DOES MEAN OSTEON SIZE CHANGE WITH AGE, SEX OR HANDEDNESS? ANALYSIS OF THE SECOND METACARPAL IN A 19TH CENTURY SAMPLE FROM BELLEVILLE, ONTARIO, CANADA

by

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ABSTRACT

Histological analysis of cortical bone can be used to provide information on age at death, health status, and the influence of biomechanical forces on bones. Specifically, a better understanding of the variation in mean osteon size can increase our knowledge about the influence of factors such as age and sex associated changes and their effects on bone metabolic functions. Previous studies suggest that these influences are bone specific and have produced varying results regarding the association between osteon size and the variables mentioned above. To date, no research has focused on mean osteon size in metacarpals. The purpose of this study was to determine if there is any correlation between age, sex, or handedness and mean osteon size in the second metacarpal. The bones used in this study derive from a mid-nineteenth century cemetery in Belleville, Ontario, Canada. One hundred and eighty second metacarpals from 102 individuals (58 females and 44 males) representing both the left (n=93) and right (n=87) sections were examined histologically to determine mean osteon size. No association was found between mean osteon size and either age or handedness. However, a statistically significant difference in mean osteon size between males and females was found at a 95% confidence level, with a p-value of 3.6×10^{-8}.

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CHAPTER ONE: INTRODUCTION

Bone histomorphometry or quantitative bone histology has been used by bone biologists to estimate age at death, infer the health status of an individual, and study the effects of varying degrees of biomechanical stress on bones. This information is important to anthropologists because it can provide insight into how the human skeleton adapts to changing lifestyles in past and present populations.

Throughout life, human bones undergo remodeling, the renewal of discrete packets of bone called osteons. These osteons are known to vary in size between bones and even within the same bone (Evans and Bang, 1967). The size of osteons is thought to be determined by multiple factors, both intrinsic and extrinsic such as age, sex and biomechanical strain. Therefore, osteon size has the potential to provide information about the influence of these three factors. The purpose of this research is to investigate the association between these variables and mean osteon size in the second metacarpal in a 19th century Euro-Canadian sample.

This large sample of known age, sex, and ancestry offers a unique opportunity to study bone biology in a population that lived labor intensive lives. Most individuals were immigrants of European descent (Saunders, DeVito, Herring, Southern, and Hoppa, 1993; Lazenby, 1994; Jimenez, 1994; Saunders et al., 2002). In this population, men are believed to have experienced high levels of mechanical loading in their hands as a consequence of the manual manipulation required in occupations such as logging, factory

work, and the railroad industry (Jimenez, 1994; Lazenby, 1994). In particular this sample provides an opportunity to study the bone microstructure of the second metacarpal, for the first time.

Studies addressing patterns of change in mean osteon size have produced varied results. Some research has reported a decrease in osteon size with age in the rib, femur and humerus (Currey, 1964; Burr, Ruff, and Thompson, 1990; Yoshino, Imaizumi, Miyasaka, and Seta, 1994), while others have found no statistically significant age associated change in the rib and femur (Landeros and Frost, 1964; Hattner, Landeros, and Frost, 1965; Takahashi, Epker, and Frost, 1965; Jowsey, 1966; Pfeiffer, 1998). Yet others document an increase in mean osteon size in the femur and tibia (Black, Mattson, and Korostoff, 1974; Burr et al., 1990). Differences between males and females and the influence of handedness are other factors that may potentially influence osteon size. Little research has focused on sex and side differences, the current study presents an opportunity to address these questions.

To asses this three hypotheses were tested:

1) Null hypothesis 1 (H_o 1) states that there is no statistically significant change in mean osteon size with increasing age in the second metacarpal. Alternative hypothesis 1 (H_a 1) states that there is a statistically significant change in mean osteon size with increasing age in the second metacarpal.
2) H_o 2 states that there is no statistically significant difference in mean osteon size between males and females in the second metacarpal. H_a 2 states that there is a

statistically significant difference in mean osteon size between males and females in the second metacarpal.

3) H_o3 states that there is no statistically significant difference in mean osteon size between left and right second metacarpals. H_a3 states that there is a statistically significant difference in mean osteon size between left and right second metacarpals.

Determination of the relationship between osteon size and age has the potential to clarify if the diminished tissue function associated with aging has an effect on mean osteon size (Frost, 1963). Sex related differences may provide information about the types and levels of mechanical loading being encountered by males and females. Differences in osteon size between left and right second metacarpals could indicate a difference in overall size of the bone being tested, or differences in mechanical loading experienced by the hands.

The organization of this research is as follows: Chapter Two discusses the functions of bone, gross and microanatomy of bones, metacarpals, growth, modeling, and remodeling and the factors that affect remodeling. The last two sections examine factors that influence mean osteon size and previous studies that have focused on it. Chapter Three discusses the sample being used for this study, including previous research this sample was included in, and the methods for this project. Chapter Four provides the results of the study. Chapter Five includes the discussion and conclusions.

CHAPTER TWO: BACKGROUND

Functions of Bone

Bones are the support system for the body. As a result they must be extremely strong while at the same time sufficiently lightweight so that the individual can move without expending excessive energy (Marieb, 2004). Like all weight bearing materials damage can occur over time due to stress and fatigue. Unlike non-biological materials, bone has the capacity to self-repair microdamage and fatigue through remodeling (Parfitt, 2003; Taylor, Hazenberg, and Lee, 2007). Bones provide support and protection for organs like the brain, spinal cord and organs of the thorax. They also aid in movement of the body (Parfitt, 2003; Marieb, 2004). Other functions include mineral storage (two of the most important of which are calcium and phosphate) and blood cell formation (hematopoiesis) (Marieb, 2004). Wolff's law, or the Law of Bone Transformation states that bone is laid down in areas where needed and is resorbed where it is not needed. This is because bone is metabolically expensive for the body to maintain in places it is not required (Wolff, 1869). The balance between strength and economy is achieved through the processes of modeling and remodeling.

Composition of Bone

Bone is comprised of two materials: collagen and hydroxyapatite. Collagen makes up a large portion of the organic content of bone. It is responsible for the elasticity, flexibility and tensile strength of bones, as well as their ability to withstand torsional

forces. Hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$), the inorganic component in bone is a dense form of calcium phosphate that gives the bones their strength and allows bone to resist compression. The mixture of collagen and hydroxyapatite allows bone to be extremely strong yet pliable (Marieb, 2004).

