

University of Nevada, Reno

**From Limb to Limb: An Analysis of Postcranial Measurements in
Prehistoric and Protohistoric Inuit Populations from
Golovnin Bay and Nunivak Island, Alaska**

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

by

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Dr. G. Richard Scott/Thesis Advisor

May, 2011

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We recommend that the thesis
prepared under our supervision by

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entitled

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Abstract

Postcranial analyses provide a great deal of information about earlier populations regarding their origins and responses to various environmental stressors. Prehistoric and protohistoric postcranial remains from Golovnin Bay and Nunivak Island were analyzed for three types of variables: stature, relative limb proportions and robusticity. An analysis of these traits allows inferences on climatic and nutritional pressures that impact the human body. Stature estimation yielded results that were consistent with contemporaneous Arctic and northeast Asian populations yet were significantly different from the stature of other world populations. Relative limb proportions and robusticity indices also suggest the two sample populations were cold adapted like other Arctic and northeast Asian populations and differed significantly in these variables from temperate and tropical world populations. The results of the comparisons to other Arctic and world populations highlights the level of cold adaptation that the populations from Golovnin Bay and Nunivak Island possess. Their short, yet robust limbs were beneficial in an extreme, cold environment.

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CHAPTER ONE: INTRODUCTION

I was cold; I was freezing; not only in the flesh but my soul was frozen. As I sat on the swaying and creaking sled the cold became an obsession, almost a hallucination, and soon I was in a delirium of cold. I was haunted by a single image: before me was a wall, immense and black, like a wall in a film. I was walking along that wall and looking for a door into it which I could not find. It was The Wall of Cold. If I could collect my thoughts, and remember the Open, Sesame! I should be saved, for beyond that wall was warmth. My brain had shrunk to the dimensions of a dried raisin. Stubbornly, painfully, almost maliciously, it clung to a single thought, made room for no other image: "I am cold!" I was not cold as people Outside are cold. I was not shivering. I was in the cold, dipped into a trough where the temperature was thirty degrees below zero and where I turned and rolled over and over in search of a non-existent issue.

-Gontran de Poncins, Kabloona 1941

Primates are by nature tropical animals. They originated in tropical environments 60 or so million years ago and are largely limited to such environments to this day. No primate has developed the physiology, morphology, or behavior that characterizes cold adapted animals, like the caribou or moose. This is no less true of humans than any other primate. The distinction between humans and their primate cousins is the adoption of cultural behaviors, notably fire, clothing, and shelter, which allow them to survive and even thrive in bitter, cold winters.

Cold was one of the last natural barriers to the human habitation of one of the earth's major geographic zones, the Arctic. No one would question that cultural adaptation has made possible human dispersal and occupation of high latitude environments with accompanying frigid winters. Somewhat less certain are the physical adaptations of Arctic populations. Has natural selection favored individuals with physiological advantages such as elevated metabolic rates or superior shivering thresholds? Has selection molded human bodies in such a way that allows for the more effective production and conservation of heat as suggested by the ecogeographical rules

of Bergmann and Allen? It is this last question that can be addressed to some extent by human skeletal remains, in particular through the analysis of the length and proportions of the limb bones of the upper and lower extremities.

This thesis analyzes the postcranial remains of skeletal samples from Golovnin Bay and Nunivak Island, Alaska, two populations that adapted to and/or endured extremely cold winters. The postcranial dimensions of these samples are compared to other Inuit and world populations to determine whether or not generalizations on cold adaptation and body form can be supported. Metric data on long bones provide different sorts of evidence to test this proposition, including estimates of living stature, relative limb proportions, and robusticity.

Before addressing the broader issue of body build and cold adaptation, this thesis addresses how the linear and circumferential postcranial measurements of Golovnin Bay and Nunivak Island differ between males and females and between the two sites. Dimensions of each sex are then compared to other Arctic samples, American Indians, and Asian, European, and African populations. My null hypotheses are: (1) there is no significant difference in stature, robusticity or relative limb proportion between males and females from the two sites; (2) there is no significant difference between the Golovnin and Nunivak samples, or between other Inuit populations; and (3) there is no significant difference in size or proportion between Inuit samples of the far north and lower latitude populations. The last hypothesis is the one that most directly tests the proposition of postcranial dimensions/proportions and cold adaptation as reflective of the ecogeographic rules of Bergmann and Allen.

The Arctic has been extensively studied by scholars interested in human migration and population history. Present-day Alaska was part of the Bering Land Bridge during the Pleistocene epoch. Beringia allowed people to cross from Asia to North America and spread south, establishing new populations in the western hemisphere. Although complete skeletons were generally excavated and catalogued, much of the research on Arctic remains focused on one part of the body – the cranium, and one methodology – craniometrics. While physical anthropologists have conducted extensive and informative research on the craniometric variation of Arctic populations (Hrdlička, 1924, 1942; Zegura, 1975; Utermohle, 1984; Utermohle and Merbs, 1979; Heathcote, 1986; Brennan and Howells, 1976), studies of the rest of the skeleton have lagged behind. Anthropologists have realized that postcranial studies can yield a wealth of information about earlier populations particularly in the Arctic, including some key data that are not provided by cranial studies. Stature, musculo-skeletal stress markers, limb bone proportionality and measures of robusticity can all be determined through postcranial remains. These types of measures supplement and complement cranial studies and serve to provide a fuller and more textured profile of earlier human populations.

Postcranial skeleton

The adult human body contains 206 bones that protect and support soft tissues and serve as anchors for ligaments, tendons, and muscles. Bones also operate as levers for muscles to create movement. They function as physiological points for the production of blood cells and storage areas for minerals elements like calcium and phosphorus. The skeletal structure is in constant flux during an individual's lifetime. Daily activities and

physical labor can alter the way bone is shaped. It is one of the strongest biological materials in terms of bearing weight, yet it is a relatively lightweight material. The entire skeleton only accounts for about 20 percent of the weight of the human body. The reason for this is due to its composition; bone is composed of protein (collagen) and mineral (hydroxyapatite), which allows for flexibility, yet provides a rigid structure for the muscular system (White and Folkens 2005). This structure allows bones to become strong enough to withstand pressures put upon them, such as habitual activities or body mass (Pearson 2000a). Because of its unique composition, bone takes much longer than other tissues to decompose and is usually the only remaining material left behind after burial. Since bone is a living tissue, it also can repair and shape itself under external pressures, such as daily activities or physical labor, which leads to certain levels of variation.

Most of the bones in the human body have a basic structure composed of an outer cortical or compact zone, an inner trabecular or spongy zone, and connective tissues on the outer (periosteum) and inner (endosteum) surfaces. Cortical bone is the outer part of the bone that is like a rigid shell. It resists deformation while the inner trabecular network or spongy bone provides strength because of its complex system of inner supports. The spaces in between the spongy bone are filled with bone marrow, and in bones that have substantial weight bearing function, such as lower limb bones, the trabecular pattern is arranged in a way to provide maximum resistance to physical stress (White and Folkens 2005). Bones are covered by two membranes: the periosteum and the endosteum. The periosteum is a membrane that surrounds the bone and serves as an attachment for tendons and muscles and contains nerves and blood vessels that feed the bone. The

endosteum is a thin layer of vascular connective tissue lining the marrow cavity (Fiske 1911:18).

There are four specific factors that lead to variation in the human skeletal system. The first is ontogeny, or growth. The second is sexual dimorphism, where males and females are dimorphic in size. In all populations, females have smaller bones and teeth than males on average. Third, there is geographic variation in postcranial morphology, size and proportions. Fourth, there is variation among individuals within a population (White and Folkens 2005). Causes of variation are either proximate or ultimate. Proximate causes include immediate changes that occur during an individual's life span, while ultimate causes of variation are those that produce genetic change across many generations in the way the skeleton grows and remodels. Ultimate causes that produce skeletal changes are attributed to selective pressures, genetic drift, and gene flow (Pearson 2000a).

There are several forms of metric analyses that are used to make inferences regarding variation within a specific data set using long bones. These are stature reconstruction, relative limb proportions, and robusticity. Stature estimation is a mathematical method of reconstructing the living stature of an individual. Prediction of stature has been extremely important in the fields of forensic anthropology and bioarchaeology, where stature can be used to assess not only individual height but also population affinities and potential climatic adaptations. The ability to estimate the stature of an individual while they were living is predicated on the strong linear correlations between specific long bone lengths and living statures. Through a combination of correlation and regression analysis, researchers have developed predictive formulae

where X is the individual long bone measurement and Y is the estimate of living stature. There are a number of regression formulas that have been derived to estimate stature in different populations (Auerbach and Ruff, 2010; Boldsen, 1984; de Mendonca, 2000; del Angel and Cisneros, 2004; Dupertuis and Hadden, 1951; Formicola, 2003, 1993; Genoves, 1967; Gustafsson and Lindenfors, 2009; Hanson, 1992; Pearson, 1899; Pearson, 2000a, 2000 b; Trotter and Gleser, 1952). Because long bone proportionality varies from population to population, there is no single pan-human formula that can be used on all populations. For that reason, one has to find stature equations derived from populations with similar limb proportions to the one under study. Although most methods use only long bone measurements, others take the dimensions of the vertebral column and cranial height into consideration (Dwight, 1894; Trotter and Gleser, 1952).

Relative limb proportions, or body proportions, have also been extensively studied and are important because they demonstrate that environmental pressures can impact the overall form of the human body (Genoves, 1967; Hall et al., 2004; Holliday and Ruff, 2001; Jantz and Jantz, 1999; Katzmarzyk and Leonard, 1998; Temple et al., 2008). For example, populations from extremely cold climates and high latitudes tend to have shorter limbs than populations from warm climates in lower latitudes. Studies on modern populations seek to correlate body or limb proportions and robusticity to temperature and latitude (Holliday, 1997; Jantz and Jantz, 1999; Katzmarzyk and Leonard, 1998; Pearson, 2000a, 2000b; Porter, 1999; Ruff, 1994; Ruff et al., 1993; Shackelford, 2007; Temple et al., 2008; Weinstein, 2005).

Robusticity is determined in several ways, including circumferential measurements and cross-sectional imaging. It has been used for modern human

populations as well as prehistoric populations to show differences in terms of size and density of the human body. It can also lead to inferences on how particular subsistence strategies affect long bones, such as when populations switch from hunting-gathering to agriculture (Larsen, 1981). Because of the various inferences researchers can make on robusticity, it is another important part of postcranial metric analyses.

CHAPTER TWO: HISTORY OF POSTCRANIAL ANALYSIS

Almost all metric analyses in physical anthropology were developed over the past 150 years. No analyses are static; they are still evolving with the introduction of new concepts and technologies. To provide some historic background on postcranial metric studies, I provide an overview of analyses that have focused on stature, relative limb proportions and long bone robusticity.

Stature

For over 100 years, stature estimation has been an important factor in characterizing individuals and populations in forensic anthropology and bioarchaeology. Unfortunately, because of between group variation in limb proportions, no single formula works for every population in the world. In fact, it has become increasingly apparent that the regression formulae used to estimate stature must be developed for a wider variety of groups because of the subtle but significant differences in long bone proportions.

There are two methods of adult stature reconstruction: anatomical and mathematical. Anatomical reconstruction includes the rearticulation of the skeleton that allows a researcher to obtain measurements for the individual components of the skeleton that contribute to height. Byers (2008) points out three distinct problems with the anatomical method of stature reconstruction: (1) all bones are required; (2) there are issues in laying out a disarticulated skeleton, in that soft tissue and curvature of the vertebral column must be taken into account; and (3) estimating the space between bones is very difficult (such as cartilage between joints and intervertebral disks in the spine). Additionally, Byers (2008) says there is an issue with secular changes in stature that have

occurred over the last century. These changes have rendered tables and formulas developed from earlier collections unusable.

The mathematical method involves regression formulae that are applied to linear measurements of the skeleton (lower limb bones, vertebral column, etc). There are many elements that go into stature: the skull, the vertebral column, and the bones of the lower limb and feet are the most noteworthy. However, there is no strong correlation between the height of the skull and stature so cranial measurements are not useful for estimating height. By contrast, the lengths of the long bones show a strong correlation with stature, in particular the bones of the lower limbs (femur, tibia, fibula). Because of these strong positive correlations, it is possible to use regression methods to develop predictive formulae whereby one can take a particular long bone measurement and estimate the stature of the individual during life. Although there is some error of estimate using regression methods, they are relatively small. The regression method for estimating stature has proven to be the most accurate and practical because individual long bones are abundant but complete skeletons are rare in the archaeological record (Raxter et al., 2006; Dwight, 1894).

Methods of stature reconstruction were reviewed by several authors in the late 19th century (Dwight, 1894; Rollet, 1888). Although Dwight (1894) recognized the two distinct methods of stature reconstruction, the anatomical method was preferred over the mathematical method at the time (Byers, 2008). Dwight's method included rearticulating the remains by pressing them into clay, and taking into account the amount of cartilage and soft tissue that would be present in a living person. He also discussed the mathematical method of calculating stature but concluded the method "...rests on the

proportion of certain bones to the height and it is obvious that even if these proportions were collected from thousands of specimens...these would give us no certainty” (Dwight, 1894:294). He rightly concluded that no single formula for stature reconstruction would work for various populations because of differences in body proportions. Like others studying stature reconstruction from skeletal remains, Dwight obtained measurements from cadavers to compare the results from the anatomical and mathematical methods.

Rollet (1888) measured fifty male and fifty female bodies before dissection and then measured the upper and lower limb bones. He used the mathematical method to derive stature formulae. From this, he determined that dry bones were on average about 2 mm shorter than bones in a fresh state and adjustments for this were made in his formulae. Manouvrier (1893) reevaluated Rollet’s work and eliminated any subject over the age of 60 because of old age and determined that two centimeters be subtracted when solving for living stature (Pearson, 1899). It was also from Rollet’s work that Karl Pearson (1899) recognized and developed population specific regression formulae that would produce estimates of stature.

In cases where a complete skeleton is present, the most commonly used stature reconstruction formula was developed by Georges Fully (1956), with later revisions by Raxter et al. (2008). This particular formula was developed in 1956 using white males from France. It estimated stature from the summed heights and lengths of skeletal elements with correction factors for soft tissue. Measurements were taken from the basion-bregma height of the cranium, the maximum height of the corpus of the C2-L5 vertebra, the anterior height of the first sacral segment, the oblique length of the femur, the maximum length of the tibia without the spine and including the malleolus, and the

articulated height of the talus and calcaneus (Raxter et al., 2006.). Fully concluded that his method of stature reconstruction came within 1 cm of the actual height. Raxter et al. (2006) found it was actually 2.4 cm under the living stature. Additionally, Fully only calculated the stature of males.

Fully and H. Pineau (1960) found the cranium, and cervical and thoracic vertebrae were not needed to accurately calculate stature. The combined lengths of the femur and tibia make up about half of the lengths of all the skeletal parts used to estimate stature. The only other parts that are the longest and most variable are the vertebral column. Based on these factors, Fully and Pineau (1960) developed a regression formula that used only the lower limb bones and the height of the spine.

Trotter and Gleser (1958) collected data from World War II and Korean War casualties whose identities and stature were known. Individuals from this collection were of white, African-American, Asian and Hispanic ancestry. They measured the maximum lengths of the right and left sides of the major limb bones, including the humerus, radius, ulna, femur, tibia and fibula, and used these measurements to refine stature regression formulae. The results indicate that different populations have different body proportions, which, when taken into account, result in more precise formulae for stature reconstruction. Trotter's measurements of the tibia, however, have caused some confusion among contemporary authors. Trotter (1970) said that measurements from the tibia were taken from the midpoint of the lateral condyle, including the malleolus, while Jantz et al. (1994) suggests that the malleolus was not included in Trotter's measurements. This seemingly small difference could have a significant impact on the final estimate of stature.

Although formulae using only the limb bones to reconstruct stature are not as exact as formulae using all skeletal remains (including the cranium), they are still accurate within a certain margin of error. Data from Trotter and Gleser (1958) demonstrate two key points in stature reconstruction. First, the correlation between right and left bones is strong so it does not matter which side is used when calculating stature. Second, lower limb bones correlate more strongly with stature than those of the upper limb. Using the tibia, femur and fibula in stature reconstruction yields more accurate results than using the ulna, radius and humerus.

Contemporary authors have developed a variety of stature reconstruction formulae, some of which are based on the Fully or Trotter and Gleser methods while others were developed independently (Auerbach and Ruff, 2010; Bennett, 1973; Boldsen, 1984; Broste, 1956; de Mendonca, 2000; del Angel and Cisneros, 2004; Dupertius and Hadden, 1951; Formicola, 1993, 2003; Hanson, 1992; Hernandez et al., 1998; Jorgensen, 1953; Konigsberg et al., 1998; Lee and Pearson, 1897; Lundy, 1983, 1988; Neumann and Waldman, 1967; Pearson, 1899; Radoinova et al., 2002; Raxter et al., 2006, 2008; Sciulli and Giesen, 1993; Sciulli et al., 1990; Stevenson, 1929). The formulae most applicable to Eskimo samples are those of Auerbach and Ruff (2010) who developed sex-specific stature estimation formulae by examining geographic patterning in body proportions. Formulae were derived for those samples that had the most similar proportions. From there, they developed equations by regressing lower limb bone lengths using Fully's (1956) technique of estimating living statures. The results were stature estimation equations specific for each group. The results of the stature equations when

applied to the samples from Golovnin Bay and Nunivak Island were less variable than the results derived from other formulae.

Relative Limb Proportions

Relative limb proportions and general body proportions have been extensively studied through postcranial metric analysis. The early work of Bergmann and Allen set the stage for evolutionary biologists to show that environmental pressures can exert an influence on body shape and size. Most studies on modern populations seek to correlate body or limb proportions to temperature and latitude as do studies on hominids.

Bergmann and Allen rules

One of the first pieces of evolutionary literature in the nineteenth century was Allen's (1877) "*The influence of physical conditions in the genesis of species*" wherein the author recognized the impact the environment can play upon shaping the body. Allen (1877:112) says that "geographic variation...may be summarized under the following heads, namely variation in general size, in the size of peripheral parts and in color, with the latter being subdivisible into variation into color with latitude and with longitude." Interestingly, in "*On the Origin of Species*," Darwin (1859) ignored the direct influence of climatic or geographical conditions upon body proportions. Instead, he believed that climate played more of an influence in the survival of a species, rather than its modification. Although Allen refers largely to animal species in his paper, it is stated that the same principle applies to the humans as well. Regarding humans, Allen (1877:137)

said that “the same original stock is found to gradually develop certain peculiar physical...characteristics when placed under diverse conditions of climate.”

Earlier, Bergmann (1847) addressed the issue of body build and climatic adaptations. Bergmann’s rule states that within a species spanning a wide geographic range, larger-bodied variants will be found in the colder parts of the range and the smaller-bodied variants will reside in warmer regions. Similarly, Allen’s rule says that under the same conditions, variants with short extremities (such as limbs) will be found in colder climates while those with longer extremities will be found in warmer climates (Holliday, 1997; Ruff, 1994). The observations of Allen and Bergmann are now referred to as "ecogeographical rules.”

Ruff (1994) says the application of ecogeographical rules to modern and fossil human variation was rare during the first half of the twentieth century. Rather than body size, one of the first applications was on nasal shape in varying climates. A study by Thomson and Buxton (1923) concluded that narrow noses were associated with colder, dryer climates, as this allowed the incoming air to be better warmed and moistened before reaching the lungs. Later studies strengthened this argument but noted that narrow noses were tied more closely to humidity rather than temperature as the key climatic factor (Davies, 1932, Weiner, 1954, Wolpoff, 1968).

