	8378.6310	1.9426	81.2328
SC X4				
SC 11	6426.8630	14676.1100	1.2836	76.3899
SC 17	8266.6810	17694.1400	1.1404	78.5586
SC B	5824.1210	16815.9000	1.8873	69.9150
SC 21	5684.1050	12900.0900	1.2695	68.1109
SC 10	5146.8200	13554.0700	1.6335	81.2034
SC 5	5167.0720	9943.0180	0.9243	59.4858
SC X3	5252.9290	12924.0200	1.4603	80.0458
SC 19	11170.0300	19452.0600	0.7415	54.2674
SC 6	12166.3400	26695.4200	1.1942	64.8195
SC A	3513.0010	7900.6490	1.2490	39.1397
SC 4	8742.5630	19494.1700	1.2298	75.5403
SC 7	4468.5280	9496.5170	1.1252	44.6714
SC 18	2742.4160	5772.3780	1.1049	42.5891

F-15: Right tibia cross-sectional geometry calculated from radiograph measurements. See B-5 for key.

Specimen ID	33	34	35	36	37	38	39	40	41	42
SC J										
SC 14	623.9439	73.8981	550.046	32064.1377	28545.3018	60609.4395	1.1233	88.1563	963.8171	358.0002
SC 20										
SC X1										
SC X2	462.0497	69.2014	392.8483	19347.0531	13640.4354	32987.4885	1.4184	85.0229	615.8150	242.5310
SC X4	608.1338	189.9093	418.2245	27971.9361	24199.9919	52171.9280	1.1559	68.7718	882.5284	498.8535
SC 11	531.1334	127.3445	403.7889	29277.2415	15046.2214	44323.4629	1.9458	76.0240	802.2371	328.3750
SC 17	630.6747	109.0761	521.5986	32115.1714	27969.3683	60084.5397	1.1482	82.7049	979.0616	462.9844
SC B										
SC 21	374.2893	124.3757	249.9137	13743.2645	7029.5114	20772.7759	1.9551	66.7702	582.9853	335.4750
SC 10	569.2095	53.3285	515.8809	27150.0725	22461.8286	49611.9011	1.2087	90.6311	777.5442	283.3717
SC 5	540.1183	184.8906	355.2277	26488.8946	14851.4365	41340.3310	1.7836	65.7685	710.9581	368.2968
SC X3	587.3993	343.5096	243.8897	20573.8376	12512.2121	33086.0498	1.6443	41.5203	686.6343	446.0433
SC 19	593.5725	118.5401	475.0324	27737.9914	25216.6889	52954.6803	1.1000	80.0294	784.0708	351.8584
SC 6										
SC A										
SC 4	596.1015	168.9863	427.1152	25552.1944	25064.8054	50616.9998	1.0194	71.6514	861.5425	377.6980
SC 7										
SC 18	487.7326	256.4168	231.3155	15014.1468	11411.1966	26425.3434	1.3157	47.4267	646.8932	392.8562

Specimen ID	43	44	45	46	47	48	49	50	51	52
SC J										
SC 14	605.8169	72968.8332	52562.4068	125531.2400	1.3882	62.8560	502.4428	115.3593	387.0835	17490.5548
SC 20										
SC X1										
SC X2	373.2840	33387.9774	18335.7849	51723.7623	1.8209	60.6163	374.1009	94.3420	279.7588	8988.74013
SC X4	383.6749	48622.9606	35595.7546	84218.7152	1.3660	43.4745	455.5309	178.1283	277.4026	12849.4793
SC 11	473.8621	63401.5873	28418.0386	91819.6259	2.2310	59.0676	429.4164	135.6540	293.7625	14091.7445
SC 17	516.0773	77912.3168	44445.0138	122357.3306	1.7530	52.7114	475.2837	120.9513	354.3324	16100.7855
SC B										
SC 21	247.5104	23350.2883	13673.0441	37023.3324	1.7078	42.4557	306.8708	125.3495	181.5212	7947.3701
SC 10	494.1725	58240.8802	29106.3470	87347.2272	2.0010	63.5556	400.0190	92.3628	307.6562	13173.7343
SC 5	342.6614	33503.2205	23510.4835	57013.7040	1.4250	48.1971	393.9557	168.3265	225.6292	10442.8110
SC X3	240.5910	27797.6121	16421.3888	44219.0009	1.6928	35.0392	433.5398	171.2247	262.3151	12110.8931
SC 19	432.2125	41122.1256	36285.1017	77407.2273	1.1333	55.1242	428.5132	146.8380	281.6752	11166.9606
SC 6										
SC A										
SC 4	483.8445	53052.7925	40866.5990	93919.3916	1.2982	56.1603	466.0553	154.8491	311.2062	13466.3315
SC 7										
SC 18	254.0370	27560.3965	15611.3910	43171.7875	1.7654	39.2703	388.7250	191.1345	197.5905	8903.4934

Specimen ID	53	54	55	56

SC J				
SC 14	19728.3046	37218.8594	0.8866	77.0403
SC 20				
SC X1				
SC X2	11195.8422	20184.5824	0.8029	74.7817
SC X4	14451.2137	27300.6930	0.8892	60.8966
SC 11	11994.5535	26086.2981	1.1748	68.4097
SC 17	16310.1894	32410.9749	0.9872	74.5518
SC B				
SC 21	4812.8722	12760.2423	1.6513	59.1523
SC 10	10617.0773	23790.8116	1.2408	76.9104
SC 5	9413.0495	19855.8605	1.1094	57.2727
SC X3	12544.5979	24655.4910	0.9654	60.5054
SC 19	14030.0330	25196.9937	0.7959	65.7331
SC 6				
SC A				
SC 4	16454.7852	29921.1167	0.8184	66.7745
SC 7				
SC 18	8093.8050	16997.2984	1.1000	50.8304

F-16: Left tibia cross-sectional geometry calculated from radiograph measurements. See B-5 for key.

Specimen ID	33	34	35	36	37	38	39	40	41	42
SC J										
SC 14	565.5024	98.9916	466.5108	25782.3373	22504.6088	48286.9461	1.1456	82.4949	848.6934	370.6765
SC 20										
SC X1	522.3762	195.0929	327.2833	22180.6173	13592.3259	35772.9431	1.6318	62.6528	655.2184	333.8256
SC X2										
SC X4										
SC 11	481.0407	133.7533	347.2874	18800.2954	14580.4170	33380.7124	1.2894	72.1950	710.8874	305.7162
SC 17	521.6615	91.2319	430.4296	19071.2567	22700.9007	41772.1574	0.8401	82.5113	828.6265	400.5138
SC B										
SC 21	375.4360	114.8880	260.5480	13623.7893	7309.4088	20933.1981	1.8639	69.3988	582.5769	355.5262
SC 10	506.2677	80.3462	425.9214	25668.0741	14753.9725	40422.0466	1.7397	84.1297	760.5089	315.1017
SC 5	483.4675	132.0961	351.3714	23613.0839	12193.0933	35806.1771	1.9366	72.6774	589.3000	298.8283
SC X3										
SC 19	429.9348	107.3875	322.5473	16820.8194	11206.9761	28027.7956	1.5009	75.0224	816.4371	482.4151
SC 6										
SC A										
SC 4	617.5115	160.5747	456.9368	26506.2552	29310.9515	55817.2067	0.9043	73.9965		93.7294
SC 7										
SC 18	429.2044	154.8020	274.4024	15320.1309	10211.1183	25531.2492	1.5003	63.9328	515.6060	265.8965

Specimen ID	43	44	45	46	47	48	49	50	51	52
SC J										
SC 14	478.0169	54527.7822	37597.7713	92125.5534	1.4503	56.3239	465.5840	111.2909	354.2931	14907.5817
SC 20										
SC X1	321.3928	35826.9137	16873.6124	52700.5260	2.1233	49.0512	433.1785	205.9235	227.2550	13839.2563
SC X2										
SC X4										
SC 11	405.1712	40480.3826	25183.0192	65663.4018	1.6074	56.9951	387.0442	140.2407	246.8035	10295.1523
SC 17	428.1127	46632.0626	36801.9968	83434.0594	1.2671	51.6653	409.7422	119.8518	289.8905	11466.4183
SC B										
SC 21	227.0508	21166.3946	13514.4547	34680.8493	1.5662	38.9735	309.2505	127.7293	181.5212	8207.6516
SC 10	445.4072	52193.5350	26384.9804	78578.5154	1.9782	58.5670	389.2433	97.8842	291.3592	11982.2014
SC 5	290.4717	30489.7269	13400.6217	43890.3487	2.2752	49.2910	388.5836	157.9828406	230.6008	10585.2981
SC X3										
SC 19	334.0220	43196.1610	25433.4770	68629.6380	1.6984	40.9122	399.2807	147.0265	252.2542	10708.6412
SC 6										
SC A										
SC 4	93.7294	152.3689	3207.6550	3360.0239	0.0475		490.4340	182.8014	307.6326	14608.0921
SC 7										
SC 18	249.7095	17574.1339	12143.9545	29718.0884	1.4472	48.4303	328.7364	197.0721	131.6641	6052.9497

Specimen ID	53	54	55	56
SC J				
SC 14	16515.7092	31423.2910	0.9026	76.0965
SC 20				
SC X1	9158.3717	22997.6280	1.5111	52.4622
SC X2				
SC X4				
SC 11	9890.5681	20185.7204	1.0409	63.7662
SC 17	12673.9013	24140.3196	0.9047	70.7495
SC B				
SC 21	4826.4443	13034.0960	1.7006	58.6971
SC 10	9759.2603	21741.4617	1.2278	74.8527
SC 5	9233.4988	19818.7969	1.1464	59.3439
SC X3				
SC 19	10873.4376	21582.0788	0.9848	63.1772
SC 6				
SC A				
SC 4	18061.2975	32669.3896	0.8088	62.7266
SC 7				
SC 18	4679.7242	10732.6739	1.2934	40.0516

F-17: Right femur cross-sectional geometry calculated from radiograph measurements. See B-5 for key.

Specimen ID	33	34	35	36	37	38	39	40	41	42
SC J										
SC 14	783.9042	175.0762	608.8280	49060.3278	42780.8967	91841.2245	1.1468	77.6661	787.7105	162.0545
SC 20	668.7327	103.2368	565.4959	35216.0233	33720.2972	68936.3205	1.0444	84.5623	718.6727	149.0624
SC X1	412.3200	97.4393	314.8806	14104.3789	11434.9408	25539.3197	1.2334	76.3680	455.1155	84.6035
SC X2	541.0700	123.3854	417.6845	22092.9784	21728.8810	43821.8594	1.0168	77.1960	567.2736	100.3194
SC X4										
SC 11	552.3137	133.6141	418.6997	27064.1660	18934.4145	45998.5805	1.4294	75.8083	612.5997	127.3975
SC 17	700.7510	211.1570	489.5940	34329.1198	36412.1138	70741.2336	0.9428	69.8670	690.0425	148.9571
SC B	546.9547	326.3491	220.6056	12265.1781	18186.0079	30451.1860	0.6744	40.3334	589.3973	351.2367
SC 21	428.0842	243.3948	184.6895	11523.6483	8373.0902	19896.7385	1.3763	43.1433	342.2596	134.3156
SC 10	513.8689	114.9229	398.9460	18750.5529	21170.3842	39920.9371	0.8857	77.6358	540.4616	77.1532
SC 5										
SC X3	533.1532	181.0468	352.1064	18737.6314	20506.4288	39244.0602	0.9137	66.0423	527.5528	171.7183
SC 19										
SC 6	826.0567	306.3144	519.7423	43387.4274	46933.7356	90321.1631	0.9244	62.9185	855.4503	263.5315
SC A										
SC 4	692.2036	247.7461	444.4575	32116.9967	34094.8933	66211.8900	0.9420	64.2091	714.6352	209.6903
SC 7	491.4359	202.9705	288.4654	15720.6177	15435.5929	31156.2106	1.0185	58.6985	480.2414	158.0437
SC 18	559.3640	305.9392	253.4248	15639.9178	18357.9267	33997.8444	0.8519	45.3059	521.2225	229.0872

Specimen ID	43	44	45	46	47	48	49	50	51	52
SC J										
SC 14	625.6561	47055.1146	47266.3217	94321.4363	0.9955	79.4272	851.1751	337.8467	513.3285	42676.2377
SC 20	569.6103	37045.4127	41422.9308	78468.3435	0.8943	79.2587	666.3424	221.6342	444.7082	30386.2153
SC X1	370.5120	16594.7858	15101.2458	31696.0316	1.0989	81.4105	449.7092	199.9027	249.8065	13132.9431
SC X2	466.9542	22940.5381	26466.6416	49407.1798	0.8668	82.3155	548.4823	198.7353	349.7470	21730.4332
SC X4										
SC 11	485.2022	37218.5555	21863.6103	59082.1658	1.7023	79.2038	644.7127	314.5691	330.1435	28971.8951
SC 17	541.0853	35076.9232	37094.4049	72171.3281	0.9456	78.4133	878.8128	545.6971	333.1156	33663.5313
SC B	238.1605	14012.2936	22322.4769	36334.7704	0.6277	40.4074	568.4746	307.5725	260.9021	16570.9561
SC 21	207.9440	12189.1482	5058.6304	17247.7786	2.4096	60.7562	592.8099	427.5602	165.2497	10850.7227
SC 10	463.3084	21718.9258	23849.9331	45568.8589	0.9106	85.7246	531.3525	216.7263	314.6262	17293.5195
SC 5										
SC X3	355.8345	17803.1378	21626.9210	39430.0588	0.8232	67.4500	560.7430	280.7491	279.9939	16806.0000
SC 19										
SC 6	591.9188	48913.3862	55504.3834	104417.7696	0.8813	69.1938	878.1517	511.6002	366.5515	36698.9183
SC A										
SC 4	504.9450	35750.1872	38321.9842	74072.1714	0.9329	70.6577	753.7839	387.4040	366.3799	32837.8018
SC 7	322.1977	17033.9735	15455.7611	32489.7346	1.1021	67.0908	587.5249	354.6330	232.8919	16631.2448
SC 18	292.1353	13945.0729	18907.9207	32852.9936	0.7375	56.0481	676.5786	494.2832	182.2954	14111.3782

Specimen ID	53	54	55	56
SC J				
SC 14	53874.4961	96550.7338	0.7921	60.3082
SC 20	32387.2979	62773.5132	0.9382	66.7387
SC X1	12575.7342	25708.6773	1.0443	55.5484
SC X2	19719.3795	41449.8127	1.1020	63.7663
SC X4				
SC 11	21881.8724	50853.7675	1.3240	51.2079
SC 17	41899.8978	75563.4291	0.8034	37.9052
SC B	18766.6629	35337.6191	0.8830	45.8951
SC 21	15737.3124	26588.0350	0.6895	27.8757
SC 10	20223.5320	37517.0515	0.8551	59.2123
SC 5				
SC X3	20150.9150	36956.9151	0.8340	49.9327
SC 19				
SC 6	44121.5157	80820.4340	0.8318	41.7412
SC A				
SC 4	33347.0475	66184.8493	0.9847	48.6054
SC 7	17250.3645	33881.6092	0.9641	39.6395
SC 18	19201.1341	33312.5123	0.7349	26.9437

F-18: Left femur cross-sectional geometry calculated from radiograph measurements. See B-5 for key.