Gross Anatomy of Bone

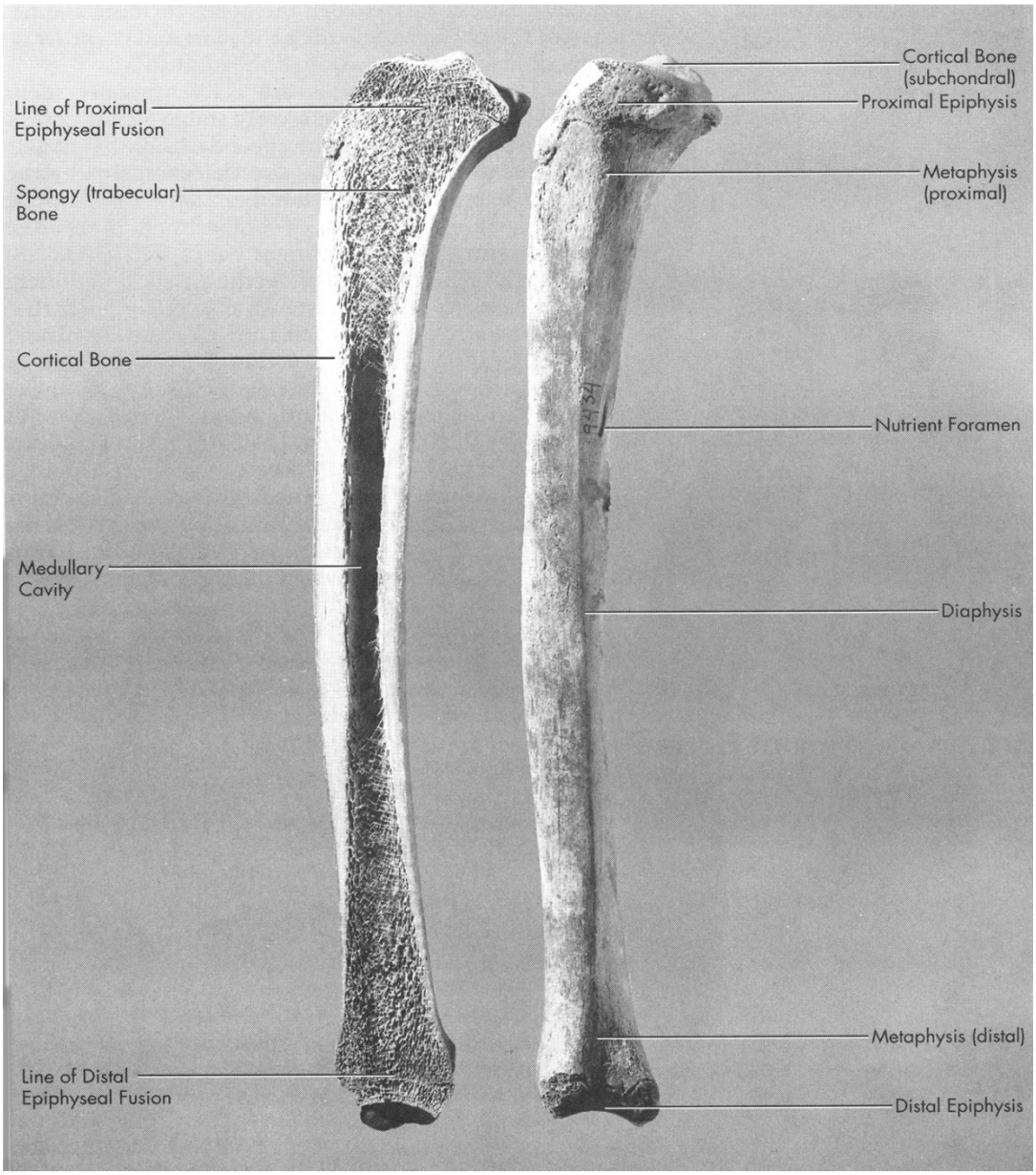

Figure 2.1 Gross Anatomy of Bone (White and Folkens, 2000)

Bone can be categorized in many ways: trabecular and cortical, or primary and secondary. Trabecular (spongy) bone develops in the ends of long bones (epiphyses), and in the flared part of the bone shaft (metaphysis) (Fig. 2.1) and has a porosity of about 75-95%. Trabecular bone is also found in vertebral bodies, beneath tendon attachment points, and within flat bones, such as the skull and pelvic bones (Marieb, 2004; Taylor et al., 2007). It is made up of thin plates or struts called trabeculae that form a lightweight but strong matrix (Martin, Burr, and Sharkey, 1998; Marieb, 2004). Cortical bone is much denser than trabecular bone and is found in the diaphysis, or shaft, of long bones and on all external bone surfaces. It is much less porous than trabecular bone with about 5-10% porosity (Martin et al., 1998; Taylor et al., 2007).

Bone can be also be categorized as primary and secondary bone. Primary bone is forms during growth and modeling on preexisting bone surfaces and can take the form of either circumferential lamellar bone or woven bone. Circumferential lamellar bone is laid down parallel to the bone surface, such as beneath the periosteum (Martin et al., 1998). It is well organized and deposited in layered sheets. Woven bone forms the primary spongiosa that is present when bones are initially forming. It forms at a faster rate, is poorly organized, and is weaker than lamellar bone. Woven bone formation is present during periods of rapid deposition, such as in tumor growth, and in trauma and pathological conditions (Martin et al., 1998). Secondary bone is produced through remodeling, the replacement of discrete packets of bone. The product of remodeling takes the form of secondary osteons, or Haversian systems (Martin et al., 1998).

The outer surfaces of bones are covered by a fibrous membrane called the periosteum. This thin two layered fibrous tissue helps nourish the bone (Fig. 2.2). The

fibrous outer layer is comprised of dense, irregular connective tissue. The inner osteogenic layer consists primarily of bone lining cells. Under the periosteum is cortical bone, followed by a similar fibrous tissue layer called the endosteum. The endosteum lines the trabeculae of spongy bone and the medullary cavity (Marieb, 2004).

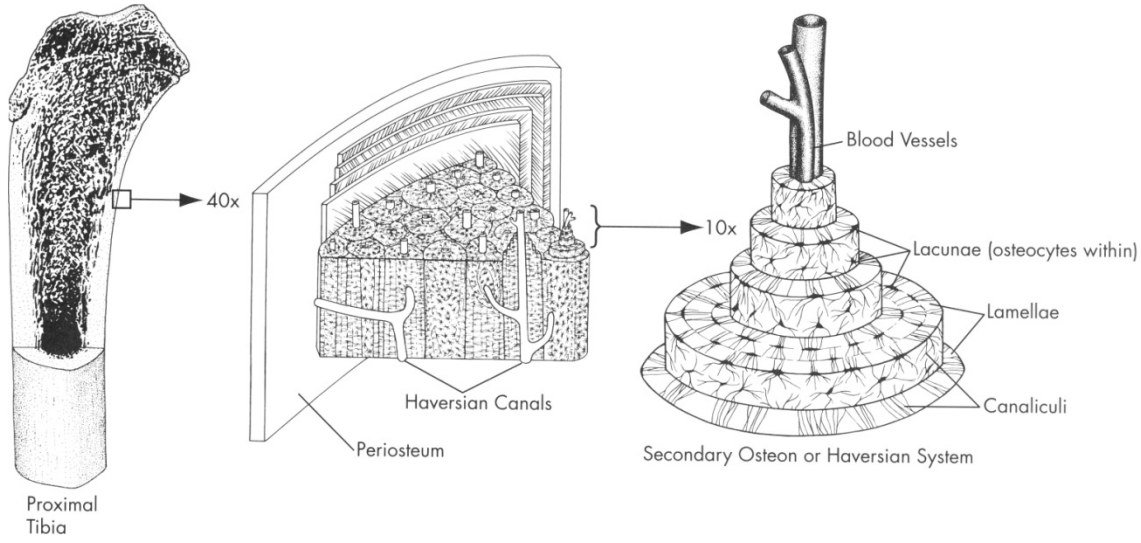

Figure 2.2 Cross Section of a Long Bone (White and Folkens, 2000)

Metacarpals

Metacarpals are cylindrical bones that support the palm of the hand (Fig. 2.3). Though small, their morphology resembles that of long bones. The diaphysis of the metacarpal is identical to the diaphysis of a long bone. It is covered by the periosteum on the outside. Underneath the periosteum is cortical bone. The central marrow cavity is lined by the endosteum. (Marieb, 2004; Bass, 2005). There are five metacarpals numbered I though V beginning on the lateral, or thumb side. The proximal end articulates with the carpals, or wrist bones, and the distal end attaches to the phalanges, or finger bones. The shaft, or middle section of the bone is cylindrical. There is a slight

concavity on the palmar side of metacarpals. The second metacarpal is typically the longest of the metacarpals and has a wide, deep base (Steele and Bramblett, 1988).