Only during the latter half of the twentieth century were Bergmann and Allen’s rules applied to human variation in body size and proportions. Ruff (1994) says this may have been because of the growing interest in zoological studies and the direct physiological testing of humans to climatic variables due to WWII. This increase of knowledge on the whole human body rather than just the cranium led to a realization

among physical anthropologists that there is a substantial range of human body size variation, some of which may be attributable to climatic factors.

Early studies that supported the application of Bergmann and Allen's rules to modern humans were more concerned about climatic adaptation relative to race categorization (Ruff, 1994). Washburn (1963) questioned the impact of cold adaptation on human populations and of the utility of this approach in racial classification. He says that groups living in cold climates have not lived under these conditions long enough to have had a major impact on body size and form. Such criticism proved there was a need to consider other factors that could interact with climatic adaptation to affect body size variation, including nutrition.

Limb Proportion and Climate

In his work on the "aborigines of the New World" (Native Americans), Newman (1954:315) found there was a concentration of short statured populations in lower latitudes. He also noted that Western and Eastern Eskimos had similar sitting heights compared to taller native groups, indicating their shortness resulted from shorter limbs and not shorter trunk length. He suggested that the short limbs were probably associated with body-heat retention. He also noted that Eastern Eskimos were slightly shorter in terms of trunk length and limb length than Western Eskimos. He hypothesized that the difference could be attributable to the heavier, cold resistant clothing of the Eastern Eskimos or possibly malnutrition, although he does not present hard evidence for either (Newman 1954:315). He also found that the stature of South American natives is

relatively short but, unlike Eskimo populations, their shortness is a function of reduced trunk length rather than reduced limb length (Newman, 1954:316).

Testing the ecogeographical rules in the Old World, Kurki et al. (2010) examined the body proportions of Later Stone Age foragers in southern Africa and found that their proportions were what would be expected of a warm-adapted population. They compared their results with small-bodied foragers from the Andaman Islands, which they found matched some but not all of the expected ecogeographic patterns. They attribute this to genetic drift or selection and energetic efficiency (the efficiency of energy utilization).

Studies on climatic adaptation are now more concerned with physiological adaptation rather than racial classification. Ruff (1994) proposes that climatic adaptation and the rules put forth by Bergmann and Allen are closely tied to the relationship between surface area (SA) and body mass (BM). Ruff's hypothesis is that SA and BM are maximized in warmer climates and minimized in colder climates. He contends that if a cylindrical model for the human body form is adopted, where the height of the cylinder is stature and the width is the maximum mediolateral breadth of the pelvis, in cases where the limbs are elongated, there will be an increase in the total body SA/BM ratio. For example, populations living in tropical environments appear to have longer and narrower limbs than higher latitude populations. These proportions allow for better heat dissipation, whereas those living in higher latitudes would have shorter, wider limbs, allowing for the conservation of body heat. This limb proportion can be measured in a number of ways, which Ruff (1994:86) lists as "the ratio between combined upper and lower limb lengths and body weight, arm span to stature or trunk length relative to stature or upper or lower limb length relative to trunk length." Derek Roberts (1953) found that

variability in human body weight was distributed according to the rules of Bergmann and Allen, in which he proposed that body weight and trunk size were inversely related to mean annual temperature. He also found that populations living in cold climates had a higher metabolic rate than other warm climate populations. Contrary to this, Roberts (1953) also found that Oceanic populations may be an exception to Bergmann's rule, as they do not appear to follow the body proportions that would be expected for a warm, tropical climate.

Bindon and Baker (1997) suggest that the exception that Roberts (1953) notes for Pacific populations is due to Neel's (1962) thrifty genotype model, which may account for some of the deviation from predicted weights among this population. Neel (1962) developed the thrifty genotype model to explain why non-insulin dependent diabetes mellitus occurs at high frequencies in some populations. Bindon and Baker (1997:205) believe that the selection for energetic efficiency could have occurred when some Oceanic populations were voyaging to and settling their island homes as they would have been in a cycle of feast, famine and energy imbalance for an extended period of time. This cycle would have reinforced the selection for the thrifty genotype, which is "a genetic predisposition for the efficient utilization of dietary energy, effected by an exaggerated secretion of insulin by the beta cells in the pancreas in response to carbohydrate intake, also known as hyperinsulinemia" (Bindon and Baker, 1997:203). Now that these populations are under conditions of modernization, the thrifty genotype is often manifested in high rates of obesity, which explains why body proportions are atypical for a warm weather population.

Bergmann's rule has also been demonstrated in birds and mammals. Meiri and Dayan (2003) reviewed the occurrence of Bergmann's rule in ninety-four species of birds and in 149 species of mammals. They found that over 72% of the birds and 65% of the mammal species follow Bergmann's rule, and that there was an overall tendency to follow the rule within orders and families.

Body proportion analysis has been applied to fossil hominids for the same reason it is applied to recent humans -- it can provide insights into environmental and climatic adaptation. Such studies are usually limited and dependent on the quality of long bone preservation of earlier hominid skeletons. Previous studies have indicated that *H. erectus* had a tall linear body, suited for a dry, open environment, a characterization supported by paleoenvironmental reconstructions. Early australopithecines were smaller in body size, suggesting they more likely lived in closed, forested environments that were cooler than open areas (Ruff, 1994).

Body proportions are not only shaped by environmental factors, but are also closely tied to genetics. A substantial amount of evidence shows that body proportions between different populations appear early in ontogeny and childhood (Holliday, 1997; Tanner et al., 1982; Y'edynak, 1976). Body proportions also appear more resistant to the effects of nutritional deficiency and disease than overall body size. Studies on human migrants show that children usually have a decrease in stature but retain the body proportions of their ancestral ethnic group (Ito, 1942; Holliday, 1997; Trotter and Gleser, 1952). Taking these observations into account, researchers have conducted studies to make inferences on modern human origins. Using data from Neanderthal, Early Upper Paleolithic, Late Upper Paleolithic and Early Holocene Mesolithic samples, Holliday

(1997) conducted analyses on limb proportion, trunk height and breadth, and relative body mass. Results showed that Early Upper Paleolithic peoples clustered with recent Africans while Late Upper Paleolithic and Mesolithic samples clustered with recent Europeans. Holliday (1997) concludes the results argue against local continuity in Europe. Rather, they are consistent with migration and gene flow from Africa, thus supporting the out-of-Africa theory for the origins of anatomically modern humans.

Body proportion analysis has also been used in several other ways. Weinstein (2005) analyzed a sample of nearly 700 individuals from the central and south-central Andean coasts, the Atacama Desert and southern Peruvian highlands. Comparisons were made of the intralimb proportions as well as limb lengths to determine the impact of altitude on the body. It was found that the intralimb proportions among the coastal groups and those from the Atacama Desert did not statistically differ, yet the intralimb proportions were found to be significantly shorter in the Peruvian group. Weinstein (2005) also found that overall body size and relative limb lengths varied based on altitude; larger individuals were from coastal environments, while those with smaller limb lengths were from higher elevations. Poor nutrition, as well as climate, is used to explain the reduction in limb lengths.

Body proportions and relative limb proportions have also been analyzed to determine the secular change that has occurred in modern populations. Several studies, such as those of Jantz and Jantz (1999), Takamura et al. (1988) and Katzmarzyk and Leonard (1998), show how secular trends have affected body and limb proportion. For example, Takamura et al. (1988) found that between 1961 and 1986, the Japanese grew taller and their limbs longer, yet trunk height remained the same. Similarly, Katzmarzyk

and Leonard (1998:494) found that body mass index (BMI) increased over the last 50 years worldwide but surface area or body mass ratio decreased. They attribute this to “the impact of acculturation and lifestyle change and the associated improvements in health care and nutrition.”

Robusticity

Robusticity is defined as thickness of long bone shafts or epiphyses relative to bone length (Pearson, 2000a). Like body proportions or relative limb proportions, robusticity is determined in several ways through postcranial metric analysis, including circumferential measurements and cross-sectional imaging of long bones. Robusticity has been used by physical anthropologists in a number of ways, including determining whether certain species of hominids were gracile or robust or making inferences about modern human populations as populations differ in terms of size and density. It is similar to relative limb proportion in that it can lead to inferences on modern human origins and the impact of climate or environment on the human body. However, unlike body proportions, robusticity is caused by “habitual activities, along with other factors, that influence the amount of bone apposition and resorption that occurs at specific sites in the skeleton” (Pearson, 2000a:569). Having a greater robusticity is usually indicative of having greater strength. The structural buttressing of a skeletal element through the addition of bone tissue is usually assumed to be a response to higher mechanical loading (Ruff et al., 1993:22). Because of this, robusticity analysis is normally used to make inferences about a population’s subsistence strategies. If there are changes over time in

the robusticity of a population, these changes can serve as evidence for changes in activity patterns.

Robusticity in Hominid Fossils

Robusticity is commonly used when describing trends in the hominid fossil record. In a study by Ruff et al. (1993), cross-sectional diaphyseal and articular properties of the femur and humerus are compared between samples of recent and earlier *Homo*. They found there has been a decline in diaphyseal robusticity in *Homo* that started in the early Pleistocene and continued to modern humans yet there has been no similar temporal decline in articular robusticity. Interestingly, they find that with the decline of robusticity in the postcranial skeleton, brain size increased. They conclude that this decline would have to be due to a decrease of mechanical loading on the postcranial skeleton, which they attribute to a change in behavior, such as sedentism or the adoption of more advanced technology (Ruff et al., 1993).

Pearson (2000b) also discusses the differences in robusticity between Neanderthals and anatomically modern humans. It is clear that modern humans do not have the same robusticity as Neanderthals. Pearson (2000b:573) says it “suggests that they no longer needed the strength of the Neanderthals for survival and successful reproduction.” This change was also attributed to a change in activity among humans. However, Pearson (2000b) says that lifestyle was only one influence on the postcranial skeleton. His study demonstrated that climate also had an impact on robusticity, which Pearson (2000b:589) believes exerted more pressure than lifestyle. Modern humans had slender limbs, suggesting they came from a warm, tropical climate. Pearson (2000b:589)

says this is “evidence for population replacement in the Middle-to-Upper-Paleolithic transition in western Europe.”

Robusticity in Modern Humans

Studies on postcranial robusticity have been conducted on anatomically modern human populations (Carlson et al., 2007; Cowgill and Hager, 2007; Jacobs, 1993; Shackelford, 2007). These studies, like previous studies on hominid fossils, strive to explain robusticity in terms of climatic adaptation and mobility and use it to determine population affinity. Many of these studies also study robusticity in terms of sexual dimorphism. Sexual dimorphism can be determined in a number of ways and is defined in terms of the postcranial differences between males and females. Robusticity, stature and relative limb proportion can all lead to inferences on levels of sexual dimorphism within a population. Many of these studies compare one linear or circumferential metric analysis, such as stature, to determine sexual dimorphism and may include historical data to help evaluate secular trends (Bennett and Hulse, 1982). Other studies compare sexual dimorphism within differing populations to make inferences on modern human origins (Armelagos and van Gerven, 1980; Frayer and Wolpoff, 1985). However, it is important to remember that studies on sexual dimorphism do have their limitations, as accurate sex determination is required to make inferences.

In other studies of modern human populations, workers have attributed increases or decreases in robusticity in the postcranial skeleton to specific subsistence strategies or mobility patterns. Stock (2006) compared cross sectional geometric properties of the diaphyses of hunter-gatherers from Africa, the Andaman Islands, Tierra del Fuego and

the Great Lakes region. In this case, the impact of climate and habitual behavior was examined. It was found that proximal and distal limb segments negatively correlated with climate but positively correlated with terrestrial and marine mobility, indicating that climate had little impact on robusticity, whereas mobility patterns had a higher impact. Likewise, Suby and Guichón (2009) found there was a higher mechanical demand on the femoral diaphysis of males and females from a sample of Patagonian hunter-gatherers whose diet relied on marine resources, compared to those with a terrestrial or mixed diet. Similar studies on other populations have shown similar results (Stock and Pfeiffer, 2004; Wescott, 2006).

Sexual dimorphism can, in some cases, explain certain behavioral activities. For example, Carlson et al. (2007) examined the robusticity and sexual dimorphism in the postcranial bones of modern hunter-gatherer Australian aborigines and compared the results to other contemporaneous populations, such as the Khoi-San, Zulu, and African American groups. They found that the aborigines had more reduced robusticity in their femoral and humeral midshafts than other populations but had more sexual dimorphism in upper limb robusticity viz. lower limb robusticity. Using ethnographic accounts, they determined that the lack of lower limb robusticity is consistent with high mobility of males and females or “compensatory effect of burden-carrying among females” (Carlson et al., 2007:20). Their findings disagree with previous ideas that the postcranial bones of hunter-gatherer groups are characterized by high levels of robusticity, so they conclude that high robusticity should not be considered a trait of hunting-gathering subsistence economy. Other studies have compared subsistence strategies to levels of sexual dimorphism within a population with similar expected results (Collier, 1993).

The link between behavior and postcranial robusticity is not always clear. Stock (2007:195) says “the link between adult long bone diaphysis morphology and behavior is based on evidence for a relationship between mechanical loading and geometric properties of cortical bone distribution in the diaphyses under experimental conditions” yet other experimental research has shown that “mechanical induced hypertrophy” of the skeleton is not always local but can be systemic. Previous studies have attempted to tie climate or subsistence strategy to localized regions of robusticity on long bones, yet Stock (2007) posits that they may actually affect the entire postcranial skeleton. When interpreting skeletal robusticity, Stock (2007:196) says there are issues we must keep in mind: “the response of skeletal tissue in mechanical loading, the influence of climatic adaptation on robusticity and differences in selective pressure for tissue economy throughout the limbs.”

Pearson’s (2000b) illustrates the proximate and ultimate influences that impact long limb bone robusticity including climate, body weight, activity, stress and cultural practices in Fig. 1. This figure also includes climate, which does secondarily impact robusticity as it affects stature.

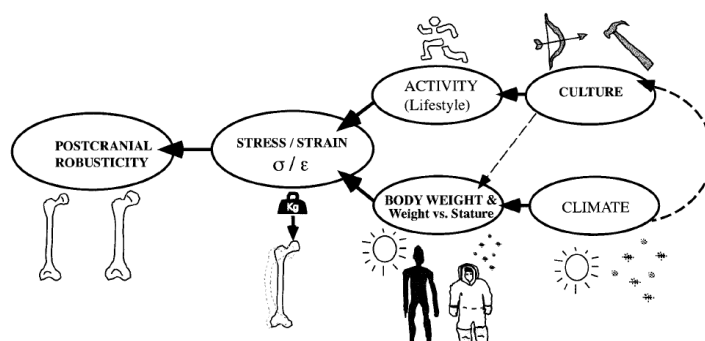


Fig. 1 Proximate and ultimate influences on postcranial robusticity (Pearson, 2000b:571)

CHAPTER THREE: MATERIALS

The skeletal samples analyzed in this study come from two communities in western Alaska. Before addressing the questions set forth in the first chapter, I first provide some perspective on a geographic and cultural description of these two communities.

Golovnin Bay

Golovnin Bay, located on the northern periphery of Norton Sound, is enclosed between two peninsulas, 70 miles east of Nome, Alaska (Fig. 2). The easternmost Golovnin Peninsula ends in Cape Darby while the westernmost peninsula culminates at Rocky Point (Mudar et al., 1996).

Marine climatic influences are strong during the summer when the sea is ice free. Summer temperatures range from 40° to 60°F, but winter temperatures



Fig. 2 Location of Golovnin Bay, Alaska. Screen capture from Google Earth

can drop down to -2° to 19°F. Occasionally, extreme cold can reach -40°F. Golovnin Bay has an annual precipitation of 19 inches with up to 40 inches of snowfall. The bay is usually frozen from early November to mid-May (U.S. Department of Commerce, 2011).

In the early nineteenth century, there were four languages spoken in the area: the Yupik dialect of Unaliq, the Inupiaq dialects of Quawiarq and Malimiut, and the Ingalik

branch of the Athapaskan language family. Each language group consisted of people with a common language and culture living within boundaries recognized by themselves and contiguous groups. This is particularly important because the distribution of the language groups, not only in Golovnin Bay but throughout Alaska and the Bering Straits region, can show the movement and intermixing of groups. Chinik/Golovin was originally settled by the Kauweramiut Eskimos, and later they mixed with Unaligmiut Eskimos. In the 1990s, both Yupik and Inupiaq speakers lived in Golovnin Bay (Mudar et al., 1996; Alaska Community Database, CIS 2011).

Most of Golovnin Bay's 146 inhabitants reside in the town of Golovin, which was originally an Inupiat village called Chinik (U.S. Department of Commerce, 2011). Both the town and bay were named after Captain Vasily Golovnin of the Russian Navy who visited Alaska in the early 19th century. Interestingly, the town name is misspelled while the bay retains the correct spelling. Inhabitants in the past subsisted primarily on marine



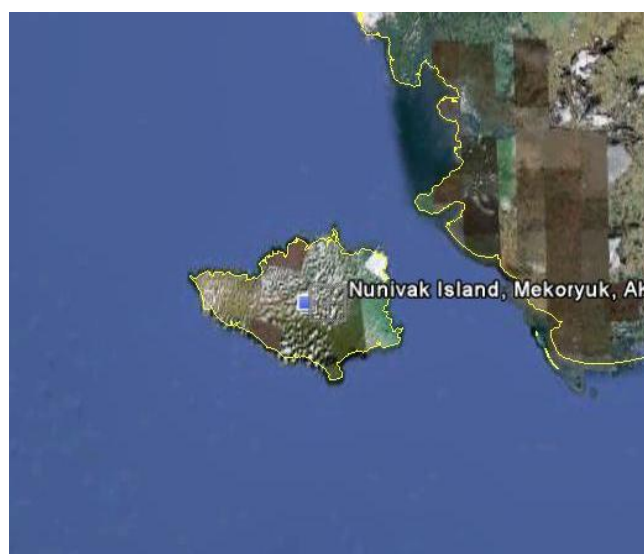
Fig. 3 Town of Golovnin. Photo from Iditarod.

resources and many of their permanent residences were along the coast, as it provided easy access to fish, seals and beluga whales (Alaska Community Database Community Information Summaries, 2011). In the early 20th century, reindeer herding was introduced, which provided

another means of subsistence for Golovin residents. These types of subsistence activities, particular seal and whale hunting and reindeer herding, are known to put stress on the human body.

Nunivak Island

Nunivak is the largest island between the Aleutians and the Seward Peninsula in the Bering Sea, about 30 miles off the western coast of Alaska, near the mouths of the Yukon and Kuskokwim Rivers (Fig. 4). Today, the island's inhabitants live in one community, Mekoryuk, which is located near Cape Etolin. In earlier times, there were many more villages



on the island. Similar to Golovnin Bay, the Bering Sea strongly influences the climate of the island. Foggy, stormy weather is frequent on the island, which receives

Fig. 4 Location of Nunivak Island, Alaska. Screen capture from Google Earth.

about 15 inches of precipitation annually. Summer temperatures range from 48° to 54°F. Snowfall averages about 57 inches annually, with winter temperatures around 0°F. Temperature extremes in the winter have been recorded as low as -48°F (Alaska Community Database Community Information Summaries, 2011).

Nunivak Islanders refer to themselves as Cup'it, a plural form of Cup-ig, considered the most divergent of all Central Yup'ik dialects (Pratt, 2009:99). Oral history

accounts and linguistic evidence suggest that current Nunivak inhabitants were descended from people from another region who arrived on the island several hundred years ago. This is partially supported by early ethnographic accounts that say the Yup'ik have had “more complex forms of social and ceremonial life than are found in any other region occupied by Eskimos” (Pratt, 2009:64). In addition, Pratt (2009:105) says that the general assumption among anthropologists is that human occupation of Nunivak Island began within the last 2,500 years during the Norton tradition. This also holds true for the inhabitants of Golovnin Bay where there is also archaeological evidence of the Norton tradition.