Specimen ID	33	34	35	36	37	38	39	40	41	42
SC J										

SC 14	776.7225	166.0398	610.6827	42216.2208	48690.8109	90907.0317	0.8670	78.6230	803.1123	157.4831
SC 20	649.1285	110.6604	538.4681	28529.6207	36998.5833	65528.2040	0.7711	82.9525	708.8296	140.3722
SC X1	444.7677	115.0049	329.7628	14740.4800	14481.9865	29222.4664	1.0178	74.1427	469.8467	82.8811
SC X2	519.2436	105.2440	413.9996	21073.3799	19879.7888	40953.1687	1.0600	79.7313	549.1142	91.8653
SC X4										
SC 11										
SC 17	690.0784	187.2078	502.8706	32111.1333	37820.9416	69932.0748	0.8490	72.8715	699.1869	148.0613
SC B										
SC 21	455.9717	140.4864	315.4853	15347.1044	13996.1144	29343.2188	1.0965	69.1897	415.7236	167.0642
SC 10	509.4103	89.1727	420.2375	19723.9099	20180.8728	39904.7827	0.9774	82.4949	515.6670	63.3226
SC 5	636.8276	285.6573	351.1704	23279.4465	26991.8521	50271.2986	0.8625	55.1437	597.5631	162.9469
SC X3										
SC 19	618.3007	222.8302	395.4705	24440.8458	27710.2751	52151.1210	0.8820	63.9609	658.2828	183.4028
SC 6	801.9383	271.0321	530.9062	42611.7805	45162.6399	87774.4204	0.9435	66.2029	872.9402	247.1892
SC A										
SC 4	657.1516	234.3870	422.7646	29840.0026	29786.9677	59626.9703	1.0018	64.3329	705.8152	234.5803
SC 7	515.6855	206.6336	309.0520	16135.7672	18908.2048	35043.9720	0.8534	59.9303	499.2070	158.4134
SC 18	530.7769	264.8996	265.8772	13641.1334	18337.0226	31978.1560	0.7439	50.0921	484.5142	199.0285

Specimen ID	43	44	45	46	47	48	49	50	51	52
SC J										
SC 14	645.6292	45749.0695	52842.6545	98591.7239	0.8658	80.3909	861.2599	341.5354	519.7246	44688.1179

SC 20	568.4575	31971.8957	45714.9621	77686.8579	0.6994	80.1966	682.1376	213.2296	468.9080	29853.4468
SC X1	386.9656	16715.9156	17124.1354	33840.0510	0.9762	82.3600	479.5901	235.1559	244.4342	13474.5747
SC X2	457.2489	22060.3340	24511.9125	46572.2465	0.9000	83.2703	547.8413	204.1832	343.6581	22048.9396
SC X4										
SC 11										
SC 17	551.1257	34427.1618	40015.5686	74442.7304	0.8603	78.8238	822.9645	410.4838	412.4807	33604.7983
SC B										
SC 21	248.6594	14012.5766	9452.7232	23465.2998	1.4824	59.8136	633.9285	439.8875	194.0410	13704.8269
SC 10	452.3444	20891.4254	20709.8187	41601.2441	1.0088	87.7203	541.4032	169.1534	372.2498	18850.3481
SC 5	434.6162	22653.6655	30010.1386	52663.8041	0.7549	72.7314	632.1103	337.9670	294.1433	19796.0341
SC X3										
SC 19	474.8800	28391.9421	34751.1253	63143.0674	0.8170	72.1392	666.9090	363.7782	303.1308	21607.8754
SC 6	625.7510	52898.4901	57512.5197	110411.0098	0.9198	71.6831	850.3798	494.2039	356.1759	33838.9324
SC A										
SC 4	471.2349	32802.3529	37500.4272	70302.7801	0.8747	66.7646	781.2877	433.4472	347.8405	31916.3536
SC 7	340.7937	16080.2545	19423.2567	35503.5111	0.8279	68.2670	623.1464	363.0852	260.0613	17431.1265
SC 18	285.4857	12430.7995	17262.6834	29693.4829	0.7201	58.9220	624.7314	450.0006	174.7308	12441.6812

Specimen ID	53	54	55	56
SC J				
SC 14	54243.0575	98931.1754	0.8238	60.3447
SC 20	37112.7629	66966.2097	0.8044	68.7410
SC X1	14190.0105	27664.5851	0.9496	50.9673

SC X2	18790.5567	40839.4964	1.1734	62.7295
SC X4				
SC 11				
SC 17	43978.8736	77583.6718	0.7641	50.1213
SC B				
SC 21	19623.9290	33328.7559	0.6984	30.6093
SC 10	23255.4477	42105.7958	0.8106	68.7565
SC 5	24613.4742	44409.5083	0.8043	46.5335
SC X3				
SC 19	28419.3656	50027.2410	0.7603	45.4531
SC 6	42450.6604	76289.5928	0.7971	41.8843
SC A				
SC 4	34579.0602	66495.4137	0.9230	44.5214
SC 7	22743.4051	40174.5316	0.7664	41.7336
SC 18	17475.0363	29916.7175	0.7120	27.9690

F-19: Right humerus cross-sectional geometry calculated from ImageJ. See B-5 for key.

Specimen ID	57	58	59	60	61	62	63	64	65	66	67
SC J	94.16	34.58	59.57	610.70	632.10	745.30	497.50	1243.00	0.97	-42.50	63.27
SC 14	469.00	146.60	322.40	16850.00	16060.00	19954.00	12956.00	32910.00	1.05	-48.20	68.75
SC 20	458.30	117.90	340.40	17109.00	14574.00	17443.00	14241.00	31683.00	1.17	-71.20	74.27
SC X1	274.80	55.72	219.10	6569.00	5225.00	7122.00	4672.00	11794.00	1.26	-61.60	79.72
SC X2											
SC X4											
SC 11	392.30	130.60	261.80	12226.00	10140.00	13884.00	8482.00	22366.00	1.21	-56.40	66.72
SC 17	389.50	91.64	297.90	10051.00	13726.00	14481.00	9295.00	23776.00	0.73	-22.40	76.47
SC B	433.60	189.40	244.20	14671.00	10266.00	15993.00	8944.00	24936.00	1.43	-64.30	56.31
SC 21	349.30	135.90	213.40	9686.00	8189.00	12309.00	5566.00	17875.00	1.18	-51.40	61.10
SC 10	333.80	95.28	238.50	9332.00	7160.00	9504.00	6988.00	16493.00	1.30	-74.80	71.46
SC 5											
SC X3											
SC 19	316.90	121.30	195.50	6892.00	7067.00	8034.00	5925.00	13959.00	0.98	-42.60	61.71
SC 6	559.80	224.90	334.90	21001.00	20138.00	25707.00	15432.00	41139.00	1.04	-47.40	59.82
SC A	350.00	208.50	141.50	6820.00	6101.00	8314.00	4607.00	12921.00	1.12	-50.60	40.43
SC 4	432.50	154.00	278.50	12918.00	12755.00	14363.00	11310.00	25672.00	1.01	-46.50	64.39
SC 7	334.10	158.60	175.50	7531.00	6419.00	7619.00	6331.00	13950.00	1.17	-74.80	52.52
SC 18	283.50	146.90	136.60	4862.00	4193.00	5380.00	3675.00	9055.00	1.16	-56.60	48.18

F-20: Left humerus cross-sectional geometry calculated from ImageJ. See B-5 for key.

Specimen ID	57	58	59	60	61	62	63	64	65	66	67
SC J											
SC 14	367.70	107.20	260.50	10862.00	9967.00	13706.00	7124.00	20830.00	1.09	-48.90	70.84
SC 20	398.80	106.20	292.60	13182.00	10870.00	13548.00	10504.00	24052.00	1.21	-69.70	73.37
SC X1											
SC X2	271.80	54.32	217.40	6840.00	4673.00	6849.00	4663.00	11513.00	1.46	-86.20	80.01
SC X4											
SC 11	365.10	112.40	252.60	10247.00	9447.00	11786.00	7908.00	19694.00	1.09	-51.00	69.20
SC 17	371.40	100.60	270.90	8929.00	12058.00	13202.00	7784.00	20986.00	0.74	-27.40	72.92
SC B	369.60	112.40	257.20	11244.00	8802.00	11847.00	8199.00	20046.00	1.28	-66.00	69.58
SC 21	327.50	134.30	193.10	8241.00	6676.00	9619.00	5298.00	14917.00	1.24	-55.60	58.98
SC 10	306.80	58.31	248.50	7740.00	6838.00	8087.00	6492.00	14579.00	1.13	-62.20	80.99
SC 5	306.80	108.60	198.20	7242.00	6460.00	8894.00	4809.00	13702.00	1.12	-50.50	64.61
SC X3	324.10	55.30	268.80	8047.00	8288.00	8864.00	7472.00	16336.00	0.97	-40.00	82.94
SC 19	307.00	108.40	198.60	5925.00	7434.00	7537.00	5823.00	13359.00	0.80	-14.10	64.70
SC 6	440.20	182.80	257.40	13574.00	12450.00	15657.00	10367.00	26024.00	1.09	-51.10	58.48
SC A	278.70	146.90	131.80	4724.00	4308.00	4725.00	4307.00	9032.00	1.10	-87.50	47.27
SC 4	394.60	121.00	273.70	11488.00	11237.00	13151.00	9575.00	22726.00	1.02	-47.00	69.35
SC 7	294.90	139.00	155.90	5980.00	4989.00	6184.00	4785.00	10969.00	1.20	-67.50	52.87
SC 18	230.20	136.90	93.24	2918.00	2663.00	3575.00	2005.00	5581.00	1.10	-49.70	40.51

F-21: Right tibia cross-sectional geometry calculated from ImageJ. See B-5 for key.

Specimen ID	57	58	59	60	61	62	63	64	65	66	67
SC J											
SC 14	615.50	70.43	545.10	34774.00	28458.00	37908.00	25325.00	63233.00	1.22	-60.10	88.56
SC 20											
SC X1											
SC X2	448.90	65.32	383.60	22250.00	12707.00	22254.00	12703.00	34957.00	1.75	-88.90	85.45
SC X4	577.90	185.50	392.40	32286.00	21018.00	33638.00	19666.00	53304.00	1.54	-71.90	67.90
SC 11	500.00	122.90	377.10	26614.00	14107.00	27241.00	13480.00	40721.00	1.89	77.68	75.43
SC 17	592.00	104.80	487.20	35273.00	22573.00	36233.00	21613.00	57846.00	1.56	-75.20	82.30
SC B											
SC 21	390.50	120.60	269.90	15694.00	8112.00	15884.00	7922.00	23806.00	1.94	81.11	69.11
SC 10	528.10	50.89	477.20	29492.00	18580.00	30195.00	17877.00	48072.00	1.59	-76.20	90.36
SC 5	468.10	179.60	288.50	21483.00	11111.00	22299.00	10295.00	32594.00	1.93	74.89	61.64
SC X3	1002.00	704.80	297.60	27701.00	19574.00	31024.00	16250.00	47275.00	1.2	-61.70	29.69
SC 19	502.50	112.40	390.10	25203.00	16845.00	26841.00	15207.00	42049.00	1.50	-68.00	77.63
SC 6											
SC A											
SC 4	513.50	166.40	347.10	26343.00	16584.00	28348.00	14579.00	42927.00	1.59	-67.60	67.59
SC 7											
SC 18	464.60	250.40	214.10	13786.00	10930.00	14088.00	10627.00	24715.00	1.26	72.80	46.10

F-22: Left tibia cross-sectional geometry calculated from ImageJ. See B-5 for key.

Specimen ID	57	58	59	60	61	62	63	64	65	66	67
SC J											
SC 14	557.20	94.86	462.30	26746.00	23988.00	32865.00	17869.00	50734.00	1.12	-50.30	82.98
SC 20											
SC X1	491.50	189.60	301.90	22532.00	13332.00	23294.00	12569.00	35863.00	1.69	74.54	61.42
SC X2											
SC X4											
SC 11	464.80	129.10	335.70	19442.00	13417.00	19490.00	13369.00	32859.00	1.45	-84.90	72.23
SC 17	506.20	86.13	420.10	21055.00	20648.00	25507.00	16197.00	41704.00	1.02	-46.30	82.99
SC B											
SC 21	398.50	111.40	287.00	16251.00	8670.00	16628.00	8293.00	24921.00	1.87	-77.70	72.03
SC 10	481.30	76.59	404.70	25758.00	13866.00	25809.00	13815.00	39624.00	1.86	86.24	84.09
SC 5	440.70	127.80	312.90	20520.00	10556.00	20526.00	10550.00	31076.00	1.94	-88.60	71.01
SC X3											
SC 19	392.20	100.40	291.90	17808.00	8663.00	17875.00	8596.00	26471.00	2.06	85.11	74.42
SC 6											
SC A											
SC 4	555.60	155.30	400.30	28968.00	21058.00	31930.00	18097.00	50027.00	1.38	-62.40	72.05
SC 7											
SC 18	413.50	150.00	263.60	16973.00	9246.00	17138.00	9082.00	26220.00	1.84	-81.80	63.74

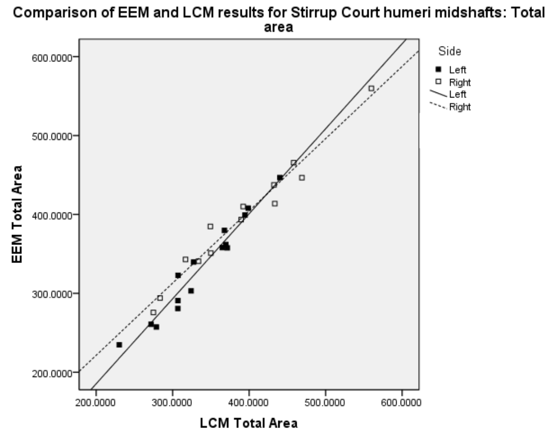
F-23: Right femur cross-sectional geometry calculated from ImageJ. See B-5 for key.