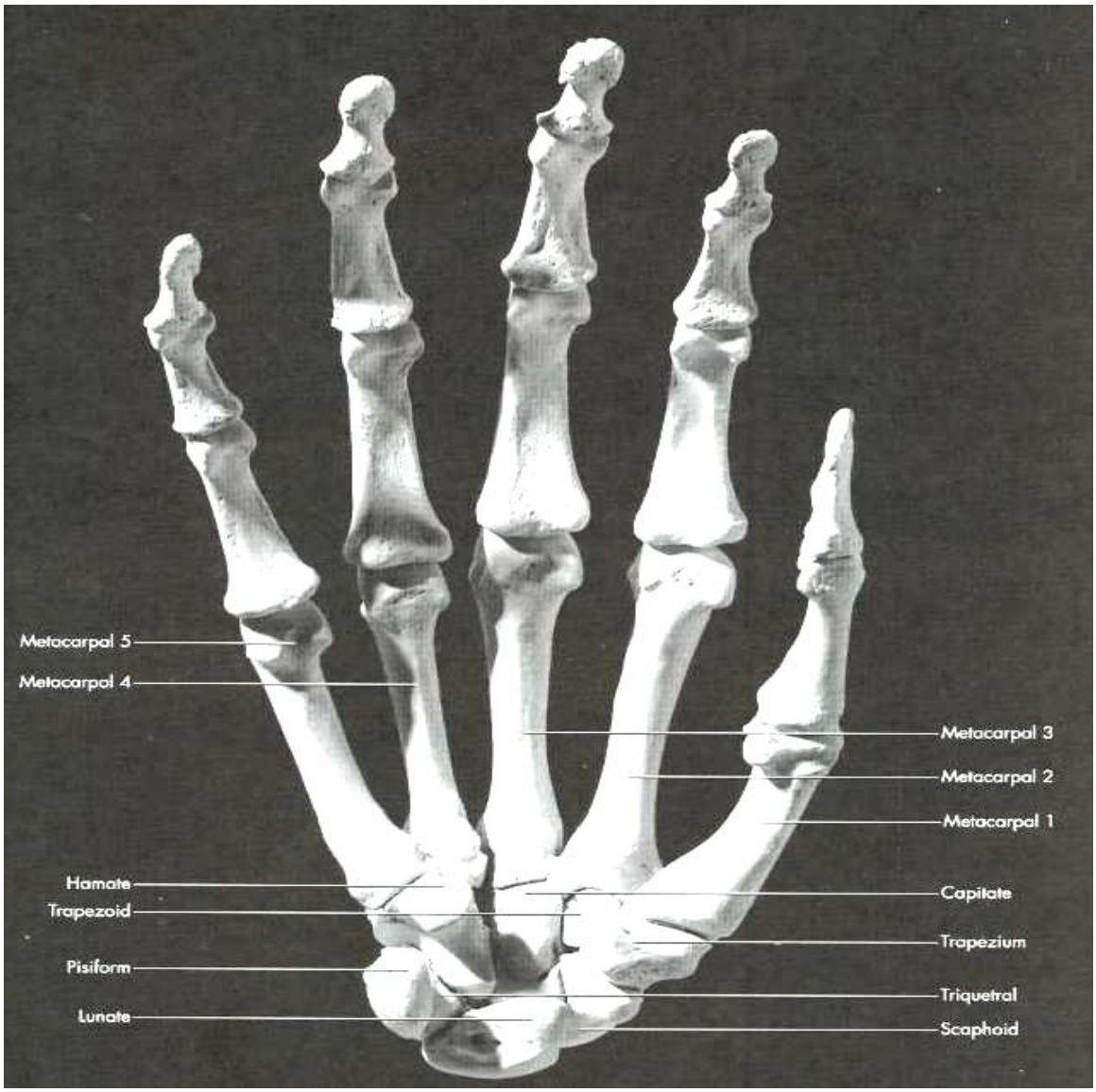

Figure 2.3 Bones of the Wrist and Hand (White and Folkens, 2000). This view is from the palmar side.

Metacarpals have been used in studies about sex identification, cross sectional geometry, variation in cortical thickness, sexual dimorphism, handedness, remodeling,

and disease related changes in bone mass (Lazenby, 1994, 1998; Sato, Asoh, and Oizumi, 1998a; Sato, Fujimatsu, Honda, Kunoh, Kikuyama, and Oizumi, 1998b; Nielsen, 2001; Lazenby, 2002a, 2002b; Lazenby, Cooper, Angus, and Hallgrimsson, 2008). They can indicate handedness of individuals and what side, if any, is undergoing increased mechanical loading. Metacarpals can provide further information about the roles of males and females in populations and the kinds of work they are doing.

Bone Cells

There are four types of bone cells: osteoblasts, osteocytes, bone lining cells, and osteoclasts (Martin et al., 1998). Osteoblasts are mononuclear cells responsible for laying down new bone matrix, or osteoid, the non-mineralized organic component of bone. Osteocytes are mature osteoblasts that have become encased in the bone matrix in small spaces called osteocytic lacunae. Osteocytes serve to maintain bone tissue, detect mechanical stress, transport minerals in and out of bone, and communicate with other bone cells (Martin et al., 1998). Bone lining cells are osteoblasts that became flattened on bone surfaces. They initiate remodeling in response to chemicals and mechanical stimuli (Miller and Jee, 1992; Martin et al., 1998). Osteoclasts are multinuclear cells that resorb bone (Martin et al., 1998; Taylor et al., 2007).

Growth and Modeling

Bones grow, are shaped and maintained through the processes of growth, modeling and remodeling, which take place throughout life. Skeletal development occurs through growth and modeling. Growth is the process by which the length and diameter of the bone is increased both internally and externally as determined by the genetic code

(Martin et al., 1998). Modeling works with growth to shape bone (Frost, 1985) and is defined by either the activation of bone forming cells (A-F) resulting in the addition of new bone, or the activation of bone resorbing cells (A-R) which leads to the resorption of bone on selective bone surfaces (Frost, 1985; Parfitt, 2003).

Remodeling

The focus of this study is the mean osteon size of secondary osteons which are the product of bone remodeling (Frost, 1985; Martin et al., 1998). This is the process by which discrete packets of bone are resorbed and replaced with new bone. Knowledge of remodeling provides information on how the skeleton repairs itself, how it adapts to changes in mechanical strain, and how bones respond to disease, aging, hormones and nutritional deficiencies (Hattner et al., 1965; Jowsey, 1966; Wu, Schubeck, Frost, and Villanueva, 1970; Lacroix, 1971; Parfitt, 1979; Thomson, 1979; Frost, 1987a, 1987b; Burr and Martin, 1989; Ericksen, 1991; Martin, 1991; Slemenda, Peacock, Hui, Zhou, and Johnston, 1997; Martin et al., 1998; Sato et al., 1998a; Sato et al., 1998b; Martin, 2003). These factors are discussed in the next section. Remodeling serves to repair old or damaged bone by replacing it with new bone (Frost, 1985; Parfitt, 2003). Remodeling always occurs in an activation, resorption, formation order (the A-R-F sequence) (Martin et al., 1998). In a longitudinal section remodeling can be depicted as a cutting cone with osteoclasts in the lead resorbing bone (Fig. 2.4). Located behind the osteoclasts are osteoblasts that lay down the unmineralized boney matrix. This group of cells is collectively called the Basic Multicellular Unit (BMU) and is estimated to move about 40μm per day. Some of the osteoblasts are embedded in the new bone and become

osteocytes that serve to maintain mature bone (Frost, 1985; Martin et al., 1998; Taylor et al., 2007).

In cross section (as in a standard histological section) the initial stage of osteon formation, during which the removal of old bone occurs, osteons appear as the resorptive bay and are the result of the resorptive action of osteoclasts (Fig. 2.4). The formation stage of development exhibits a number of concentric lamellae with osteocytic lacunae containing the embedded osteocytes. The completed secondary osteon is composed of concentric rings of lamellae surrounding an Haversian canal containing blood vessels, nerves and lymphatic tissue (Frost, 1985). As previously stated, remodeling occurs at a baseline rate throughout life. A change in the rate of remodeling can indicate diseases processes, or the repair of accumulated microdamage caused by excess mechanical loading.