As of 2009, there were 174 residents in the city of Mekoryuk (2009 DCCED Certified Population) and there is a federally-recognized tribe located within the



Fig. 5 Field Camp on Nunivak Island. Image from the University of Alaska.

community, called the Native Village of Mekoryuk. Like Golovnin Bay, their economy is dependent on commercial fishing, as well as construction and other service industries. Coastal Villages Seafood Inc. has provided more opportunities

for employment within commercial fishing as they process halibut and

salmon in Mekoryuk (Alaska Community Database Community Information Summaries, 2011). The island was recently designated as a wildlife refuge which has complicated

traditional subsistence patterns because it limits the amount of wildlife they can hunt (Speaker, 1996). Despite this, many inhabitants continue to hunt, gather and fish in the same locations they have traditionally used.

In terms of ethnographic history, Nunivak Islanders share commonalities with other Eskimo and Inuit peoples in general and are very similar to other Yupik populations. They are unique in the fact that their isolation on the island allowed them to keep older Norton and Old Bering Sea Period traditions when other Eskimo groups outside of Nunivak were transitioning to the Neo-Eskimo Tradition. It also suggests that much of the cultural development of the Bering Sea region (including Nunivak Island and Golovnin Bay) was internally generated rather than externally stimulated, and that later traditions were not carried to the area by new people. The changes that did occur in the Bering Sea area primarily involved the integration of new technology, such as the dogsled, into the older patterns with little impact on the overall social and cultural structure (Speaker, 1996:8). Because these cultural changes suggest there was not much influence from outside or an influx of new people prior to European contact, it is likely that any intermixing among Eskimo groups in Nunivak and Golovnin was relatively low.

Skeletal samples

The Smithsonian Institution sponsored extensive anthropological field research in Alaska during the first half of the twentieth century. This research was directed toward the recovery and removal of human skeletal remains from sites across Alaska for the purpose of identifying and characterizing populations that had migrated from Siberia to Alaska. Some of the Smithsonian researchers involved in these efforts included Henry

Collins, Aleš Hrdlička, James Ford and T. Dale Stewart (Mudar et al., 1996). For many decades, remains recovered in Alaska were stored at the Smithsonian Institution. Some collections were intensively studied for a variety of research questions while others were largely neglected. However, all skeletal remains from Alaska came to the forefront with the passage of NAGPRA.

The Native American Graves Protection and Repatriation Act (NAGPRA) is a Federal law that was passed in 1990. It provides a process for museums and Federal agencies to return Native American cultural items, including human remains, funerary objects and other sacred objects, to lineal descendants, Indian tribes and Native Hawaiian organizations (NAGPRA, 2011). Under NAGPRA, the President of the Native Village of Mekoryuk on Nunivak Island, Mr. Solomon Williams, made a repatriation request in December of 1993 for the human skeletal remains and funerary objects from Nunivak housed in the National Museum of Natural History (NMNH). Prior to this, a similar request was made from the people of Golovnin Bay by Mr. Matt Ganley, the Staff Archaeologist for the Bering Straits Native Corporation in 1993. Human remains and objects from Golovnin Bay were also housed at the National Museum of Natural History. As a result of these requests, several archaeological and ethnographic reports were written in subsequent months to document the remains and objects in the collection before their repatriation. The remains from Golovnin Bay were sent as a loan by the NMNH to the Department of Anthropology, University of Alaska Fairbanks, in 1995, for a full skeletal analysis following the Smithsonian protocol, prior to reburial. This work was completed in the summer of 1995 and the remains were returned to the inhabitants of Golovnin Bay. In 1996, the skeletal collection from Nunivak Island followed a similar

path. It was loaned to researchers at the University of Alaska Fairbanks for a complete analysis in the summer of 1996. In August of that year, the remains were returned to Nunivak Island for reburial. This thesis analyzes the measurements of long bones specified in the Smithsonian protocol from the Golovnin Bay and Nunivak Island skeletal series prior to their repatriation.

The Golovnin Bay sample, numbering 154 individuals, was excavated by Aleš Hrdlička, Henry Collins and James Ford. Context suggests that most if not all of the remains represent a post-European contact population. About 120 burials came from cemeteries associated with communities on the southern tip of the Rocky Point Peninsula, which forms part of Golovnin Bay. Seven other individuals were recovered from the site of Chingikchuak, which is also located on the Rocky Point Peninsula. Twelve sets of human remains were removed from a settlement on the coast of Norton Sound, east of Golovnin Bay. Finally, 14 additional burials were removed from a cemetery associated with a settlement on the Koyuk River (Mudar et al., 1996), while one burial came from White Mountain on the Fish River.

Henry B. Collins and T. Dale Stewart, working on behalf of the Smithsonian Institution, collected the remains of 246 individuals from Nunivak Island in 1927. Most of these burials were associated with the village of Mekoryuk. The skeletons from Nunivak Island are thought to be of a “recent age” although some evidence suggests they come from both prehistoric and protohistoric sites (Speaker et al., 1996). The exact points of excavation where the burials were recovered are not known. Many of the remains were engraved with cryptic markings, possibly representing attempts by Collins and Stewart to identify site location. Unfortunately, only eight sites could be identified

and individuals could only be assigned to six with accuracy. The sites that were identified were Nunivak Island in general (5 individuals), Tetsiakimuing (84 individuals), Cape Etolin and various points south and southeast of the cape (49 individuals), Miksakimiuny (22 individuals), Nash Harbor (71 individuals) and Koot (15 individuals) (Scott et al., 1995; Speaker et al., 1996). Table 1 shows the excavation sites and the number of individuals recovered from each site around Golovnin Bay and Nunivak Island.

Table 1. List of excavation sites and number of individuals recovered.

Region	Excavation Site	Number of Individuals
Golovnin Bay	Rocky Point Peninsula	120
Golovnin Bay	White Mountain	1
Golovnin Bay	Chingikchuak	7
Golovnin Bay	Norton Sound	12
Golovnin Bay	Koyuk River	14
Nunivak Island	General area	5
Nunivak Island	Tetsiakimuing	84
Nunivak Island	Cape Etolin	49
Nunivak Island	Nash Harbor	71
Nunivak Island	Miksakimiuny	22
Nunivak Island	Koot	15

CHAPTER FOUR: METHODS

This thesis analyzes the long bones from Nunivak Island and Golovnin Bay in three ways. First, stature reconstruction formulae are applied to generate stature estimates of the individuals. Second, indices of relative limb proportion are compared to test Allen's (1877) rule of the correlation of cold climate to shorter limbs. Finally, indices of diaphyseal robusticity are determined to help understand the mechanical stress loads on the long bones. The following sections detail the methods for these analyses.

Primary data are the postcranial measurements collected from Nunivak Island and Golovnin Bay skeletons. To ensure consistency among all researchers doing work on skeletal remains in the process of being repatriated, the methods outlined in *Physical Anthropology Laboratory Manual* (Verano and Urcid, 1994) provided the standard landmarks used in taking measurements of the long bones. The lengths of the long bones were measured using sliding calipers (Fig. 6) and a standard osteometric board (Fig. 8) to the nearest 0.1mm. If the distal and proximal ends were not intact, they were not measured. A flexible metric steel tape was



Fig. 6 Sliding calipers in use.
Image from ReRod.



Fig. 7 Osteometric board with femur. Image from Paleo-Tech Concepts

used to measure the circumference of the long bone shafts. The standards for the laboratory manual came from Zobeck (1983), Bass (1987) and

Moore-Jansen and Jantz (1989). Of these sources, only Zobeck assigned a three lettered mnemonic to identify each measurement (for example: maximum humeral length is HML) which was adopted for all Golovnin Bay and Nunivak Island measurements. A short list of the most commonly used abbreviations in this thesis is provided in Table 2. For a complete list of measurements, their abbreviations and descriptions of the methods used to collect the measurement, see Appendix A.

TABLE 2. List of common measurements and their abbreviations.

Measurement	Abbreviation
Humerus maximum length	HML
Radius maximum length	RML
Ulna maximum length	UML
Femur maximum length	FML
Tibia maximum length	TML
Fibula maximum length	BML

Sex determination for each set of remains was broken into five categories: male, likely male, female, likely female and unknown. Sex was determined using a complete innonimate following the modified Walker System (in Buikstra and Ubelaker, 1994), which scores the ventral arc, subpubic concavity, subpubic angle, ischio-pubic ramus ridge, articular surface elevation, curvature of the sacrum, femoral head diameter and

humeral head diameter. When a cranium was available, determination of sex was also supported by morphological features of the skull.

As a postcranial analysis requires complete epiphyseal fusion for all the long bones, the sample from Golovnin Bay and Nunivak Island are comprised only of adults over eighteen years of age. There were 90 measurable sets of remains from Nunivak (39 male or likely male, 31 female or likely female, and 20 sex unknown). For Golovnin Bay, there were 78 usable sets of remains (32 were male or likely male, 41 female or likely female, and 5 sex unknown). Sample size is summarized in Table 3.

TABLE 3. Sample size for Golovnin Bay and Nunivak Island.

	Golovnin Bay	Nunivak Island
	n	n
Male and Likely Male	32	39
Female and Likely Female	41	31
Unknown	5	20
Total	78	90

Stature

Because the stature estimation formulae used in this analysis requires complete long bones, all samples without long bone measurements were excluded. Additionally, individuals represented only by crania were excluded out of necessity. The stature formulae are sex specific, so all individuals of unknown sex were excluded as well. Since all of the stature formulae used different limb bones, the sample size varied according to the formula. Table 4 shows the sample size per formula.

TABLE 4. Stature sample size by sex and author.

Formula	Golovnin Bay		Nunivak Island		Total	
	n		n		n	
	Male	Female	Male	Female	Male	Female
Trotter & Gleser	30	35	28	27	58	62
Neumann & Waldman	25	32	19	21	44	53
Pearson	30	37	26	27	56	64
Auerbach & Ruff	30	35	26	25	56	50
Genoves	30	35	26	25	56	60

Individuals living in colder climates tend to be shorter than populations at lower latitudes. This is attributed to Bergmann's rule (1874), where a smaller body and more body mass will contain more heat in colder climates. Because there is a high correlation between long bone length and stature, researchers have been able to develop regression equations to estimate living stature based on long bone lengths. Limb proportionality varies among populations, so stature formulae are specific to racial groups and are typically derived for distantly related populations. Asians and American Indians are the closest relatives of Eskimos, so their formulae are more appropriate to use in this case than formulae for Europeans or Africans.

Stature for males and females was calculated using five different regression formulae. These were taken from the Trotter and Gleser (1952) formula for Mongoloid populations, the Neumann and Waldman (1967) formulae for Mississippian and Amerindian populations, the Pearson (1899) formula for Europeans (the only formula available from Pearson also provides a baseline to compare other formulae to test

accuracy), the Auerbach and Ruff (2010) formula for populations living in the Arctic region, and the Genoves (1967) formula for Mesoamericans. All authors except Auerbach and Ruff use the maximum length measurements for each bone. Auerbach and Ruff utilize femoral bicondylar length (FBL) and tibial maximum length (TML). A table containing these regression formulae and the measurements used to calculate stature can be found in Appendix B.

Relative Limb Proportion

Measurements for males and females were used to determine relative limb proportions. Individuals missing measurements for FML, TML, HML and RML were excluded from the sample. The sample included 33 individuals from Golovnin Bay and 30 individuals from Nunivak Island (Table 5).

TABLE 5. Relative limb proportion sample size.

	Golovnin Bay	Nunivak Island	Total
	n	n	n
Males	12	14	26
Females	21	16	37
Total	33	30	63

Limb proportions are ratios that compare one or several measurements, in this case long bone measurements, to one another. Usually geographic origin can be determined from limb proportions because they vary around the world relative to latitude/climate. Populations living in cold climates tend to have shorter limbs (Allen,

1877) because it reduces the amount of surface area that is exposed. With less surface area exposed, there is less of a chance that body heat will dissipate, allowing these individuals to control their core temperature. Without this type of adaptation, individuals exposed to the cold have an increased risk of hypothermia.

Indices of relative limb proportion were calculated for the upper long bones and the lower long bones using the following measurements: femur maximum length (FML), tibia condylo-malleolar length (TML), maximum humeral length (HML) and maximum radial length (RML). Formulae used to calculate indices can be seen in Table 6. The intermembral index was calculated by taking lower limb length (femur, FML, and tibia, TML) and dividing it by upper limb length (humerus, HML and radius, RML). The brachial index was calculated by dividing RML by HML, showing the ratio of the length of the radius (forearm) to the humerus (upper arm). The crural index was calculated by dividing TML by FML, which shows the ratio of the length of the tibia compared to the femur. Lastly, the humero-femoral index was calculated by dividing HML by FML, which shows the ratio of the length of the tibia compared to the femur.

TABLE 6. Indices of relative limb proportion.

Index	Formula
Intermembral Index	$100 * [(HML + RML) / (FML + TML)]$
Brachial Index	$100 * (RML / HML)$
Crural Index	$100 * (TML / FML)$
Humero-femoral	$100 * (HML / FML)$

Robusticity

Individuals missing measurements of the humerus, radius, ulna, femur and tibia were excluded from this analysis because they are needed to calculate indices of robusticity. Table 7 displays the number of individuals used for each index.

Robusticity is the thickness of long bone shafts or epiphyses relative to total long bone length. Determining long bone robusticity can allow a researcher to make inferences on bone strength related to body size, behavior, and climate, especially when used in conjunction with other metric analyses, such as stature estimation and relative limb proportion (Stock and Shaw, 2007). It can also allude to the mechanical stress that specific bones may have faced during their lifetime. For the purpose of this study, only measurements of diaphyseal robusticity were taken, as it is a nondestructive measurement. Usually cross-sectional long bone measurements are preferred but in this case, they would have led to the destruction of the remains, which is not allowed under

TABLE 7. Sample size for Pearson's (2000a) indices of robusticity.

	Golovin Bay		Nunivak Island		Total	
	Males	Females	Males	Females	Males	Females
Humerus	21	30	23	24	44	54
Radius	17	24	17	18	34	42
Ulna	17	21	14	14	31	35
Femur	27	30	24	25	51	55
Tibia	28	31	21	13	49	44

the terms of NAGPRA. The diaphysis is the shaft of the long bone, so diaphyseal robusticity refers to measuring the thickness of the shaft.

Diaphyseal robusticity was determined through the use of indices. First, average circumferential measurements were obtained for the humerus, ulna, radius, femur, and tibia. These were then used to calculate indices of diaphyseal robusticity by using Pearson's (2000a) formula for the femur, tibia, humerus, radius and ulna. For the long bones used, the midshaft maximum and minimum diameters correspond to the antero-posterior (AP) and medio-lateral (ML) planes. The AP plane on the human body is the front (antero) and back (posterior). The ML plane is the right of the midline (medio) and left of the midline (lateral) in the human body. For the humerus, radius, and ulna, the midshaft maximum and minimum diameters are usually at an angle to the AP and ML planes, so the midshaft maximum and minimum diameters of these bones were used to calculate their robusticity indices. The formulae used for diaphyseal indices of robusticity are shown in Table 8.

TABLE 8. Pearson's (2000a) formulae for diaphyseal robusticity indices.

Bone	Formula
Femur	$100 * [(midshaft\ AP + ML\ diameter) / bicondylar\ length]$
Tibia	$100 * [(midshaft\ AP + ML\ diameter) / articular\ length]$
Humerus	$100 * [(midshaft\ maximum + minimum\ diameter) / maximum\ length]$
Radius	$100 * [(midshaft\ maximum + minimum\ diameter) / radial\ articular\ length]$
Ulna	$100 * [(midshaft\ maximum + minimum\ diameter) / ulnar\ articular\ length]$

The measurements from Golovin Bay and Nunivak Island individuals were analyzed to estimate their living stature, the robusticity of their long bones, and their relative limb proportions. The results of these analyses were compared in several ways: 1) between males and females from the same site, 2) between males from Nunivak Island to males from Golovin Bay, and 3) between females from Nunivak Island to females from Golovin Bay. Then the results were aggregated and also compared against each other (Golovin Bay versus Nunivak). This type of comparison is particularly important as it allows any significant differences between the two groups, and between males and females, to come to light.



Fig. 8 Mekoryuk street scene. *Qiawigar*, Kay Hendrickson and child in sled, circa 1940. Margaret Lantis photo from www.nunivakisland.org.

CHAPTER FIVE: STATURE

Stature is commonly used in physical anthropology as a measure of biological development on the level of both individuals and populations. As a single trait, it is sensitive to a number of factors, including sex, age, race, body composition, social stratum and climate. Attained stature plays an important role in assessing health, sexual dimorphism and temporal trends in extinct and extant populations. Although it is often used as the classic example of a quantitative genetic trait, it is susceptible to a variety of environmental influences that are clearly evidenced in secular trends over the past few centuries. The proportions of the components of stature, including the extremities and trunk, reveal variability in relation to overall stature within and between populations (Kozak, 1996:84; Raxter et al., 2008).

Based on the maximum lengths for the humerus, radius, ulna, femur, fibula and tibia, stature was estimated for Golovnin Bay and Nunivak Island males and females using five different stature formulae that are specific to sex and genetic background. These long bones are used because the regression formulae developed to estimate stature show they give reliable results, comparable to those from formulae that utilize the vertebrae and crania. Additionally, the lower limb bones are better indicators of stature than upper limb bones. Table 9 contains the means and standard deviations for stature reconstruction of the Golovnin Bay and Nunivak Island data set for each formula used in this analysis.

Results from the Trotter and Gleser (1952) formulae are consistently higher for males and lower for females than those given by other formulae. Results show little difference between the Golovnin Bay and Nunivak Island samples. Between the males

TABLE 9. Stature estimation: mean and standard deviation (sd) in cm.

	Trotter & Gleser		Neumann & Waldman		Pearson		Auerbach & Ruff		Genoves	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Golovin Bay										
Males	165.6	4.06	164.8	23.22	161.9	3.88	159.7	4.14	161.0	3.79
Females	145.6	3.61	155.3	25.73	150.6	3.53	149.8	3.67	150.6	4.22
Nunivak Island										
Males	164.7	3.21	163.0	19.09	160.9	3.42	158.1	3.65	160.0	3.32
Females	145.2	3.02	154.7	24.20	150.7	3.37	148.6	4.05	149.3	4.73

from Golovnin Bay and Nunivak Island, there is a difference of 0.88 cm. in stature estimates. Between females, the difference is 0.40 cm.

The results from the Neumann and Waldman (1967) formulae are similar to those from Trotter and Gleser (1952) for each group, but the contrast between male and female estimates is notable. While male stature estimates are about the same as those derived from Trotter and Gleser (1952), female estimates are close to 10 cm. taller. Because Neumann and Waldman (1967) do not offer standard errors for their formula, it is hard to judge whether the results fall within the expected range of variation. For Golovnin Bay and Nunivak Island males, there is a difference of 1.81 cm. For females from the samples, the difference is 0.61 cm. Results from Neumann and Waldman's (1967) formula had the highest variance among stature formula results which indicates their formulae may not be applicable to populations living at high latitudes.

Results from the Pearson (1899) formulae fall in the middle of the range of stature estimates for males and females and differ little between the Golovnin Bay and Nunivak Island samples. Between males, the difference is 0.97 cm. Between females, the difference is 0.02 cm. Variance was not high for males and females, although it was higher than Auerbach and Ruff's variance.

Estimates from the Auerbach and Ruff (2010) formulae for Arctic populations give the lowest statures for males out of all formulae used. The results from their formulae also had the lowest variance in stature when applied to all long bones, indicating it may provide the best and most consistent stature estimates. Using the estimates from Auerbach and Ruff (2010), significance testing was employed to determine if differences in stature were significant or not. An F-test was first conducted to determine which t-test to use when comparing males to females from Golovnin Bay, males to females from Nunivak Island, Golovnin Bay females to Nunivak Island females and Golovnin Bay males to

Nunivak Island males. In each case, the results of the test indicated that the variances were the same, so a t-test assuming equal variances was employed.