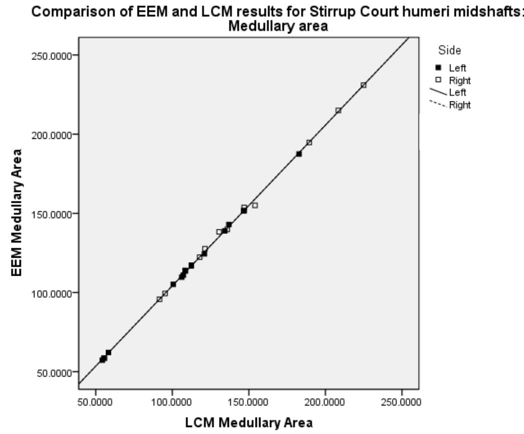
Specimen ID	57	58	59	60	61	62	63	64	65	66	67
SC J											
SC 14	751.40	170.40	581.00	46272.0	41212.00	47425.00	40058.00	87484.00	1.12	-66.70	77.32
SC 20	664.20	101.20	563.00	34593.00	36061.00	41114.00	29541.00	70655.00	0.96	-41.40	84.76
SC X1	436.00	94.37	341.60	16448.00	12701.00	16539.00	12609.00	29149.00	1.30	81.24	78.36
SC X2	505.90	119.60	386.30	20102.00	19256.00	20302.00	19056.00	39358.00	1.04	-66.40	76.35
SC X4											
SC 11											
SC 17											
SC B	560.50	319.90	240.60	14768.00	19353.00	21667.00	12454.00	34121.00	0.76	-30.10	42.93
SC 21	425.80	237.90	187.90	10634.00	9325.00	12173.00	7787.00	19960.00	1.14	53.68	44.12
SC 10	506.00	112.50	393.50	18490.00	20749.00	20770.00	18469.00	39239.00	0.89	5.41	77.77
SC 5											
SC X3	578.90	176.70	402.30	21824.00	26515.00	26629.00	21710.00	48339.00	0.82	-8.76	69.48
SC 19											
SC 6	763.30	299.90	463.40	39640.00	40834.00	44012.00	36463.00	80474.00	0.97	40.45	60.71
SC A											
SC 4	663.90	242.90	420.90	29501.00	31592.00	31667.00	29426.00	61093.00	0.93	10.55	63.41
SC 7	472.40	198.40	274.00	15117.00	14906.00	17246.00	12776.00	30022.00	1.01	46.35	58.00
SC 18	524.30	300.20	224.10	11980.00	16000.00	16443.00	11537.00	27980.00	0.75	17.50	42.74

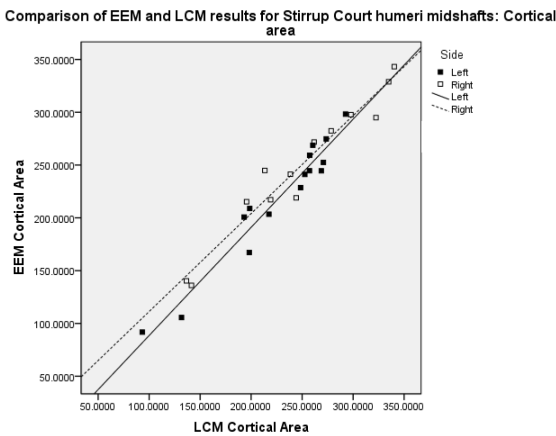
F-24: Left femur cross-sectional geometry calculated from ImageJ. See B-5 for key.

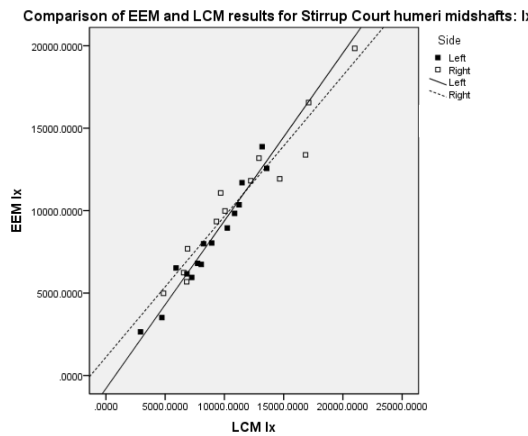
Specimen ID	57	58	59	60	61	62	63	64	65	66	67
SC J											
SC 14	717.70	162.69	555.00	37335.00	42304.00	44273.00	35365.00	79638.00	0.88	-28.05	77.33
SC 20	640.40	107.81	532.60	29024.00	36858.00	38868.00	27014.00	65882.00	0.79	-24.32	83.17
SC X1	473.90	111.94	362.00	17301.00	16392.00	17587.00	16107.00	33693.00	1.06	-63.94	76.38
SC X2	487.60	101.44	386.10	20884.00	15788.00	20885.00	15788.00	36673.00	1.32	89.59	79.20
SC X4											
SC 11											
SC 17	662.70	182.22	480.50	30714.00	35677.00	38035.00	28356.00	66391.00	0.86	-29.58	72.50
SC B											
SC 21	438.00	137.49	300.50	14926.00	13537.00	15234.00	13229.00	28463.00	1.10	66.93	68.61
SC 10	494.60	86.74	407.90	19634.00	18794.00	20224.00	18204.00	38427.00	1.04	-57.29	82.46
SC 5	580.70	279.74	301.00	16326.00	23108.00	24042.00	15392.00	39434.00	0.71	-19.18	51.83
SC X3											
SC 19											
SC 6	751.70	264.20	487.50	40015.00	39937.00	41131.00	38820.00	79951.00	1.00	-45.97	64.85
SC A											
SC 4	634.90	228.29	406.70	28424.00	28654.00	31021.00	26058.00	57079.00	0.99	-43.67	64.05
SC 7	506.10	202.04	304.00	16641.00	18354.00	18477.00	16519.00	34995.00	0.91	14.50	60.08
SC 18	502.30	259.72	242.60	10353.00	16465.00	16489.00	10328.00	26818.00	0.63	3.60	48.29

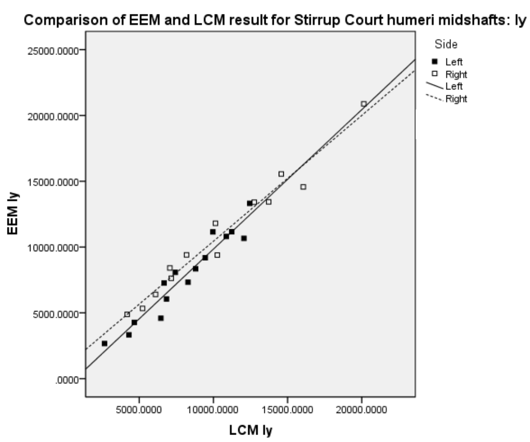
F-25: Humerus mid-shaft LCM and EEM comparisons in the Stirrup Court sample

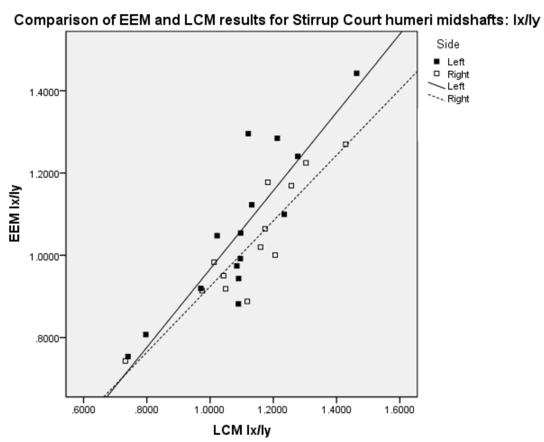


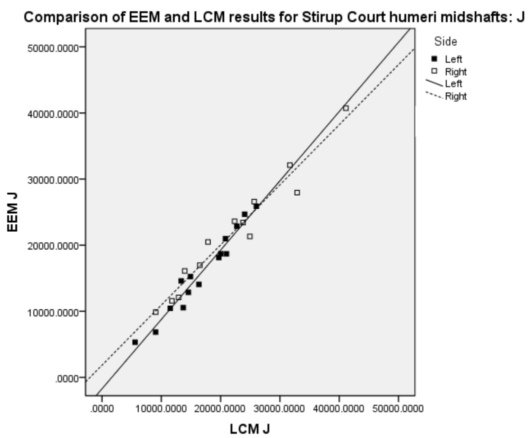


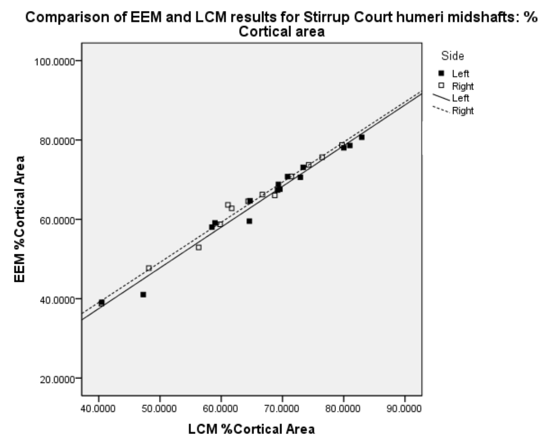




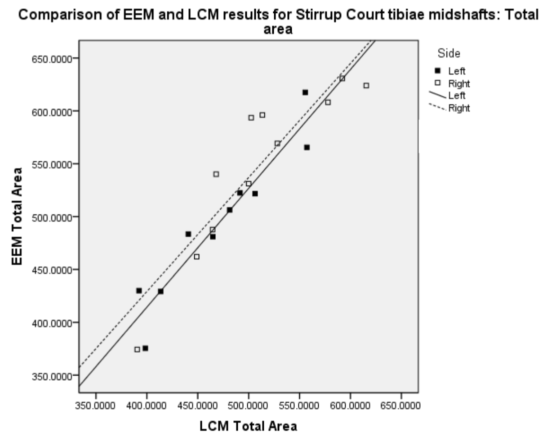


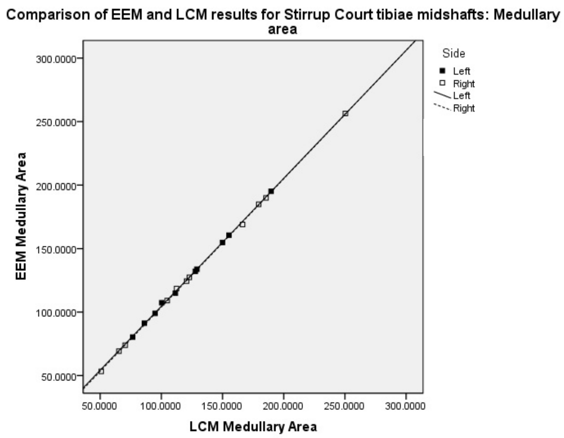


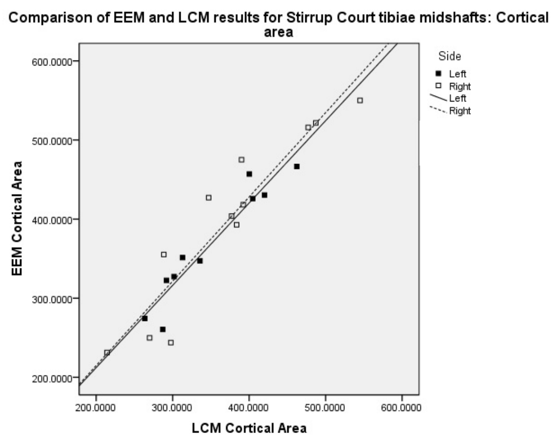

Comparison of EEM and LCM results for Stirup Court humeri midshafts: J
Side
Left
Right
Left
Right
EEM J
LCM J
50000.0000
40000.0000
30000.0000
20000.0000
10000.0000
.0000
10000.0000
20000.0000
30000.0000
40000.0000
50000.0000

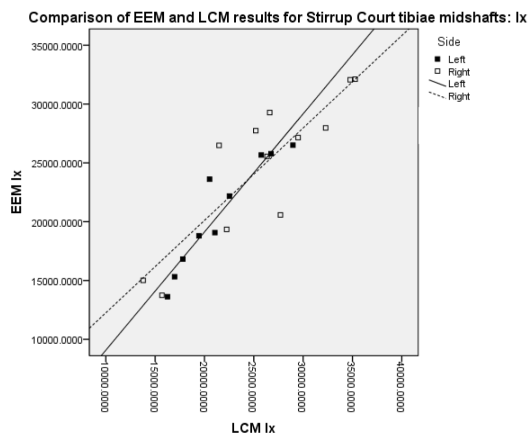

Comparison of EEM and LCM results for Stirrup Court humeri midshafts: % Cortical area
Side
Left
Right
Left
Right
EEM %Cortical Area
LCM %Cortical Area
100.0000
80.0000
60.0000
40.0000
20.0000
40.0000
50.0000
60.0000
70.0000
80.0000
90.0000

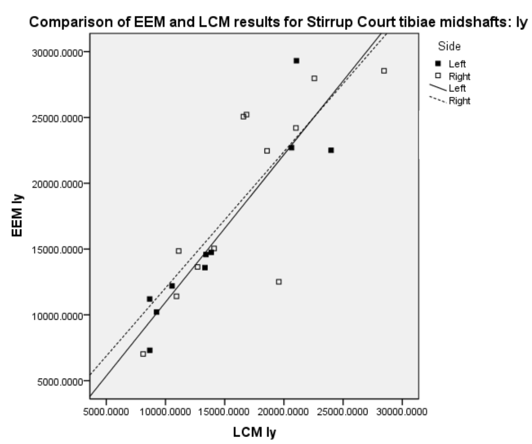
F-26: Tibia mid-shaft LCM and EEM comparisons in the Stirrup Court sample

