INVESTIGATION OF HISTOMORPHOMETRIC VALUES IN AN EAST ARCTIC FORAGING GROUP, THE SADLERMIUT

by

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The following individuals read and discussed the thesis submitted by student Joseph Kenneth Purcell, and they evaluated his presentation and response to questions during the final oral examination. They found that the student passed the final oral examination.

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ABSTRACT

Investigation of Histomorphometric Values in an East Arctic Foraging Group, the Sadlermiut

A sample of second metacarpals (n=78) obtained from the Sadlermiut, Inuit (1285-1903 A.D.), a genetically isolated East Arctic foraging group, was analyzed histologically in this study. The Sadlermiut subsisted nearly exclusively on small marine mammals and fowl. Based on known adaptations to a cold environment, a high level of physical activity, and a diet high in protein, it was predicted that Inuit bones would show elevated levels of cellular activity. The size and density of secondary osteons in the Sadlermiut are used in this study to compare their bone metabolic processes with known data from a sample of Euro-Canadian metacarpals (n=63) from an historic cemetery in Ontario, Canada. Exact ages were known for the Euro-Canadian group, while the individuals in the Inuit sample are only known as young, middle, and old. Students' t-tests were used to investigate variation in histological values based on age, sex, and handedness. Additionally, cross-sectional measures were compared between the two groups. Differences in osteon density between the three age categories of the Inuit were found to be significant at the .05 level. Variation between right and left hands and those based on sex were not significant. The Sadlermiut were also found to have smaller cross-sections of bone and increased medullary area but smaller osteon density, comparatively.

The decreased cellular activity in the Sadlermiut suggests that even though they had smaller cortices, they were adapted to the strain levels in their hands.

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CHAPTER 1: INTRODUCTION

The function of bone is to protect internal organs, provide support, and act as a reservoir for minerals (Martin et al., 1998). To meet the biomechanical demands placed upon it, bone needs to be both durable and flexible. It is composed of calcium for rigidity and collagen for plasticity (Martin et al., 1998). Bone is dynamic, capable of responding to various environmental and mechanical stimuli through the regulation of bone metabolic processes at the tissue and cellular levels (Frost, 1985; Parfitt, 2004; Martin et al., 1998). The responses of bone to various stimuli leave a lasting record, often observable long after an individual has perished. Therefore, the influence of age, sex, ancestry, physical activity, and pathology is interpretable in past populations.

The last half century has seen an increase in the application of bone histology, primarily to develop methods to estimate age at death (Kerley, 1965; Ahlqvist and Damsten, 1969; Singh and Gunberg, 1970; Kerley and Ubelaker, 1978; Thompson, 1979; Ericksen, 1991; Kimura, 1992; Stout and Paine, 1992; Cho et al., 2002; Streeter, 2010). The same information used to estimate age can also be applied to the study of other aspects of bone biology, such as indicators of environmental and biomechanical stresses (Stout and Simmons, 1979; Frost, 1985; Uytterschaut, 1993; Stout and Paine, 1994; Stout and Lueck, 1995; Abbott et al., 1996). Histomorphometric data from modern populations provide a baseline of values for use in comparison with past populations and offers the opportunity to study the impact of temporal, cultural, or biomechanical influences on bone. This is because bone adapts to stress in two primary ways, modeling (selective cellular activity on bone surfaces) and remodeling (the creation of discrete packets of new bone called osteons) (Currey, 1964; Frost, 1985; Enlow, 1976; Parfitt, 2004; Stout and Lueck, 1995; Mulhern and Van Gerven, 1997). Parameters such as osteon size and density can inform about stresses incurred during growth and development and the physiological adaptation occurring after skeletal maturity is reached (Pfeiffer and Lazenby, 1994; Abbott et al., 1996; Martin et al., 1998; Pfeiffer et al., 2006).

In the present research, histological values (osteon density and osteon area) observed in the Sadlermiut 2nd metacarpal are examined by sex, side of the hand, and age, which are known to generally affect bone metabolic processes. The relatively geographically isolated, extinct, east Arctic, foraging Sadlermiut subsisted nearly exclusively on marine animals and were known to only use lithic and bone tools. Additionally, this study compares measures of cross-sectional geometry and histomorphometric values in the 2nd metacarpal between the Sadlermiut, a 19th century cemetery sample of Euro-Canadians in Ontario, Canada, and two modern samples (Japanese, Baltimore).

Bone responds to biomechanical stresses by adding diameter and thus increasing the robustness, creating greater resistance to bending (Ruff et al., 1984; Ruff et al., 1993; Ruff et al., 1994; Stock, 2004). Research has demonstrated that as a result of greater strain levels, bone incurs more microfractures and consequently must increase repair (remodeling) responses (Martin et al., 1998). In an active population like the Sadlermiut, who moved about the terrain in search of food, increased bone repair would be expected. Martin et al. (1998) discuss biomechanical influence on osteon size, suggesting that smaller osteons are structurally better adapted to a high-strain environment than larger osteons. Based on this relationship between osteon size and strain, the Sadlermiut would be expected to have smaller sized osteons compared to the less active Euro-Canadian sample.

Past research on histomorphometric parameters in bone has focused on describing and comparing metabolic processes in modern and pre-agricultural groups (Stout and Teitelbaum, 1976; Thompson, 1979; Ericksen, 1980; Stout and Lueck, 1995; Mulhern, 2000). Other studies have examined osteon population density (OPD), and mean osteon size (On.Ar) in temperate foraging groups or in Pleistocene hominids (Stout and Lueck, 1995; Abbot et al., 1996). Only one study to date (Thompson and Gunness-Hey, 1981) has examined histomorphometric values in Arctic populations. However, they analyzed cores from femurs, which are weight-bearing bones and, unlike the 2nd metacarpal, would reflect the increased impact of biomechanical forces during locomotion. Analysis of the Sadlermiut 2nd metacarpal will provide histomorphological values from non-weight-bearing bones and thus provide information on a baseline of metabolic activity with the (influence of) biomechanical forces playing a minor role.

The purpose of this research was to evaluate the possible differences between males and females, loading in the left and right hands, and age-related changes in histomorphometric values, OPD and On.Ar, in the Sadlermiut. Age, sex, and the biomechanical influence on hand dominance have been demonstrated to influence both OPD and On.Ar. For this reason, the resulting histological data was analyzed according to these variables. For this analysis, the Sadlermiut were divided into three broad age categories, young (<35), middle (36-50), and old (51+), and t-test's were used to test for significant differences in OPD and On.Ar among the age ranges. Additionally, the significance of the variance found in the results between males and females and the sides of the hand was analyzed. The following hypotheses sets were tested for these purposes.

Hypotheses

First Hypotheses Set

H_O 1: There are no statistically significant sex differences between males and females in OPD, in the 2nd metacarpal.

H_A 1: There are statistically significant sex differences between males and females in OPD, in the 2nd metacarpal.

Second Hypotheses Set

H_O 2: There are no statistically significant sex differences between males and females in On.Ar, in the 2nd metacarpal.

H_A 2: There are statistically significant sex differences between males and females in On.Ar, in the 2nd metacarpal.

Third Hypotheses Set

H_O 3: There are no statistically significant differences in OPD of the 2nd metacarpal between the left and right hands.

H_A 3: There are statistically significant differences in OPD of the 2nd metacarpal between the left and right hands.

Fourth Hypotheses Set

H_O 4: There are no statistically significant differences in On.Ar of the 2nd metacarpal between the left and right hands.

H_A 4: There are statistically significant differences in On.Ar of the 2nd metacarpal between the left and right hands.

Fifth Hypotheses Set

H_O 5: There are no statistically significant changes in osteon population density (OPD), with increasing age, in the 2nd metacarpal.

H_A 5: There are statistically significant changes in OPD, with increasing age, in the 2nd metacarpal.

Sixth Hypotheses Set

H_O 6: There are no statistically significant changes in mean osteon size (On.Ar) with increasing age, in the 2^{nd} metacarpal.

H_A 6: There are statistically significant changes in On.Ar with increasing age, in the 2^{nd} metacarpal.

The organization of this analysis is as follows: Chapter 2 is a review of the ethnographic background of the Sadlermiut sample, including their diet and physical activity patterns that could impact bone processes in the 2^{nd} metacarpal. In Chapter 3, there is a detailed discussion of bone, bone histology, and how histomorphometric parameters are influenced by factors such as sex, biomechanical loading, and age. Chapter 4 discusses the Sadlermiut sample and methods of histological data collection and the details of the statistical analysis by sex, age and handedness. In Chapter 5, the results of the microstructural investigation of the Sadlermiut are reported. Chapter 6 consists of the discussion and interpretation of the results within the Sadlermiut and compares values with other studies of the 2^{nd} metacarpal. Finally, Chapter 7 is a statement of conclusions and suggestions for future research.

CHAPTER 2: ETHNOGRAPHIC BACKGROUND

Understanding of the cultural background of the Sadlermiut Inuit is necessary to comprehend the impact that lifestyle can have on their bone biological processes. The term Inuit specifically refers to modern arctic foraging people living in the circumpolar regions of Russia, Greenland, Alaska, and northern Canada. The term is also used in the literature to refer to past archaeological groups of that region, including the Dorset, Thule, and Sadlermiut.

The subject of this study, the now extinct Sadlermiut, were a group of Inuit primarily known from their cultural remains at Native Point (KkHh-1) on Southampton Island, Hudson Bay, Canada (Picture 1) (Laughlin, 1963; VanStone, 1959; Clark, 1980; Merbs, 1983; Pelly, 1987; Coltrain et al, 2004; Holland, 2007; Coltrain, 2009). The Native Point Sadlermiut site located just south of the Arctic Circle is on the western edge of an isolated plateau overlooking Native Bay (Collins, 1956a; Collins, 1956b; Collins, 1957; Holland, 2007). There are no natural harbors, a fact that contributed to their relative isolation from neighboring Inuit and from European whalers. The western edge of Southampton Island is also cut off from the rest of the island by a canal that is difficult to navigate (Holland, 2007). Due to the group's remoteness, lack of appreciable resources, or a safe harbor, the Sadlermiut came into contact with Europeans much later than other Inuit groups in that area (VanStone, 1959; Holland, 2007). The first documented European contact with the Sadlermiut was in 1824 with a group of English whalers, and contact always remained infrequent (VanStone, 1959; Merbs, 1983; Pelly, 1987; Coltrain et al., 2004; Holland, 2007; Coltrain, 2009).

Picture 1. Map of Southampton Island showing the Native Point and Prairie Point sites (From Jumonville, 2012a)

In 1902, the area surrounding Southampton Island had experienced an epidemic outbreak, and in spite of their relative isolation, it appears that an unidentified disease had been introduced into the Native Point Sadlermiut village. Accounts are that a few individuals from the Sadlermiut visited a nearby trading post and carried the disease back to the Native Point site (Laughlin, 1963; Merbs, 1983; Pelly, 1987; Coltrain et al., 2004; Holland, 2007; Coltrain, 2009). Over the winter of 1902-03 every resident of Native Point died (Laughlin, 1963; Merbs, 1983; Pelly, 1987; Coltrain et al., 2004; Holland, 2007; Coltrain, 2009). Neighboring Aivilingmiut reported that when they arrived at the village in the spring of 1903, they found everyone dead. Some individuals were still in their beds, and others were found in the corridors between houses (Merbs, 1983; Holland, 2007; Coltrain, 2009). In describing the condition of the village upon their arrival, the Aivilingmiut informants stated that the group's domesticated dogs survived on the full winter stores the group had collected, indicating that the Sadlermiut did not succumb to starvation (Merbs, 1983).