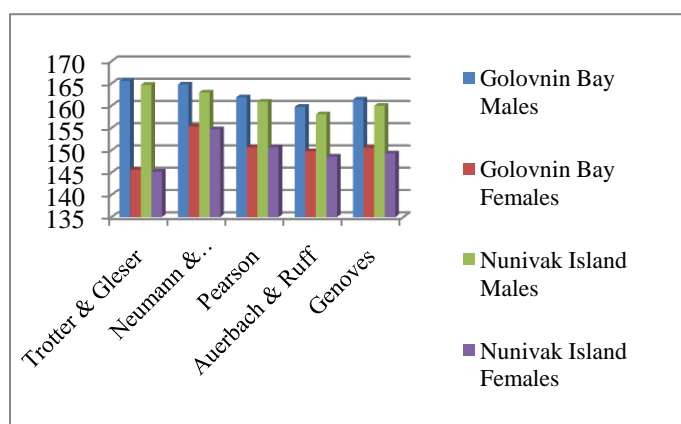


Fig. 9 Stature estimation results in cm.

When the stature of males from Golovnin Bay was compared to that of females, the difference was significant. When the stature of Nunivak Island males was compared

to that of the females, the difference was significant. When Golovnin Bay males and females were compared to Nunivak Island males and females, the differences in stature were not statistically significant. The results of these tests are shown in Table 10.

TABLE 10. Significance testing of stature.

Summary statistics	Golovnin Bay		Nunivak Island		Statistic probability	Gol M-F	Nun M-F	Gol-Nun M-M	Gol-Nun F-F
	M	F	M	F					
X	159.7	149.8	158.1	148.6	t value	10.27	8.78	1.58	1.17
S.D.	4.14	3.67	3.65	4.05	P	0.00	0.00	0.12	0.25
n	30	35	26	25					

In an anthropological survey of Alaska, Hrdlička (1930) found that the average height of Eskimo males was between 160 and 170 cm. For females, the average was between 150 and 160 cm (Anderson and Eells, 1939). Interestingly, Anderson and Eells (1939) say that Collins took measurements of twenty-four females from Nunivak Island in 1927 and found an average height of 153.1 cm. Although the stature estimates made using Trotter and Gleser (1952) and Auerbach and Ruff (2010) are the most divergent from these recent sample values, the measurements of Collins and Hrdlička (1930) were taken on relatively modern populations. Secular changes in height could account for the disparity.

The samples from Golovnin Bay and Nunivak Island do not significantly differ from each other in terms of stature. This is not surprising given that both share a relatively recent common ancestor and were also subjected to the same environmental stressors along the western coast of Alaska. This relates to earlier discussions of

Bergmann (1847) and Allen's (1877) rules where shorter stature and greater body mass are climatically advantageous in cold environments.

Arctic Stature Variation

To show the differences in stature among widely distributed Arctic populations, the average results from Auerbach and Ruff (2010), Jorgensen (1953), and the present study are shown in Table 11 for male Inuit and Aleut samples. Jorgensen's stature estimates were recalculated using Auerbach and Ruff's formulae based on mean measurements published in "*The Eskimo Skeleton*." Because only means were available, standard error was not calculated. The overall range of variation for Arctic males is quite limited, varying between 152.9 and 159.7 cm (ca. 5'0" – 5'3"). Even though the Golovnin Bay and Nunivak Island samples fall toward the upper end of this range, their stature is nonetheless normal for an Inuit population. All groups are relatively small compared to other Native Americans. This fact is consistent with a body form adapted to conserving body heat in accordance with Bergmann's rule.

Comparisons of stature were also made for females from Golovnin Bay and Nunivak Island relative to other Arctic populations (Auerbach and Ruff, 2010; Jorgensen, 1953). Stature estimates for the female sample in Jorgensen (1953) were recalculated using the formulae of Auerbach and Ruff.

TABLE 11. Average male stature estimates for Arctic populations.

Population	Source	Males
Inugsuk	Jorgensen 1953	152.9
Western Arctic: Point Hope Ipiutak	Auerbach and Ruff 2009	154.3
Labrador	Jorgensen 1953	154.8
Naujan	Jorgensen 1953	156.6
Western Arctic: Point Barrow	Auerbach and Ruff 2009	156.7
Western Arctic: Kuskowagamiut	Auerbach and Ruff 2009	156.8
Western Arctic: Pre-Aleut	Auerbach and Ruff 2009	156.8
Old Igloo	Jorgensen 1953	157.7
Mackenzie Eskimos	Jorgensen 1953	158.0
Central Arctic: Kiklewait	Auerbach and Ruff 2009	158.1
Nunivak Island: Auerbach and Ruff	-	158.1
Western Arctic: Ikogmiut	Auerbach and Ruff 2009	158.2
Central Arctic: Sadlermiut	Auerbach and Ruff 2009	158.7
Northeast Greenland	Jorgensen 1953	158.9
Point Hope	Jorgensen 1953	158.9
Prehistoric Siberia	Jorgensen 1953	159.1
Western Arctic: Neo-Aleut	Auerbach and Ruff 2009	159.3
Western Arctic: Point Hope Tigara	Auerbach and Ruff 2009	159.3
Golovin Bay: Auerbach and Ruff	-	159.7

Table 12 shows average stature variation among prehistoric and protohistoric Inuit females. Comparable to the males, the range of variation across this broad geographic zone is limited. The smallest average female height is 146.4 cm. while the tallest is 154.3 cm. (i.e., 4'10" – 5'1"). Mean female statures for Golovnin and Nunivak fall in the middle of the range for circumpolar groups. Overall, there is little differentiation in stature between western Alaskan samples and other Arctic populations. As with males, the short statured females also have a body form consistent with effective heat conservation.

TABLE 12. Average female stature estimates for Arctic populations.

Population	Source	Females
Inugsuk	Jorgensen 1953	146.4
Labrador	Jorgensen 1953	146.4
Western Arctic: Point Hope Ipiutak	Auerbach and Ruff 2009	146.4
Western Arctic: Neo-Aleut	Auerbach and Ruff 2009	147.2
Western Arctic: Kuskowagamiut	Auerbach and Ruff 2009	147.5
Western Arctic: Point Hope Tigara	Auerbach and Ruff 2009	147.8
Western Arctic: Ikogmiut	Auerbach and Ruff 2009	148.3
Nunivak Island: Auerbach and Ruff	-	148.6
Western Arctic: Point Barrow	Auerbach and Ruff 2009	149.2
Naujan	Jorgensen 1953	149.5
Old Igloo	Jorgensen 1953	149.6
Western Arctic: Pre-Aleut	Auerbach and Ruff 2009	149.6
Golovin Bay: Auerbach and Ruff	-	149.8
Northeast Greenland	Jorgensen 1953	149.9
Central Arctic: Kiklewait	Auerbach and Ruff 2009	150.6
Central Arctic: Sadlermiut	Auerbach and Ruff 2009	151.1
Prehistoric Siberia	Jorgensen 1953	154.3

Worldwide Stature Variation

To test my second hypothesis, that groups from Golovnin Bay and Nunivak Island differ significantly in terms of stature from other world populations that live in warmer climates, I compared my results to Old World and New World male populations compiled by Deniker (1900). These tables contain populations from diverse climatic conditions, including other groups from cold climates. Deniker (1900) did not collect statures for females, so these comparisons are not possible. However, given the relatively

constant sex dimorphism across many different geographic groups, the pattern exhibited by either sex is likely to be similar.

The stature data compiled by Deniker (1900) were collected in the late nineteenth century. Thus, these groups do not show the dramatic secular trend in stature that occurred in many populations during the twentieth century. Secular trend refers to the increased height in populations generally associated with improvements in nutrition and medicine. In some ways, this is fortuitous since the samples from Alaska clearly predate 20th century secular trends.

In Table 13, the statures for Golovnin Bay and Nunivak Island males group with other short populations, such as the Japanese, Lapps, and Kalahari Bushmen. The Inuit in general fall toward the high end of the range for short statured world populations. They are notably shorter than populations considered either medium or tall in height, such as European, Asiatic Indian and some African populations.

Although Inuit populations in the north are short, there are also short statured groups that reside in warmer climates. Short stature is not solely an adaptive response to cold. Some of the shortest populations in the world live in tropical areas, including Pygmies in the Congo and Oceanic Negritos in southeast Asia; both groups average less than 150 cm. for attained height in adult males. Lapp populations, only distantly related to Eskimos, are a short statured European population living at high latitudes. Plasticity is clearly one of the hallmarks of this biological variable. Research on stature points to multiple factors that heavily influence the height of a population, including climate, nutrition, health, hormones, genes, and myriad other factors (Hirschhorn and Lettre, 2009).

TABLE 13. *Old World male stature means (Deniker, 1900).*

Region	n	Mean Height
<i>Short Stature</i>		
Akka Negrilloes of Monbutus	38	137.8
Aeta Negritos of the Philippines	42	146.5
Kalahari Bushmen	64	152.9
Lapps of Scandinavia	259	152.9
Lapps of Russian Lapland	25	155.5
Southern Indian	33	156.4
Japanese (workmen and coolies)	32	157.0
Islanders of Bavean	125	158.7
Japanese (middle and upper classes)	1,100	159.0
Sundanese of Java	76	159.1
<i>Medium Stature</i>		
Jews of Russian Poland	4,220	161.2
Chuvashes	3,313	161.2
Javanese	80	161.6
Sardinians	6,607	161.9
Southern Chinese	15,582	162.2
Poles of Russian Poland	167,677	162.4
Conscripts of German Switzerland	31,707	162.9
Australians of Southern New South Wales	40	163.0
Dravido-Hindu castes, N.W. prov. And Oudh	1,443	163.4
Malayalim of Southern India	1,616	163.4
Sicilians (soldiers)	32,024	163.5
Portuguese	800	163.7
Spanish Basques	4,894	163.8
Papuans of New Guinea	142	164.0
Batekes of the Congo	36	164.1
Russians of European Russia	1,771,948	164.2
Italians	344,371	164.2
Spaniards	7,396	164.5
French	447,172	164.6
Rumanians	59,761	165.0
Russians of Asiatic Russia	84,141	165.4
Belgians	35,416	165.5
Berbers of Tunis	1,103	166.3
Brahmans and other high castes	979	166.6
Australians of Central Australia	233	167.0
Northern Chinese	54	167.4
Karelians of Finland	22,979	168.0
Blacks in the US	2,020	168.1
Dutch	9,345	168.5
Danes	3,000	168.5
German emigrants to the US	89,021	169.3
<i>Tall Stature</i>		
Dutch from Overijssel	605	170.1
Swedes in general	232,367	170.5
English in general	6,194	171.2
Norwegians	106,446	172.0
Somalis	56	172.3
Darfur	25	173.0
Polynesians in general	414	173.0
Scotch in general	1,304	174.6

In Table 14, stature data for New World populations (Deniker, 1900) show that the samples from Golovnin Bay and Nunivak Island group with other short statured populations, including an Eskimo population from Labrador and tropical Carib populations of the three Guianas and Venezuela. Based on this, it is clear that short stature can be the product of different environmental stresses. However, the Inuit are shorter than all North American Indian populations.

By comparing the statures of Golovnin Bay and Nunivak Island to populations in both the Old World and New World, it is clear these populations fall within the range of cold adapted groups that differ notably from most groups that reside in temperate and tropical climates. In some instances, however, Inuit populations group with short statured populations that live in tropical climates. Stature does exhibit plasticity and is influenced not only by climate but also by nutrition and other factors. Still, short statured populations living in tropical and cold climates are small for entirely different reasons. In equatorial regions, you can find both tall statured and short statured populations. The latter live primarily in dense forests. Small stature in this context may reflect soil quality, micronutrients, and general food availability as it is not only humans that shrink in body size in this setting. For example, there are also pygmy hippos in west Africa that are one third as long and one tenth as heavy as East African river hippos. In this environmental context, heat conservation is secondary to nutritional adaptations.

Inuit populations such as those found in Golovnin Bay and Nunivak Island are short in stature not because of reduced trunk length, but because their limbs are relatively short. The shortening of the limbs is a response to cold stress. Shorter limbs conserve heat in the core of the body, thus improving chances of survival in extreme cold climates.

TABLE 14. *New World stature average for males (Deniker, 1900).*

Region	n	Mean Height
<i>Short Stature</i>		
Caribs of three Guianas and Venezuela	28	157.2
Eskimo of Labrador	26	157.5
Tupis	50	158.8
<i>Medium Stature</i>		
Salishans (Harrison Lake, British Columbia)	90	161.3
Salishans of Frazer River	30	161.8
Eskimo of Greenland	614	162.1
Zunis of New Mexico	73	162.3
Eskimo of Alaska	85	163.0
Kwakiutl Indians	55	163.9
Hupa Indians	32	166.1
Ute Indians	121	166.1
Tsimshian Indians	37	166.6
Cherokees of the East	104	167.7
Comanches	74	167.8
Klamath Indians	30	167.9
Cree Indians	57	168.5
Apaches and Navajo	147	168.6
Nez Perces	71	169.7
<i>Tall Stature</i>		
Yuma Indians	111	170.0
Choctaws	260	170.0
Pimas	100	170.3
Cherokees of the West	76	171.2
Ojibwas of the South	198	171.2
Ojibwas of the East	1,413	172.3
Siouans	612	172.6
Iroquoians	94	172.7
Crow Indians	213	173.2
Creek Indians	53	173.5
Mohaves of California	35	174.0
Cheyennes	50	174.5

In the far reaches of the north, there is no dichotomy in stature. All populations who have resided in this frigid region are small statured. There is some variation but it all falls within the small statured range. Thus, it is highly likely that the inhabitants of Golovnin Bay, Nunivak Island, and all other Arctic regions in both the New World and Old World are short because of cold stress. Periods of food scarcity may have played a minor role in attained adult height but it is mostly a function of cold adaptation.



Fig. 10 Short limbs but a relatively long trunk characterize most longstanding Arctic populations (Garn, 1970; Human Races)

CHAPTER SIX: RELATIVE LIMB PROPORTIONS

Stature provides one summary measure of an individual's or population's total height that is comprised of several different elements. Although cranial height and vertebral column length contribute to stature, the emphasis here is on long bone measurements. Although the long bones are used to estimate stature in forensic anthropology and bioarchaeology, these measurements do not tell the same story in all populations (as noted by the use of different stature formulae). The aim of this chapter is to address proportional indices among the major long bones and note how these proportions relate to climatic adaptation.

Summary statistics for HML, RML, UML, FML, TML and BML show that males from both samples possess slightly longer bones than females (Table 15). A t-test assuming equal variances was used to determine if male long bone lengths differ significantly from those of females. It was found that males and females from Golovnin Bay differed significantly in lengths of the humerus, ulna, radius, femur, tibia and fibula. Lengths of the long bones belonging to Nunivak Island males and females also differed significantly in every instance. These significant differences in long bone length indicate that males and females exhibit a consistent sexual dimorphism. When males from the two populations were compared to each other, the only significant difference was in tibial length. Males from Golovnin Bay possessed tibia that were about one centimeter longer. A similar difference was found when comparing females, where Golovnin Bay again possessed a significantly longer tibia. The fibula was also significantly longer for Golovnin females.

TABLE 15. Length of long bones in cm. of Golovnin Bay and Nunivak Island.

Bone measurement	Summary statistics	Golovnin Bay		Nunivak Island		Statistic probability	Golovnin M-F	Nunivak M-F	Gol-Nun M-M	Gol-Nun F-F
		M	F	M	F					
Humerus length (HML)	X	31.1	28.4	30.8	28.9	t value	7.43	4.89	0.79	1.29
	S.D.	1.29	1.26	1.14	1.27	P	0.00	0.00	0.44	0.20
	n	12	21	14	16					
Ulna length (UML)	X	25.3	23.1	25.2	22.5	t value	5.11	7.42	0.02	1.42
	S.D.	1.61	1.48	1.02	1.61	P	0.00	0.00	0.98	0.17
	n	17	21	14	15					
Radius length (RML)	X	23.1	20.8	23.1	20.5	t value	4.73	7.47	0.01	0.82
	S.D.	1.4	1.33	0.97	0.88	P	0.00	0.00	0.99	0.42
	n	12	21	14	16					
Femur length (FML)	X	43.7	40.1	43.1	40.2	t value	7.66	5.60	1.40	0.21
	S.D.	2.19	1.66	1.48	1.52	P	0.00	0.00	0.17	0.83
	n	12	21	14	16					
Tibia length (TML)	X	35.1	32.7	34.1	31.6	t value	5.93	5.45	2.18	2.67
	S.D.	1.89	1.67	1.65	1.37	P	0.00	0.00	0.03	0.01
	n	12	21	14	16					
Fibula length (BML)	X	34.2	32.0	33.5	31.1	t value	4.31	5.29	1.19	2.12
	S.D.	2.59	1.26	1.33	1.62	P	0.00	0.00	0.24	0.04
	n	16	23	17	18					

Relative limb proportions were calculated by comparing: (1) the length of the upper limbs to the lower limbs (intermembral index); (2) the length of the radius to the humerus (brachial index); (3) the length of the tibia to the femur (crural index); and (4) the length of the humerus to the femur (humero-femoral index). Comparing these indices paints a picture of the level of adaptation that specific groups face in relation to climate. High brachial and crural indices are normally found in populations living in tropical areas. These groups range from 76.4 to 78.7 in brachial indices while high crural indices range from 82.8 to

85.8. Given their high latitude and exposure to cold stressors, lower indices are expected for the Golovnin Bay and Nunivak Island populations.

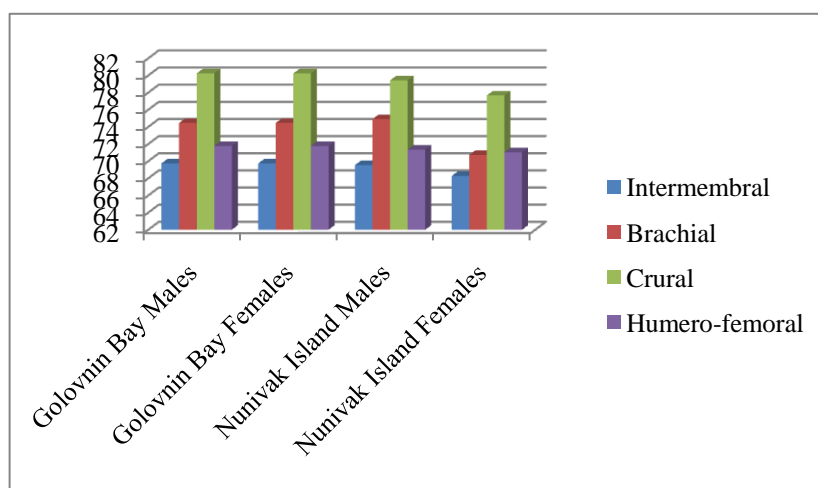


Fig. 11 Intermembral, brachial, crural and humero-femoral indices.

Table 16 shows the four limb length indices are similar for males and females from both samples. However, the indices vary slightly when comparing males and females from the same sample. Males from both samples tend to have higher indices than females. Males from Golovnin Bay had intermembral and humero-femoral indices that were significantly higher than those of females. For Nunivak Island, males have significantly higher intermembral, brachial and crural indices.

TABLE 16. Limb proportion indices of Golovnin Bay and Nunivak Island.