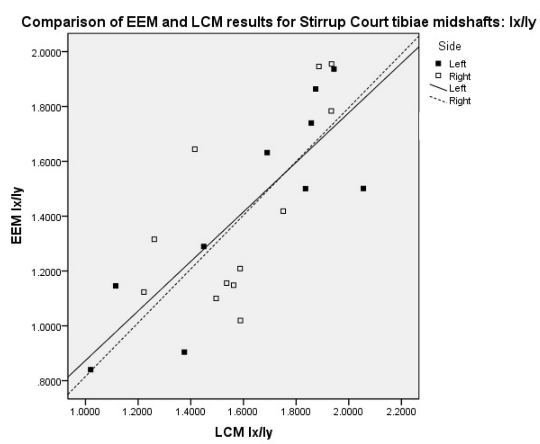


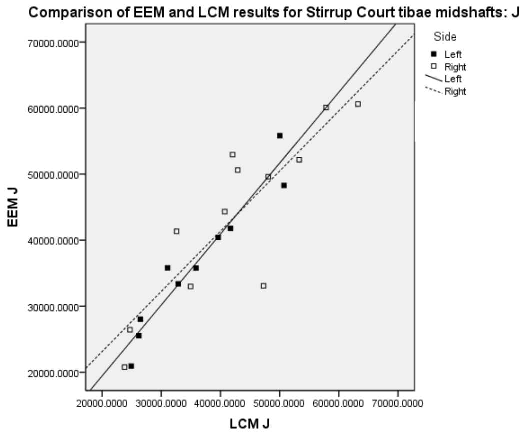


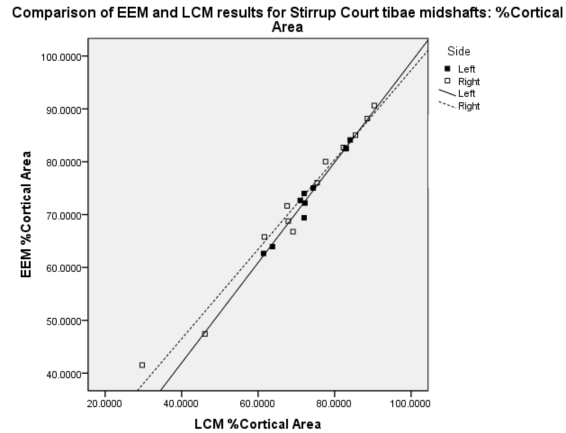




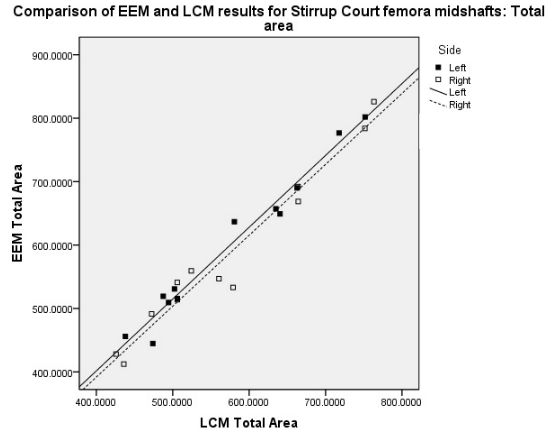


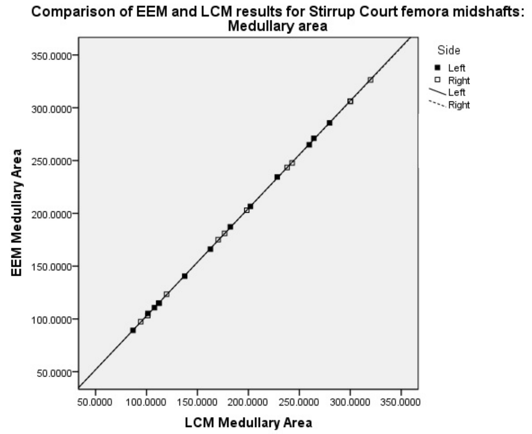


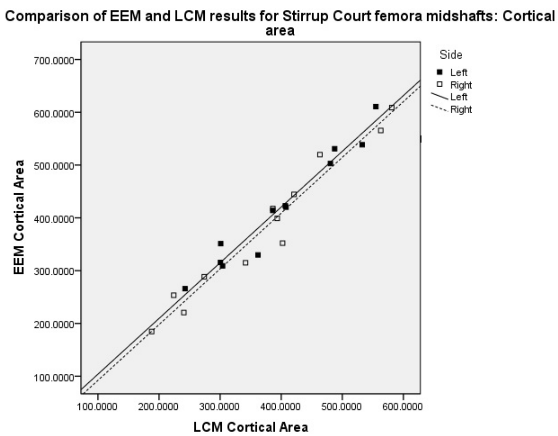

Comparison of EEM and LCM results for Stirrup Court tibae midshafts: J
EEM J
70000.0000
60000.0000
50000.0000
40000.0000
30000.0000
20000.0000
20000.0000
30000.0000
40000.0000
50000.0000
60000.0000
70000.0000
LCM J
Side
Left
Right
Left
Right

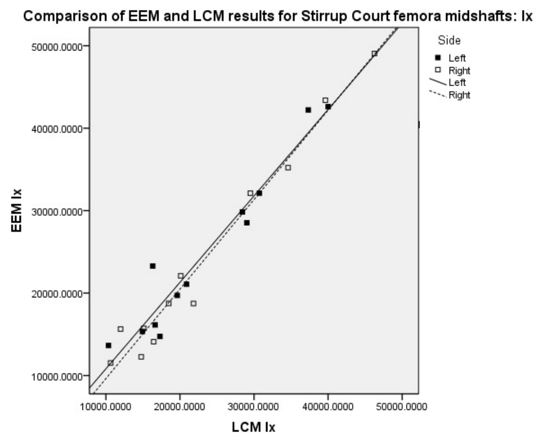

Comparison of EEM and LCM results for Stirrup Court tibae midshafts: %Cortical Area
EEM %Cortical Area
100.0000
90.0000
80.0000
70.0000
60.0000
50.0000
40.0000
20.0000
40.0000
60.0000
80.0000
100.0000
LCM %Cortical Area
Side
Left
Right
Left
Right

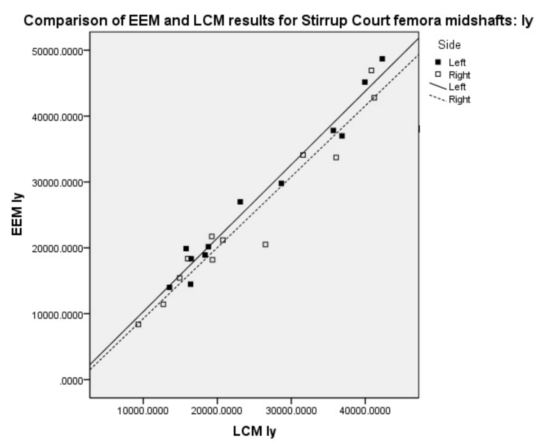
F-27: Femur mid-shaft LCM and EEM comparisons in the Stirrup Court sample

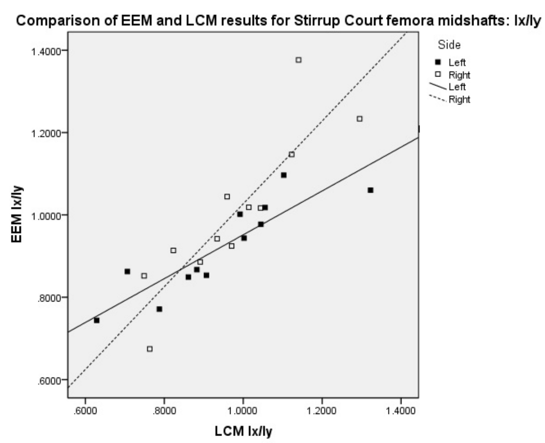


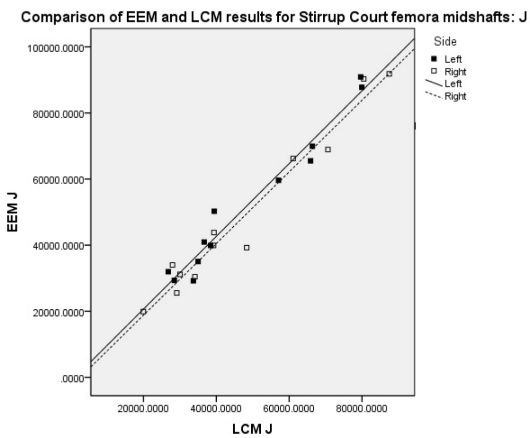


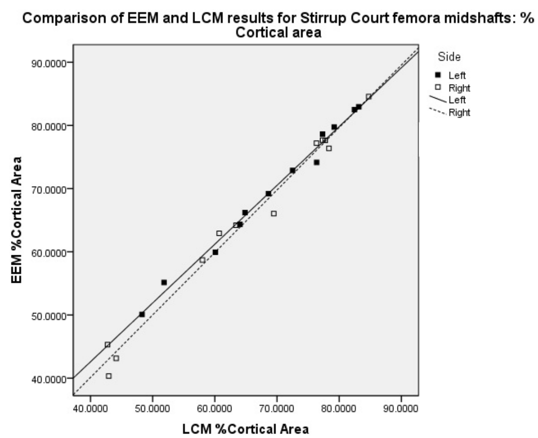






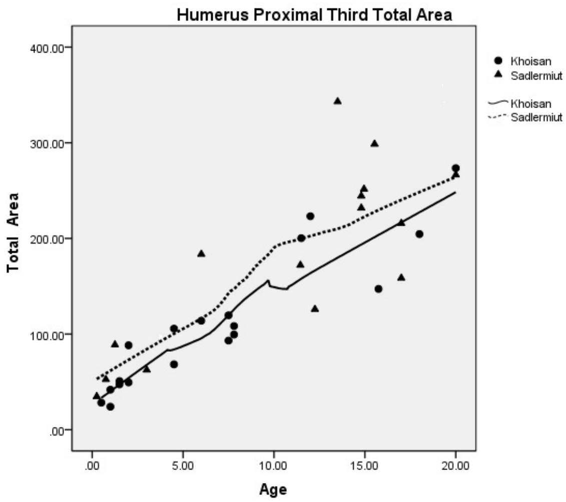


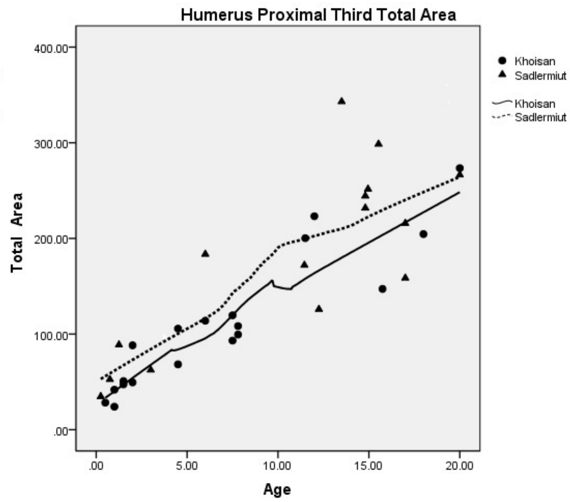

Comparison of EEM and LCM results for Stirrup Court femora midshafts: J
EEM J
LCM J
Side
Left
Right
Left
Right
100000.0000
80000.0000
60000.0000
40000.0000
20000.0000
.0000
20000.0000
40000.0000
60000.0000
80000.0000

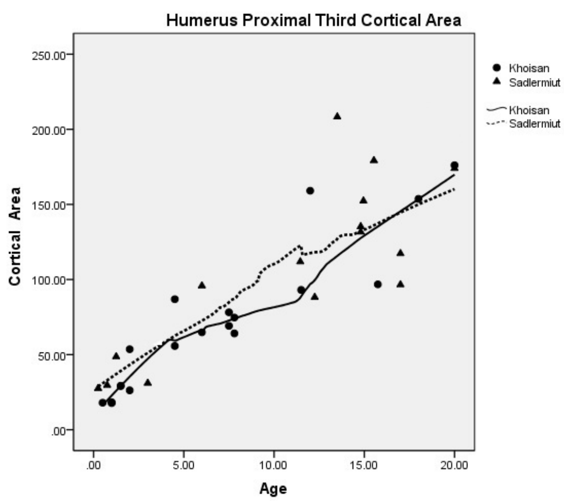

Comparison of EEM and LCM results for Stirrup Court femora midshafts: % Cortical area
EEM %Cortical Area
LCM %Cortical Area
Side
Left
Right
Left
Right
90.0000
80.0000
70.0000
60.0000
50.0000
40.0000
40.0000
50.0000
60.0000
70.0000
80.0000
90.0000

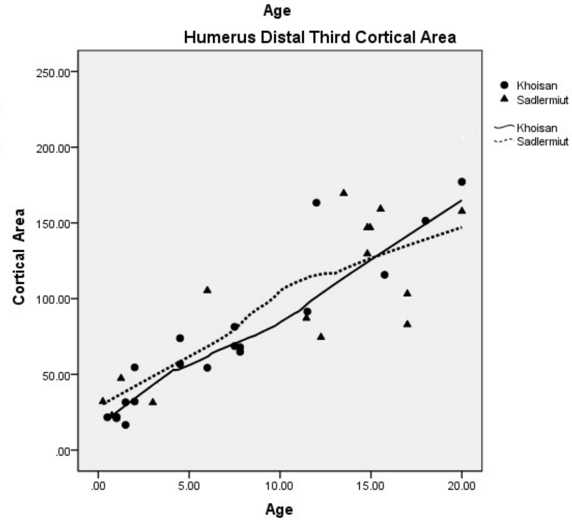
Appendix G: Khoisan and Sadlermiut juvenile graphs