Preservation of skeletal tissue was generally good because only a small amount of soil and biological debris from decomposition covered the remains (Merbs, 1983). In a few cases, scavengers or the growth of lichen negatively impacted taphonomy. Sadlermiut burials were located above ground (Merbs, 1983; Holland, 2007; Coltrain, 2009); this was likely due to the semi-frozen and gravel nature of the soil. Decedents were placed either on the natural ground surface, on cobbles, or, in some cases, on large limestone slabs, and then a stone structure or cairn was built over the top of the grave (Merbs, 1983; Coltrain et al., 2004; Holland, 2007; Coltrain, 2009). Generally, remains were interred individually with the exception of a few double burials (Merbs, 1983). The Sadlermiut sites have yielded approximately 789 individuals (Holland, 2007).

Material Culture

The Sadlermiut are described as being unique among local Inuit and Eskimo groups, only utilizing Stone Age tools (Clark, 1980; Merbs, 1983; Pelly, 1987; Coltrain et al., 2004; Coltrain, 2009). There are various opinions regarding the origins of the Sadlermiut, some consider the group to have derived from the Thule tradition, based on similarities in architecture, and nonlithic artifacts (Clark, 1980; Pelly, 1987; Taylor Jr., 1957). An analysis of cranial metric traits indicated that the Sadlermiut were more similar to area Thule groups (Naujan, Kamarvik, and Silumiut) than to the Dorset (Mayhall, 1979; Utermohle and Merbs, 1979), though the Dorset sample in this research only consisted of two individuals and considering the variation within groups, are unlikely to provide a complete picture of cranial variation in the Dorset.

Within the last decade, it has been suggested that the Sadlermiut were an admixture of both the Dorset and Thule (Coltrain et al, 2004; Holland, 2007; Coltrain, 2009). This is primarily based on the ancient DNA study by Hayes et al. (2005), which found that the Sadlermiut sampled were a nearly equal combination of the Dorset haplogroup (group D), and Thule haplogroup (group A).

Local Inuit groups are known to refer to the Sadlermiut as the Tunnit or Legendary Inuit, and the Native Point area as Tunermiut (Collins, 1956a; 1956b; Clark, 1980; Pelly, 1987), indicating their belief that the Sadlermiut represented a remnant of the ancestral group. Reports of their culture come from limited contact with European whalers, from whom has come the oldest image produced (a sketch) of an individual from the group (Merbs, 1983; Coltrain et al., 2004). Information also comes from the oral traditions of other Inuit groups.

Another source of Sadlermiut culture is archaeological evidence (Collins, 1956a; 1956b; 1957; Taylor, Jr., 1957; Merbs, 1983; Holland, 2007; Coltrain et al., 2004). Excavation of Sadlermiut villages has yielded information on architecture, including building material choices (bone, vertical limestone slabs, and sod) and style (subterranean) (Merbs, 1983; Taylor Jr., 1957; Holland, 2007). In addition, descriptions of midden and lithics added data on diet and technology (Merbs, 1983; Taylor Jr., 1957). Excavations of human skeletal remains provided material for anthropometric studies, isotope analysis, and paleopathological studies (Mayhall, 1979; Utermohle and Merbs, 1979; Merbs, 1983; 1996; 2002; Coltrain et al., 2004; Coltrain, 2009).

There are few descriptions of Sadlermiut cultural materials. Lithic points were the most commonly described cultural items. Sadlermiut lithic points were found in excavations of various residences and in midden piles (Taylor Jr., 1957; Merbs, 1983). The most commonly utilized stone for harpoons, arrowheads, and scrappers was chert (Merbs, 1983). Other materials used in the construction of hunting implements included walrus ivory and bone (Merbs, 1983; Taylor Jr, 1957). Members of the group, which relied solely on stone technology until their demise (Pelly, 1987; Merbs, 1983), were considered master lithic workers by their Aivilingmiut neighbors (Merbs, 1983). Unlike neighboring groups, the Sadlermiut refused to adopt the use of metal and other European implements into their culture (Hayes et al., 2005; Holland, 2007).

Diet

It has been shown that poor nutrition can negatively affect bone metabolic processes (Frost, 1966; Stout, 1982; Pfeiffer and Lazenby, 1994; Lazenby, 1997); therefore, a complete understanding of a group’s subsistence strategy is important in furthering our understanding of the impact of diet on bone. Few archaeological investigations of the Sadlermiut have reported on faunal remains. Merbs addressed the Sadlermiut diet and game choice based on the lithic forms found during excavations (1983). He found harpoon points used for hunting whales and varying sizes of arrowheads that would have been used for hunting seals, other small mammals, marine fowl, and fish (Merbs, 1983).

Within the last decade, isotopic analysis of some of the Sadlermiut skeletal series was undertaken by Coltrain et al. (2004). The authors analyzed isotopic values in an attempt to determine if the group was relying on primarily one faunal source, i.e., whales, seals, or caribou. Their analysis showed that for the period studied 1289-1896, the Sadlermiut primarily subsisted on marine fauna as evident from gamma levels, demonstrating that approximately 90% of their diet came from marine sources (Coltrain et al., 2004; Coltrain, 2009). The authors compared these values with other local skeletal remains from the Thule and Dorset groups and found that the Sadlermiut were the most dependent on marine fauna of the groups analyzed (Coltrain et al., 2004; Coltrain, 2009). By comparing the gamma values in the Sadlermiut to those of other known whaling groups, they demonstrated that the group did not eat much whale meat; instead they primarily foraged on ringed seal (*Pusa hispida*), piscivores seabirds (fish eating seabirds), and occasionally salmon (Salmonidae) (Coltrain et al., 2004; Coltrain, 2009).

VanStone (1959) reviewed the utilization of fauna by modern indigenous groups on Southampton Island. He observed seasonal subsistence strategies and found that seal hunting was more likely to occur in the spring when seals are on the ice near the island. The island is also a breeding area for many species of marine fowl (piscivores) and walruses (*Odobenus rosmarus*) in the spring, making them particularly vulnerable to local hunters. Additionally, fox (canidae) and polar bears (*Ursus maritimus)* are trapped in large numbers during the winter months (VanStone, 1959). These observations contradict previous reports (Taylor Jr., 1957) based on archaeological evidence but are consistent with the isotopic analysis of Coltrain et al. (2004). It is likely this discrepancy can be explained by two factors; VanStone (1959) reported on the entire island, whereas the Sadlermiut were primarily confined to the small southwestern portion, and comprehensive archaeological accounts of faunal numbers are rare.

Physical Activity Patterns

As mentioned above, in addition to diet and genetics, physical activity patterns are known to impact modeling and remodeling in bone (Kerley, 1965; Thompson, 1979; Stout and Lueck, 1995; Abbott et al., 1996; Martin et al., 1998; Cho et al., 2002; Parfitt, 2004). Similar to many other foraging societies, the Sadlermiut were an active population focused on procuring, preparing, or storing food on a daily basis. The group is also characterized as practicing a sexual division of labor (Merbs, 1983). For this reason, it is worthwhile to investigate osteological evidence of differences in activity patterns based on sex. Because of the inferred division of labor within the Sadlermiut culture, one might expect to detect indications of varying levels of physical activity between the hands of males and females.

In Sadlermiut society as in most Arctic foraging groups, men were primarily responsible for hunting and the subsequent transporting of their game (Merbs, 1983). Energy expenditure and tools used are game-specific. For instance, harpooning required the use of the dominate hand. In contrast, paddling is an activity that required the use of both hands (Merbs, 1983). Whaling in the traditional Inuit manner would have required the use of the hand in both the location of (paddling) and killing (harpooning). Bows and arrows were used to hunt smaller animals such as seals or marine fowl. Bow hunting would have required the use of both hands (Merbs, 1983).

Sadlermiut men participated in two additional activities, both related to foraging, which could have resulted in increased biomechanical stress in the bones of the hands. These were butchering game and flint knapping (Merbs, 1983). Sadlermiut men are described by Aivilingmiut informants as rapidly butchering an animal at a kill site (Merbs, 1983). Ethnographic information also indicates that Sadlermiut men flint knapped (Merbs, 1983), which can also influence the biodynamics of the metacarpals.

Sadlermiut females were primarily responsible for food preparation, sewing, and preparing hides (Merbs, 1983). Merbs identified higher incidents of osteoarthritis in the hands of Sadlermiut females with a predominance of this condition in the right hand. He attributes the arthritis to sewing, which required the strenuous piercing of tough animal hides with bone needles (Merbs, 1983).

Ethnographic and archaeological sources have demonstrated that the Sadlermiut were a group that subsisted nearly exclusively on marine fauna, which is high in protein. Males in the group hunted, butchered prey, and flint knapped, all of which would increase strain levels in the 2^{nd} metacarpals. Females in the Sadlermiut were known to sew tough hides with their hands, also increasing the amount of loading.

CHAPTER 3: BONE BIOLOGY BACKGROUND

Bone Composition

Bone is a specialized connective tissue that consists of an organic matrix (32%), water (25%), a mineral matrix mostly made of calcium (42%), and other organic proteins (1%) (Martin et al., 1998). These components combine to give bone the strength and durability to perform biomechanical functions in life. The organic portion of bone is primarily composed of type 1 collagen, the most common protein in the human body. The collagen is organized into fibers that provide both tensile strength and flexibility (Martin et al., 1998). The mineral matrix of bone consists of hydroxyapitite, $Ca_{10}(PO_4)_6(OH)_2$. This compound is infused around the collagen fibrils, providing strength in compression and rigidity (Martin et al., 1998).

Gross Morphology

Long bones (bones of the limbs) and 2nd metacarpals are morphologically similar. Bone can be categorized several ways, by formation type or by microscopic organization. Two types of observable bone tissue in the human body are trabecular bone (cancellous) and compact bone (cortical) (Figure 1). Cancellous bone, which is spongy and organized into struts, provides biomechanical support and is found in the ends of bones, the metaphysis (the flared portion of long bones), and the epiphysis (ends) (Figure 1). Smooth dense cortical bone forms the diaphysis (shaft) of bones and also comprises the thin dense shell on the entire outer surface of the bones. The interior and exterior surfaces of bones are covered with a fibrous membrane. The periosteum covers the outside of bones while the endosteum lines the cancellous bone and marrow cavity. In addition to these two bone surfaces, there is also the Haversian envelope (surface), which will be discussed below.