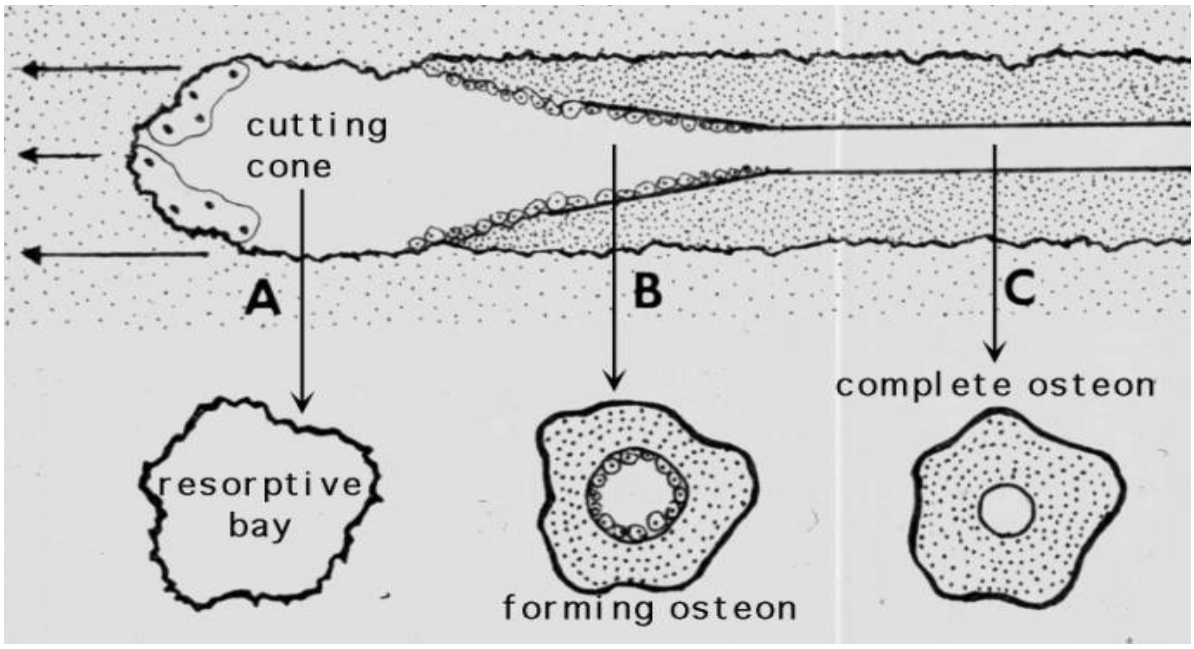

Figure 2.4 Forming Osteon (Robling and Stout, 2008)

Factors Affecting Remodeling

Osteons are the product of remodeling. There are many factors that can affect remodeling, especially the rate. Some these factors are age; sex; mechanical strain, including disuse and overuse; certain diseases; and nutritional deficiencies (Hattner et al., 1965; Jowsey, 1966; Wu et al., 1970; Lacroix, 1971; Parfitt, 1979; Thompson, 1979; Frost, 1987a, 1987b; Burr and Martin, 1989; Ericksen, 1991; Martin, 1991; Slemenda et al., 1997; Martin et al., 1998; Sato et al., 1998a; Sato et al., 1998b; Martin, 2003). During infancy remodeling rates are at their highest point then slowly decreases through childhood until adulthood is reached (Jowsey, 1960; Lacroix, 1971). At this point, a baseline rate of about 1 mm^2 per year is maintained, unless otherwise affected by activity or disease processes (Slemenda et al., 1997; Martin et al., 1998). Men have been shown to have higher remodeling rates than females (Thompson, 1979; Ericksen, 1991) while remodeling rates in menopausal women have been shown to increase (Parfitt, 1979).

Mechanical strain causes microdamage in bones that is repaired by remodeling (Frost, 1987a). Therefore with overuse and heavy mechanical loading remodeling rates increase (Martin, 2003). The same has also been found in cases of disuse, such as in individuals who are confined to bed (Frost, 1987b; Martin, 2003). There are also many pathogenic conditions that affect remodeling rates. For example, Osteogenesis Imperfecta (OI), hyperparathyroidism (HP), hemiplagia in stroke patients, Padget's disease, Osteomalacia, and thyroxine can all increase the rate of remodeling, while adreanal coricoids, increased estrogen, osteopetrosis, diabetes, and postmenopausal osteoporosis can all decrease remodeling rates (Frost, 1963; Wu et al., 1970; Burr and Martin, 1989; Ericksen, 1991; Martin, 1991). Nutritional deficiencies, such as vitamin D, increase the

amount of parathyroid hormone released, increasing remodeling. Vitamin D deficiency has also been linked to decreased bone mass density (Sato et al., 1998a). Although many studies have been done on the affects of disease and health on remodeling, no research has focused on their impact on mean osteon size.

Mean Osteon Size

The average size of an osteon, or the mean osteon size, includes bone formed within the reversal line of a whole, complete osteon. Mean osteon size has been determined for several human bones, such as the rib (Landeros and Frost, 1964; Hattner et al., 1965; Takahashi et al., 1965; Jowsey, 1966; Pfeiffer, 1998), the femur (Currey, 1964; Jowsey, 1966; Burr et al., 1990; Pfeiffer, 1998), the humerus (Yoshino et al., 1994), and the tibia (Black et al., 1974). It is important to remember that mean osteon size varies within a cross section of bone, as well as between bones of the body (Fig. 2.5) (Evans and Bang, 1967). In a number of studies mean osteon size has also been found to vary based on age, sex, and magnitude of mechanical strain (Currey, 1964; Jowsey, 1966; Burr et al., 1990; Yoshino et al., 1994).

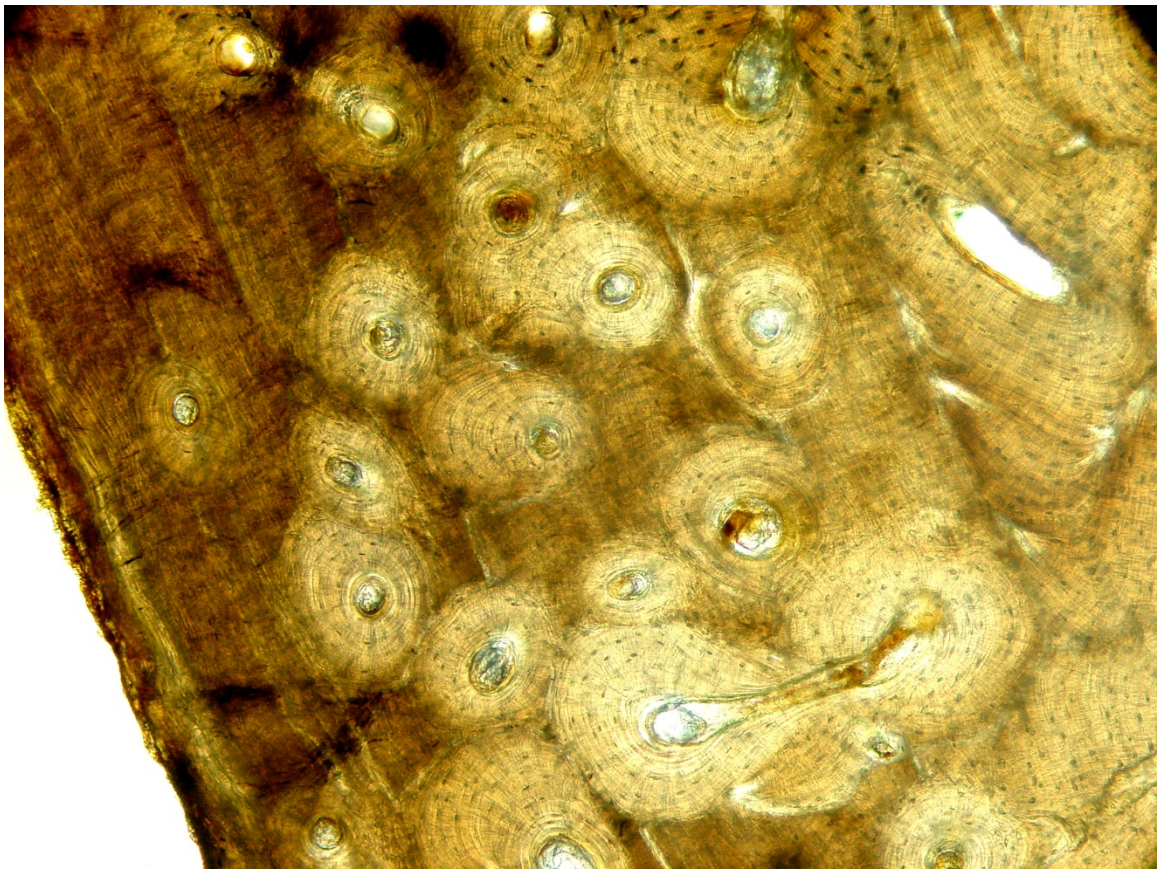

Figure 2.5 Cross Section of Bone Notice the variation in osteon size within this cross section.