Index	Summary statistics	Golovnin Bay		Nunivak Island		Statistic probability	Gol M-F	Nun M-F	Gol-Nun M-M	Gol-Nun F-F
		M	F	M	F					
Intermembral	X	69.5	67.3	69.6	68.3	t value	4.86	2.78	0.17	2.23
	S.D.	1.14	1.30	1.09	1.38	P	0.00	0.01	0.86	0.03
	n	12	21	14	16					
Brachial	X	74.4	73.0	74.9	70.8	t value	1.40	4.20	0.53	2.20
	S.D.	2.15	3.23	2.76	2.66	P	0.17	0.00	0.60	0.03
	n	12	21	14	16					
Crural	X	80.3	80.9	79.4	77.7	t value	0.78	2.78	0.91	5.55
	S.D.	2.64	2.05	2.12	1.29	P	0.44	0.01	0.37	0.00
	n	12	21	14	16					
Humero-femoral	X	71.8	70.4	71.3	71.0	t value	2.28	0.54	0.91	1.10
	S.D.	1.66	1.76	1.00	1.80	P	0.03	0.59	0.37	0.28
	n	12	21	14	16					

For between site comparisons of long bone indices, males do not show any significant differences. Females, on the other hand, differed significantly for the intermembral, brachial and crural indices. Females from Golovnin Bay have higher brachial and crural indices while Nunivak Island females had higher intermembral indices.

Body proportions covary with climate as a result of long term natural selection. Ontogenetic research and migrant studies have demonstrated that body proportions are largely genetically controlled and are under low selective pressure meaning that it can take thousands of years for humans to fully adapt to a new climate (Holliday, 1997). Because of this, studies of body form can provide evidence for evolutionarily short-term dispersals and/or gene flow. The Bergmann rule states that, “...within a polytypic warm-blooded species, the body size of the subspecies usually increases with decreasing mean temperature of its habitat” (Bergmann, 1847). Allen’s rule states that, “...in warm-blooded species, the relative size of exposed portions of the body decreases with decrease of mean temperature” (Allen, 1877).

In general, humans appear to follow the ecological rules of Bergmann (1847) and Allen (1877), such that those individuals inhabiting colder regions are heavier and have shorter relative limb lengths, resulting in a decreased ratio of surface area to body mass (Katzmarzyk and Leonard, 1998:484). Circumpolar peoples are known to have foreshortened limb segments and broader trunks and are heavier on average than populations at even the mid-latitudes (Holliday and Hilton, 2010). Researchers attribute

low brachial (radius/humerus), and crural (tibia/femur) indices to cold adaptation. Some examples of populations that possess such indices include modern day Lapps, Siberians and Eskimos.

Relative Limb Proportions for Arctic Males

To test my first hypothesis, that Golovnin and Nunivak would not differ significantly from other Arctic groups, I compared average limb proportions of these samples to four other populations living in the Arctic. Computation of the indices for these populations was done by Holliday and Hilton (2010) for Ipiutak, Tigara and Koniaq samples and by Auerbach and Ruff (2010) for Alaskan Eskimo populations (crural indices only). Table 17 shows the results of this comparison for males. In general, males from Golovnin Bay and Nunivak Island had intermembral indices that were similar for all groups except the Koniaq, who had a somewhat higher index than all other Arctic populations. Brachial indices were similar for all populations. Based on that assumption, males from Golovnin Bay and Nunivak Island were generally quite similar to other Arctic groups, which supports my first hypothesis.



Fig. 12 *Qayarkilzngur*, ca. 1923.
Photo from University of Alaska, Fairbanks,
Rasmuson Library Archives, L.J. Palmer.

TABLE 17. Relative limb proportion comparison for males.

Males				
	Intermembral Index	Brachial Index	Crural Index	Humero-femoral Index
Ipiutak	69.6	75.1	81.1	71.9
Tigara	67.0	75.7	82.8	69.7
Koniag	72.5	74.8	80.8	75.0
Golovnin Bay	69.7	74.4	80.3	71.8
Nunivak Island	69.5	74.9	79.4	71.3
Ikogmiut	-	-	82.3	-
Kuskowagamiut	-	-	79.5	-
Neo-Aleut	-	-	81.3	-
Point Barrow	-	-	81.5	-
Point Hope Ipiutak	-	-	81.2	-
Point Hope Tigara	-	-	83.1	-
Pre-Aleut	-	-	81.0	-
Average	69.1	72.8	82.3	74.4

The indices of males from Golovnin Bay and Nunivak Island were compared to the average indices of Arctic populations because Holliday and Hilton (2010) and Auerbach and Ruff (2010) only provide means and not the actual long bone measurements. The only significant difference found was in the crural indices of males from Nunivak Island. Nunivak Island had a relatively low crural index compared to other Arctic populations.

TABLE 18. Statistical tests and probabilities for comparing Golovnin Bay and Nunivak Island males to average male Arctic means.

Index	Statistic probability	Golovnin-Arctic	Nunivak-Arctic
Intermembral	t value	0.13	0.09
	P	0.91	0.94
Brachial	t value	1.15	0.33
	P	0.27	0.74
Crural	t value	1.43	3.11
	P	0.17	0.01
Humero-femoral	t value	0.24	0.55
	P	0.84	0.64

To evaluate the relationship between body proportions and climate, crural indices were plotted on a graph against latitude for 13 Eskimo-Aleut samples (Fig. 12). This index was chosen because it has the most data points available. If proportions conform to the Bergmann/Allen ecogeographical rules, the prediction is that as latitude increases, the crural indices should decrease. A colder environment (i.e. high latitude) should result in shorter limbs. Instead, when the crural indices for the two western Alaskan Eskimo samples and other Arctic populations are plotted against latitude, the graph shows a positive rather than negative slope. As the crural index is the ratio of tibial length to femoral length, it is possible that the entire lower limb is shortened and not just the tibia. However, we are dealing with a small number of samples and a restricted range of variation. To show the relationship between the crural index and latitude, it may require a broader world view that includes a variety of Arctic, temperate and tropical populations.

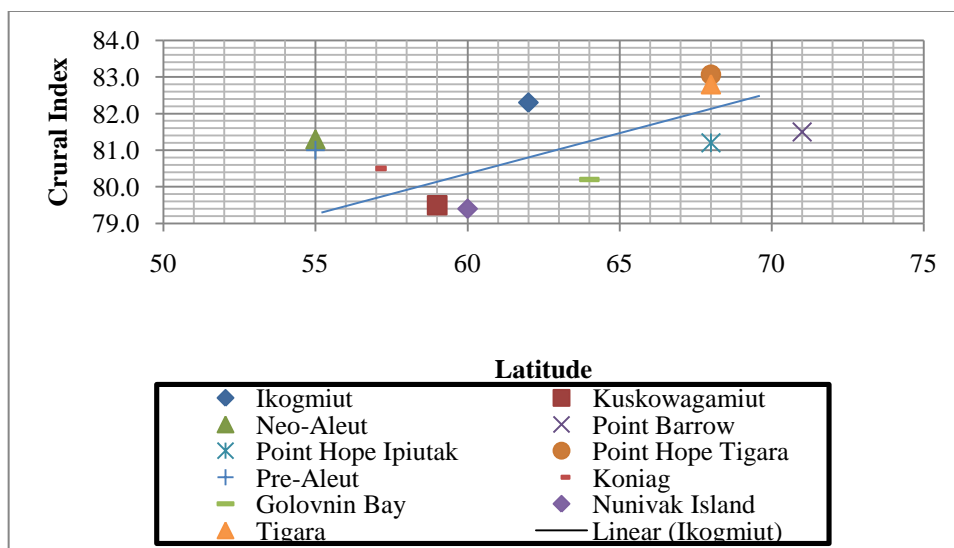


Fig. 13 Crural index vs. latitude for males of Arctic populations

Relative Limb Proportion For Arctic Females

Body proportional indices were also compared between Golovnin Bay and Nunivak Island females and other Arctic samples (Table 19). In general, females from Golovnin Bay and Nunivak Island had intermembral, crural and humero-femoral indices similar to the Arctic averages. Females from Golovnin Bay had brachial indices slightly under average while females from Nunivak Island had a considerably lower index than average.

TABLE 19. Relative limb proportion comparison for females

	Females			
	Intermembral Index	Brachial Index	Crural Index	Humero-femoral Index
Ipiutak	69.6	73.1	79.8	72.3
Tigara	66.4	74.4	82.4	69.5
Koniag	70.2	75.9	80.2	71.9
Golovnin Bay	67.3	72.9	80.9	70.4
Nunivak Island	68.3	70.8	77.7	71.0
Average	68.7	74.5	80.8	71.2

The indices of females from Golovnin Bay and Nunivak Island were compared to the average indices of Arctic populations to evaluate statistical significance (Table 20). No index differed significantly between Golovnin Bay and other Arctic populations. The intermembral and humero-femoral indices of Nunivak Island did not differ significantly from the other populations, but both the brachial and crural indices were significantly smaller than the Arctic average, indicative of small upper and lower limb proportions.

TABLE 20. Tests of relative limb proportion indices of Golovnin Bay and Nunivak Island females compared to average female Arctic means.

Index	Statistic probability	Golovnin-Arctic	Nunivak-Arctic
Intermembral	t value	1.68	0.49
	P	0.11	0.63
Brachial	t value	0.79	2.31
	P	0.44	0.03
Crural	t value	0.09	3.84
	P	0.93	0.00
Humero-femoral	t value	0.78	0.17
	P	0.45	0.87

Relative Limb Proportions for Worldwide Males

To test the validity of my second hypothesis, that the relative limb proportions of Golovnin Bay and Nunivak Island differ significantly from other world populations, I compared my results to the indices of twenty-one other populations: Gurkhas and Bantu (Porter, 1999) Jomon and modern Japanese (Takigawa, 2006; Mizoguchi, 2001, 2002, 2003a, 2003b), Puebloan, Bohemia, Germany, Norse, Romano-British, Anglo-Saxon, France, Bosnia, Euro-American, Egypt, Nubia, Kerma, W. Africa, San, Pygmy, E.

Africa, and African American (Holliday and Hilton, 2010). A table with these indices can be found in Appendix B. Because only means were available, populations were grouped by region to determine if their indices differed significantly from those of Golovnin Bay and Nunivak Island. Bohemia, Germany, Norse, Romano-British, Anglo-Saxon, France, Bosnia and Euro-American were grouped into one region representing northern Europe. Egypt, Bantu, Nubia, Kerma, W. African, San, Pygmy, E. Africa and African Americans were combined to represent Africa. Gurkhas and Puebloans were omitted from significance testing as they could not be grouped with any of the available populations.

In Table 21, mean long bone indices are compared between Golovnin and Nunivak Island males and average European and African males. Golovnin Bay and Nunivak Island differ significantly from Europeans in only the crural index. Both samples differ significantly from Africans for the intermembral, brachial and crural indices. Interestingly, the humero-femoral index does not differ significantly between the Inuit samples and either Europeans or Africans. The results of these comparisons suggest major differences in limb bone proportions between the Inuit and Africans, consistent with a significant contrast in temperature stress between equatorial and Arctic zones. The contrast to temperate Europeans is less subtle with only the crural index showing a significant difference. The European samples are what Holliday and Hilton (2010) consider as “cold” climate, meaning that the populations come from the far northern reaches of Europe. Because of their location, these samples are exposed to cold stress somewhat like our Inuit samples so the limbs show more similar proportions for the most part.

TABLE 21. Limb proportion indices of Golovnin Bay and Nunivak Island males compared to Europeans and Africans.

Index	Summary statistics	Golovnin	Nunivak	European	African	Statistic probability	Golovnin	Nunivak	Golovnin	Nunivak
		Bay	Island				Europe	Europe	Africa	Africa
		M	M	M	M					
Intermembral	X	69.5	69.6	69.1	68.5	t value	0.88	1.10	1.85	2.12
	S.D.	1.14	1.09	0.89	1.13	P	0.39	0.29	0.08	0.05
	n	12	14	8	8					
Brachial	X	74.4	74.9	75.7	78.7	t value	1.61	0.98	4.89	3.55
	S.D.	2.15	2.76	0.88	1.49	P	0.12	0.34	0.00	0.00
	n	12	14	8	8					
Crural	X	80.3	79.4	82.6	85.5	t value	2.19	3.61	6.64	10.05
	S.D.	2.64	2.12	1.66	0.62	P	0.04	0.00	0.00	0.00
	n	12	14	8	8					
Humero-femoral	X	71.8	71.3	71.8	71.1	t value	0.09	1.07	0.95	0.42
	S.D.	1.66	1.00	0.63	1.57	P	0.93	0.30	0.35	0.68
	n	12	14	8	8					

Because means and standard deviations are available for Jomon and modern Japanese, significance testing was done for each population against Golovnin Bay and Nunivak Island. Table 22 shows that the difference in the intermembral index for Golovnin and Jomon males was not significant, but the difference between males from Nunivak and Jomon males was significant. For brachial, crural and humero-femoral indices, Golovnin Bay and Nunivak Island males differed significantly from Jomon males. The Jomon have higher brachial and crural indices and lower humero-femoral indices. Basically, the Jomon had longer arms and legs, while males from Golovnin Bay and Nunivak Island had relatively shorter limbs.

When comparing the indices of Golovnin Bay and Nunivak Island males to modern Japanese, the results were very different than comparisons with the Jomon. Golovnin Bay and Nunivak Island males do not differ significantly from the modern Japanese males for any index ($p > 0.05$). This indicates that Golovnin Bay and Nunivak Island are very similar to the Japanese for long bone proportions.

The differences between the two Alaskan samples and the Jomon and their similarity to modern Japanese is interesting in a number of regards. First, it is widely accepted that the Jomon were not ancestral to the living Japanese population. Instead, they were allied with populations of southeast Asia and their living descendants are the Ainu (Turner, 1987, 1990). The Japanese are more closely related to mainland Asians, including populations from northern China and Korea. These populations, according to Birdsell (1951), are all derived from a common ancestor in northeast Asia that was subjected to the stresses associated with cold climates. From a dental standpoint, the Inuit show linkages to north and east Asian populations, while the Jomon show their closest

TABLE 22. Limb proportion indices of Golovnin Bay and Nunivak Island males compared to Jomon and Japanese indices.

Index	Summary statistics	Golovnin	Nunivak	Jomon	Japanese	Statistic probability	Golovnin	Nunivak	Golovnin	Nunivak
		Bay	Island				Jomon	Japanese	Japanese	Japanese
		M	M	M	M					
Intermembral	X	69.5	69.6	68.5	70.0	t value	1.83	2.08	1.29	1.19
	S.D.	1.14	1.09	0.73	0.53	P	0.09	0.05	0.21	0.25
	n	12	14	6	7					
Brachial	X	74.4	74.9	80.4	75.3	t value	8.82	6.96	1.34	0.36
	S.D.	2.15	2.76	0.70	0.72	P	0.00	0.00	0.20	0.72
	n	12	14	6	7					
Crural	X	80.3	79.4	83.8	80.5	t value	3.05	4.64	0.28	1.71
	S.D.	2.64	2.12	1.3	0.7	P	0.01	0.00	0.79	0.10
	n	12	14	6	7					
Humero-femoral	X	71.8	71.3	69.8	72.0	t value	2.69	3.10	0.33	1.57
	S.D.	1.66	1.00	1.05	0.90	P	0.02	0.01	0.74	0.13
	n	12	14	6	7					

affinity to populations residing on or around the Sunda Shelf in southeast Asia (Scott and Turner, 1997). In this instance, we see that a shared common ancestry is reflected not only in teeth and genes (Cavalli-Sforza et al., 1994) but also in limb proportions.

Stature is not influenced by climate alone but can also be affected by other factors, including food scarcity. The results of the relative limb proportion comparisons show starvation does not have as much of an impact on the proportions of limbs as it does on stature. In this case, our results show that populations from Golovnin Bay and Nunivak Island had limb proportions that are consistent with cold adaptation. Porter (1999) speculates that small brachial and crural indices are less tied to climate and instead could be adaptive for hunters in hilly and difficult terrain that is sometimes snowbound. These hunters often face killing large mammals and then carrying heavy loads back to their home base so short limbs would be advantageous while navigating such a terrain. This is supported by the subsistence strategies found specifically in Nunivak. Pratt (2009) says that the resources available to Arctic groups, specifically Nunivak Islanders, include seal, silver salmon, caribou and cliff-dwelling seabirds. Hunters that gather these resources would face difficult terrain, consistent with Porter's (1999) speculation for small brachial and crural indices.

The intermembral, crural, humero-femoral and brachial indices of all the populations including the two male populations from Golovnin Bay and Nunivak Island and other Arctic populations are plotted on a graph against latitude to help determine if there is any correlation between limb proportion and geographic location. For these populations above the equator, lower latitude correlates to a higher average annual

temperate, whereas high latitude indicates a lower temperature. Positive latitude degrees indicate the latitude above the equator, while negative degrees are below the equator.

The intermembral index is the ratio of the upper long bones (humerus and radius) compared to the lower long bones (tibia and femur). In humans, the normal distribution is under 100, with a mean around 70. This indicates that the upper long bones are shorter than the lower long bones (due primarily to bipedalism). Figure 13 shows that as latitude increases, so does the intermembral index. The Norse, the Romano-British and the Pygmy all have relatively high intermembral indices, which means that their arms are a little longer than their legs in comparison to other populations with lower indices; however, the Koniag have the highest index (72.5). This means that their legs are comparatively shorter than other populations, which is usually seen in groups living in extremely cold climates.

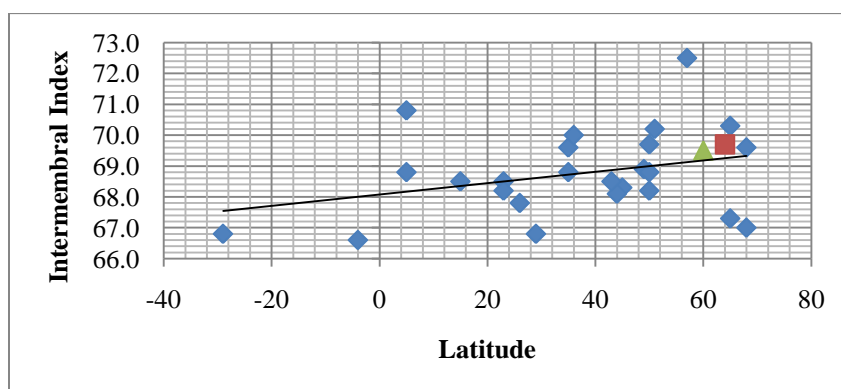


Fig. 14 Intermembral index vs. latitude for all male populations

The crural index is the ratio of the tibia to the femur. Figure 14 shows that populations living in higher latitudes (colder climates) tend to have lower crural indices than warm climate populations. This means that the lengths of the lower leg bones in colder populations are shorter relative to the femur than those of warm climate

populations. With but few outliers, there is a strong inverse relationship between crural index and latitude.