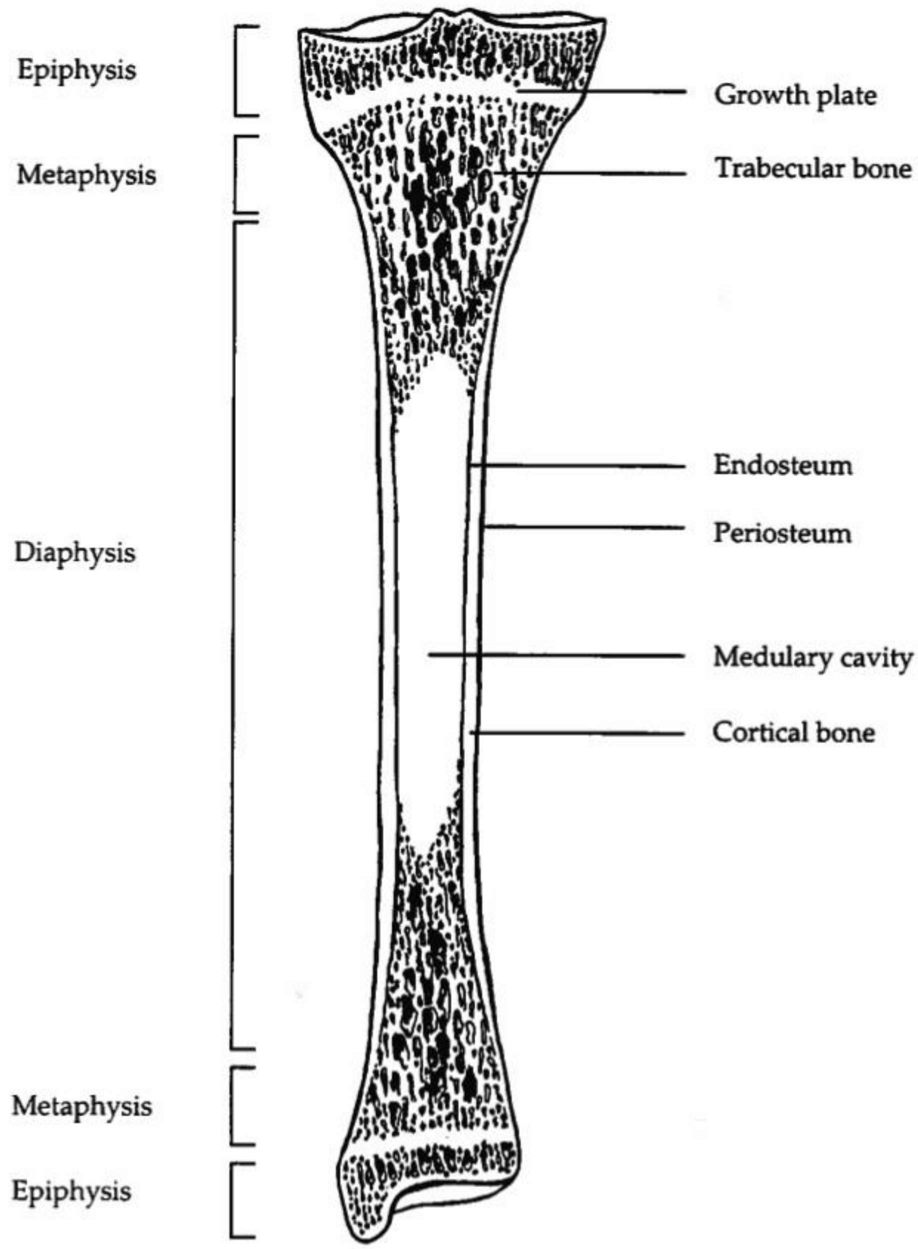

Figure 1. Gross bone morphology and bone surfaces (from Streeter, 1999)

Morphology of the 2nd Metacarpal

The 2nd metacarpal, the focus of this study, is useful in bone studies because of the five metacarpals it is the least asymmetrical between the left and right sides of the hand (Kusec et al., 1990; Lazenby, 1998b; Lazenby et al., 2008). The bone is located medial to the first digit (thumb), with a diaphysis capped by a head and base (Figure 2). When viewed in anatomical position (palm up), the distal end (the epiphysis) is the head of the metacarpal that articulates with the proximal phalanx. The proximal epiphysis articulates with three carpals (capitate, trapezoid, trapezium), and medially with the 3rd metacarpal. At the base, the dorsal interosseus muscle attaches on the proximal ¾ of the diaphysis on both the medial and lateral side (Figure 2). These muscles have relevance because they attach in the area of the 2nd metacarpal from which the samples originate, and their contraction could influence the response of the bone to biomechanical stress.

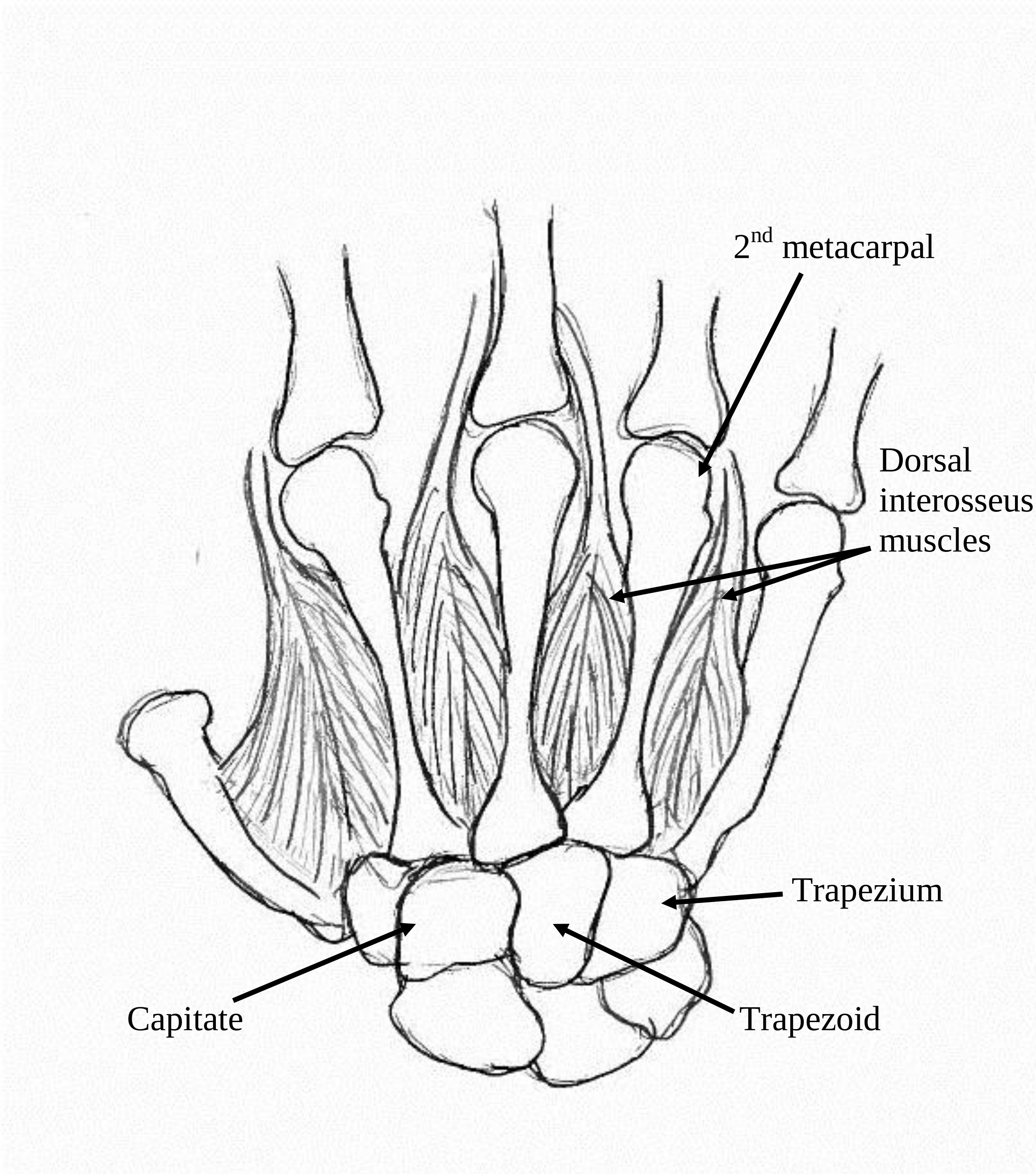

Figure 2. Gross morphology and muscle attachments of the 2nd metacarpal (palmer view) (From Jumonville, 2012b)

Bone Cells

Four primary types of cells are responsible for the growth and maintenance of bone: osteoclasts, osteoblasts, osteocytes, and bone-lining cells (Frost, 1966; Enlow, 1976; Frost, 1985; Parfitt, 1994). Osteoclasts are large multinucleated cells responsible for resorbing bone that originate in the bone marrow (Parfitt, 1994). This is accomplished by dissolving bone using hydrochloric acid that is created in the organelles at the base of the osteoclast (Parfitt, 1994). Osteoblasts are small, single-nucleated cells that are responsible for synthesizing unmineralized bone, osteoid (Martin et al., 1998). Osteoblasts are also responsible for bone mineralization, and they produce the type I collagen found in bone. Osteocytes are osteoblasts that have become trapped in the bone during the mineralization processes. They maintain bone physiology, including mineral homeostasis. Osteocytes are located in a fluid-filled space referred to as the osteocytic lacunae. Extensions of the lacunae (canaliculi) conduct branches of the osteocyte and assist in the transport of various materials and connect to other osteocytes. Through these connections, osteocytes signal cellular processes in bone (Parfitt, 1994; Qiu et al., 2002). It is currently hypothesized that disruption of the osteocytic connections (osteocyte apoptosis) or changes to pressure maintained in the liquid of the osteocytic lacunae (microstrain) signal cellular repair (Parfitt, 1994). Bone-lining cells are flattened, quiescent, osteoblasts that line the periosteum and other surfaces. Bone-lining cells are also involved in bone physiology and are a part of the osteocyte sensory network. Unlike osteocytes, bone-lining cells have the capability to be reactivated into osteoblasts when needed.

Growth

There are two processes responsible for skeletal formation, endochondral and intramembranous ossification (Enlow, 1976; Frost and Jee, 1994; Robling, 1998). The appendicular skeleton (limbs) forms through endochondral ossification. In this process, growth occurs from an uncalcified cartilage anlag (model) and proceeds towards the ends of the bone. In this way, endochondral ossification achieves growth in the length of bone (Frost, 1985). The flat bones, such as those of the skull and pelvis, are formed by intramembranous ossification (Enlow, 1976). Unlike endochondral growth, intramembranous ossification does not start with a cartilage model. Instead, bone is formed in association with a membrane onto existing bone. This appositional growth occurs on all bone surfaces throughout life and accounts for an increase in the diameter of bones (Enlow, 1976).

Modeling

Modeling works with growth to shape bones to meet the mechanical demands placed upon it during life (Enlow, 1976). The distinct characteristic of modeling is that deposition and resorbtion occur on different surfaces independently. Modeling is responsible for adding cortical bone at the periosteum, which increases both cortical area (Ct.Ar), and total area (Tt.Ar) (Table 3.1). The area of the medullary cavity (Es.Ar) initially increases in the very young, then contracts during puberty. After midlife, the endosteal expansion that has been responsible for increasing Es.Ar outpaces Ct.Ar expansion at the periosteum, and bones start to lose Ct.Ar. Percent cortical area (% Ct.Ar) is calculated by dividing cortical area into Tt.Ar and is the percent of the total area that is composed of cortical bone. Research has shown that increased muscular loading before prepuberty of long bones, including metacarpals, increases cross-sectional area measures (Jones et al., 1977; Ruff et al., 1984; Ruff et al., 1993; Ruff et al., 1994). Cross-sectional area measures are closely tied to histomorphometric values because thicker bone is stronger and more resistant to micro fracture. Thinner cortexes are less resistant to strain and therefore require more microstructural bone repair.

Table 3.1 Definitions and abbreviations of variables used in analysis

Variables	Abbreviation	Definition
Osteon population density	OPD	The total number of intact and fragmentary osteons/mm^2
Mean osteon size	On.Ar	The average area of bone (including Haversian canals) contained within the cement lines of structurally intact osteons
Total area	Tt.Ar	The cross-sectional area contained within the periosteum
Medullary area	Es.Ar	The cross-sectional area contained within the endosteum (marrow cavity)
Cortical area	Ct.Ar	The cross-sectional area of the bone contained within the periosteum minus the marrow cavity area (TA-MA)
Percent cortical area	% Ct.Ar	Percent of total area composed of bone (CA/TA)

Remodeling

Unlike growth, the process of remodeling occurs throughout an individual's life (Enlow, 1962; Frost, 1966; Enlow, 1976; Parfitt, 2004). In humans, remodeling occurs on all bone surfaces; however, this research focuses on samples from the middiaphyseal cross-section only, so only Haversian or intracortical remodeling is considered here. Intracortical remodeling is the gradual replacement of old or damaged bone with discrete packets of new bone called Haversian systems (osteons) (Figure 3) (Frost, 1966; Enlow, 1976). This process is achieved through the action of the bone multicellular unit (BMU). These three dimensional tubular structures consist of osteoclasts and osteoblasts working in concert to resorb and form new bone (Figure 3). Cellular activity occurs within the same unit through the activation-resorbtion-formation (ARF) sequence. This structure, in longitudinal view, appears as a cutting cone (Figure 3). BMU formation starts with the activation of osteoclasts by either osteocytic apoptosis (programmed cellular death), bone necrosis, or in response to microstructural damage (Enlow, 1962; Martin et al., 1998; Parfitt, 2004).