Studies investigating the relationship between mean osteon size and age in several human bones have reached conflicting conclusions. Earlier studies did not use statistical tests, only means and standard deviations were provided (Landeros and Frost, 1964; Currey, 1964; Hattner et al., 1965; Takahashi et al., 1965; Jowsey, 1966; Black et al., 1974; Burr et al., 1990). Yoshino et al. (1994) and Pfeiffer (1998) used regression analysis and ANOVA, respectively, to analyze their data. Table 2.1 summarizes these studies. Landeros and Frost (1964) analyzed rib sections (n = 80) from metabolically normal individuals ranging in age from 0 to 80. They report a decrease in mean osteon size throughout life. Currey (1964) analyzed the bone sections of 19 femurs form

individuals ranging in age from 23-89 years. A decrease in mean osteon size was reported. The Jowsey study (1966) did not specify the number of rib sections used but provided an age range from 20-90 years. This study also found a decrease in mean osteon size with age. Yoshino et al. (1994) tested 40 humeral sections from males with an age range from 23-80 using a regression test with a significance level of .01. Their study also found a decrease in mean osteon size with age.

Hattner et al. (1965) analyzed human rib sections (n = 60), with an age range from 5-65 years and found no change in mean osteon size with age. Takahashi et al. (1965) used the rib (n = 130) in their study with an age range of 10-70 years and found no age related changes in mean osteon size as well. Jowsey (1966) used 26 femur sections with an age range of 20-90 years and also found no change in mean osteon size with age. Pfeiffer (1998) studied ribs and the femurs from two sites, Spitalfields, London (9 females, 26-37 years and 11 males, 25-50 years) and St. Thomas Anglican Church Cemetery in Belleville, Ontario, (7 females, 17-67 years and 14 males 20-81 years). A third sample included in Pfeiffer's study, originating from cadavers housed at the University of Cape Town, included only ribs (15 females and 15 females of mixed ancestry with an age range of 24-95 years). Statistical analysis was done using ANOVA with multiple p-values including .05, .02, and .01. No statistically significant changes in mean osteon size occurred with age in any of the samples analyzed by Pfeiffer.

In contrast to the studies cited previously Black et al. (1974) analyzed tibial sections from the Philadelphia Veterans Administration Hospital of unspecified sex (21-83 year) and found an increase in mean osteon size with age. However, this study utilized a very small sample (n = 7) and did not report the actual number of osteons

measured. Burr et al. (1990) investigated archaeological femurs from Pecos Pueblo, New Mexico (27 female, 22-60 and 28 males 21-60 years) and found that in males mean osteon size decreased with age, while in females it increased.

Based on these studies the association between mean osteon size and age is unclear. There was a wide range in sample sizes between all studies that may have played a role in the mixed conclusions. Others factors that could have added to this are the differences in how the results were analyzed, whether statistical tests were used, the sex of the sample, and the use of different bones. Studies on different bones cannot be compared to one another since mean osteon size differs between bones of the body (Evans and Bang, 1967).

Table 2.1 Results of Previous Studies of Mean Osteon Size

Study	Bone	Number of Individuals	# of Osteons	Sex	Age Range	Results
Landeros and Frost (1964)	Rib	80	All Osteons	Not Specified	0-80 yrs	Decrease
Currey (1964)	Femur	19	40	Not Specified	23-89yrs	Decrease
Hattner et al. (1965)	Rib	60	90-150	Not Specified	5-65yrs	No Change
Takahashi et al. (1965)	Rib	130	1,759 in Total	Not Specified	10-70yrs	No Change
Jowsey (1966)	Femur	26	100+	Not Specified	20-90yrs	No Change
Jowsey (1966)	Rib	Not Specified	100+	Not Specified	20-90yrs	Decrease
Black et al. (1974)	Tibia	7	Not Specified	Not Specified	21-83yrs	Increase
Burr et al. (1990)	Femur	28	All Osteons	Males	21-60yrs	Decrease
Burr et al. (1990)	Femur	27	All Osteons	Females	22-60yrs	Increase
Yoshino et al. (1994)	Humerus	40	Not Specified	Males	23-80	Decrease
Pfeiffer (1998)*	Femur	41	50	Combined	20-95	No Change
Pfeiffer (1998)*	Rib	71	50	Combined	17-95	No Change

*Sample from multiple sites, see text for details

Sex

Sex based differences in osteon size have been the focus of a number of studies. While Pfeiffer (1998) did not find sex related differences in osteon size Burr et al. (1990) observed smaller osteons in males than females in the archaeological sample from Pecos, New Mexico (Table 2.1).

Handedness

Most people are right handed and therefore experience more mechanical stress in the right hand than the left when engaged in activities that only require one hand. As a result, smaller osteon area might be expected on bones of the right hand based on the following model (Roy, Ruff, and Plato, 1994). van Ores et al. (2008) developed a computer model to explain the relationship between mechanical strain and mean osteon size. The authors propose that osteocytes sense mechanical strain. When the mechanical strain reaches a certain level osteocytes inhibit osteoclasts and increase osteoblast activity. Therefore, the space resorbed by osteoclasts should, theoretically, become smaller, decreasing the overall diameter of the osteon. An inverse relationship was found between mechanical strain and osteon size. van Ores et al. (2008) state that in a real life situation the same strength of inverse relationship would not necessarily be observed. Small mean osteon area may also indicate certain activities that place heavy mechanical loading on the hands.

Previous Studies on this Sample

This section discusses osteological studies that have been done on this 19th Euro-Canadian sample of metacarpals from St. Thomas Cemetery in Belleville, Ontario. Determination of mean osteons size is part of a larger collaborative study between

anthropologists at University of Montreal and Boise State University comparing cross-sectional geometry and histomorphometric analysis to gain insight into the metabolic history and mechanical strain encountered by individuals.

Lazenby (1994) examined the affects of asymmetry in sex identification by applying a method developed by Scheuer and Elkington (1993). This method tested metacarpals I through V for sex identification based on gross osteometric measurements on a sample of metacarpals from cadavers of known sex, side was not specified. They found the second metacarpal to be the most reliable of all metacarpals for sex identification with a correct identification rate of 79%. Scheuer and Elkington (1993) also found that in males the second metacarpal was larger on the right side, especially for individuals thought to be right handed. When comparing right and left second metacarpals in left handed individuals the degree of asymmetry was significantly decreased, but the right second metacarpal was still found to be slightly larger. These results were found in females as well (Garn, Mayor, and Shaw, 1976; Plato and Purifoy, 1982; Scheuer and Elkington, 1993). Lazenby tested Scheuer and Elkington's (1993) method for sex identification on this sample of second metacarpals and found a 90% correct identification rate for males with better results found in the larger right second metacarpal. In females only a 65% overall identification rate was seen, with a higher identification rate on the smaller left second metacarpal (Lazenby, 1994). Therefore, sex identification based on the second metacarpal can a useful tool.

An additional study by Lazenby (2002a) analyzed variation of cortical wall thickness in the palmar, medial, lateral, and dorsal cortices of the second metacarpal, including factors such as sex, age and mechanical forces. The medial, lateral, and dorsal

cortices showed no significant differences related to age, sex or side. The palmar cortex showed thickness in both sexes, sides and for all ages. The increased palmar thickness corresponds to the region of maximum compressive strain for the function of full flexion (grasping). Concerning the endocortical surface, women were found to have significant decrease in thickness across all age groups, whereas men showed a slight decrease after middle age (Lazenby, 2002a).

Lazenby (2002b) compared this sample from St. Thomas (Euro-Canadian) and an Inuit sample and examined sexual dimorphism in the size of the second metacarpal. Multiple morphological variables were measured and in all variables the St. Thomas sample was more dimorphic than the Inuit sample. These results, Lazenby suggests, negates the argument that technological progress has decreased dimorphism (Lazenby, 2002b). Another possible explanation for males having larger skeletal dimensions is that they are engaging in heavier physical labor in their hands, causing more bone to be laid down in certain areas to compensate for the greater strain.