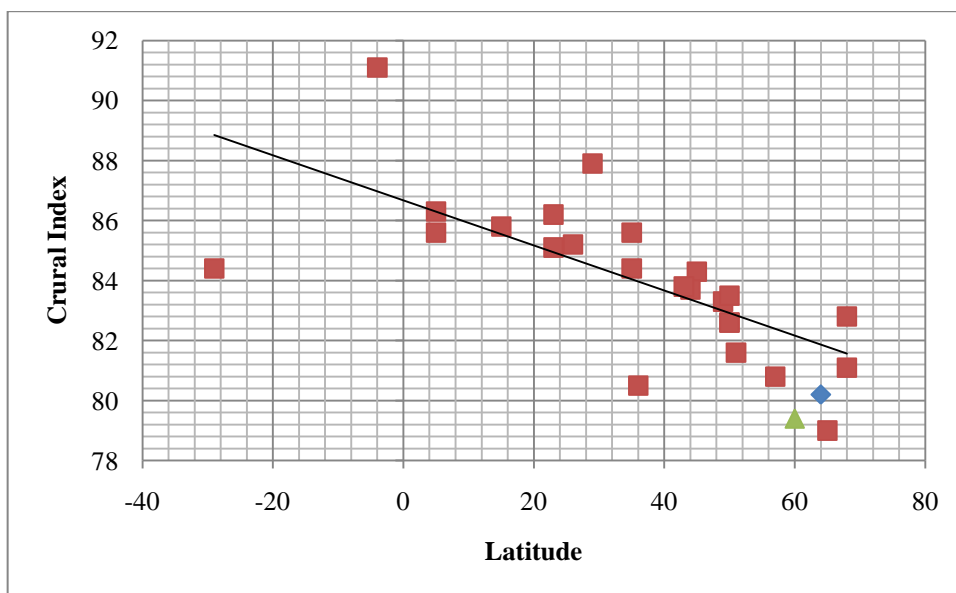


Fig. 15 Crural index vs. latitude for all male populations

The humero-femoral index is the length of the humerus divided by the length of the femur. This gives an overall ratio of the major upper and lower limb components. In modern humans, the upper arm segment (humerus) is shorter than the length of the thigh (femur). Figure 15 shows this particular index remains relatively flat (neither increases or decreases) with latitude, indicating that for the most part, upper and lower limbs remain proportional despite climate. Even though limbs can shorten in response to climate, it is primarily the bones of the forelimb (ulna, radius) and calf (tibia, fibula) that shorten in response to cold stress. Thus, the ratio of the humerus to the femur is little impacted by cold stress, and remains relatively constant across all latitudes.

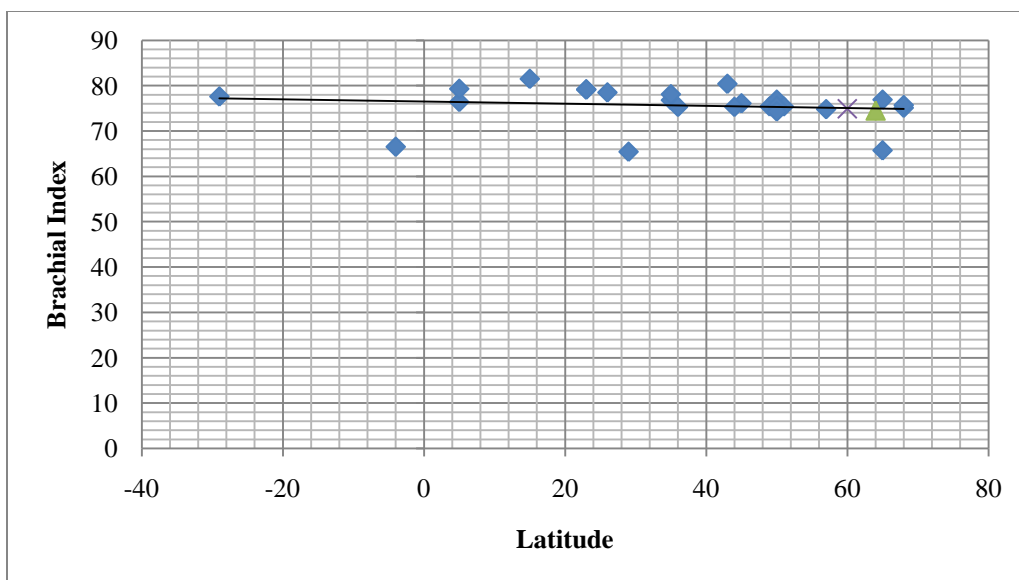


Fig. 17 Brachial index vs. latitude for all male populations

Correlation coefficients calculated between the four indices and latitude are shown in Table 23. Although some of the figures depict a strong correlation between latitude and indices of relative limb proportions, only one was significant. Correlation coefficients for crural indices and latitude show a significant negative correlation; as latitude increases, the crural index goes down. The rest of the coefficients were not statistically different from zero.

TABLE 23. Correlation coefficients and significance for all indices of male populations.

	Coefficient	<i>p</i>
Intermembral	0.350	0.074
Crural	-0.530	0.004
Humero-Femoral	-0.023	0.911
Brachial	-0.152	0.450

Relative Limb Proportions of Worldwide Females

Indices of relative limb proportions for Golovnin Bay and Nunivak Island females were compared to Puebloan, Bohemia, Germany, Norse, Romano-British, Anglo-Saxon, France, Bosnia, Euro-American, Egypt, Nubia, Kerma, W. Africa, San, Pygmy, E. Africa, and African Americans (Holliday and Hilton, 2010), and also the Jomon and modern Japanese (Mizoguchi, 2001, 2002, 2003a, 2003b), which can be seen in Table B in Appendix B. Holliday and Hilton (2010:288) say their data were collected from a “broad sample of modern humans from Europe, Africa and North America.”

Populations were grouped because of the availability of only mean indices, similar to the males. Bohemia, Germany, Norse, Romano-British, Anglo-Saxon, France, Bosnia and Euro-American were grouped into a region representing northern Europe. Egypt, Bantu, Nubia, Kerma, W. African, San, Pygmy, E. Africa and African American were grouped to represent Africa. Means and standard deviations were available for Jomon and modern Japanese so significance testing was done for each population against Golovnin Bay and Nunivak Island.

Golovnin Bay and Nunivak Island female indices were compared to those of European and African samples (Table 24). Golovnin Bay females differed significantly from Europeans for the intermembral, crural, and humero-femoral indices. Females from Nunivak Island differed significantly from Europeans for the brachial and crural indices. Golovnin Bay and Nunivak Island females differed significantly from African females for the brachial and crural indices but not the intermembral and humero-femoral indices.

TABLE 24. Limb proportion indices of Golovnin Bay and Nunivak Island females compared to European and African indices.

Index	Summary statistics	Golovnin Bay F	Nunivak Island F	European F	African F	Statistic probability	Golovnin Europe	Nunivak Europe	Golovnin Africa	Nunivak Africa
Intermembral	X	67.3	68.3	68.6	67.8	t value	2.64	0.62	0.96	0.72
	S.D.	1.30	1.38	0.86	1.54	P	0.01	0.54	0.35	0.48
	n	21	16	8	8					
Brachial	X	73.0	70.8	74.2	77.6	t value	1.56	4.59	5.35	6.75
	S.D.	3.23	2.66	0.92	1.45	P	0.13	0.00	0.00	0.00
	n	21	16	8	8					
Crural	X	80.9	77.7	83.0	84.9	t value	4.00	10.74	7.86	17.93
	S.D.	2.05	1.29	0.77	0.69	P	0.00	0.00	0.00	0.00
	n	21	16	8	8					
Humero-femoral	X	70.4	71.0	72.1	70.6	t value	2.57	1.86	0.28	0.59
	S.D.	1.76	1.80	0.98	1.65	P	0.02	0.08	0.78	0.56
	n	21	16	8	8					

The results of this analysis show some similarities to the male analysis but the overlap is not perfect. For males, only crural indices differed significantly between the Inuit and Europeans. Several additional contrasts are significant for females. For Inuit-African male comparisons, all means differed significantly except for the humero-femoral index. Given the contrast between male and female findings, the most significance should be placed on the difference in crural index between the Inuit and Europeans and the brachial and crural indices for Inuit-African comparisons.

When females from Golovnin Bay and Nunivak Island were compared to female Jomon, their intermembral and humero-femoral indices did not differ significantly (Table 25), but there were significant differences between these groups in the brachial and crural indices. The lack of significance in difference of the intermembral index is expected as it only suggests the proportions of the upper limbs to the lower limbs. For almost all populations, this index should be similar. Jomon females had higher brachial and crural indices, indicative of their longer upper and lower limbs. The results are similar to the findings for males from Golovnin Bay and Nunivak Islander when they were compared to Jomon males.

When females from Golovnin Bay and Nunivak Island were compared to modern Japanese females, the only significant difference was in the brachial indices of Nunivak Island and the modern Japanese. This was also found in the comparison of males from Nunivak Island to modern Japanese. In this case, the modern Japanese had a higher brachial index than females from Nunivak Island, whereas males from Nunivak Island had a higher index than the modern Japanese. This simply indicates that females from Nunivak Island had slightly longer upper limbs than modern female Japanese. All

TABLE 25. Limb proportion indices of Golovnin Bay and Nunivak Island females compared to Jomon and Japanese indices.

Index	Summary statistics	Golovnin	Nunivak	Jomon	Japanese	Statistic probability	Golovnin	Nunivak	Golovnin	Nunivak
		Bay	Island				Jomon	Japanese	Jomon	Japanese
		F	F	F	F					
Intermembral	X	67.3	68.3	67.9	70.8	t value	1.94	0.91	1.97	1.41
	S.D.	1.30	1.38	0.40	4.72	P	0.06	0.37	0.10	0.21
	n	21	16	6	7					
Brachial	X	73.0	70.8	78.9	73.2	t value	-4.17	-6.53	0.31	6.35
	S.D.	3.23	2.66	2.45	0.31	P	0.00	0.00	0.76	0.00
	n	21	16	6	7					
Crural	X	80.9	77.7	83.9	84.5	t value	-3.36	-10.43	0.96	1.85
	S.D.	2.05	1.29	1.09	9.73	P	0.00	0.00	0.37	0.11
	n	21	16	6	7					
Humero-femoral	X	70.4	71.0	69.8	75.7	t value	1.24	1.62	1.48	1.29
	S.D.	1.76	1.80	0.70	9.42	P	0.23	0.12	0.19	0.24
	n	21	16	6	7					

other comparisons showed there were no significant differences. Observations on females are consistent with those of males when the two Inuit samples are compared to the Jomon and Japanese. This provides an additional line of support that shows the distant relationship of the Inuit and the Jomon and the shared ancestry and common adaptive regime of the Japanese and the Inuit.

Similar to the male results for Golovnin Bay and Nunivak Island, females from these two groups also display evidence for cold adaptation in their limbs but the differences are not as dramatic as those of males. Auerbach and Ruff (2010) also had crural indices for females from other Arctic populations (Table 26). Females from Golovnin Bay had an index that fell between those of Kuskowagamiut and Point Hope Ipiutak but Nunivak Island had the lowest index among all Arctic populations.

TABLE 26. Crural indices from Auerbach and Ruff (2010) with Golovnin Bay and Nunivak Island results

	Crural Index
	Males
Ikogmiut	82.3
Kuskowagamiut	79.5
Neo-Aleut	81.3
Point Barrow	81.5
Point Hope Ipiutak	81.2
Point Hope Tigara	83.1
Pre-Aleut	81.0
Koniag	80.5
Golovnin Bay	80.2
Nunivak Island	79.4

The intermembral, crural, humero-femoral and brachial indices for females were plotted against latitude as was done for males. Figure 17 shows that the intermembral index has a positive slope: the higher the latitude, the higher the index. The results are more pronounced than what was evident for males.

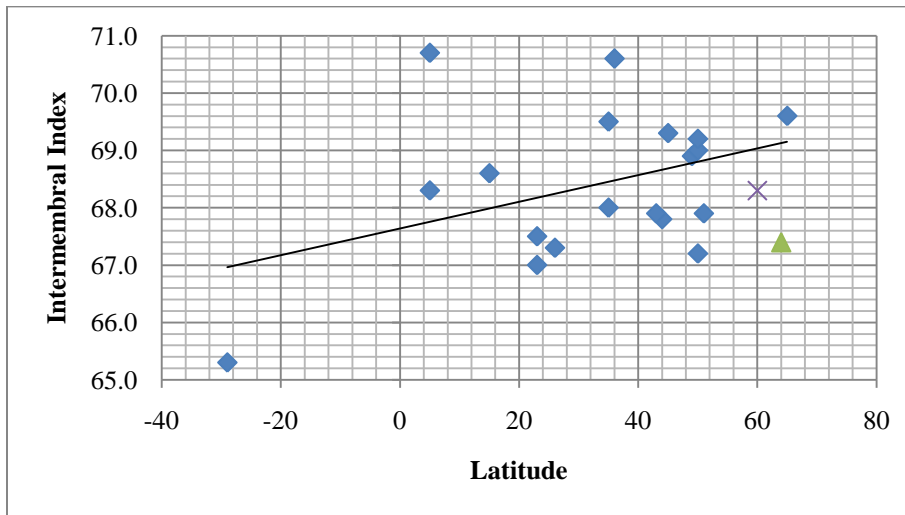


Fig. 18 Intermembral index vs. latitude for all female populations

The crural index is the ratio of the tibia to the femur. In Fig. 18, the crural index of the two samples and other world populations were plotted against latitude. The trend shown in the figure shows a negative slope, meaning that the higher the latitude, the lower the crural index, as expected. It is clear that populations living in areas furthest from the equator, with colder average temperatures, have shorter limbs than those in lower latitudes. This is another indication of cold adaptation, where the body tries to retain heat by shortening limb length.

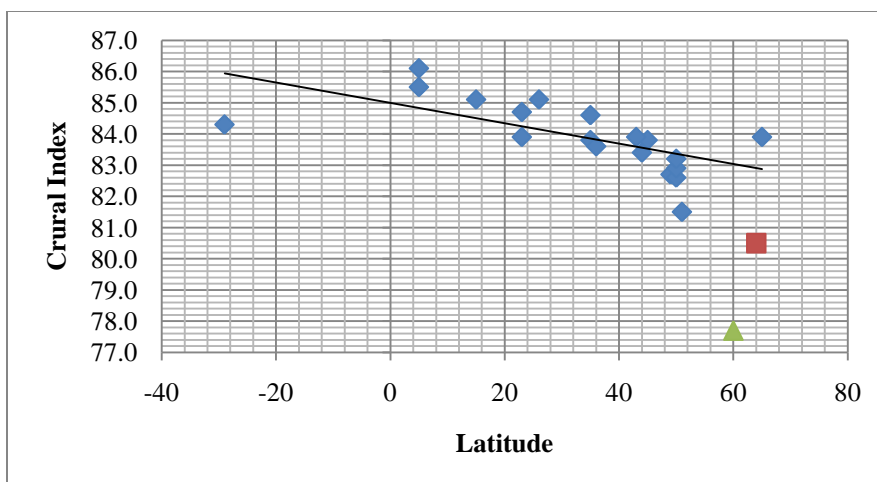


Fig. 19 Crural index vs. latitude for all female populations

The humero-femoral index is the length of the humerus divided by the length of the femur and is similar to the intermembral index because it gives an overall ratio of limbs, rather than a specific ratio of the upper or lower limbs. In Figure 19, this index increases with latitude, which indicates that populations living in colder climates tend to have relatively longer legs than arms. The results for males are not as pronounced as for females, but the difference likely has no biological significance.

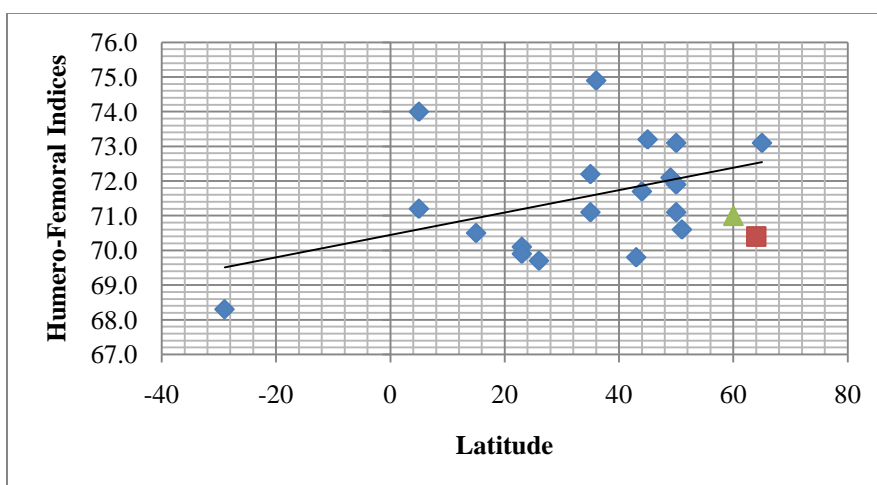


Fig. 20 Humero-femoral index vs. latitude for all female populations

The brachial index is the proportion of the radius to the humerus. Figure 20 shows that the brachial index has a negative slope which indicates that as latitude increases, the brachial index decreases. With higher latitude and colder environments, the upper limbs become shorter. This index conforms to the pattern shown in the humero-femoral index, where it was found that the lower limbs are proportionately longer than the upper limbs. Males also displayed a similar correlation, again consistent with cold adaptation at high latitudes.

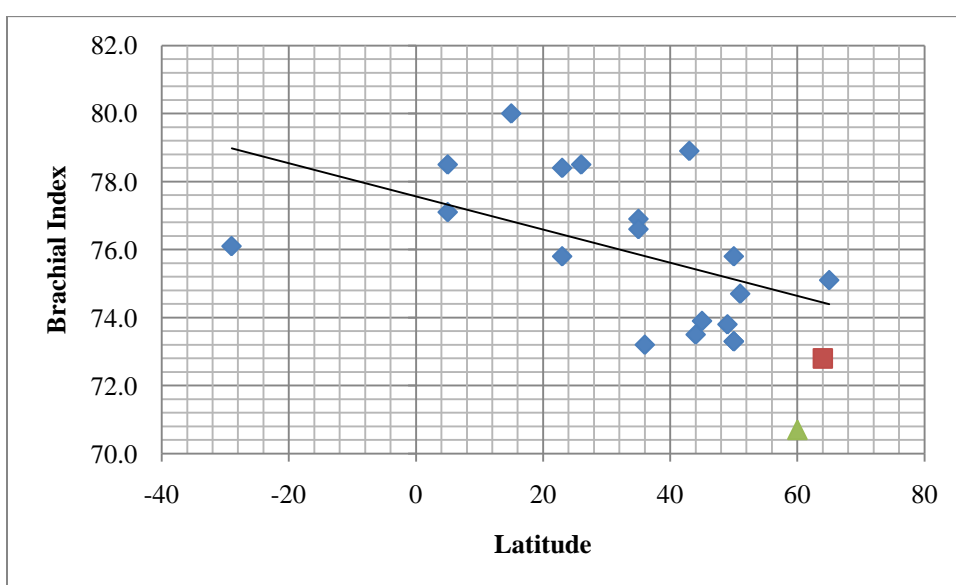


Fig. 21 Brachial index vs. latitude for all female populations

Correlation coefficients between the four indices and latitude are shown in Table 27, along with standard error and significance. For the intermembral indices, there is a small positive correlation with latitude, but this is not significant. Correlation coefficients for crural indices and latitude show a negative correlation; as latitude increases, the crural index goes down. This relationship is significant as it also was for males. The correlation between humero-femoral indices and latitude is positive but non-significant. The

correlation between brachial indices and latitude is negative -- as latitude increases, the brachial index decreases. This relationship is significant.

TABLE 27. Correlation coefficients between relative limb proportion indices and latitude and significance for all indices of female populations.

	Coefficient	<i>p</i>
Intermembral	0.195	0.411
Crural	-0.695	0.001
Humero-Femoral	0.120	0.614
Brachial	-0.558	0.010

In summary, males and females from Golovnin Bay and Nunivak Island differ significantly in all linear long bone measurements. However, same sex comparisons between the two samples show no significant differences. Thus, there is consistent sex dimorphism but not significant intersite difference in long bone lengths. Four indices were calculated for the two populations: intermembral, crural, brachial and humero-femoral. Males and females from Golovnin Bay differed significantly in terms of the intermembral and humero-femoral indices. Males and females from Nunivak Island differed significantly in terms of the intermembral, brachial and crural indices.

Males from Golovnin Bay and Nunivak Island were compared to males from other Arctic populations. For limb proportions, Golovnin Bay did not differ significantly from average Arctic indices. Nunivak Island males differed significantly from other Arctic groups in the crural index. Their lower limbs are proportionately smaller which may have been advantageous in terms of mobility. When females from the two western Alaskan Eskimo samples were compared to other Arctic populations, females from

Golovnin Bay did not show any significant differences. Females from Nunivak Island differed significantly from Arctic averages for the crural and brachial indices.