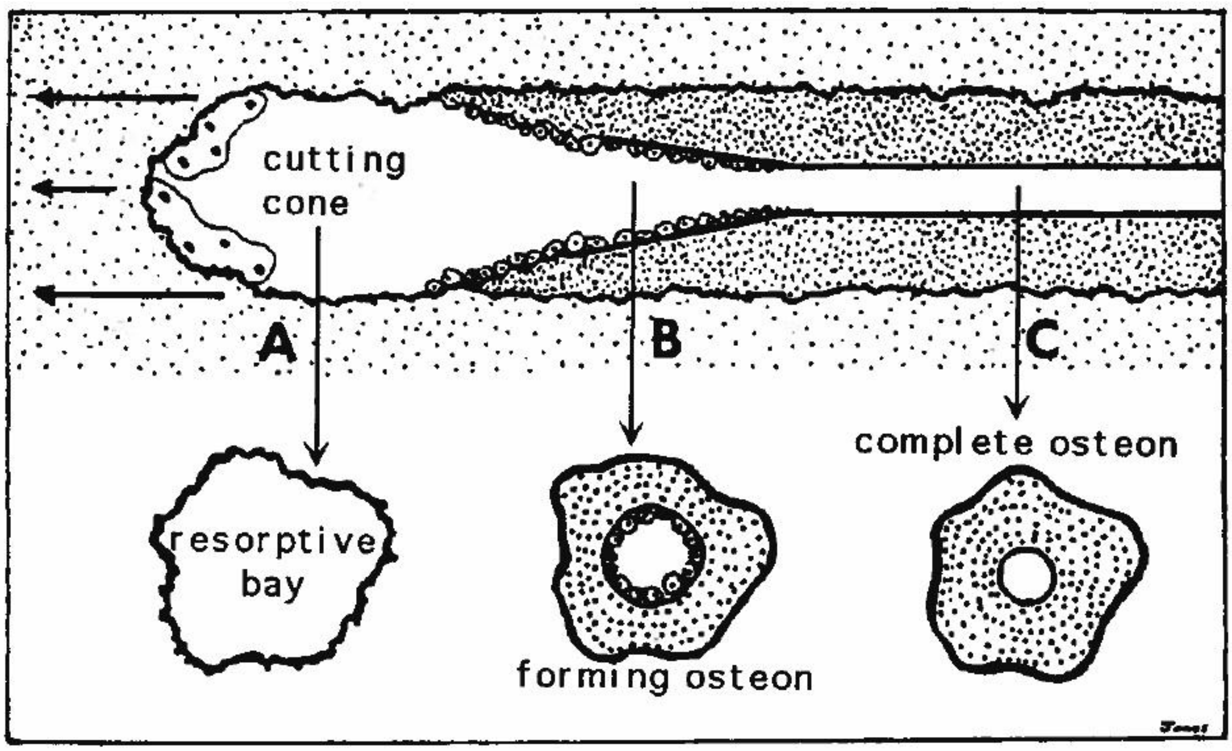

Figure 3. Longitudinal cross-section view of a cutting cone (from Stout, 1982)

In transverse view, osteons of varying stages of development are observable (Figure 3). The remodeling process starts with the activation of osteoclasts that dissolve bone, creating a characteristic resorbtive bay. The resorbtive phase is followed by a short lag time and then a reversal period, creating a reversal line (Figure 4) that is used to differentiate secondary osteons from other morphologically similar looking bone microstructures (primary vascular canals). After the reversal stage, osteoblasts then fill in the space in concentric layers of bone, lamellae. The cavity is filled centripetally until only a small space called the Haversian canal remains in the middle. The space is lined with bone-lining cells, and it allows nerves and blood vessels to pass through. Once completed, this forms the bone structural unit (BSU) or osteon (Figure 4). In humans, this process takes about three months and yields an osteon approximately 100 µm (Martin et al., 1998).

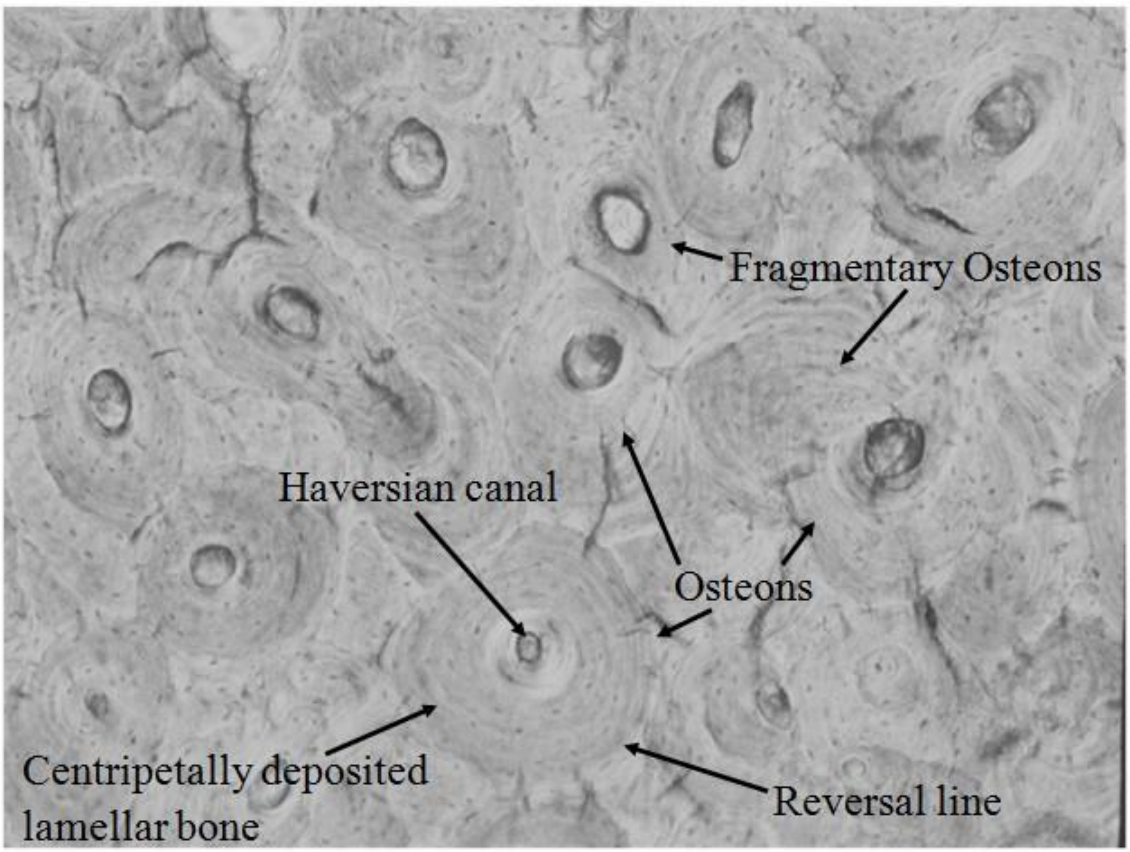

Figure 4. Morphology of an osteon (from Streeter, 1999)

In cross-section, osteons are more or less circular in appearance and are delineated by a reversal line that surrounds the concentric lamellae (Figure 4). The mean size of osteons (On.Ar) varies by bone and species and is thought to be influenced by overall metabolic rate (Abbott et al., 1996). Osteon size is determined by the number and speed of osteoclasts and osteoblasts: less vigorous cell activity produces smaller osteons (Abbott et al., 1996). Less vigorous cell activity can be the result of increased strain levels or a disruption of the bone metabolic rate (Abbott et al., 1996).

Osteon accumulation is correlated with age. The association between age and osteon accumulation forms the basis for histological age estimation (Kerley, 1965; Ahlqvist and Damsten, 1969; Kerley and Ubelaker, 1978; Thompson, 1979; Ericksen, 1991; Kimura, 1992; Stout and Paine, 1992; Cho et al., 2002; Streeter, 2010). As a new (BSU) is created, it can obliterate part or all of a preexisting osteon, creating a fragmentary osteon (Figure 4) (Frost, 1985; Enlow, 1976; Parfitt, 2004).The cells recruited for the BMU process are transported and arrive through the vessels in the Haversian canal.

Factors Affecting Remodeling

Osteon population density (OPD) and osteon size (On.Ar) are bone and site specific (Frost, 1985; Thompson, 1979; Stout and Paine 1992; Cho et al., 2002). The larger weight-bearing bone of the lower limbs experience greater strain levels. But their thicker cortices enable them to incur less mechanical strain (Martin et al., 1998). Smaller bones and non-weight-bearing bones have similar rates (Lazenby et al., 2008). This is because strain levels can vary due to mechanical influences, and in non-weight-bearing bones mechanical loading would have less of an impact. Remodeling varies between bones, and by anatomical regions. Bone remodeling is affected by a variety of intrinsic and extrinsic factors, including sex, age, ancestry, diet, pathology, and mechanical loading as described below (Kerley, 1965; Evans, 1976; Thompson, 1979; Stout and Lueck, 1995; Abbott et al., 1996; Martin et al., 1998; Parfitt, 2004).

Age

Based on the age-associated increase in osteons and osteon fragments, histological aging methods have been developed for the many long bones (Kerley, 1965; Thompson, 1979; Ericksen, 1991), the ribs (Stout and Paine, 1992; 1994; Streeter, 2010), and the 2nd metacarpal (Kimura, 1992). Several authors note an increase in mean On.Ar with age until the third decade; after that osteon size is said to decrease (Takahashi et al., 1965; Frost, 1987; Martin and Burr, 1989; Pfeiffer, 1998). However, a study of the correlation of On.Ar with age on a sample of 2nd metacarpals from a 17th century Euro-Canadian sample reported that there was no decline in On.Ar with age (Denny, 2010).

Sex

Differences in OPD based on sex have been reported (Frost, 1985), but these differences were not deemed to be significant enough to develop sex-specific age formulas (Kerley, 1965; Stout and Paine, 1992; Streeter, 2010). However, Thompson (1979) did use sex specific aging methods. Females are known to have accelerated osteon formations especially in later life, due to hormone changes associated with menopause (Martin et al., 1998).

With regard to the effect of sex on osteon size, the reports are conflicting. While some studies (Mulhern and Van Gerven, 1997; Pfeiffer, 1998; Burr et al., 1990) found larger osteons in females, others report (Pfeiffer, 1998; Mulhern, 2000) that males have larger osteons. It should be noted that previous studies were conducted on ribs and femurs rather than on the 2nd metacarpals considered here. Denny (2010) found that males had significantly larger osteons than females in the 2nd metacarpal.

Ancestry

Methods developed for aging are most accurate when they are population-specific: for example, Cho et al. (2002) has demonstrated African-Americans have lower OPD when compared to European-Americans of the same age. This finding has also been supported by other research (Meier et al., 1992; Han et al., 1997). Conversely, Schnitzler and Mesquita (2006) analyzing iliac crests report that African Blacks have a higher turnover rate than African Whites. Thompson and Gunness-Hey (1981), looking at femoral cores from several arctic populations (Yupik and Inupiaq), noted differences in osteon density.