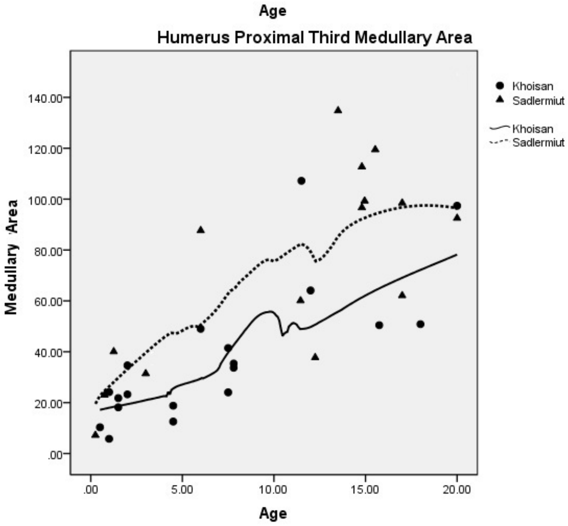
G-1: Humerus results

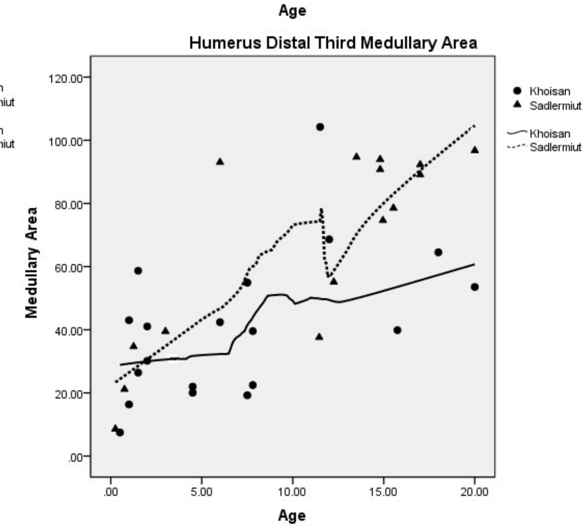


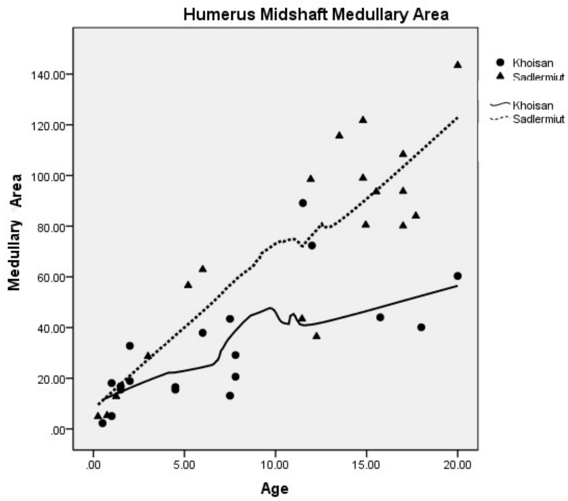


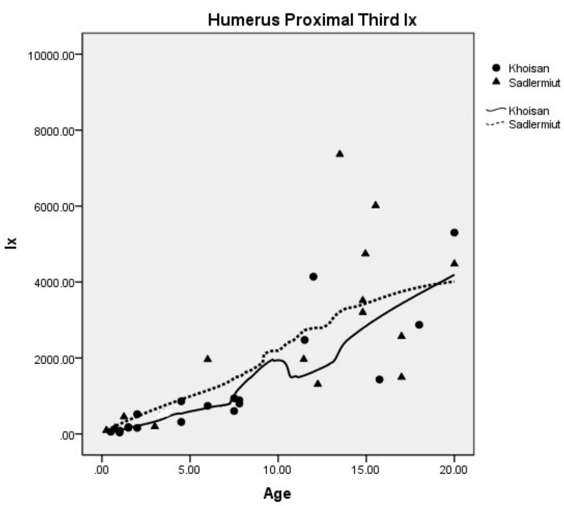


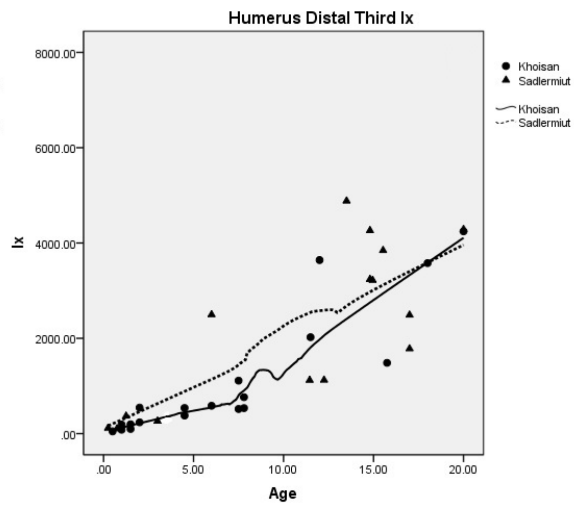


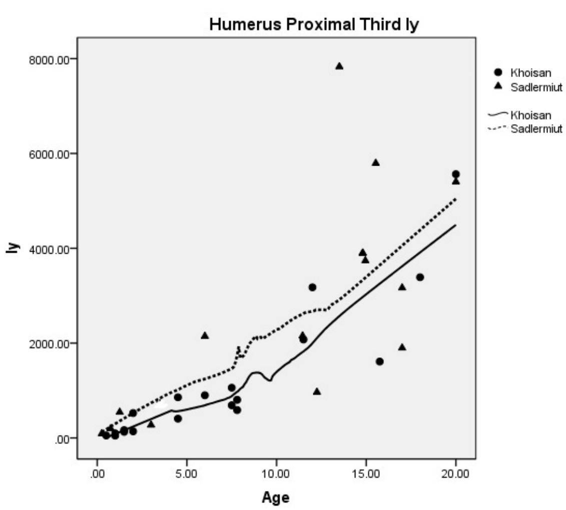


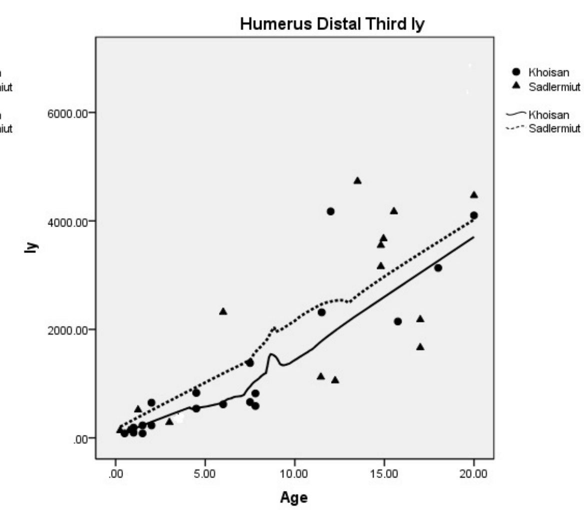


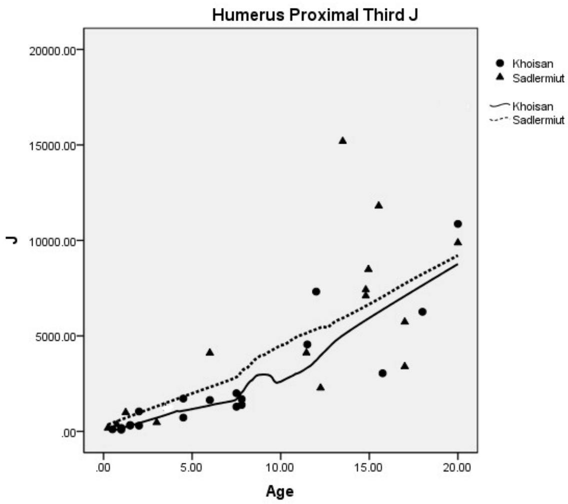

Humerus Midshaft Medullary Area
Medullary Area
140.00
120.00
100.00
80.00
60.00
40.00
20.00
.00
.00
5.00
10.00
15.00
20.00
Age
Khoisan
Sadlermiut
Khoisan
Sadlermiut

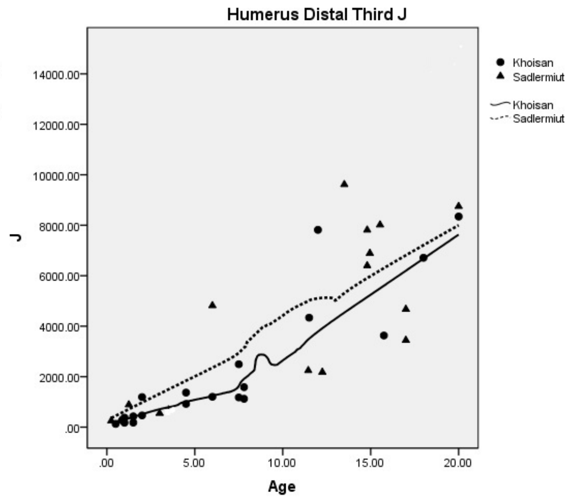

Humerus Proximal Third Ix
Ix
10000.00
8000.00
6000.00
4000.00
2000.00
.00
.00
5.00
10.00
15.00
20.00
Age
Khoisan
Sadlermiut
Khoisan
Sadlermiut

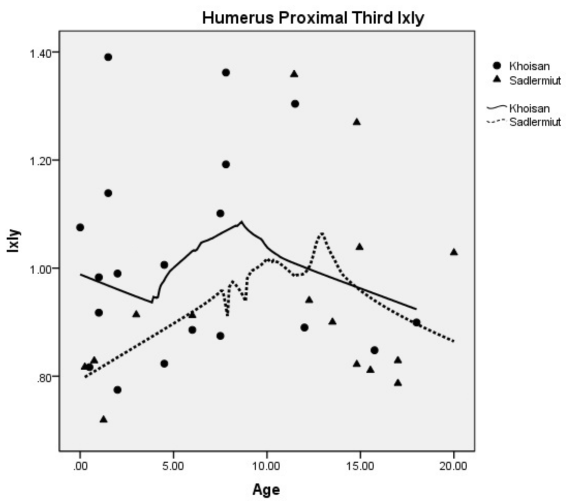

Humerus Distal Third Ix
Ix
8000.00
6000.00
4000.00
2000.00
.00
.00
5.00
10.00
15.00
20.00
Age
Khoisan
Sadlermiut
Khoisan
Sadlermiut

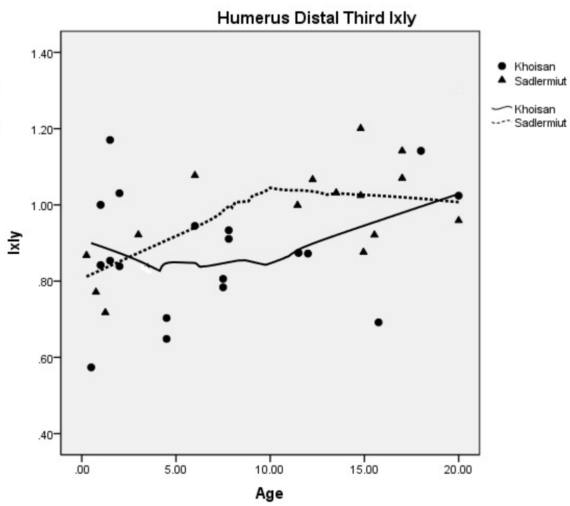

Humerus Proximal Third Iy
Iy
8000.00
6000.00
4000.00
2000.00
.00
.00
5.00
10.00
15.00
20.00
Age
Khoisan
Sadlermiut
Khoisan
Sadlermiut

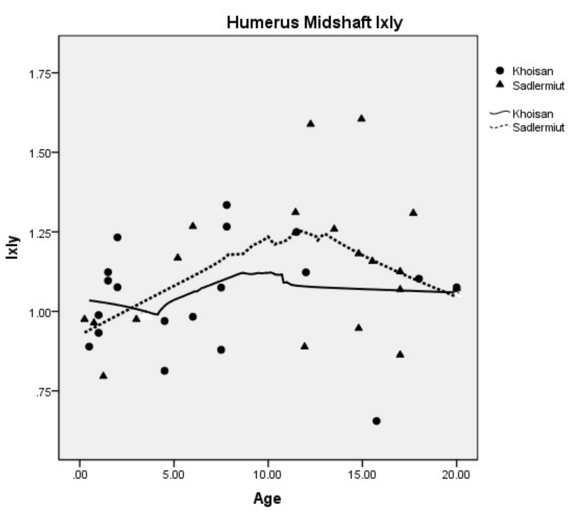

Humerus Distal Third Iy
Iy
6000.00
4000.00
2000.00
.00
.00
5.00
10.00
15.00
20.00
Age
Khoisan
Sadlermiut
Khoisan
Sadlermiut

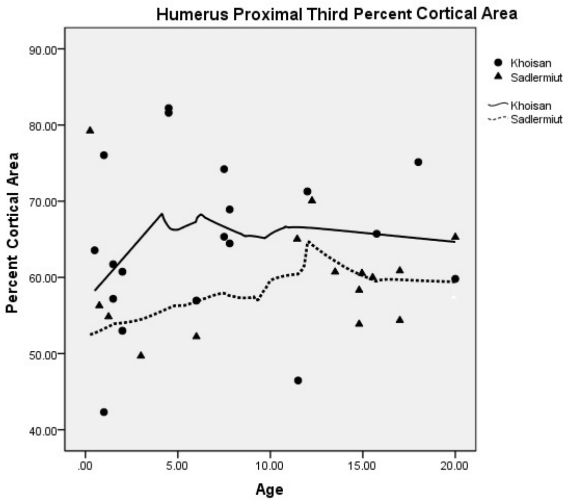

Humerus Proximal Third J
J
Age
Khoisan
Sadlermiut
20000.00
15000.00
10000.00
5000.00
.00
5.00
10.00
15.00
20.00