The indices of the males from Golovnin Bay and Nunivak Island were then compared to indices from populations around the world, including the Jomon and modern Japanese. When the indices of these samples were compared to those of northern Europe and Africa, it was found they did differ significantly in the crural index from both Europe and Africa. They also differed significantly from African groups for the brachial index.

Golovnin Bay and Nunivak Island differed significantly from the Jomon for the brachial, crural and humero-femoral indices, while Nunivak Island males also differed in the intermembral index. In each case, the males from Golovnin Bay and Nunivak Island had smaller indices. Comparisons to modern Japanese were very different. The only significant difference found was between Nunivak Island and the Japanese for the brachial index. This analysis highlights the uniqueness of the Jomon, who are not ancestral to the living Japanese population. It suggests that northeast Asians such as the Japanese share similar cold adaptations with Arctic populations, in line with their more recent common ancestry.

My first hypothesis was that Golovnin Bay and Nunivak Islanders would not differ significantly from other Arctic populations. Based on comparisons of their limb indices to average indices for Arctic populations, this hypothesis was supported. My second hypothesis was that Golovnin Bay and Nunivak Islanders would have significant differences in limb proportions from other world populations. There was a slight contrast between my Eskimo samples and temperate Europeans and more dramatic contrasts with equatorial Africans, consistent with expectations associated with Bergmann's and Allen's

rules. Moreover, the close similarity in indices between the two Eskimo samples and the Japanese, along with the difference shown between these samples and the Jomon, suggests that limb proportions reflect not only climatic adaptation but also shared ancestry.



Fig. 22 Excelia at fishcamp. From www.nunivakisland.org.

CHAPTER SEVEN: ROBUSTICITY

Robusticity provides a means of evaluating skeletal characteristics generally associated with a physically demanding lifestyle. Using measures of robusticity, we can determine if our two Inuit samples exhibit gracile or robust postcranial skeletons relative to other hunter-gatherer, agricultural or industrialized populations (Davivongs, 1963; Collier, 1989; Thorne, 1981). Structural properties of long bones are determined, in part, by body size and shape (Holliday and Falsetti, 1995; Ruff, 2000; Holliday and Ruff, 2001). In terms of structural characteristics, robusticity is defined most accurately as the amount and distribution of bone in a cross section relative to a standardized measurement of body size, such as bone length, body mass, or the product of bone length and body mass (Ruff et al., 1993; Trinkaus et al., 1994; Ruff, 2000). Variation in robusticity can tell us about behavioral differences and osteological changes associated with shifts to different means of subsistence, particularly agriculture (Larson, 1981). This research has documented wide variation in degrees of adult postcranial robusticity and has provided insights into how levels of physical activity, mobility and mechanical loading varied among past populations (Cowgill and Hager, 2007:235-236).

Indices of diaphyseal robusticity can be used to explain why certain bones become thicker, or more robust, than others. Putting mechanical stress on the bones, usually through repetitive behaviors or actions such as hunting large game or fishing for large marine animals like seals and whales, stimulates a physiological response in the body. It causes bones to thicken in response to the stress to avoid injury or fractures. To calculate the indices, average circumferential measurements were obtained for the

humerus, ulna, radius, femur, and tibia. These were then used to calculate indices of diaphyseal robusticity using Pearson's (2000a) formula for this set of long bones. This is the midshaft of the anterior-posterior plus the medio-lateral diameter divided by the maximum or articular length (depending on the bone) multiplied by 100.

Results from Pearson's (2000a) formula for robusticity indices are similar for the Golovnin Bay and Nunivak Island data samples (Table 28). Males tend to have slightly more robust long bones than females in general, but there was a major difference between the two samples. Males from Golovnin Bay were significantly more robust for every long bone except the radius than their female counterparts. The sex difference was less pronounced for Nunivak Island as males differed significantly in robusticity only for the humerus. When indices were compared between females from Golovnin Bay and Nunivak Island, only tibial robusticity differed significantly, with females from Nunivak Island having a higher index. When robusticity indices for males was compared between the two samples, there were no significant differences.

Inter-site comparisons of males and females from Golovnin Bay and Nunivak Island show similar levels of robusticity in their long bones. However, sex dimorphism differs between the two sites. Males and females from Nunivak Island are remarkably similar, whereas Golovnin Bay males are consistently more robust than females. This sexual dimorphism suggests males and females from Golovnin Bay may have had a division of labor among the sexes that involved different levels of stress on the skeleton. The lack of significant differences between males and females from Nunivak Island suggests a less pronounced division of labor or at least participation in different activities that were equally strenuous, resulting in comparable levels of robusticity.

TABLE 28. Robusticity indices of Golovnin Bay and Nunivak Island.

Robusticity Index	Summary statistics	Golovnin Bay		Nunivak Island		Statistic probability	Gol M-F	Nun M-F	Gol-Nun M-M	Gol-Nun F-F
		M	F	M	F					
Humerus	X	13.3	12.7	13.9	12.8	t value	2.42	3.51	1.68	0.27
	S.D.	0.99	0.83	1.33	0.92	P	0.02	0.00	0.10	0.79
	n	21	30	23	24					
Radius	X	11.7	11.7	11.6	11.4	t value	0.00	0.66	0.11	0.99
	S.D.	1.13	1.08	1.04	0.71	P	1.00	0.51	0.91	0.33
	n	17	24	17	18					
Ulna	X	12.0	11.2	11.9	11.2	t value	2.27	1.33	0.30	0.01
	S.D.	1.08	0.98	1.27	0.79	P	0.03	0.20	0.77	0.99
	n	17	21	14	14					
Femur	X	13.5	13.0	13.1	13.0	t value	2.33	0.45	1.82	0.01
	S.D.	1.07	0.58	0.56	0.53	P	0.02	0.66	0.07	0.99
	n	27	30	24	25					
Tibia	X	16.8	15.4	17.0	16.6	t value	5.15	1.17	0.62	5.46
	S.D.	1.26	0.84	1.41	0.78	P	0.00	0.25	0.54	0.00
	n	28	31	21	13					

To further evaluate robusticity, the means and standard deviations of circumferential measurements

of the humerus, radius, ulna, femur and tibia were computed (Table 29).

Regarding sex dimorphism in Golovnin Bay, males were significantly more robust than

females for the humerus,

radius, ulna, femur and tibia. Results were similar for Nunivak Island, as males were significantly more robust than females for all five limb bones. For inter-site comparisons, males from Golovnin Bay and Nunivak Islander were generally quite similar. The only significant different was for femoral means, which were significantly more greater in the

Golovnin Bay sample. More differences were evident for females. Nunivak Island females had significantly greater means for the radius and tibia. The contrast shown by the tibia was also reflected in the indices of robusticity noted earlier.

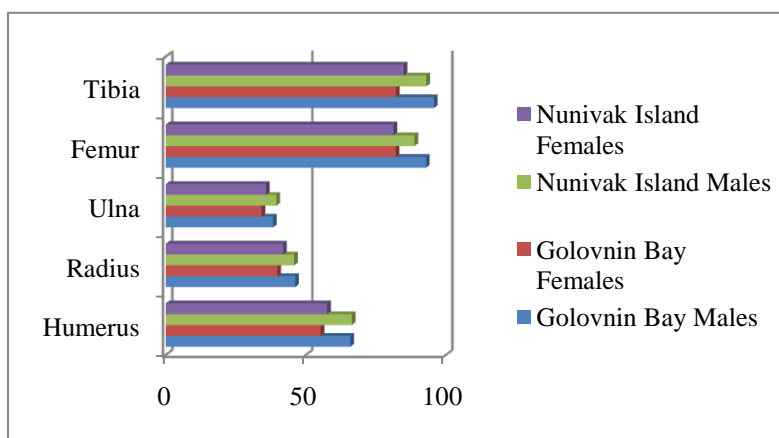


Fig. 23 Circumferential means in cm.



Fig. 24 Mekoryuk residents gathered around dogsled. 1956. Photo from Margaret Lantis, www.nunivakisland.org.

TABLE 29. Circumferential measurements of Golovnin Bay and Nunivak Island.

Robusticity Measurement	Summary statistics	Golovnin Bay		Nunivak Island		Statistic probability	Golovnin M-F	Nunivak M-F	Gol- Nun M-M	Gol-Nun F-F
		M	F	M	F					
Humerus	X	65.9	55.3	66.4	57.6	t value	8.87	3.86	0.25	1.28
	S.D.	4.77	3.14	7.43	7.76	P	0.00	0.00	0.81	0.21
	n	21	29	21	21					
Radius	X	46.2	39.8	45.8	41.9	t value	5.61	3.24	0.24	2.52
	S.D.	4.57	3.15	4.83	2.25	P	0.00	0.00	0.81	0.02
	n	20	26	19	20					
Ulna	X	38.3	34.2	39.5	35.8	t value	3.60	2.93	0.84	1.70
	S.D.	5.04	2.88	4.26	3.44	P	0.00	0.01	0.41	0.10
	n	23	28	20	18					
Femur	X	92.9	82.1	88.8	81.3	t value	9.61	5.98	2.94	0.82
	S.D.	5.38	3.64	4.57	4.27	P	0.00	0.00	0.00	0.41
	n	27	38	25	25					
Tibia	X	95.7	82.2	93.0	84.9	t value	11.81	3.80	1.26	2.21
	S.D.	4.87	4.33	8.55	4.82	P	0.00	0.00	0.22	0.03
	n	29	36	21	21					

Differences in robusticity indicate several things. First, males and females from Golovnin Bay and Nunivak Island are sexually dimorphic as males possess more robust long bones than females. Second, females from Nunivak Island had more robust tibiae than females from Golovnin Bay. Third, males from Golovnin Bay have more robust femurs than males from Nunivak Island. These results suggest that males and females were likely participating in different subsistence activities. Males were largely responsible for hunting and fishing, while women cooked and processed meat and hides (Freuchen, 1961; de Poncins, 1941). It is also likely that females from Nunivak Island and males from Golovnin Bay were more mobile or dealt with rough terrain, contributing to their robust tibiae and femurs, respectively.

Arctic and World Population Indices of Robusticity

To determine whether or not Golovnin Bay and Nunivak Islanders differ significantly in robusticity from Arctic populations and world populations living at lower latitudes, indices of diaphyseal robusticity were compared among these groups using data from Pearson (2000a). A complete table of these indices for males and females can be found in Table C, Appendix B. Table 31 contains their mean indices. Pearson (2000a) already groups populations by cold or warm climate. The Mesolithic, Sami, U.S. White, Inuit, and Chinese are all classified as “cold climate” groups. He does not note where the Inuit sample comes from but classifies them generally as ‘Eskimo from Alaska.’ The Khoisan, Jebel Sahaba, Zulu, African American and Australian

TABLE 30. Robusticity indices of Golovnin Bay and Nunivak Island males relative to warm and cold climate populations.

Robusticity Measurement	Summary statistics	Golovnin	Nunivak	Cold M	Warm M	Statistic probability	Golovnin	Nunivak	Golovnin	Nunivak
		Bay M	Island M				Cold	Cold	Warm	Warm
Humerus	X	13.3	13.9	12.4	12.5	t value	0.10	2.02	1.46	1.99
	S.D.	0.99	1.33	0.50	0.96	P	0.92	0.06	0.16	0.06
	n	21	23	5	4					
Radius	X	11.7	11.6	12.4	11.3	t value	1.27	1.46	0.70	0.68
	S.D.	1.13	1.04	0.55	0.68	P	0.22	0.16	0.49	0.51
	n	17	17	5	4					
Ulna	X	12.0	11.9	12.5	11.4	t value	1.58	1.64	1.17	1.05
	S.D.	1.08	1.27	0.38	0.68	P	0.13	0.12	0.26	0.31
	n	17	14	5	5					
Femur	X	13.5	13.1	12.9	12.4	t value	2.35	0.80	5.29	5.24
	S.D.	1.07	0.56	0.42	0.15	P	0.03	0.43	0.00	0.00
	n	27	24	5	4					
Tibia	X	16.8	17.0	15.5	14.6	t value	2.22	2.33	8.49	7.51
	S.D.	1.26	1.41	0.67	0.24	P	0.03	0.03	0.00	0.00
	n	28	21	5	5					

are grouped as “warm climate.” Because only means were available from Pearson (2000a), these grouping conventions were kept for the purposes of comparison.

Mean robusticity indices for Golovnin Bay and Nunivak Island males are compared to cold climate and warm climate groups. Compared to the cold climate group, Golovnin males had significantly higher indices for the femur and tibia. This same contrast is evident when Golovnin is compared to warm climate groups. When comparing males from Nunivak Island to the cold climate groups, the only significant difference was in the tibial index where it was slightly higher for Nunivak. Compared to warm climate groups, Nunivak males also had significantly higher indices for the femur and tibia.

Comparisons of female robusticity indices between the Alaskan samples and cold and warm climate groups are shown in Table 31. The Golovnin Bay and Nunivak females show almost no significant differences from the cold climate group. The single significant difference is for tibial robusticity which is higher for Nunivak females. In contrast to males, however, Alaskan females differed significantly in most indices from the warm climate grouping.

Golovnin Bay and Nunivak Island males differ consistently from warm climate populations, but they also differ significantly from cold climate populations. Robusticity, unlike stature and relative limb proportion, is not closely associated with climate. It usually points to differences in lifestyle (sedentary, mobile, etc.) and subsistence strategies (agriculture, hunter-gatherer, etc.). In comparing Golovnin Bay and Nunivak Island males to cold and warm climate samples, the two Inuit groups have relatively high indices of robusticity. These high indices may be an indicator of greater mobility,

TABLE 31. Robusticity indices of Golovnin Bay and Nunivak Island females relative to warm and cold climate populations.

Robusticity Measurement	Summary statistics	Golovnin	Nunivak	Cold F	Warm F	Statistic probability	Golovnin	Nunivak	Golovnin	Nunivak
		Bay F	Island F				Cold	Cold	Warm	Warm
Humerus	X	12.7	12.8	12.3	11.3	t value	0.93	0.95	3.20	2.94
	S.D.	0.83	0.92	0.42	0.76	P	0.36	0.35	0.00	0.01
	n	30	24	4	4					
Radius	X	11.9	11.4	11.9	10.5	t value	0.42	1.32	2.10	2.24
	S.D.	1.08	0.71	0.63	0.51	P	0.68	0.20	0.05	0.04
	n	24	18	4	4					
Ulna	X	11.2	11.2	11.6	10.4	t value	0.79	0.92	1.68	1.93
	S.D.	0.98	0.79	0.51	0.72	P	0.44	0.37	0.11	0.07
	n	21	14	4	5					
Femur	X	13.0	13.0	12.6	11.9	t value	1.30	1.40	3.62	3.87
	S.D.	0.58	0.53	0.29	0.38	P	0.20	0.17	0.00	0.00
	n	30	25	4	4					
Tibia	X	15.4	16.6	14.5	13.8	t value	1.93	5.24	3.72	7.36
	S.D.	0.84	0.78	0.61	0.35	P	0.06	0.00	0.00	0.00
	n	31	13	4	4					

associated with hunting some combination of terrestrial and marine mammals. Because females also have higher indices of robusticity, it is likely that these populations from Golovnin Bay and Nunivak Island were highly mobile hunter-gatherers. Firsthand accounts from de Poncins (1941) show that Inuit males and females have a sexual division of labor but women still accompany or assist men in hunting and other stressful subsistence strategies.

Robusticity is but one indicator of rigorous and extended stress on the Eskimo skeleton. These two populations also exhibit a suite of pronounced musculo-skeletal stress markers (Steen and Lane, 1998) and extensive damage to the vertebral column that takes the form of spondylolysis, spina bifida imperfecta, Schmorl's nodes, and osteoarthritis (Legge, 2001). In general, modern industrialized populations tend to under-utilize their skeletal system. Alaska Inuit, by contrast, utilized their skeletal system to almost a maximal extent.



Fig. 25 Nunivak couple removing blubber from bearded seal. Mekoryuk, 1954. Photo from www.nunivakisland.org.

CHAPTER EIGHT: DISCUSSION

What does it all mean? In studies of human adaptability, researchers study a hierarchy of adaptive responses to environmental stress – cultural, physiological and genetic. In response to any type of stress, the first alternative of a human group is cultural or behavioral. In hot environments, individuals avoid working during the hottest parts of the day and utilize shade to keep cool. For a disease stressor like malaria, cultural adaptations include draining stagnant water where mosquito vectors breed, using bug spray to ward off bites and taking anti-malarial medicines just in case they manage to contract malaria (Imbahale et al., 2009; World Health Organization, 2006).

Physiologically, in response to heat, individuals sweat, allowing them to cool their bodies through the loss of body heat through evaporation. For hypoxic stress at altitude, individuals have elevated levels of blood volume and hemoglobin so the circulatory system can provide peripheral cells with adequate levels of oxygen (Majmundar et al., 2010). Finally, if populations reside in a stressful environment for a long period of time and where cultural and physiological adaptations are simply not enough to alleviate stress, genetic adaptations may be required. The classic case of this is the sickle-cell gene (S) in a malarial environment. Under normal circumstances, this gene would be maintained in a frequency consistent with its mutation rate as the sickle-cell homozygote (SS) has a fitness of zero (they survive for a short period of time and do not reproduce). In African populations however, the frequency of S is up to 0.2 in certain populations. When a normally deleterious allele attains a frequency of that magnitude, there has to be a reason. In this case, researchers have demonstrated that when individuals are heterozygous for a normal (A) and sickle cell (S) gene, or A/S, both males and females

enjoy increased fertility and longer life spans compared to the normal hemoglobin genotypes (A/A). The cost (i.e. genetic load) to the population is that each generation, four individuals out of every 100 will homozygous for the sickle cell gene (i.e., $S=q$, $SS=q^2$, if $q=0.20$, then $q^2=0.04$, or 4/100) (Livingstone 1958).

Remarkably, the classic case of sickle cell anemia as a genetic adaptation in a malarial environment has few parallels in human biology. It has been extremely difficult to demonstrate adaptations for any environmental stressor that is genetically based. However, one classic example relates to the ecogeographic rules of Bergmann and Allen. These rules propose that overall body form and limb length have been forged by the anvil of thermoregulatory responses to cold and heat stress in mammals. Newman (1954), Roberts (1953) and others have extended these rules to explain geographic variation in stature and limb proportions in world populations.

In applying the adaptive hierarchy to the Alaskan Inuit samples, the primary environmental stressor is cold augmented by seasonal food shortages. Humans, like all primates, are inherently tropical animals. To survive the bitter cold of the Arctic, they need to develop highly efficient forms of clothing, shelter and fire. Unfortunately, there are few combustibles on a frozen wasteland so fire per se contributed in only a minor way to alleviate cold stress. Sea mammal oils could be burned for heating and cooking to only a minor extent. Far more significant were technological developments in clothing, including air tight parkas and boots. Clothes, such as parkas, were made of seal or other animal skins that provided warmth while dissipating heat. Shelter that is waterproof but retains heat, use of seal oil lamps, sharing of body heat and diet are all developments or behaviors that these populations used to survive the cold (Moran, 1981:6).

Although the Inuit developed a highly efficient microclimate to buffer them from the effects of cold, they still had to go out into the bitter cold of winter to hunt sea mammals. This involved exposure of the face and hands although the core was mostly protected by well-designed clothes. Visors were also developed to filter out sunlight reflecting off of the snow, allowing better visibility and avoiding snow blindness while hunting (de Poncins, 1941). Northern Siberian populations have similar tools, clothing, footwear and homes as Eskimo populations. Gurvich (1979) notes that indigenous Siberian populations, the Koryak and Chukchi, have parkas with a small breast of fur that protects the front of the parkas near the throat from the moisture of breathing. This same breast piece can be found among Eskimos, the Tlingits and Plains Indians (Gurvich, 1979:33). Additionally, specific embellishments on clothing among Koryak women, specifically rosettes, are widespread among their Eskimo neighbors as well as leather strips that are manufactured in a distinct manner.