Pathology

Bone metabolism is known to be influenced by pathological conditions (Wu et al., 1970; Martin and Burr, 1989; Eriksen et al., 1989). The influence of conditions such as Diabetes mellitus and hyperparathyroidism is well documented (Wu et al. 1970; Frost, 1985; Kochersberger et al., 1987). In the case of diabetes, bone formation rates are decreased (Wu et al., 1970). Hyperparathyroidism causes bone metabolic processes to increase, especially resorbtion, causing bones to become more brittle (Kochersberger et al., 1987). Localized trauma is also known to impact bone metabolism. Trauma, like a fracture, can cause regional acceleratory phenomena (RAP) (Frost, 1983). In these instances, bone turnover rates are increased to rapidly repair damaged bone.

Mechanical Loading

Bone is a dynamic material that responds to the mechanical loads applied to it. There are two primary ways that bone adapts to biomechanical strain, through modeling and remodeling (Enlow, 1976; Frost, 1987). Frost (1987), to clarify this relationship, proposed a feedback mechanism hypothesis termed “mechanostat theory”, which defines bones’ response to mechanical forces. Frost (1987) postulated that the responses of bone (modeling or remodeling) is signaled by strain thresholds determined by the amount of minimum effective strain (MES). Normal loading strains in mammalian bone run between 100 and 1500με (microstrain); under these conditions, bone is said to be adapted to its mechanical loading environment. For peak strain levels above the minimum effective strain threshold (MES_M), 1500με remodeling is the major form of adaptation to the increased microfractures incurred at this level of strain (Frost, 1987). Below the MES_M of 100με, bone adapts to the lower strain through modeling in the form of marrow cavity expansion and increased remodeling, which reduces the total amount of bone.

Relevant to a discussion of the impact of physical activity on bone metabolic processes in the hand is handedness. Handedness in humans results in the preferential use of one hand over another for various tasks. Most modern populations, and likely past groups, had the propensity toward having a significantly greater number of right-handed individuals (Lazenby, 2002). This would mean greater mechanical loading in the right versus the left hand. If increased loading occurs in childhood, then bone will respond by forming thicker cortexes (Jones et al., 1977). Consequently, cross-sectional area is increased in the favored hand (Roy et al., 1994). Increased usage leads to greater microstrain propagation, and in adults, the bones respond by increasing remodeling

(Martin et al., 1998). This response would result in increased OPD counts in the right over the left 2nd metacarpal.

Osteon area can be impacted by biomechanics and bone mass. It has been observed that On.Ar is larger in weight-bearing bone (such as the femur) and smaller in non-weight-bearing bones (such as the ribs) (Stout, 1982). Recently, a theoretical model has been utilized to study the relationship between strain and On.Ar in the femur (Van Oers et al., 2008). Van Oers et al. (2008) reported that in response to heavier loading, On.Ar decreased. This has yet to be demonstrated in actual bones. Conversely, Martin et al. (1998) suggest that larger osteons would be less structurally sound than smaller osteons and that bones incurring greater strain (e.g., weight-bearing bones) could also adapt by decreasing On.Ar and increasing OPD (Drapeau and Streeter, 2006).

A comparison of values between the Sadlermiut and other groups offers the opportunity to examine basic bone metabolic processes in a physically active group. The group's exclusive production of stone tools would have increased the mechanical strain these individuals experienced in the hand, especially the males who were known to be the producers of tools.

Diet

Good nutritional health must be maintained for bone health. Bone processes require vitamins and minerals to maintain homeostasis. When an individual is nutritionally deficient in a given vitamin or mineral, such as Vitamin D or calcium, bone will attempt to correct the imbalance. Specifically, a diet high in protein can lead to a condition called acidosis (Iwaniec, 1997, Wengreen et al., 2004). When ph levels in the blood decrease, bone metabolism is increased to balance the ph levels by flooding the blood with calcium ions (Iwaniec, 1997). Blood acidosis has been reported to cause the morphology of osteons to vary. Different types of osteons are created in greater number (Stout and Simmons, 1979; Iwaniec, 1997). The Sadlermiuts' heavy reliance on animal protein coupled with the unavailability of edible plants could result in protein acidosis. An adaptation observed among the Inuit, including the Sadlermiut, is that they are known to have consumed bones (Merbs, 1983), which would have increased calcium levels. Presumably this would be enough to prevent or stop acidosis.

Adequate calcium intake alone is not enough to maintain basic bone metabolic processes, vitamin D is also needed for calcium synthesis (Chaplin and Jablonski, 2009). Human populations gain most of their vitamin D through an interaction between the skin and UV radiation. For this reason, populations that live in areas with diminished UV radiation or those who have adapted culturally by using clothing in cold environments are at risk for being deficient in vitamin D (Sharma et al., 2011). The two common diseases of vitamin D deficiency observable in bone are rickets in children and osteomalacia in adults. In both cases, bones are more pliable and lack biomechanical strength due to the inability of the bones to mineralize properly (Mays et al., 2006). The Sadlermiut, who lived in a cold arctic environment, would have had their skin covered most of the time. However, they were not documented as having rickets in their population (Merbs, 1983).

Past Histologic Work in Hunters and Gatherers

Several researchers (Thompson and Gunness-Hey, 1981; Stout and Lueck, 1995; Pfeiffer et al, 2006) have examined various histological variables (OPD, and On.Ar) in past foraging populations. Mean results for OPD and On.Ar for these studies are given in Table 3.2. Stout and Lueck (1995) compared OPD and On.Ar in the ribs of the early archaic pre-agricultural group (6000-5000 B.C.) from the Windover site, Florida, to values from two later archaeological agricultural groups (Ledders and Gibson) and a modern group. The researchers found that remodeling rates were decreased in the archaeological populations when compared to more modern population. Ribs, like the 2nd metacarpal, are small tubular bones, and are considered non-weight-bearing, making general comparisons between the two element groups possible. In an examination of anatomically modern femurs and ribs, Pfeiffer et al. (2006) found a smaller On.Ar in the ribs (.032 mm^2) as opposed to the femurs (.035 mm^2), demonstrating the possible effect that mechanical loading has on On.Ar values.

Table 3.2 Past histologic research on hunting and foraging groups

Author (year)	**Site/Specimen**	**Element**	**OPD ($/mm^2$)**	**On.Ar (mm^2)**
Stout and Lueck (1995)	Windover	Ribs	17.4	0.035
Thompson and Gunness-Hey (1981)	St. Lawrence Is.	Femurs	10.5*	0.034
	Kodiak Is.	Femurs	13*	0.046
	Southampton Is.	Femurs	12.9*	0.038
	Baffin Is.	Femurs	11.8*	0.035
Pfeiffer et al. (2006)	Anatomically modern	Femurs	**	0.035
		Ribs	**	0.032
* Value calculated with complete osteons only	** Value unavailable			

In a study of both density values and histological variables from femur bone cores, Thompson and Gunness-Hey (1981) examined several groups of arctic Inuit foragers (Baffin Island, Kodiak Island and St. Lawrence Island), including an unspecified sample from Southampton Island and two modern samples, a young European-American forensic group, and an older European-American cadaver group. The authors found that the Inuit groups had a lower osteon density when compared to the older cadaver group (Thompson and Gunness-Hey, 1981).

As previously mentioned, factors such as diet, level of physical activity, and age are known to impact the density and size of osteons. The Sadlermiut were a cold-adapted, physical group; it would be expected that they would have increased bone area measures and increased remodeling rates in response to these environmental factors. It is possible the high protein diet or lack of exposure to UV radiation could negatively impact bone turnover in the Sadlermiut.

CHAPTER 4: MATERIALS AND METHODS

Materials

The Sadlermiut 2nd metacarpals present an opportunity to study the bone of a relatively genetically isolated marine foraging group. The 2nd metacarpal sample, previously embedded in resin, was provided by Dr. Richard Lazenby (University of Northern British Columbia). The sample of 78 adult individuals (Males n= 47, Females n= 31, Right n= 39, Left n= 39) consisted of cross-sections from the midshaft of the 2nd metacarpal. The Sadlermiut were previously dated from 1289 to 1903 (Merbs, 1983, Coltrain et al., 2004, Coltrain, 2009).

Methods

In this study, osteon population density (OPD) and mean osteon size (On.Ar) in the 2nd metacarpal were compared between males and females, the left and right hands, and age categories. The Sadlermiut ages were only given as a range due to imprecise aging methods. Individuals in the sample were only known as young (<35), middle (36-50), and old (51+) (Lazenby personal communication, 2011). Finally, in the analysis of age, only 2nd metacarpals assigned to one of the broad age categories were used in this analysis (males n= 46, females n= 30).

Histological Slide Preparation

Bone cross-sections were prepared following the wafer preparation techniques developed by Frost (1985). Thin sections of the 2nd metacarpal were mounted onto microscope slides using Permount and were cover-slipped.

Calculating Osteon Population Density

A Nikon eclipse 80*i* research microscope at magnification 100x (10x objective, and 10x oculars) and fitted with a Merz eyepiece grid (Merz and Schenk, 1979), was used to determine OPD and On.Ar by the point count method. In order to get a good approximation of osteon density over the entire bone cross-section, a sampling technique employing the eyepiece grid was used. Grid area was examined in two parallel columns from periosteum to endosteum separated by on column width (Figure 5). This pattern was followed, counting both complete and fragmentary osteons.

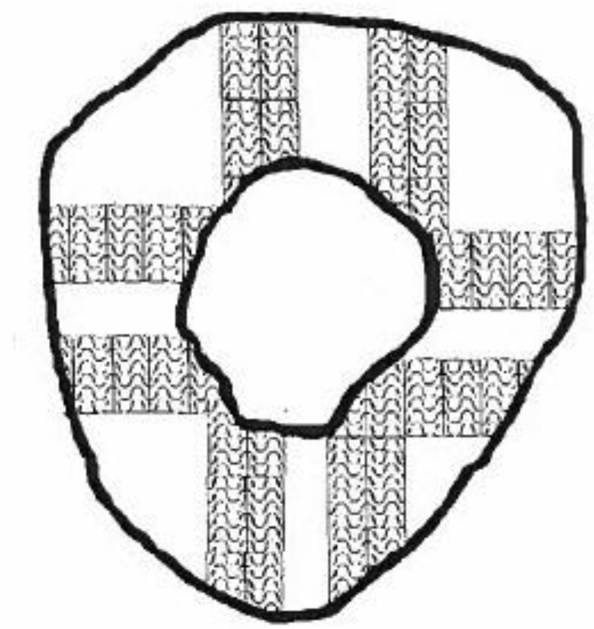

Figure 5. Sampling pattern used on the 2nd metacarpal (from Raguin, 2010)

Calculating Mean Osteon Size

Slides were then reread using the same research microscope at magnification 200x. Fifty osteons per slide were read when possible. In this calculation, only osteons with a circular Haversian canal were used. Osteons vary in size across the cortex with osteons near the endosteum tending to be larger (Evans and Bang, 1967). To compensate for this distribution, osteons were sampled in a pattern from periosteum to endosteum.

Statistical Analysis

The goal of this research was to determine if there were any statistically significant differences in OPD and On.Ar in the Sadlermiut 2nd metacarpal sample. Statistical analysis was used to test the six hypotheses sets. Descriptive statistics including mean, range, and standard deviation were determined for males and females, for both the left and the right 2nd metacarpals, and by age category. Whisker and box charts were generated for comparison of sex, side, and age differences and are presented later in the Results Chapter.

To test H 1- H 4, to ascertain that there were no significant differences between males and females or the right and left hand for OPD and On.Ar values in the Sadlermiut, a t-test was used. The resulting p-values were compared to the scientific standard α of .05. When the p-value is greater than alpha, the null hypothesis of no statistical differences between the variance of the two samples is accepted. If the p-value is less than alpha, then the null hypothesis is rejected because the variance between the samples is statistically significant. To test if there were any significant age changes (H 5, H 6) a similar procedure was used. A t-test was used to evaluate the young age group against both of the two older age categories, and the resulting p-values were compared to α.