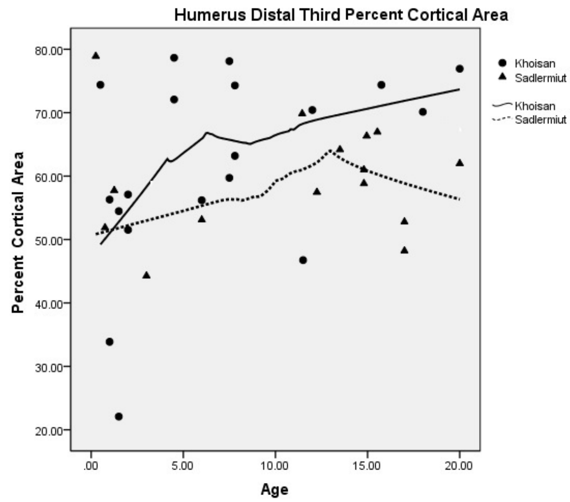

Humerus Distal Third J
J
Age
Khoisan
Sadlermiut
14000.00
12000.00
10000.00
8000.00
6000.00
4000.00
2000.00
.00
5.00
10.00
15.00
20.00


Humerus Proximal Third IxIy
IxIy
Age
Khoisan
Sadlermiut
1.40
1.20
1.00
.80
.00
5.00
10.00
15.00
20.00

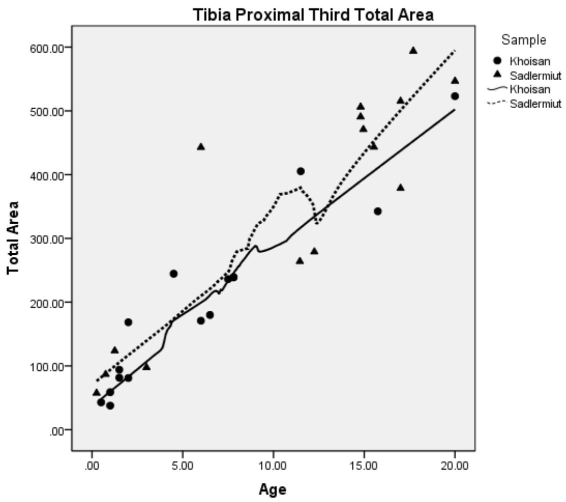

Humerus Distal Third IxIy
IxIy
Age
Khoisan
Sadlermiut
1.40
1.20
1.00
.80
.60
.40
.00
5.00
10.00
15.00
20.00

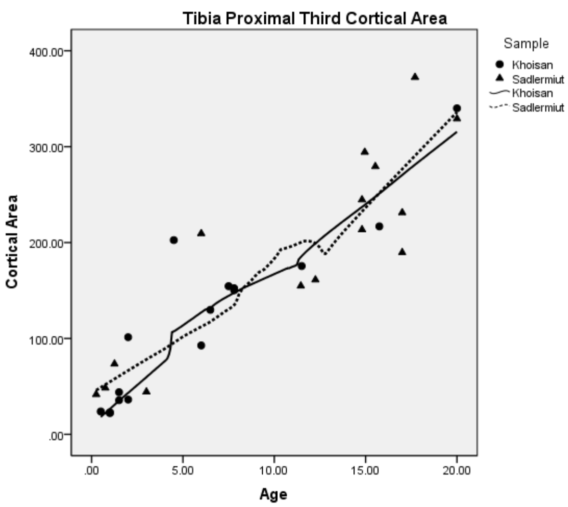

Humerus Midshaft IxIy
IxIy
Age
Khoisan
Sadlermiut
1.75
1.50
1.25
1.00
.75
.00
5.00
10.00
15.00
20.00

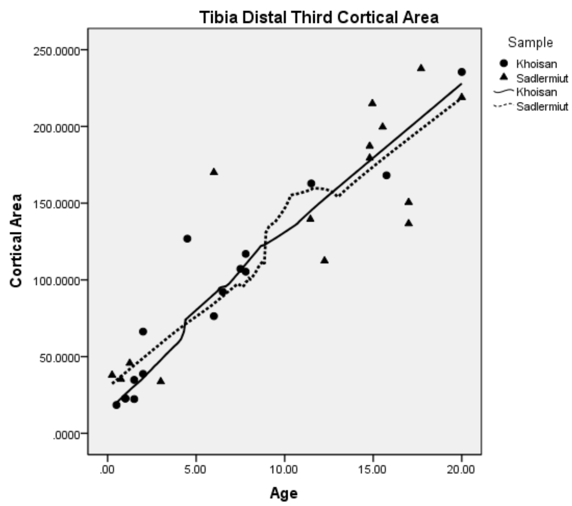

Humerus Proximal Third Percent Cortical Area
Percent Cortical Area
Age
Khoisan
Sadlermiut
Khoisan
Sadlermiut
90.00
80.00
70.00
60.00
50.00
40.00
.00
5.00
10.00
15.00
20.00

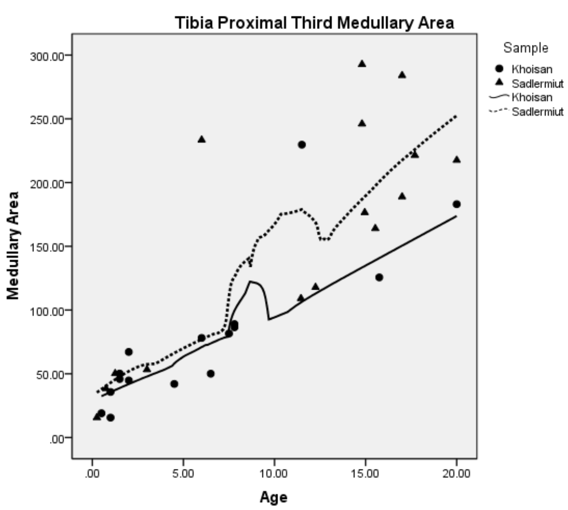

Humerus Distal Third Percent Cortical Area
Percent Cortical Area
Age
Khoisan
Sadlermiut
Khoisan
Sadlermiut
80.00
70.00
60.00
50.00
40.00
30.00
20.00
.00
5.00
10.00
15.00
20.00

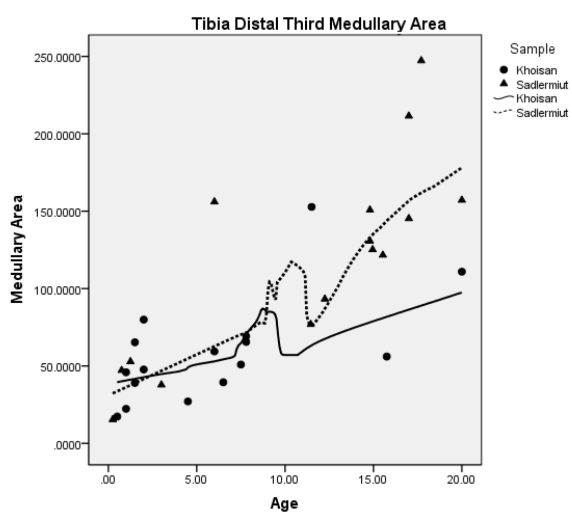
G-2: Tibia results

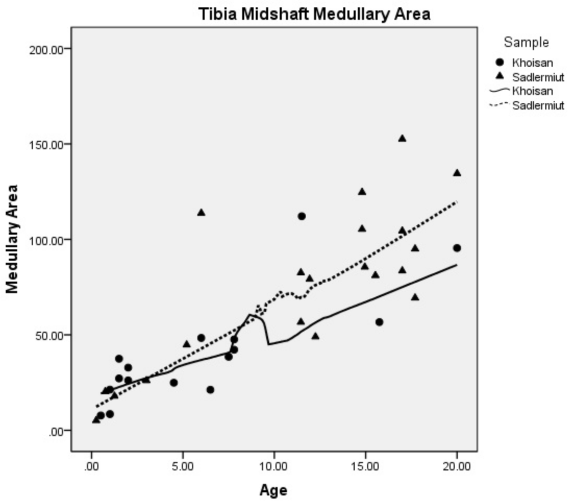




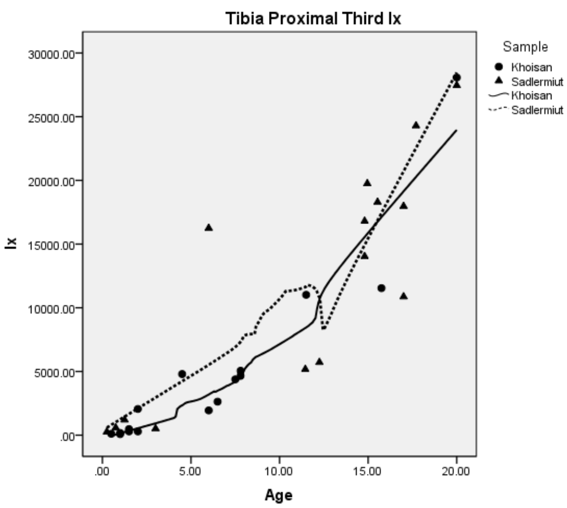




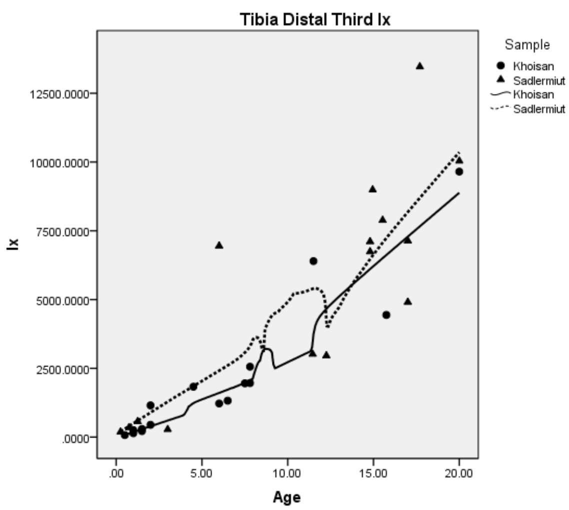




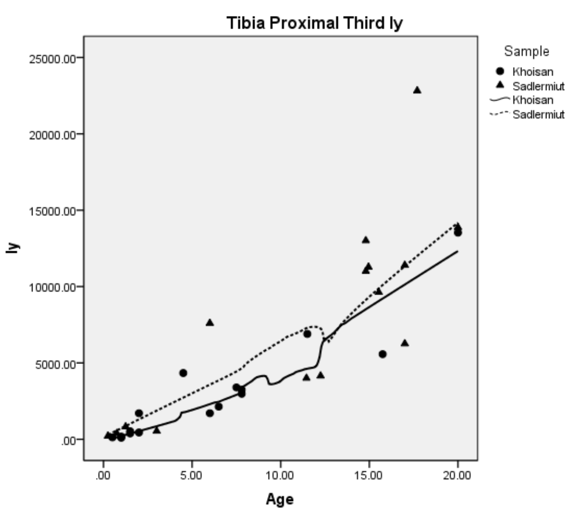
Tibia Midshaft Medullary Area
Sample
Khoisan
Sadlermiut
Khoisan
Sadlermiut
Medullary Area
Age



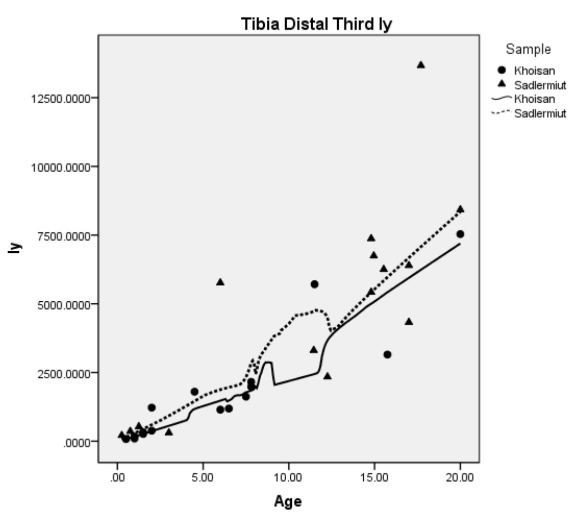
Tibia Proximal Third Ix
Sample
Khoisan
Sadlermiut
Khoisan
Sadlermiut
Ix
Age



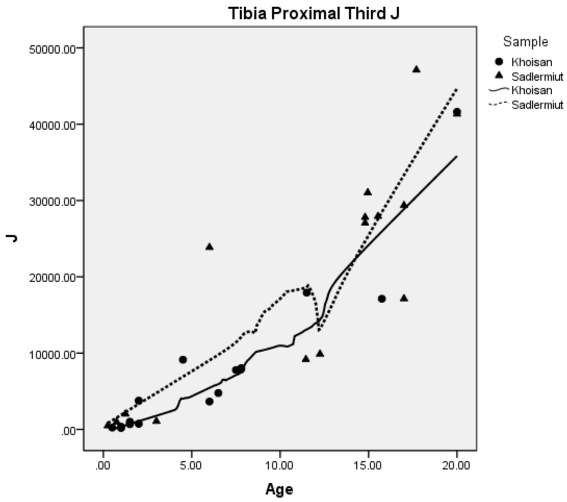
Tibia Distal Third Ix
Sample
Khoisan
Sadlermiut
Khoisan
Sadlermiut
Ix
Age

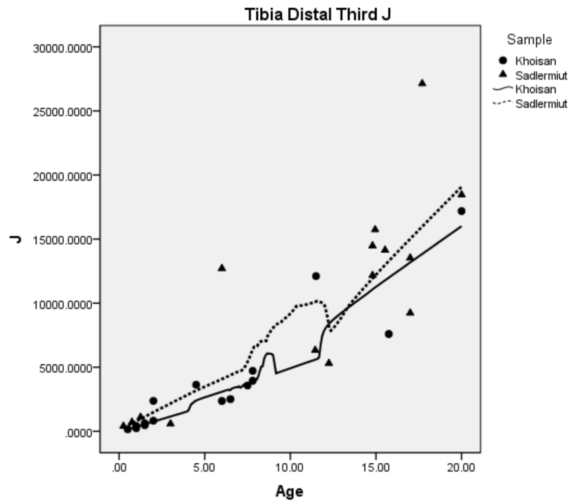


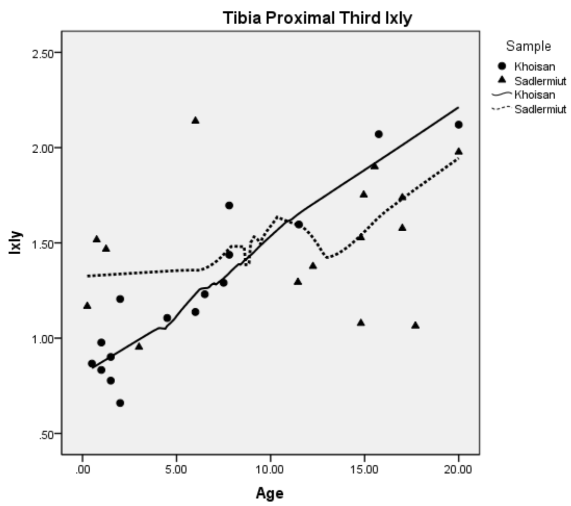
Tibia Proximal Third Iy
Sample
Khoisan
Sadlermiut
Khoisan
Sadlermiut
Iy
Age