Lazenby et al. (2008) tested the effects of handedness on directional asymmetry in the second metacarpal using both mean-difference and confidence-difference models. For both methods to assess structural strength and midshaft geometry, a right hand bias was found. A right hand bias was reported in mediolateral articular size but in the dorsopalmar articular dimension no pattern was found. The authors suggest the right hand bias could reflect directional asymmetry in hand breadth at the distal palmar arch. They report that in the head of the right second metacarpal there is greater bone volume, bone surface density, trabecular number, and connectivity. It also appears more platelike than rodlike suggesting a greater resistance to both axial compressive and shear strains

for the head at the metacarpophalangeal arthrosis. These results are consistent with previous results supporting structural asymmetries and limb dominance (Lazenby et al., 2008).

CHAPTER THREE: MATERIALS AND METHODS

Materials

The second metacarpal sample used in this study was obtained from Richard Lazenby (University of Northern British Columbia). These specimens originated from an historic cemetery excavated at St. Thomas Anglican church in Belleville, Ontario, Canada. The church cemetery was in use between 1821 and 1874, and most individuals interred were Caucasian immigrants from Western Europe, primarily the British Isles and Ireland. One Mohawk Indian and two "persons of color" were also buried in the cemetery, as identified by the burial register (Saunders et al., 1993; Lazenby, 1994). It is unclear whether these three individuals are included in the current sample, that information was not available. Belleville is located on the north shore of Lake Ontario's Bay of Quinte and was originally a rural farming area inhabited by immigrants but by the mid 19th century industry flourished in town.

Despite the rise in industry, Belleville was still considered a rural farming community (Jimenez, 1994; Saunders et al., 2002). Few doctors had formal medical training in the area and medical treatment was bartered for with property and farm animals (Jimenez, 1994; Saunders et al., 2002). Although it is well documented that the majority of the population was made up of low to middle class immigrant factory workers and farmers, no specific information is available about the socio-economic standing of each individual buried in the cemetery. If the sample from the cemetery is primarily

comprised of individuals who did not engaged in heavy physical labor, such as a more elite population, no differences in mean osteon size between sexes or hands might be expected.

Industries flourishing during this time included grist and saw mills, woolen factories, tanneries, foundries, breweries, lath and carriage factories, sash and shingle factories, a paper mill, logging, and railroad industry (Jimenez, 1994). Based on the amount of physical labor endured through work by the population both males and females led very active lifestyles, with higher mechanical loading forces than current populations (Lazenby, 1994). These conditions lead to larger skeletal dimensions than are seen in current populations. However a range in cross-sectional size in the second metacarpal was seen in this sample (Lazenby, 1994).

In this study mean osteon size in second metacarpals from 102 individuals (58 males, 44 females) were analyzed for trends related to sex, age, or side. The age range of this sample is 20 to 61 years for males and 19 to 60 years for females. Both right and left second metacarpals were available for 78 individuals. The remaining 24 individuals had only one second metacarpal available. A total of 180 second metacarpal slides were analyzed (87 right and 93 left). This sample was well preserved and had no evidence of trauma or physiologic pathology (Lazenby et al., 2008).

This sample of 180 second metacarpals is a subsample of the 576 individuals excavated in 1989 by Northeastern Archaeological Associates for church expansion (Saunders et al., 1993; Lazenby, 1994). The firm and the church were given legal permission to disinter the remains from the cemetery located adjacent to the church over

a four month period (Saunders et al., 1993; Jimenez, 1994). A total of 576 individuals were collected from the cemetery during the excavation. The sample removed was only 37% of the total population buried in the cemetery according to church records (Saunders et al., 1993). Age and sex are known for all individuals in the cemetery sample through records kept by church officials (Saunders et al., 1993).

Histological Slide Preparation

Bone sections of the second metacarpal were prepared using standard histological methods (Streeter, 2005). A 2 cm section of the midshaft of each second metacarpal was removed, it was not specified how. Midshaft sections were based off the interarticular length (IAL), the centermost point on the metacarpal, and spanned 1 cm proximally and distally (Lazenby, 1998). The sections were then cleaned and embedded in a clear epoxy resin. The method of cleaning was not specified. The embedded bone sections were then cut with a diamond slow-speed saw (Lazenby, 1998). Wafers were mounted on slides by putting two small drops of Permount onto the center of the slide, placing the wafer on top of the Permount, and adding one more drop on top of the wafer. A cover slip was positioned on top of the wafer by placing the edge of the cover slip down first, then lowering it onto the wafer. The slides were allowed to dry flat for twenty-four hours (Streeter, 2005).

Calculation of Mean Osteon Size

A Nikon eclipse 80*i* research microscope at a magnification of 200x (20x objective and 10x oculars) and fitted with a Merz eyepiece grid located in one ocular (Fig. 3.1) (Merz and Schenk, 1979) was used to determine mean osteon size using the

point-count method. The Merz grid was superimposed over the osteon and the number of line intersections that fell within the reversal line of the osteon were counted.

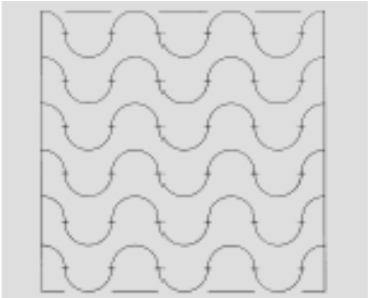

Figure 3.1 Merz Grid (Parfitt, 1983)

Fifty osteons per slide were measured and used in the calculation of mean osteon size. For this study only whole circular, osteons with round Haversian canals were examined. As previously discussed, osteons vary in size within a cross section of bone (Evans and Bang, 1967). To compensate for this osteons from all areas of the cortex were sampled.

Mean osteon area is calculated by first determining the number of possible intersections of the grid that overly a given osteon, and the possible area. To find the possible intersections, the number of fields, or osteons measured (50) is multiplied by the number of possible hits per osteon (36). To find the possible area, the number of fields multiplied by the area of magnification (.36 mm^2 in this case). To calculate the actual area, the number of hits is divided by the possible hits. This is then multiplied by the possible area, and this result is then divided by the number of osteons used (50). The calculation shown below is an example of how to calculate actual area. In this example # of fields, # of possible hits, and area magnification are constant variables, # of hits depends on how many hits are seen in all 50 osteons.

Possible hits = # of fields (50) x # of possible hits per osteon (36) = 1800 hits

Possible area = # of fields (50) x area magnification (.36 mm^2) = 18 mm^2

Actual area = # of hits (237)/possible hits (1800) = .1317

= .1317 x possible area (18 mm^2) = 2.37 mm^2

= 2.37/# of osteons (50) = .047 mm^2

Statistical Analysis

The purpose of this research is to determine if there are any age, sex or side associated changes in mean osteon size. Statistical analysis was used to test three hypotheses. As can be seen in Table 2.1this is the largest sample to date used in a study of mean osteon size.

Descriptive statistics, including mean, range, and standard deviation were determined for mean osteon size in males, females, the right second metacarpal, and the left second metacarpal, as well as age of males and females. Scatterplots, bar graphs, and whisker and box plots were used for comparison of age and mean osteon size, and the comparison of means and are shown in the results section.

To test H_o 1, that there is no age related change in mean osteon size, a Pearson's correlation test was used to determine if there was a statistically significant relationship between age and mean osteon size with sexes combined. Males and females were then tested separately also using the Pearson's correlation test.

H_o 2, that there is no statistically significant difference in mean osteon size between males and females, and $H_0$3, that there is no statistically significant difference between left and right second metacarpals, were both tested using a t-test to compare

means with a significance level set at .05. To use the t-test, both males and females had to be tested for a normal distribution using the Shapiro-Wilk test of normality. First males and females were compared with right and left second metacarpals combined. Then male and female means were then compared for the right side and left side separately, again using a t-test with a significance level set at .05. For $H_0$3 left and right second metacarpals were first compared with males and females combined. Then the means of right and left second metacarpals were compared with the sexes separate also using the t-test with a significance level set at .05.