CHAPTER 5: RESULTS

The results of the histomorphometric analyses of the Sadlermiut 2nd metacarpal are given in two sections. First, descriptive statistics for the sample are reported, and second, the results of the statistical analyses of the different variable combinations are reported.

Descriptive Statistics

Descriptive statistics for histomorphometric values for the Sadlermiut 2nd metacarpals (n= 79) are given in Table 5.1. Overall, mean osteon population density (OPD) was 10.9 /mm^2, with OPD values ranging from 5.3 /mm^2 to 17.7 /mm^2 and a standard deviation of 3. Mean osteon size (On.Ar.) in the Sadlermiut 2nd metacarpal ranged from .032-.047 mm^2 with a mean of .036 mm^2.

Table 5.1 Mean values for osteon density and osteon size in the 78 Sadlermiut 2nd metacarpals by sex

	Combined	Males	Females
OPD (/mm^2) (Sd)	10.9 (3)	10.8 (3.1)	11.0 (2.9)
On.Ar (mm^2) (Sd)	0.036 (.004)	0.036 (.004)	0.036 (.003)

When the Sadlermiut are separated by sex (males n= 47, females n= 31), the mean OPD for females was 11 /mm^2 and 10.8 /mm^2 for males, with a standard deviation of 2.9 and 3.1, respectively (Table 3). Female OPD values ranged from 5.3 /mm^2 to 17.6 /mm^2, while male values ranged from 5.5 /mm^2 to 17.7 /mm^2 (Figure 6). Values for On.Ar in both females and males were .036 mm^2, with a standard deviation of .003 for females and .004 for males. Mean On.Ar in females ranged from .032 mm^2 to .043 mm^2, and in males the range was .032 mm^2 to .047 mm^2 (Figure 7).

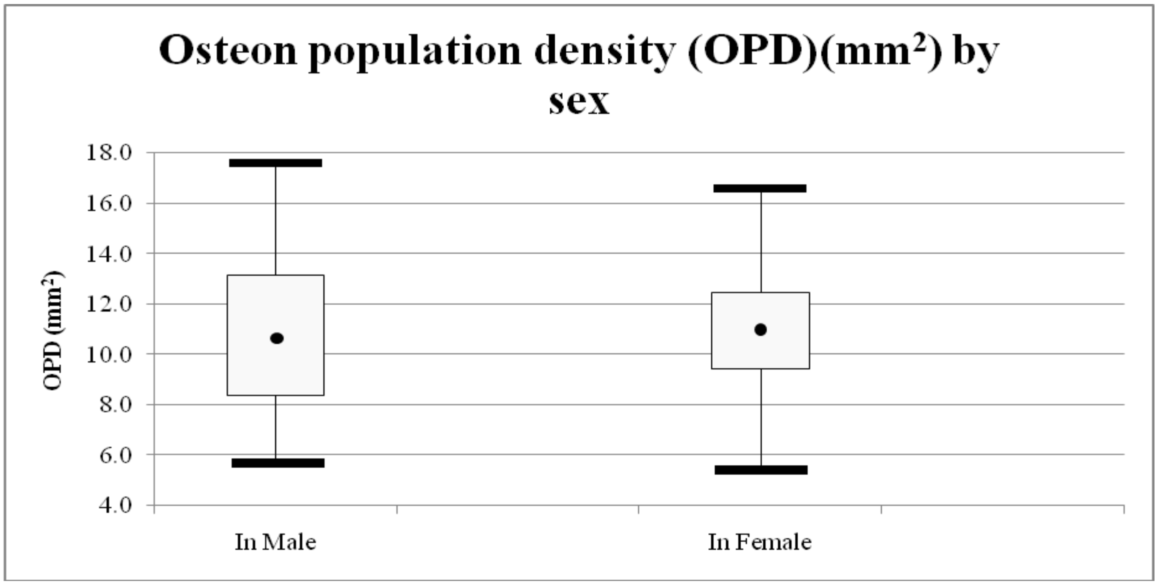

Figure 6. Box and whisker chart for osteon population density by sex in the Sadlermiut

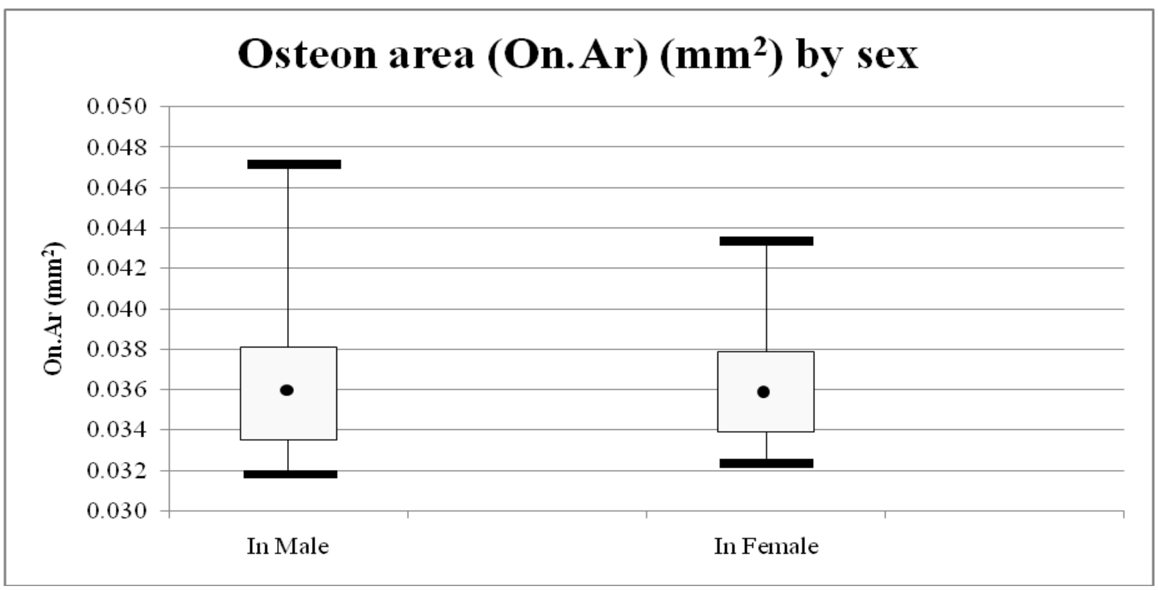

Figure 7. Box and whisker chart of mean osteon area by sex in the Sadlermiut

Table 5.2 presents the mean histological values for OPD and On.Ar, comparing the left and right 2nd metacarpals in the sample (right n= 39, left n= 39). Mean OPD values ranged from 5.5 /mm^2 to 16.8 /mm^2 in the right hand (Figure 8), with a mean of 10.8 /mm^2 and a standard deviation of 2.8. Values in the left hand ranged from 5.3 /mm^2 to 17.7 /mm^2 (Figure 8). The mean OPD in the left side of all Sadlermiut combined was 10.9 /mm^2 with a standard deviation of 3.2. On.Ar values in the right hand ranged from .032 mm^2 to .046 mm^2 and ranged from .032 mm^2 to .047 mm^2 for the left hand (Figure 9). Mean On.Ar in the right and in the left hand was determined to be .036 mm^2, with standard deviations of .0004.

Table 5.2 Comparison of mean osteon density (OPD) and osteon size (On.Ar) in the left and right 2nd metacarpal by sex and side of the hand in the Sadlermiut

	Combined		**Males**		**Females**	
	Left	**Right**	**Left**	**Right**	**Left**	**Right**
OPD (mm^2) (Sd)	10.9 (3.2)	10.8 (2.8)	10.7 (3.3)	10.9 (3.0)	11.1 (3.2)	10.8 (2.7)
On.Ar (mm^2) (Sd)	0.036 (.004)	0.036 (.004)	0.036 (.004)	0.036 (.004)	0.036 (.003)	0.037 (.004)

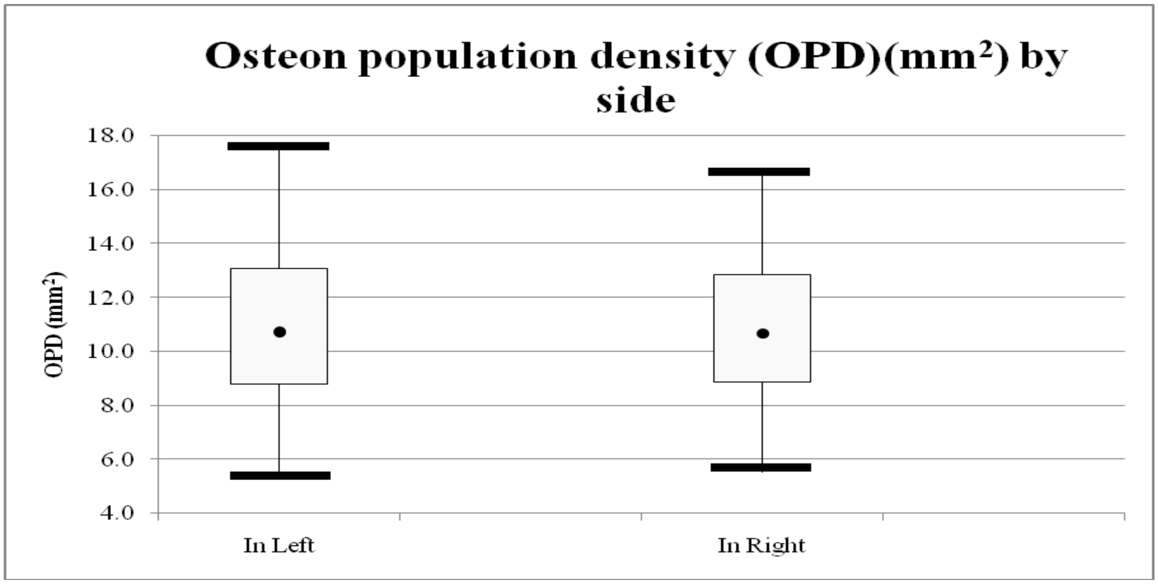

Figure 8. **Box and whisker chart for osteon population density by side in the Sadlermiut**

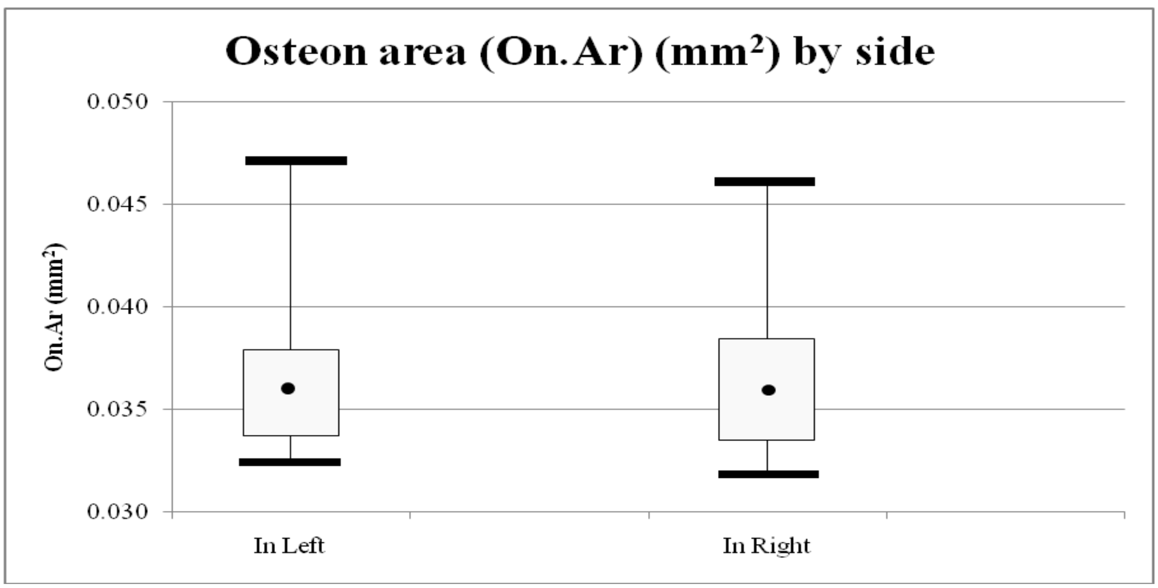

Figure 9. **Box and whisker chart for mean osteon area by side in the Sadlermiut**

Precise age ranges for the Sadlermiut were not known, so for the present analysis they were divided into three age categories: young (<35 years), middle (36-50 years), and old (51+ years). Mean values for On.Ar and OPD by age category are given in Table 5.3.