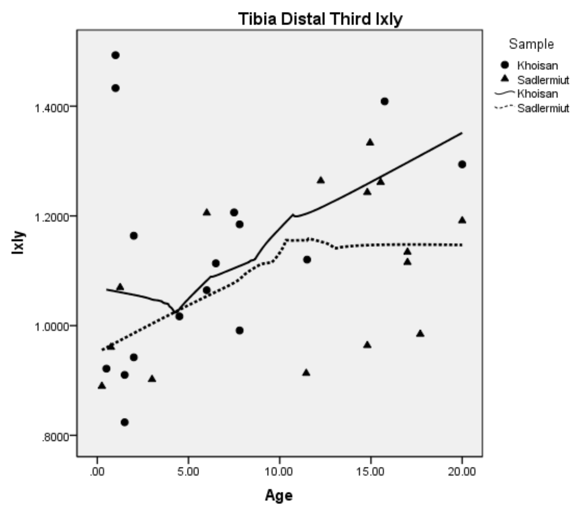


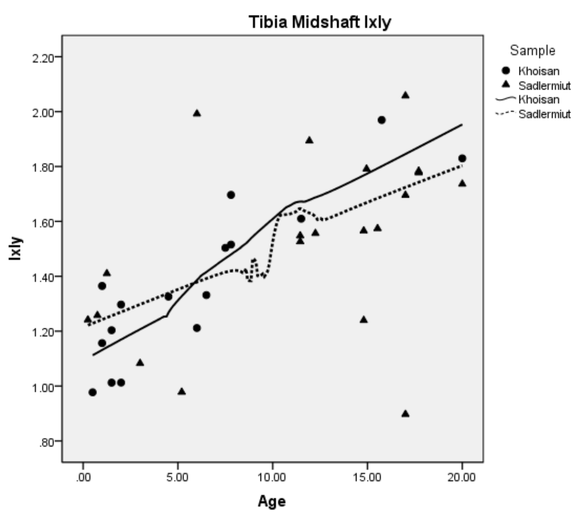
Tibia Distal Third Iy
Sample
Khoisan
Sadlermiut
Khoisan
Sadlermiut
Iy
Age

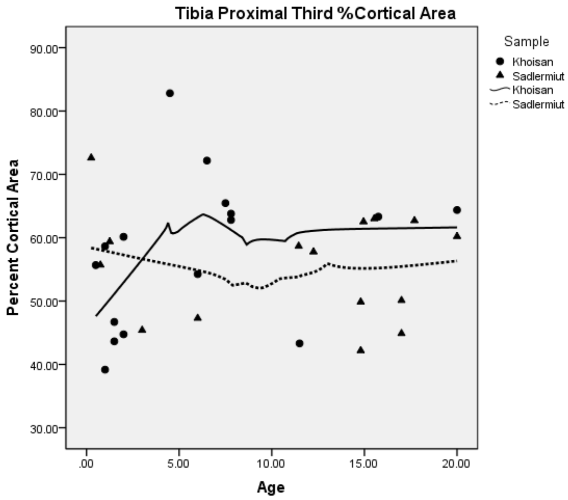

Tibia Proximal Third J
Sample
Khoisan
Sadlermiut
Khoisan
Sadlermiut
J
Age

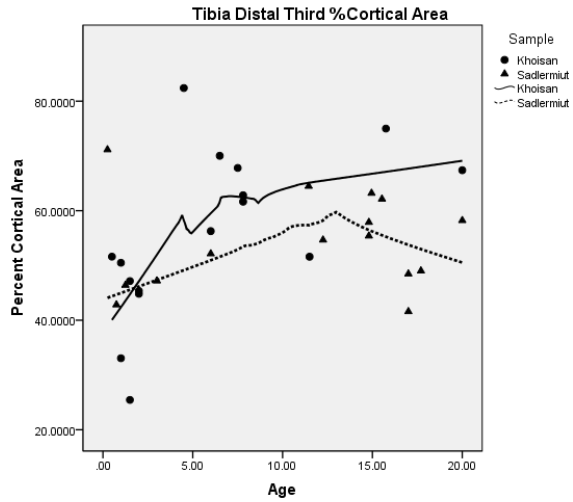

Tibia Distal Third J
Sample
Khoisan
Sadlermiut
Khoisan
Sadlermiut
J
Age


Tibia Proximal Third Ixly
Sample
Khoisan
Sadlermiut
Khoisan
Sadlermiut
Ixly
Age

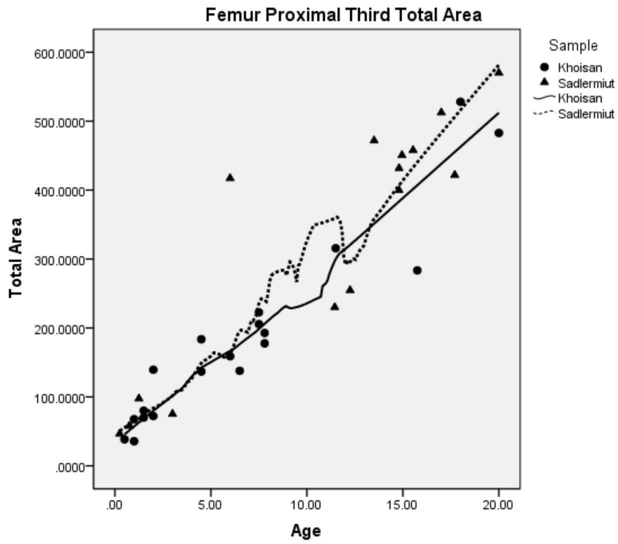

Tibia Distal Third Ixly
Sample
Khoisan
Sadlermiut
Khoisan
Sadlermiut
Ixly
Age

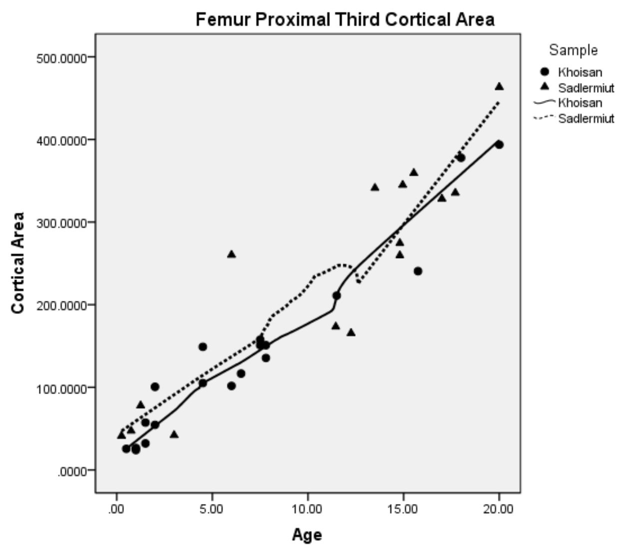

Tibia Midshaft Ixly
Sample
Khoisan
Sadlermiut
Khoisan
Sadlermiut
Ixly
Age

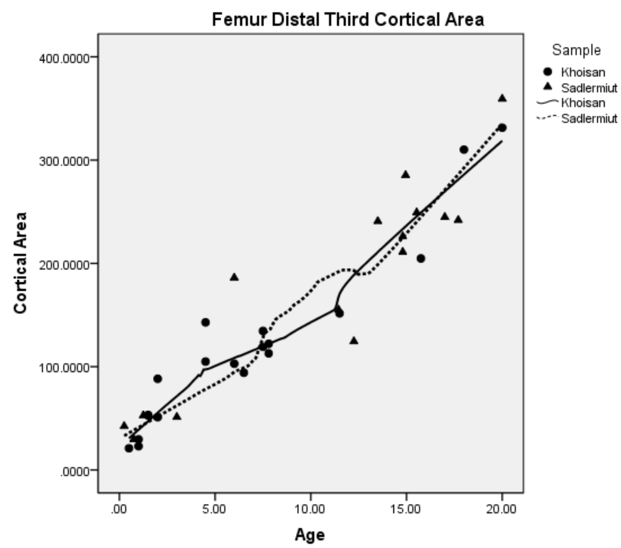

Tibia Proximal Third %Cortical Area
Percent Cortical Area
Age
Sample
Khoisan
Sadlermiut
Khoisan
Sadlermiut
90.00
80.00
70.00
60.00
50.00
40.00
30.00
.00
5.00
10.00
15.00
20.00

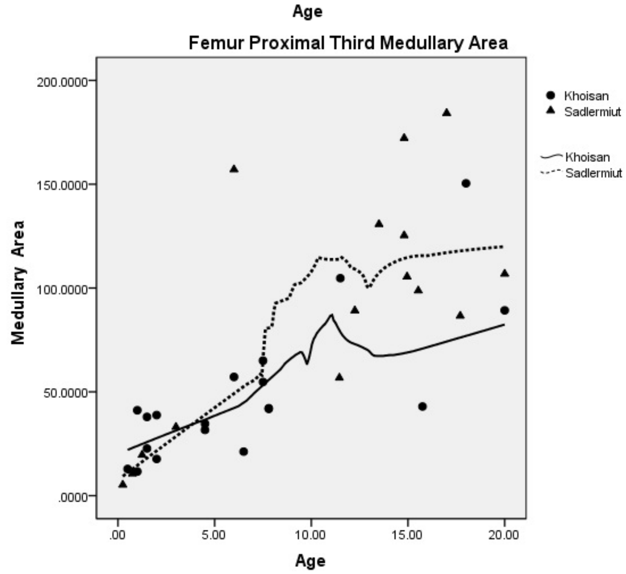

Tibia Distal Third %Cortical Area
Percent Cortical Area
Age
Sample
Khoisan
Sadlermiut
Khoisan
Sadlermiut
80.0000
60.0000
40.0000
20.0000
.00
5.00
10.00
15.00
20.00

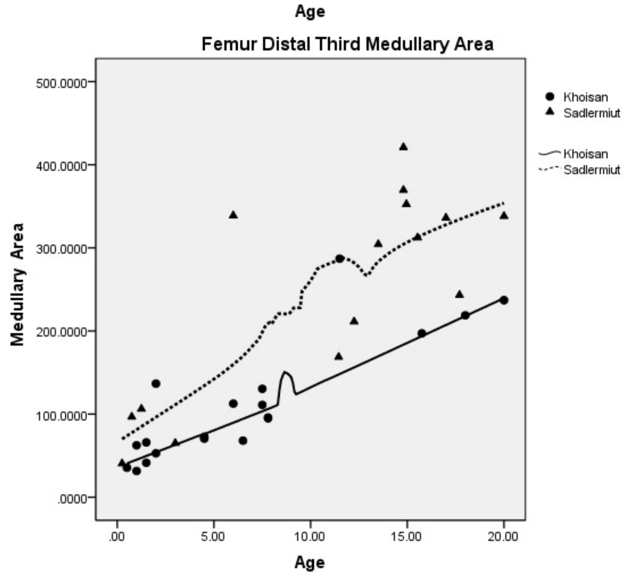
G-3: Femur results

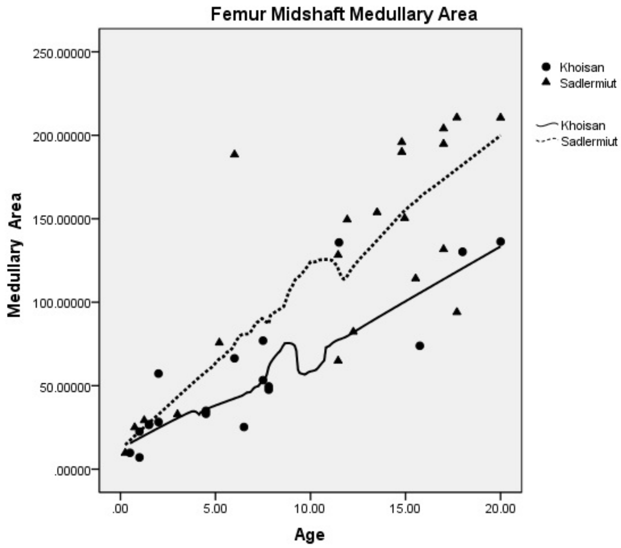




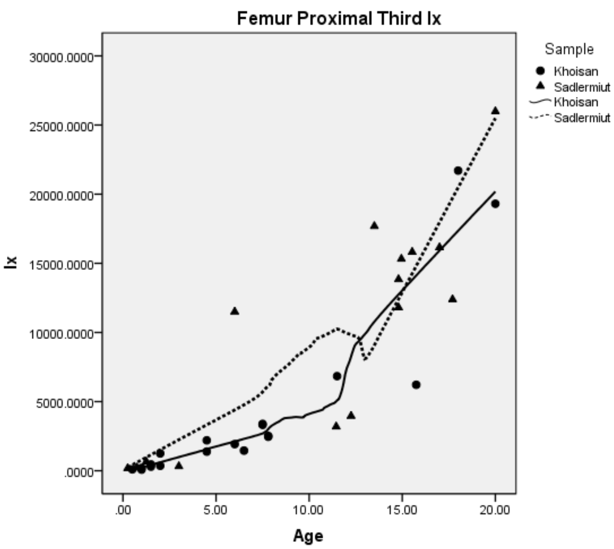




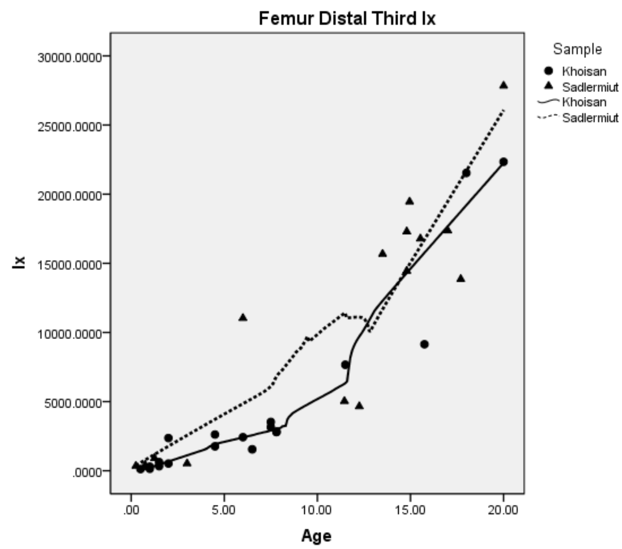




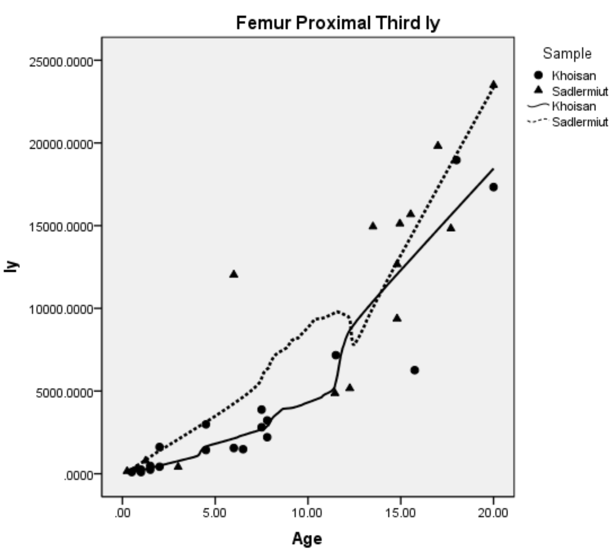
Femur Midshaft Medullary Area
Medullary Area
Age
Khoisan
Sadlermiut
Khoisan
Sadlermiut