CHAPTER FOUR: RESULTS

Table 4.1 Results of Statistical Analysis

Statistical Test	**Variables Tested**	**r-value and p-value**	**Significance Level**	**Results**
Correlation	Age related, sexes combined	-.002		Failure to reject H_o1
	Age related, male	-.037		Failure to reject H_o1
	Age related, female	.025		Failure to reject H_o1
T-Test	Male and female, sides combined	3.6×10^{-8}	.05	Reject H_o2
	Male and female, right	3.6×10^{-4}	.05	Reject H_o2
	Male and female, left	2.9×10^{-5}	.05	Reject H_o2
	Right and left, sexes combined	.676	.05	Failure to reject H_o3
	Right and left, male	.858	.05	Failure to reject H_o3
	Right and left, female	.696	.05	Failure to reject H_o3

As previously stated, males had an age range of 20 to 61 with a mean of 43 and females had an age range of 19 to 60 with a mean of 42. Both samples were tested for normality using the Shapiro-Wilk test and plotted on a histogram. In both cases, the results of the Shapiro-Wilk test indicated a normal distribution (Figs. 4.1 and 4.2). Normal distribution is required for the t-test to be used.

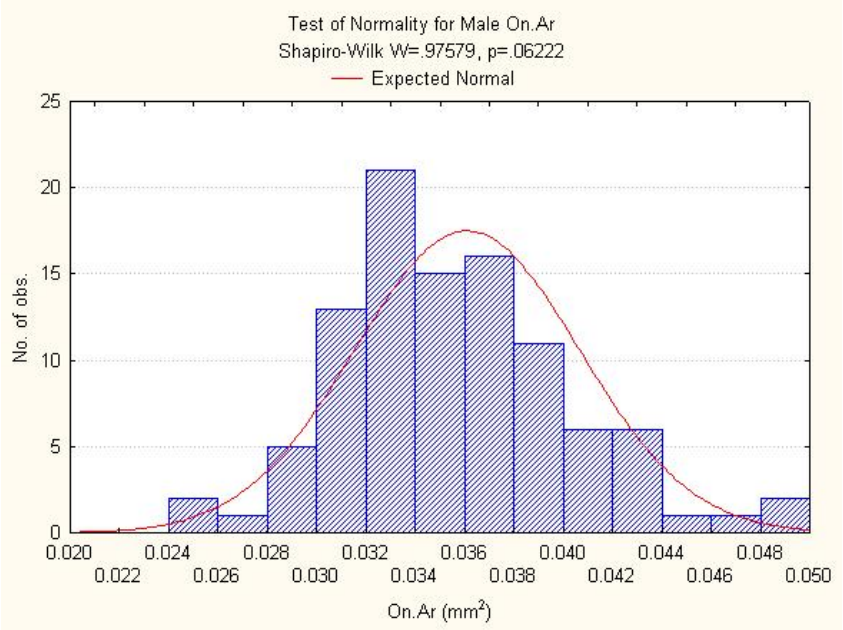

Figure 4.1 Test for Normality in Males This figure shows the normal distribution of males and the results of the Shapiro-Wilk test for normality results.

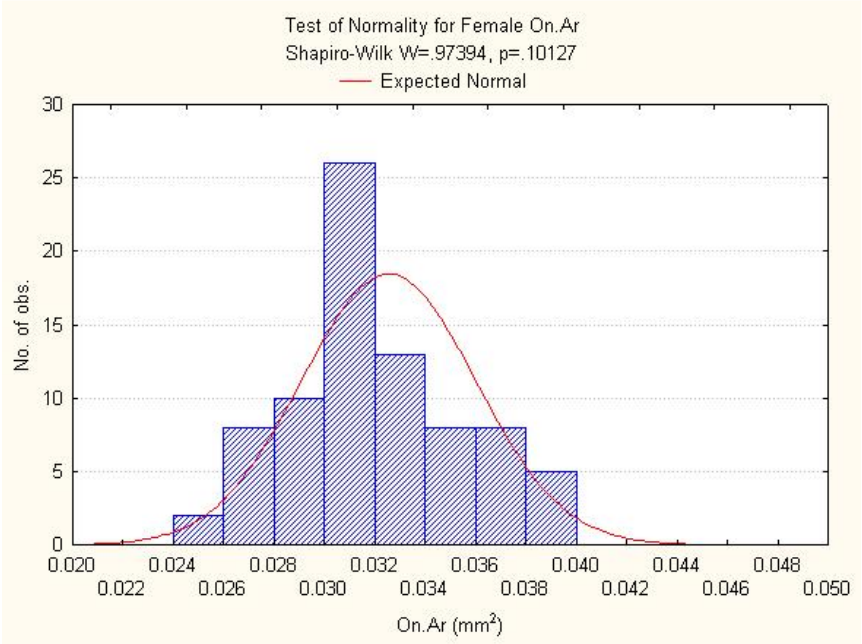

Figure 4.2 Test of Normality in Females This figure shows the normal distribution of females and the results of the Shapiro-Wilk test for normality.

Age Related

Table 4.2 Descriptive Statistics for Mean Osteon Size and Age

	Combined	Males	Females
On.Ar			
Mean ($mm^{2)}$	.035	.036	.032
Standard Deviation	.004	.005	.003
Range	.025-.049	.026-.049	.025-.040
Age			
Mean	42.8	42.9	42.3
Standard Deviation	11.5	10.6	12.5
Range	19-61	20-61	19-60

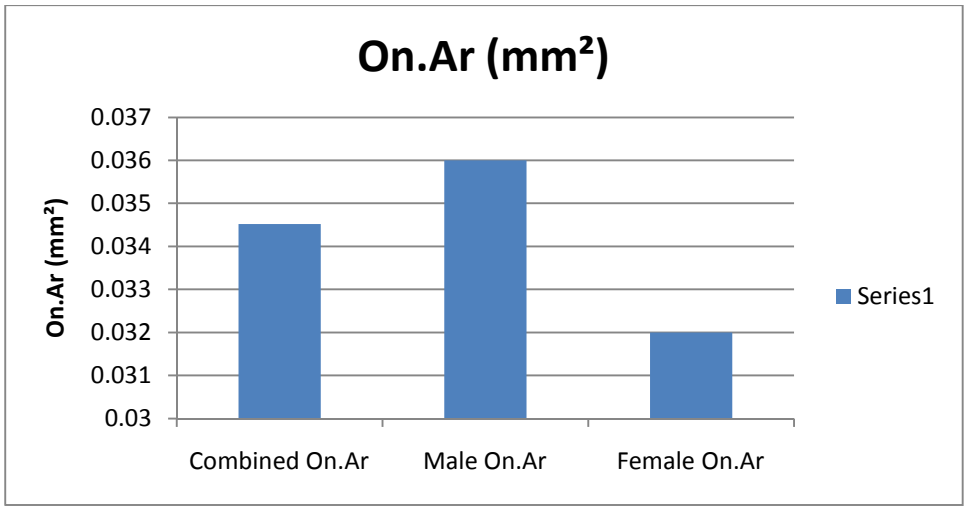

Figure 4.3 On.Ar by Sex Combined On.Ar refers to all means for the entire sample both male and female combined.

Table 4.1 lists the results for the statistical tests used in this study. H_o1 states there is no statistically significant change in mean osteon size (On.Ar) with increasing age in the second metacarpal (MC2). H_a1 states that there is a statistically significant change in mean osteon size with increasing age in the second metacarpal. Descriptive statistics for mean osteon size and age for the whole sample combined and for males and females separately can be found in Table 4.2. Figure 4.3 shows the combined mean osteon size

for the whole sample, the mean for both females and males. The results of the Pearson correlation analysis concerning age and mean osteon size for males and females combined was an r-value of -.002 and an r^2 value of 4 x 10^{-6} (Fig. 4.4). This indicates essentially no correlation between age and mean osteon size. The r-value leads to the decision to not reject H_o1. Therefore, with a confidence level of 95% there is no statistically significant change in mean osteon size with increasing age for the entire sample.