OPD values for the young category (n= 18) ranged from 5.3 /mm^2 to 12.8 /mm^2 (Figure 16), with a mean of 8.4 /mm^2 and a standard deviation of 2.2. In the middle age category (n= 43), OPD values ranged from 5.5 /mm^2 to 17.7 /mm^2 (Figure 10), with a mean of 11.7 /mm^2 and a standard deviation of 3. In the oldest category (n= 13), OPD ranged from 7.5 /mm^2 to 14.5 /mm^2, a standard deviation of 2.5 and a mean of 11.5 /mm^2.

Mean On.Ar in the youngest cohort ranged from .032 mm^2 to .047 mm^2, from .034 mm^2 to .044 mm^2 for the middle age group, and .032 mm^2 to .046 mm^2 for the eldest category (Figure 11). The mean On.Ar for the youngest and middle age groups were the same value (.037 mm^2). Mean osteon size in the eldest group was .036 mm^2 with a standard deviation of .004.

Table 5.3 Mean osteon area (On.Ar) and osteon density (OPD) in the 2nd metacarpal by age category

	Young	**Middle**	**Old**
OPD (mm^2) (Sd)	8.4 (2.2)	11.7 (3.0)	11.5 (2.5)
On.Ar (mm^2) (Sd)	0.037 (.004)	0.037 (.004)	0.036 (.004)

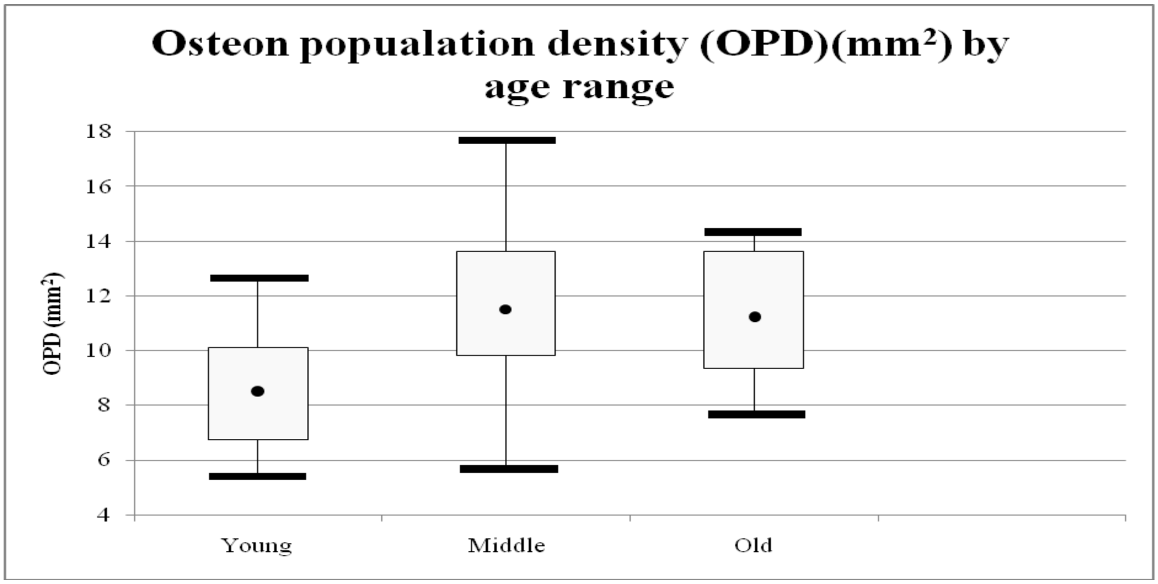

Figure 10. **Box and whisker chart comparing osteon density in the 2nd metacarpal of the three age categories in the Sadlermiut**

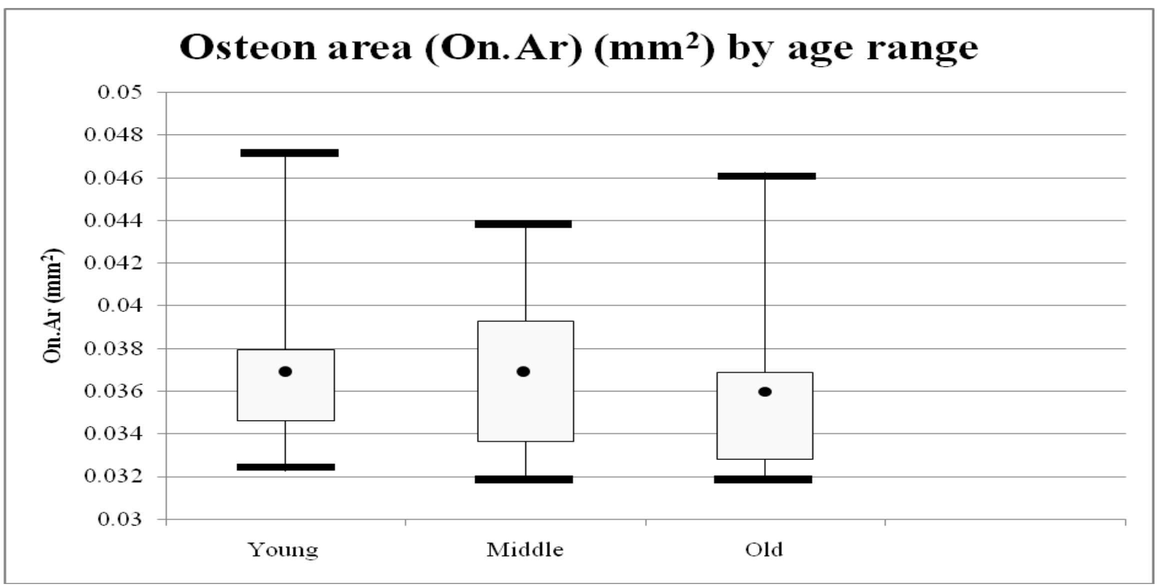

Figure 11. **Box and whisker chart comparing osteon size values in the second metacarpal of the three age categories in the Sadlermiut**

Significance Testing

The resulting p-values for all t-tests were compared with alpha set at .05 and are given in Table 5.4.

First Null Hypothesis

The first null hypothesis states that there are no statistically significant differences in OPD between the males and females in the 2nd metacarpal of the Sadlermiut. A t-test was used, and the resulting p-value was .37. The value, which is greater than the alpha of .05, means that a null hypothesis of no significant difference between the OPD of males and females would be accepted.

Table 5.4 Statistical analysis and resulting p-values for all variables compared in the Sadlermiut

Statistical Test	Variables Tested	p-value	Significance Level
t-test	OPD between the males and females (Ho 1)	0.39	0.05
	On.Ar between males and females (Ho 2)	0.49	0.05
	OPD between the left and right hand (Ho 3)	0.49	0.05
	On.Ar between the left and right hand (Ho 4)	0.48	0.05
	OPD between the young and middle age categories (Ho 5)	**<0.0001**	0.05
	OPD between the young and old age categories (Ho 5)	**<0.0008**	0.05
	OPD between the middle and old age categories (Ho 5)	0.88	0.05
	On.Ar between the young and middle age categories (Ho 6)	0.46	0.05
	On.Ar between the young and old age categories (Ho 6)	0.45	0.05
	On.Ar between the middle and old age categories (Ho 6)	0.4	0.05
Bolded values statistically significant			

Second Null Hypothesis

The second null hypothesis states that there are no significant differences in On.Ar between the 2nd metacarpals of males and of females. The data collected from these bones were analyzed using a t-test and based on the p-value result of .49, which was greater than alpha, the null hypothesis was accepted.

Third Null Hypothesis

Null hypothesis number three states that there are no statistically significant differences in OPD values between 2nd metacarpals of the right and left hands in the Sadlermiut. The t-test resulted in a p-value of .49, a value greater than alpha, and therefore the null hypothesis was accepted.

Fourth Null Hypothesis

The fourth null hypothesis states that there are no statistically significant differences in On.Ar between 2nd metacarpals of the left and right hands. The resulting p-value of the t-test was .48. Based on the p-value being greater than the alpha value, the null hypothesis of no difference was accepted.

Fifth Null Hypothesis

The fifth null hypothesis states that there are no statistically significant changes in OPD with age in the 2nd metacarpal of the Sadlermiut. A t-test was used to analyze the variance between the three age categories. The p-values between the young and middle age groups (.0001) and the young and old age groups (.0008) are significant when compared with an alpha set at .05. Conversely, the difference between the middle and old age groups was not significant, with a p value of .88. As expected, OPD does increase with age in the Sadlermiut 2nd metacarpal.

Sixth Null Hypothesis

The sixth null hypothesis states that there is no statistically significant change in On.Ar with age. The p values for the young-middle, young-old and middle-old (.46, .45, .40 respectively) were not significant statistically.

There was no significant difference in OPD or On.Ar of the 2nd metacarpals between the males and females in the Sadlermiut. Mean OPD values in the Sadlermiut were found not to be significantly different between the left and the right hands. There were no differences in mean On.Ar in the comparisons between the right and left hands. There were significant increases in OPD with age, between the youngest category and two oldest categories, which is consistent with previous studies (Kerley, 1965; Thompson, 1979; Ericksen, 1991; Kimura, 1992; Stout and Paine, 1992; Streeter, 2010). However, there was only a slight decrease in On.Ar, not significant and generally not reported in past research.

CHAPTER 6: DISCUSSION

The difference in osteon population density (OPD) between the males and females in the Sadlermiut sample was not statistically significant given values of 10.8 /mm^2 and 11.0 /mm^2, respectively (Table 5.1). The slightly higher OPD in females is consistent with that reported by other researchers (Mulhern, 2000; Raguin, 2010; Ericksen, 1980; Burr et al., 1990). The 2nd metacarpals in males might be expected to have a higher OPD because they have larger muscles and incur greater strain, but in fact, the Sadlermiut females have higher OPD. The higher OPD in females could be the result of their smaller bones, which would be more susceptible to microfractures in an elevated-strain environment, or the elevated OPD in females with respect to males could reflect the effect of a secession of estrogen production related to menopause. Smaller bones are less resistant to strain and, as a result, would incur more microfractures and therefore be expected to remodel at a higher rate than in large male bones (Drapeau and Streeter, 2006; Pfeiffer et al., 2006). As described in Chapter 3, bones can adapt either through modeling (adding bone where needed) or remodeling (bone renewal) in response to microfractures due to strain.

The results of the comparison of mean osteon size (On.Ar) between Sadlermiut males and females proved not to be significant. The mean value for both sexes was .036 mm^2. This finding differs from the results reported by Denny (2010) of her analysis of a 19th century Euro-Canadian sample of 2nd metacarpals showing that males had significantly larger osteons. The lack of difference in the size of osteons in histological values between the males and females in the Sadlermiut suggests that they incurred similar stress levels in their hands, which would not support the premise of a sexual division of labor.