There are many similarities found between Eskimo populations and northern Siberian populations. These can range from tools, to folklore and even death rituals. There are numerous migration models that exist to explain how the Americas were populated. One thing that most of these models have in common is that a land bridge existed between northeastern Siberia and Alaska which allowed nomadic hunters from Siberia to cross over and populate the New World (Goebel et al., 2008, Vasil'ev et al., 2002). How long ago they crossed over, the number of migrations existed and the method they used to cross the land bridge are matters up for discussion. What needs to be emphasized here is that the groups populating the New World came from Siberia and were already cold adapted and had been for a very long time.

All of the comparisons of stature, relative limb proportion and robusticity indicate that the inhabitants of Golovnin Bay and Nunivak Island were indeed cold adapted, much like other circumpolar groups. This is clearly evident in the significant differences found between these two populations and populations from much different environments such as Africa or Europe (except for the Pygmy populations in terms of stature). Africa has a much hotter climate and is in much lower latitude than the Arctic and while Europe is also in lower latitude, the climate is more temperate. The different kinds of environmental pressures can influence the plasticity of the human body, which is evident in my results but other factors can also play into the development of long bones as well. Malnutrition is a stressor that has little impact or only impacts a population for a short period of time. This would not be reflective in a large population covering a long time span (Holliday and Hilton, 2010).

Numerous studies have been conducted on cold modification of the body, with special emphasis on cranio-facial morphology. Cranio-facial architecture associated with cold adapted groups is characterized as “being dominated by a long, low, often narrow nose flanked with a large protrusive malars (making a relatively long flat face) and heavy jaws. Cephalic or cranial form ranges from long to round, and they also tend towards large heads and bodies and relatively short, sturdy legs” (Stegmann and Platner, 1968:28). To test this assumption, experimental studies on rats subjected to cold had a suite of significantly different measurements than their normal temperature counterparts. The cold temperature rats had narrower nasal passages, shorter sagittal neuro-cranial length and a longer face, shorter and broader malars, and femurs that were shorter, more curved and of greater robusticity (Stegmann and Platner, 1968:28). Subsequent studies

of humans have not found a relationship between facial morphology and cold climate. Steegmann (1970) notes there is no evidence for the “cold adapted Mongoloid face” with his experiment involving Japanese and European subjects. Instead, it was suggested that “the external features of the Mongoloid face are less a response to cold stress than a result of internal structural configurations” (So, 1980:66). Morphological changes such as increased malar size could be due to biting force rather than cold climate, etc. We see an increase in malar size among in these Arctic populations around the same time that they moved into colder climates and started modifying cultural practices to adapt to the temperature change (i.e. processing seal skin using their teeth as tools) (So, 1980).

Other studies on cranial morphology and size demonstrated that “climatic adaptation was observed in populations living under extreme cold conditions” (Hubbe et al., 2009:1728; Roseman, 2004, Harvati and Weaver, 2006), meaning that there are not significant differences in cranial morphology and size among populations in temperate regions but that significant changes can be seen in those living in severe climatic conditions. These same studies also confirm that anatomical differences are affected by population history, which they assume is related to geographic distance and share ancestry. Interestingly, populations living in the colder parts of Siberia (Northeast Asia) are remarkably similar in terms of postcranial and cranial morphology (Hubbe et al., 2009).

In discussing Pleistocene migration routes into the Americas, Hall et al. (2004:136) talks about the biological implications of cold adaptation, including immediate responses such as shivering and vasoconstriction but states that over time “changes in metabolic rate, body weight and the amount of fat can also occur.” This can

happen to any person regardless of age but the greatest change is observed in developmental responses in children, who develop improved physiological capacities, like an enhanced ability to keep extremities, such as fingers and toes, warm or a change in their growth patterns (Hall et al., 2004:136). Elevated metabolic rates are not only seen in Arctic populations but among cold adapted Siberian populations as well, supporting the fact that these Pleistocene populations that moved into the New World came from already cold-adapted Siberian populations (Leonard et al., 2005).

Much like the sickle cell gene is a response to malarial environments, the shortening of limbs and subsequently stature are bodily responses to an extremely cold environment. It allows for a higher chance of survival in the freezing and severe climate when coupled with behavioral modifications such as clothing, fire and shelter. Additionally, the robusticity seen in the tibias of both males and females from Golovnin Bay and Nunivak Island exemplify that both groups were used to navigating through rough terrain and hunting large game. Alaskan Eskimo populations, including Nunivak Island and Golovnin Bay display all the signs of cold adaptation culturally, physiologically, and morphologically.

CHAPTER NINE: CONCLUSIONS

My first hypothesis was that Golovnin Bay and Nunivak Island did not differ significantly from other Arctic populations in terms of stature, relative limb proportions and robusticity of the major long bones. The first goal was to compare the two Alaskan Inuit samples to other Arctic populations for a number of postcranial measurements and indices. The results of these analyses demonstrated that populations from Golovnin Bay and Nunivak Island had statures, limb proportions and measures of long bone robusticity that were generally consistent with other Arctic populations, thus supporting my first hypothesis.

My second hypothesis was that the Alaskan samples would differ significantly from populations living in warm climates for stature, relative limb proportions and robusticity. The results were also compared to other world populations to determine how climate or latitude was correlated with height, limb proportions, and postcranial robusticity. These comparisons illustrate marked differences in postcranial variables between Arctic groups and warm climate populations, illustrating the cold adapted postcranial skeleton of the Golovnin Bay and Nunivak Island populations also supporting my second hypothesis.

Stature, relative limb proportion and robusticity are interconnected. The results of the comparisons to other Arctic and world populations highlights the level of cold adaptation that the populations from Golovnin Bay and Nunivak Island possess. Their short, yet robust limbs were beneficial in an extreme, cold environment. Short limbs and stature help conserve body heat while robust long bones are associated with a highly stressful subsistence lifestyle aimed at marine and terrestrial mammals and fish.

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Appendix A: Table with Description of Long Bone Measurements Used

Bone	Measurement	Description
Humerus	Maximum length (HML)	Osteometric board - head placed against fixed vertical of board and movable upright is adjusted to distal end
	Maximum diameter midshaft (MDS)	Sliding calipers - exactly mid-length
	Minimum diameter midshaft (MDM)	Sliding calipers - taken at right angle to maximum diameter
	Maximum diameter of head (MDH)	Sliding calipers - taken from point on edge of articular surface across opposite side
	Epicondylar breadth (EBR)	Sliding calipers - maximum distance across epicondyles on distal end
	Least circumference of shaft (LCS)	Steel tape - taken at second third of shaft, distal to deltoid tuberosity
Radius	Maximum length (RML)	Osteometric board - maximum length from head to tip of styloid process
	Anterior/posterior diameter of shaft (RSD)	Sliding caliper - distance from anterior to posterior surface of midshaft
	Medial/lateral diameter of shaft (RTD)	Sliding calipers - distance between lateral and medial surfaces of midshaft
	Neck shaft circumference (MCS)	Steel tape - taken at point superior to radial tuberosity
Ulna	Maximum length (UML)	Osteometric board - maximum length from top of olecranon process to tip of styloid process

	Anterior/posterior diameter of shaft (UAD)	Sliding calipers - maximum diameter of diaphysis where crest exhibits greatest development
	Medial/lateral diameter of shaft (UMD)	Sliding calipers - diameter measured perpendicular to antero-posterior diameter at level of greatest crest development
	Least circumference of shaft (ULC)	Steel tape - taken above distal epiphysis
Femur		
	Maximum length (FML)	Osteometric board - distal condyles placed against fixed vertical and movable upright to the head
	Bicondylar length (FOL)	Osteometric board - both condyles in contact with fixed vertical
	Anterior/posterior diameter midshaft (APL)	Sliding calipers - taken at midshaft point
	Medial/lateral diameter midshaft (APM)	Sliding calipers - taken at right angle to anterior-posterior diameter
	Maximum horizontal diameter of head (HHD)	Sliding calipers - maximum diameter in horizontal plane passing through axis of neck
	Epicondylar breadth (FEB)	Sliding calipers - measured over outstanding points of epicondyles
	Circumference midshaft (FCS)	Steel tape - measured at midshaft at same level as anterior-posterior and medial-lateral diameters
Tibia		
	Condylar-malleolar length (TML)	Osteometric board - end of malleolus against vertical wall, bone on dorsal surface, block applied to most prominent part of lateral half of lateral condyle
	Circumference at nutrient foramen (TCF)	Steel tape - measured at level of nutrient foramen

Anterior/posterior diameter of nutrient foramen	Sliding calipers - maximum anterior-posterior diameter of shaft at nutrient foramen
Medial/lateral diameter of nutrient foramen	Sliding calipers - maximum transverse diameter at right angle to anterior-posterior diameter
Fibula	
Maximum length (BML)	Osteometric board - maximum distance between proximal and distal extremities

Appendix B: Additional Tables

TABLE A. Stature reconstruction formulae using long limb bones, separated by author

Author	Formulae	SE
Trotter and Gleser: Males – Asian	$St = 2.68 * Hum + 83.19 \text{ cm.}$	4.25
	$St = 3.54 * Rad + 82.00 \text{ cm.}$	4.60
	$St = 3.48 * Uln + 77.45 \text{ cm.}$	4.66
	$St = 2.15 * Fem + 72.57 \text{ cm.}$	3.80
	$St = 2.40 * Fib + 80.56 \text{ cm.}$	3.24
	$St = 1.22 * (Fem + Tib) + 70.37 \text{ cm.}$	3.24
<hr/>		
Neumann and Waldman: Males -	$St = 1177.29 \text{ mm.} + 1.134 * Fem \text{ mm.}$	-
Hopewellian and Mississippi Amerindians	$St = 1117.34 \text{ mm.} + 1.489 * Tib \text{ mm.}$	-
	$St = 1100.56 \text{ mm.} + 0.706 * (Fem + Tib) \text{ mm.}$	-
<hr/>		
Neumann and Waldman: Females	$St = 1091.76 \text{ mm.} + 1.201 * Fem \text{ mm.}$	-
	$St = 876.81 \text{ mm.} + 2.018 * Tib \text{ mm.}$	-
	$St = 828.49 \text{ mm.} + 0.992 * (Fem + Tib) \text{ mm.}$	-
<hr/>		
Pearson: Males - General	$St = 81.306 + 1.880 * Fem \text{ cm.}$	-
	$St = 70.641 + 2.894 * Hum \text{ cm.}$	-
	$St = 78.664 + 2.376 * Tib \text{ cm.}$	-
	$St = 85.925 + 3.271 * Rad \text{ cm.}$	-
	$St = 71.272 + 1.159 * (Fem + Tib) \text{ cm.}$	-
	$St = 71.443 + 1.220 * Fem + 1.080 * Tib \text{ cm.}$	-
	$St = 66.855 + 1.730 * (Hum + Rad) \text{ cm.}$	-
	$St = 69.788 + 2.769 * Hum + .195 * Rad \text{ cm.}$	-
	$St = 68.397 + 1.030 * Fem + 1.557 * Hum \text{ cm.}$	-
	$St = 67.049 + 0.913 * Fem + 0.600 * Tib + 1.225 * Hum - 0.187 * Rad \text{ cm.}$	-
<hr/>		
Pearson: Females	$St = 72.844 + 1.945 * Fem \text{ cm.}$	-
	$St = 71.475 + 2.754 * Hum \text{ cm.}$	-
	$St = 74.774 + 2.352 * Tib \text{ cm.}$	-
	$St = 81.224 + 3.343 * Rad \text{ cm.}$	-
	$St = 69.154 + 1.126 * (Fem + Tib) \text{ cm.}$	-
	$St = 69.561 + 1.117 * Fem + 1.125 * Tib \text{ cm.}$	-
	$St = 69.911 + 1.628 * (Hum + Rad) \text{ cm.}$	-
	$St = 70.542 + 2.582 * Hum + 0.281 * Rad \text{ cm.}$	-

	$St = 67.435 + 1.339 * Fem + 1.027 * Hum \text{ cm.}$	-
	$St = 67.469 + 0.782 * Fem + 1.120 * Tib + 1.059 * Hum - 0.711$ $* Rad \text{ cm.}$	-
<hr/>		
Auerback and Ruff: Males -	$St = 0.225 * FBL + 62.73$	2.9
Arctic Region	$St = 0.255 * TML + 69.51$	2.99
	$St = 0.128 * FBL + 0.126 * TML + 59.86$	2.62
<hr/>		
Auerback and Ruff: Females	$St = 0.213 * FBL + 64.82$	2.99
	$St = 0.231 * TML + 74.71$	3.01
	$St = 0.117 * FBL + 0.120 * TML + 64.00$	2.82
<hr/>		
Genoves: Males -	$St = 2.26 * Fem + 66.379$	2.61
Mesoamericans	$St = 1.96 * Tib + 93.752$	2.81
<hr/>		
Genoves: Females	$St = (2.59 * Fem + 49.742) - 2$	3.82
	$St = (2.72 * Tib + 63.78) - 2$	3.51
<hr/>		

TABLE B. Relative limb proportion indices for males in diverse environmental settings from Porter (1999), Holliday and Hilton (2010) and Mizoguchi (2003).

Males				
	Intermembral Index	Brachial Index	Crural Index	Humero-femoral Index
Puebloan	69.6	76.8	84.4	72.6
Bohemia	68.9	75.4	83.3	72.1
Germany	68.8	76.9	82.6	71.0
Norse	70.3	76.9	79.0	71.1
Romano-British	70.2	75.4	81.6	72.7
Anglo-Saxon	69.7	75.5	82.6	72.5
France	68.3	76.1	84.3	71.5
Bosnia	68.1	75.3	83.7	71.4
Euro-American	68.2	74.3	83.5	71.8
Egypt	67.8	78.5	85.2	70.3
Nubia	68.5	79.1	86.2	71.3
Kerma	68.2	79.2	85.1	70.4
W. Africa	68.5	81.5	85.8	70.1
San	66.8	77.6	84.4	69.3
Pygmy	70.8	76.4	85.6	74.5
E. Africa	68.8	79.3	86.3	71.4
African-American	68.8	78.1	85.6	71.6
Gurkhas	66.8	65.4	87.9	79.8
Bantu	66.6	66.5	91.1	80.4
Jomon	68.5	80.4	83.8	69.8
Modern Japanese	70.0	75.3	80.5	72.0
Golovnin Bay	69.7	74.5	80.2	71.9
Nunivak Island	69.5	74.9	79.4	71.3

TABLE C. Results of relative limb proportion indices for females from diverse regions from Holliday and Hilton (2010) and Mizoguchi (2003).

Females				
	Intermembral Index	Brachial Index	Crural Index	Humero-femoral Index
Ipiutak	69.6	73.1	79.8	72.3
Tigara	66.4	74.4	82.4	69.5
Koniag	70.2	75.9	80.2	71.9
Puebloan	69.5	76.9	83.8	72.2
Bohemia	68.9	73.8	82.7	72.1
Germany	69.0	75.8	82.6	71.9
Norse	69.6	75.1	83.9	73.1
Romano-British	67.9	74.7	81.5	70.6
Anglo-Saxon	69.2	73.3	82.9	73.1
France	69.3	73.9	83.8	73.2
Bosnia	67.8	73.5	83.4	71.7
Euro-American	67.2	73.3	83.2	71.1
Egypt	67.3	78.5	85.1	69.7
Nubia	67.0	75.8	83.9	70.1
Kerma	67.5	78.4	84.7	69.9
W. Africa	68.6	80.0	85.1	70.5
San	65.3	76.1	84.3	68.3
Pygmy	70.7	77.1	85.5	74.0
E. Africa	68.3	78.5	86.1	71.2
African-American	68.0	76.6	84.6	71.1
Jomon	67.9	78.9	83.9	69.8
Modern Japanese	70.6	73.2	83.6	74.9
Golovnin Bay	67.4	72.8	80.5	70.4
Nunivak Island	68.3	70.7	77.7	71.0

TABLE D. Indices of diaphyseal robusticity from Pearson (2000a): males

	Author	Humerus	Radius	Ulna	Femur	Tibia
Mesolithic	Pearson	13.8 ± 1.3	12.3 ± 1.2	12.3 ± 1.2	13.2 ± 0.7	16.2 ± 0.7
Sami	Pearson	13.7 ± 0.9	13.0 ± 1.0	13.0 ± 0.8	13.0 ± 0.6	15.5 ± 0.9
U.S. white	Pearson	13.1 ± 0.9	12.6 ± 1.1	12.7 ± 1.1	12.6 ± 0.8	15.1 ± 1.2
Inuit	Pearson	13.6 ± 1.1	12.4 ± 1.0	12.4 ± 1.0	13.3 ± 0.7	16.1 ± 1.0
Chinese	Pearson	12.6 ± 1.0	11.5 ± 0.9	12.0 ± 1.0	12.3 ± 0.8	14.6 ± 0.8
Khoisan	Pearson	11.1 ± 0.9	10.3 ± 1.0	10.8 ± 1.1	12.5 ± 0.7	14.6 ± 1.1
Jebel Sahaba	Pearson	-	-	10.7 ± 0.4	-	14.7 ± 0.5
Zulu	Pearson	13.0 ± 0.9	11.4 ± 1.0	11.8 ± 0.9	12.5 ± 0.6	14.9 ± 0.9
African American	Pearson	12.8 ± 0.9	11.9 ± 1.0	12.3 ± 0.9	12.3 ± 0.8	14.3 ± 0.8
Australian	Pearson	13.2 ± 0.8	11.5 ± 1.0	11.3 ± 1.1	12.2 ± 0.7	14.4 ± 1.1
Golovnin Bay		13.3 ± 1.0	11.7 ± 1.1	12.0 ± 1.1	13.5 ± 1.1	16.8 ± 1.3
Nunivak Island		13.9 ± 1.3	11.6 ± 1.0	11.9 ± 1.3	13.1 ± 0.6	17.0 ± 1.4

TABLE E. Indices of diaphyseal robusticity from Pearson (2000a): females

	Author	Humerus	Radius	Ulna	Femur	Tibia
Mesolithic	Pearson	12.6 ± 1.5	11.3 ± 0.9	11.1 ± 0.8	12.6 ± 0.4	14.1 ± 0.9
Sami	Pearson	12.6 ± 0.7	12.8 ± 1.2	12.3 ± 0.8	12.6 ± 0.8	15.1 ± 1.0
U.S. white	Pearson	11.7 ± 1.2	11.9 ± 1.2	11.4 ± 1.1	12.3 ± 0.9	13.9 ± 1.0
Inuit	Pearson	12.3 ± 0.8	11.7 ± 0.9	11.7 ± 0.9	13.0 ± 0.6	15.0 ± 0.8
Khoisan	Pearson	10.8 ± 0.9	10.2 ± 0.7	10.2 ± 0.8	12.0 ± 0.7	13.6 ± 1.2
Jebel Sahaba	Pearson	-	-	9.7 ± 0.6	-	-
Zulu	Pearson	11.9 ± 0.9	10.8 ± 0.7	11.3 ± 0.8	12.3 ± 0.7	14.3 ± 1.0
African American	Pearson	12.0 ± 1.0	11.1 ± 1.0	11.1 ± 1.0	12.0 ± 0.8	13.6 ± 1.0
Australian	Pearson	10.5 ± 1.0	10.0 ± 0.6	9.9 ± 1.3	11.4 ± 0.8	13.6 ± 0.7
Golovnin Bay		12.7 ± 0.8	10.3 ± 1.1	11.2 ± 1.0	13.0 ± 0.6	15.4 ± 0.8
Nunivak Island		12.8 ± 0.9	11.4 ± 0.7	11.2 ± 0.8	13.0 ± 0.5	16.6 ± 0.8