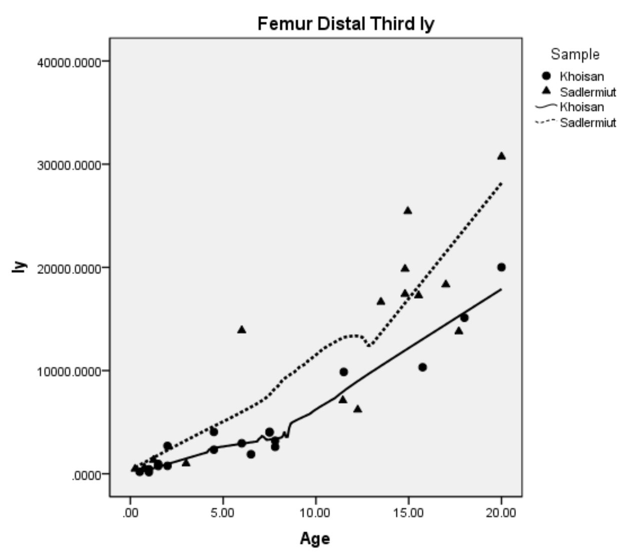
Femur Proximal Third Ix
Ix
Age
Sample
Khoisan
Sadlermiut
Khoisan
Sadlermiut



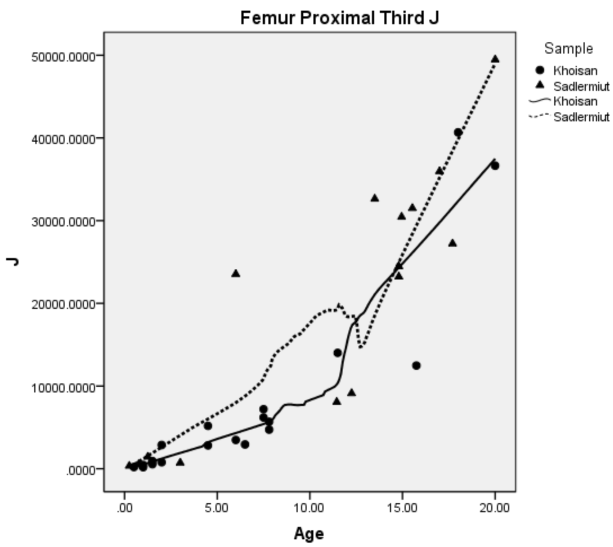
Femur Distal Third Ix
Ix
Age
Sample
Khoisan
Sadlermiut
Khoisan
Sadlermiut

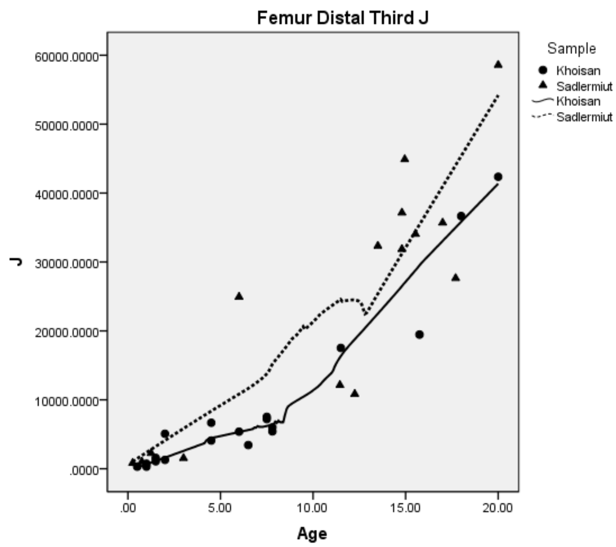


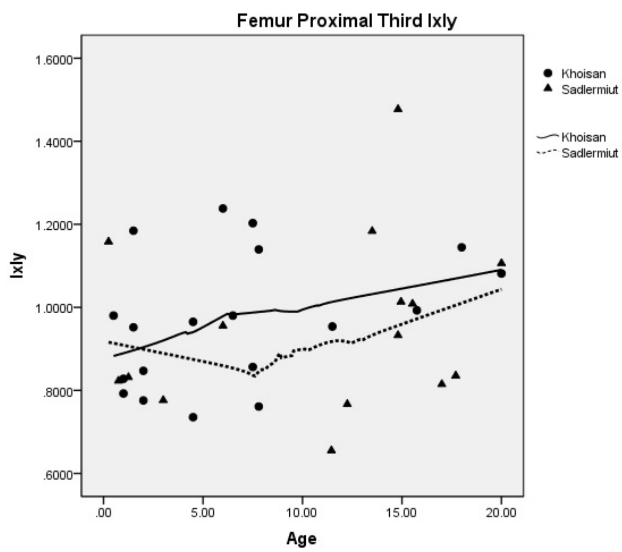
Femur Proximal Third Iy
Iy
Age
Sample
Khoisan
Sadlermiut
Khoisan
Sadlermiut

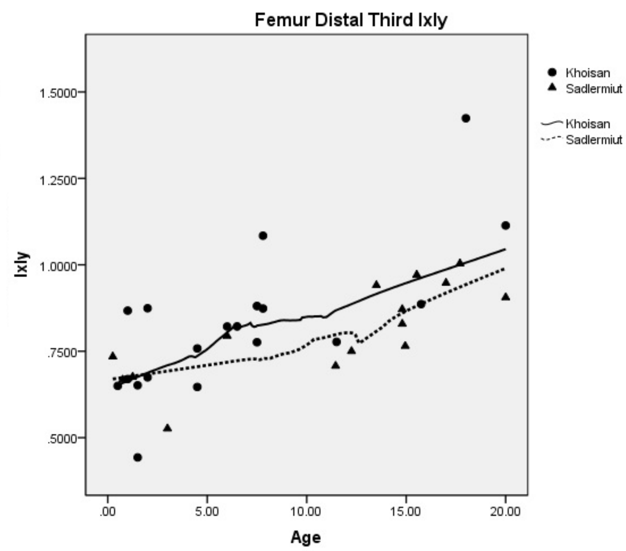


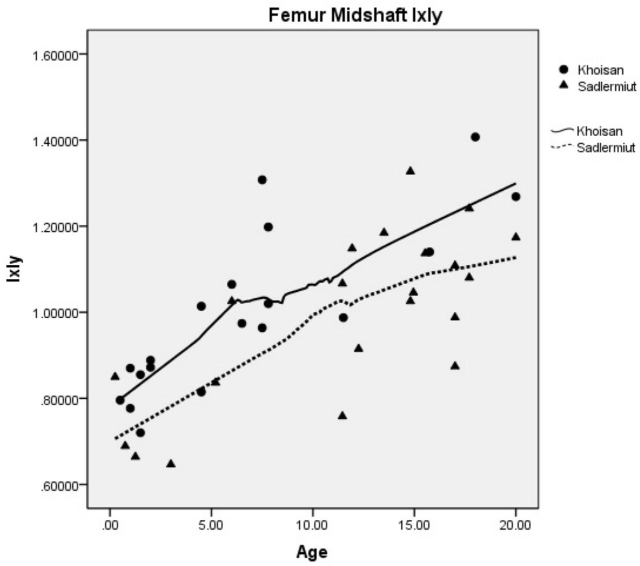
Femur Distal Third Iy
Iy
Age
Sample
Khoisan
Sadlermiut
Khoisan
Sadlermiut

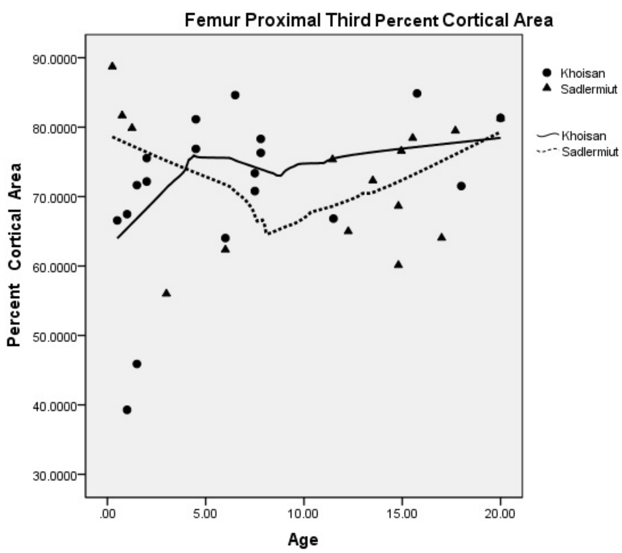

Femur Proximal Third J
Sample
Khoisan
Sadlermiut
Khoisan
Sadlermiut
J
Age

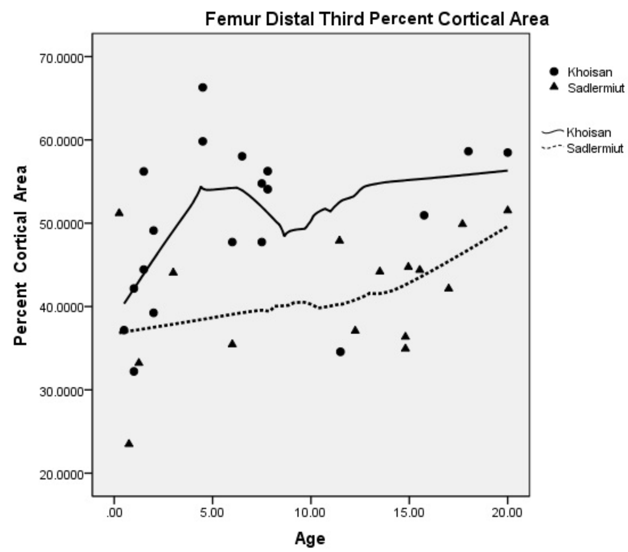

Femur Distal Third J
Sample
Khoisan
Sadlermiut
Khoisan
Sadlermiut
J
Age


Femur Proximal Third Ixly
Khoisan
Sadlermiut
Khoisan
Sadlermiut
Ixly
Age


Femur Distal Third Ixly
Khoisan
Sadlermiut
Khoisan
Sadlermiut
Ixly
Age


Femur Midshaft IxIy
IxIy
Age
Khoisan
Sadlermiut
Khoisan
Sadlermiut
1.60000
1.40000
1.20000
1.00000
.80000
.60000
.00
5.00
10.00
15.00
20.00


Femur Proximal Third Percent Cortical Area
Percent Cortical Area
Age
Khoisan
Sadlermiut
Khoisan
Sadlermiut
90.0000
80.0000
70.0000
60.0000
50.0000
40.0000
30.0000
.00
5.00
10.00
15.00
20.00


Femur Distal Third Percent Cortical Area
Percent Cortical Area
Age
Khoisan
Sadlermiut
Khoisan
Sadlermiut
70.0000
60.0000
50.0000
40.0000
30.0000
20.0000
.00
5.00
10.00
15.00
20.00

Curriculum Vitae

NAME:	Kaye-Lynn Boucher
DATE OF BIRTH:	July 26, 1988
CITIZENSHIP:	Canadian
EDUCATION:	M.A. Bioarchaeological Anthropology, 2010-2012 The University of Western Ontario
	B.A. Honours Specialization Anthropology, 2006-2010 The University of Western Ontario
STATUS/POSITION:	M.A. Candidate The University of Western Ontario
AREAS OF INTEREST:	Paleoanthropology, paleopathology, paleoepidemiology, osteology, biomechanics, hominin evolution, climatic adaptation
ACADEMIC AWARDS:	Social Science Dean's Honour List 2008-2010 The University of Western Ontario
	WGRS: Western Graduate Research Scholarship 2010-2012 The University of Western Ontario
PUBLICATIONS:	"*Collaboration for Conservation in Ankarana, Madagascar*" 2011 TOTEM: The University of Western Ontario Journal of Anthropology, 19(1).
PROFESSIONAL AFFILIATIONS:	Member of the Graduate Anthropology Volunteer Effort, 2011-2012
	Member of the Publish, Present or Perish Organization, 2011-2012
	Member of the American Anthropological Association, 2011-2012
	Member of the Western Anthropology Graduate Society, 2010-2012
	Member of the Canadian Association for Physical Anthropology, 2010-2011