Examination of On.Ar between the in the left and the right hands of the Sadlermiut showed a slight but not statistically significant difference. Similar results were found for osteon density, this is somewhat surprising because in human populations the majority of people are right handed. As a result, OPD values would be expected to be higher in the more stressed right hand. It is possible the values in the hands of the Sadlermiut lefts and rights demonstrate little difference because they incur similar stresses.

Age-associated changes in OPD in the 2nd metacarpal were significant. As expected, given the known positive correlation between OPD and age (Kerley, 1965), the youngest age group had fewer osteons (8.4 per mm^2) than the two older age groups (11.7 $/mm^2$ in the middle age group and 11.5 $/mm^2$ in the older group). The unexpected decreased OPD in the older age group compared to the middle age group could be accounted for by the disparity in the size of the two samples (middle n= 43, older n= 13) or by bone loss due to endosteal expansion associated with older age.

There was no difference in mean On.Ar values between the three Sadlermiut age categories. Comparisons between the mean On.Ar values for the younger and middle age groups were the same .037; while there was a slight decline in osteon size in the oldest age group (.036), it was not statistically significant. This contrasts with reports by many researchers of a decrease in On.Ar with age. Burr et al. (1990) found that in the Pecos

Indians, On.ar decreased with age in males but that in females mean On.Ar increased. However, these studies were on femurs. In the Sadlermiut 2nd metacarpals, no significant age-associated decline in On.Ar was detected.

The histological values obtained for the Sadlermiut 2nd metacarpals can best be interpreted by a comparison with data obtained from other studies of the same bone. Table 6.1 lists the mean values for OPD and On.Ar reported for an historic Euro-Canadian cemetery sample and a modern Japanese sample. The Euro-Canadian sample was derived from the St. Thomas, a cemetery sample from the 19th century. St. Thomas church is located in Belleville, Ontario, and the sample complete with records of age at death was composed primarily of Caucasian immigrants from Western Europe. The group was described as being involved in both farming and factory work (Lazenby, 1998a; 1998b). Osteon density and mean osteon area results for the St. Thomas 2nd metacarpals were reported by Raguin (2010) and Denny (2010), respectively. The 20th century Japanese sample was reported by Kimura (1992), who utilized microstructural age changes to create a population-specific histological aging technique applicable to the 2nd metacarpal of modern Japanese. In the Kimura (1992) study, total osteon density (TOD), a value that is roughly comparable to OPD, was used in the analysis.

Table 6.1 Comparison of values for osteon density (OPD), and mean osteon size (On.Ar) in the 2nd metacarpal between the Sadlermiut, St. Thomas and modern Japanese.

Group (n) Author Year	Time Period	Mean age	OPD	OPD ♂	OPD ♀	On.Ar	On.Ar ♂	On.Ar ♀
Sadlermiut in this study (78)	13th-20th centuries	Middle (36-50)	10.9	10.8	11.1	0.036	0.036	0.036
St. Thomas (63) Raguin 2010	19th century	41	11.8	11.2	12.6	**		
St. Thomas (180) Denny 2010	19th century	43	**			.035	0.036	0.033
Japanese (227) Kimura, 1992	20th century	69	13.8*	12.99*	14.58*	**		

* Calculation similar to OPD ** Values not available

As can be seen in Table 6.1 the values for OPD between the three populations are similar. The highest mean OPD are in the modern Japanese, followed by the St. Thomas sample, and the lowest OPD is in the Sadlermiut. A student t-test of variance on the OPD between the St. Thomas population and the Sadlermiut resulted in a p-value that was not significant when compared to an alpha of .05. Unfortunately, due to a lack of data on standard deviation in the Japanese sample, significance testing could not be calculated.

Mean osteon density values were greater in both the modern Japanese and in St. Thomas samples (Raguin, 2010; Kimura, 1992). The higher values in the Japanese could be attributed to genetics or bone morphology. As previously noted, mean osteon density increases with age (Kerley, 1965; Thompson, 1979; Stout and Paine, 1992), therefore the increased OPD in the modern Japanese could reflect an older mean age.

Though this study focuses on the interpretation of bone microstructure; a discussion of the relationship between bone remodeling and cross-sectional area studies is applicable here. Greater cross-sectional area makes bone more resistant to biomechanical stress (Roy et al., 1994, Trinkaus et al., 1994). Roy et al. (1994) examined cross-sectional area measures from radiographs of the 2nd metacarpal in modern individuals from Baltimore (Table 6.2). A comparison of the mean values for cross-sectional area, total area (Tt.Ar), medullary cavity area (Es.Ar), cortical area (Ct.Ar), and percent cortical area (% Ct.Ar) in the Baltimore study, the Sadlermiut, and the Euro-Canadian study reveals that the modern Baltimore sample had the largest Tt.Ar, Ct.Ar, and % Ct.Ar values, followed by the St. Thomas sample. The Sadlermiut had the smallest values for these three cross-sectional area measures. For measures of Es.Ar, the Sadlermiut had the largest values, followed by the St. Thomas sample, and the modern Baltimore sample had the smallest medullary area.

Table 6.2 Mean values of cross-sectional area in the 2nd metacarpal of three groups

Group (n)	Author/year	Mean age	Total area		Medullary area		Cortical area		% Cortical area	
Sadlermiut (78)		Middle (36-50)	48.6		17.9		30.8		64	
			R	L	R	L	R	L	R	L
			50.8	46.4	18.6	17.1	32.2	29.4	64	64
St. Thomas (63)		41 years	54.4		14.5		40.4		74	
			55.3	54.3	14.5	14.2	40.8	40.1	74	74
Baltimore (992)	Roy et al., 1994	59	R 64.5	R 61.6	R 13.3	R 10.5	R 51.1	R 51.1	R 79.6	R 83.8
			L 61.7	L 63.8	L 12.2	L 11.2	L 49.5	L 52.2	L 80.5	L 83.2

The bones of cold-adapted populations are described as being shorter and thicker in diameter (Laughlin, 1963; Leppaluoto and Hassi, 1991; Holliday, 1997; Lazenby, 1997; Stringer et al., 1998; Stock, 2004), as described in Bergman's Rule. It has also been demonstrated in the humerus and other limb bones that increased mechanical loading in early development causes increased bone shaft robusticity (Jones et al, 1977; Ruff et al., 1984; Ruff et al., 1993; Ruff et al., 1994; Stock, 2004). However, the Sadlermiut have smaller measures of Tt.Ar, Ct.Ar, and %Ct.Ar compared to the St. Thomas sample and larger Es.Ar, resulting in thinner cortices (Thompson and Gunness-Hey, 1981; Pfeiffer and Lazenby, 1994). As Es.Ar increases, Ct.Ar and % Ct.Ar decline. The Euro-Canadian sample has larger cortical area values in every area measure except Es.Ar, reflecting thicker cortices. The variance in cortical area measures between the Sadlermiut and St. Thomas samples is significant for all area measures. When the Sadlermiut and St. Thomas area values are compared with the area measures reported for the Baltimore sample, the modern Baltimore metacarpals are larger even than those in the St. Thomas group.

A factor that could contribute to decreased cross-sectional area is related to the role that vitamin D plays in bone metabolism (Thompson and Gunness-Hey, 1981; Pfeiffer and Lazenby, 1994). In humans, Vitamin D is synthesized in the skin during exposure to UV radiation. Populations that live in areas with diminished UV radiation, such as higher latitudes, are at greater risk for Vitamin D deficiency and the conditions associated with it, rickets in children and osteomelacia in adults (Merbs, 1996; Veith, 2003; Chaplin and Jablonski, 2009). Populations living in the arctic are subject to low UV radiation for many months during the winter and even in the summer, with its longer hours of sunlight the higher latitudes, still do not receive the high levels of UV radiation experienced closer to the equator (Sharma et al., 2011). The lack of vitamin D due to low UV radiation for long periods combined with limited exposure of skin surfaces potentially lead to the Vitamin D deficiency sufficient to cause decreased cortical thickness. However, the consumption of sea fish, which are a rich source of dietary Vitamin D, by arctic populations is thought to account for the lack of skeletal evidence of rickets. While the extent of Vitamin D deficiency in arctic populations may not be severe enough to cause rickets, a milder form could hamper calcium synthesis leading to thinner cortices (Thompson and Gunness-Hey, 1981).

In addition, comparison of mean OPD values between the Sadlermiut, the St. Thomas population, and the modern Japanese demonstrated that remodeling density was lowest in the Inuit sample. The thinner cortices combined with the lower OPD demonstrate that in the 2nd metacarpals, the Sadlermiut are adapted to their biomechanical environment. If the group were not well adapted, then OPD would be expected to have increased to compensate for more microfracture propagation (Burr et al., 1990). The exact mechanism that causes the thinner cortices in the Sadlermiut and other arctic groups is unknown but the clinal distribution mirrors the reduction of UV radiation in the northern latitude.

CHAPTER 7: CONCLUSIONS

Six sets of hypotheses were tested to evaluate the impact of sex, handedness and age on histomorphometric values within the Sadlermiut 2nd metacarpal. There were no statistically significant differences in osteon density (OPD) between males and females (H 1). Mean osteon area (On.Ar) between the males and females and between right and left hands was not statistically significant within the Sadlermiut (H 2, H 4). Similarly, OPD values between left and right hands were also not statistically significant (H 3). As expected, given the known correlation between age and OPD, there were significant changes in OPD values with age between the young age category and both older age categories (H 5). Individuals in the youngest age group averaged fewer osteons than individuals in the two older age groups. Though there was a slight decline with age in mean On.Ar, it was not statistically significant (H 6). This is in agreement with the findings of Denny (2010), who also examined metacarpals and found no change in osteon size with increasing age in the St. Thomas sample.

The mean OPD values between the Sadlermiut, St. Thomas inhabitants, and modern Japanese were similar. The Japanese group had a slightly higher OPD in the 2nd metacarpal than did the Sadlermiut and St. Thomas sample. A comparison of OPD between the Sadlermiut and the St. Thomas metacarpals revealed there were no significant differences between the two groups, but the St. Thomas metacarpals had a higher mean OPD than the Sadlermiut. The lower OPD in the Sadlermiut, who were cold-adapted and led a rigorous lifestyle compared to the St. Thomas and the modern Japanese group, was unexpected. This could indicate that the St. Thomas and modern Japanese group incurred higher levels of strain in their hands than did the Sadlermiut.

The metacarpals of the Sadlermiut had the smallest total cross-sectional area (Tt.Ar) when compared with the Baltimore and St. Thomas samples. The small cross-sectional area in the Sadlermiut combined with the largest medullary area (Es.Ar) results in a thin cortex. Previous studies have shown that cold-adapted groups have large bones (Laughlin, 1963; Leppaluoto and Hassi, 1991; Holliday, 1997; Stringer et al., 1998; Stock, 2004); however, these studies focused on Pleistocene hominids. Studies specifically on arctic populations (Thompson and Gunness-Hey, 1981; Thompson et al., 1981; Pfeiffer and Lazenby, 1994) also report larger marrow cavities creating thinner bones, as was found in the Sadlermiut. Consistent with previous studies, the thinner cortices in the Sadlermiut when compared to the other two 2nd metacarpal studies (St. Thomas, Baltimore) are consistent with past findings that describe a clinal distribution. Indigenous populations that live closest to the Article Circle experience marked thinning in the cortex when compared to populations from more southern latitudes (Thompson and Gunness-Hey, 1981; Pfeiffer and Lazenby, 1994).

Future research should focus on further exploration of the significance and mechanism of the clinal distribution of thinner cortical bone in arctic populations. Elucidation of the impact of protein acidosis in cortical bone formation and remodeling would further our understanding of human adaptation to challenging environmental conditions. Additionally, analysis of other Sadlermiut bones like the ribs and femurs allows for comparisons with more groups.

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