When males and females were tested separately for a correlation between mean osteon size and age the result was an r-value of -.034 and an r^2-value of .0014 for males (Fig. 4.5). Females produced an r-value of .025 and an r^2-value of .0006 (Fig. 4.6). Both r-values produced show almost no correlation between mean osteon size and age. Again, H_o1 fails to be rejected meaning at a 95% confidence level there is no statistically significant change in mean osteon size with increasing age in the second metacarpal when males and females are tested separately.

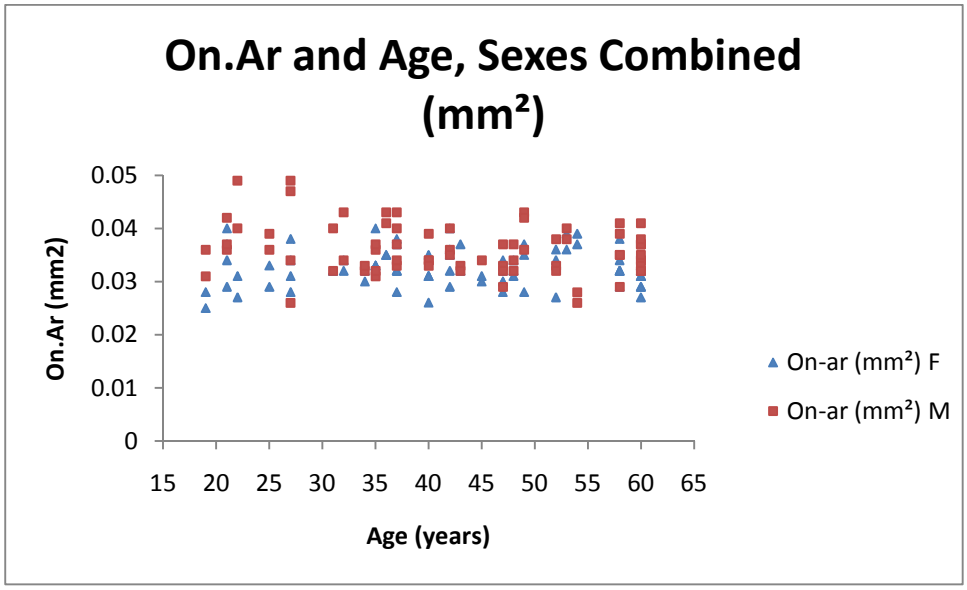

Figure 4.4 Regression of Mean On.Ar, Sexes Combined

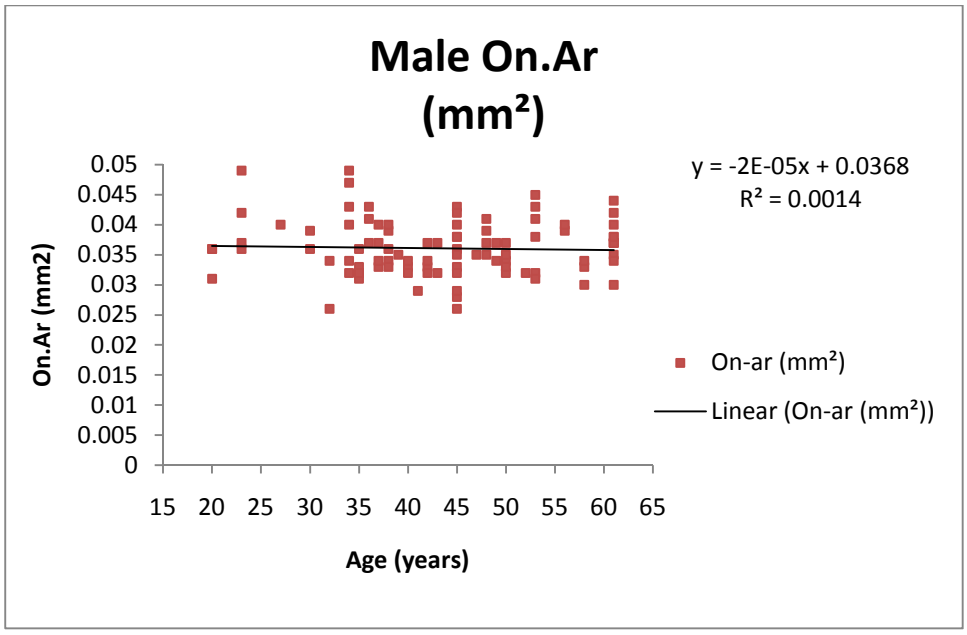

Figure 4.5 Regression of On.Ar on Age in Males The trendline shows little slope suggesting no significant change in mean osteon size with increasing age in males.

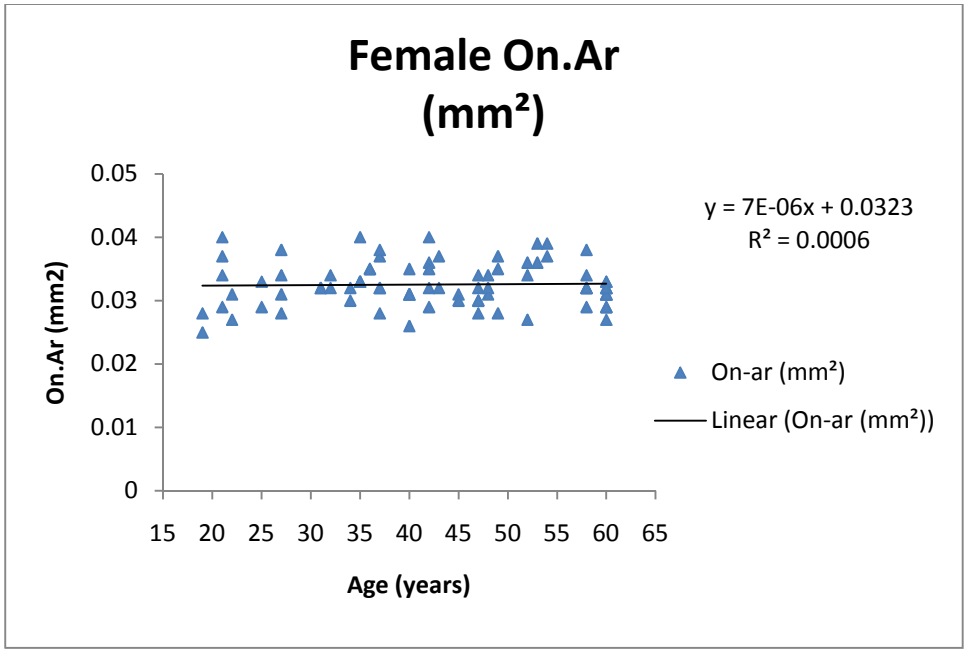

Figure 4.6 Regression of On.Ar on Age in Females The trendline shows almost no slope suggesting no significant change in mean osteon size with increasing age in females.

Males versus Female

Table 4.3 Descriptive Statistics for Male and Female On.Ar, Sides Combined

	Male On.Ar (mm^2)	**Female On.Ar (mm^2)**
Mean	.036	.032
Standard Deviation	.005	.003
Range	.026-.049	.025-.040

Table 4.4 Descriptive Statistics for Male and Female On.Ar, Sides Separate

	Males	**Females**
Left MC2 On.Ar (mm^2)		
Mean	.036	.032
Standard Deviation	.004	.003
Range	.026-.047	.026-.040
Right MC2 On.Ar (mm^2)		
Mean	.036	.033
Standard Deviation	.005	.004
Range	.026-.049	.025-.040

Table 4.3 shows the descriptive statistics for male and female mean osteon size with left and right second metacarpals combined. H_o 2 states that there is no statistically significant difference in mean osteon size in the second metacarpal between males and females. While H_a 2 states that there is a statistically significant difference. Mean osteon size for males is .036 mm^2, with a standard deviation of .005. Mean osteon size for females is .033 mm^2, with a standard deviation of .003. A t-test was used to compare the group means of right and left second metacarpals with the significance level set at .05. The resulting p-value was 3.6×10^{-8} (Table 4.1). This p-value indicates that H_o2 should be rejected; therefore H_a2 is accepted. At a 95% confidence level there is a statistically

significant difference in mean osteon size between males and females, when right and left second metacarpals are combined.

Table 4.4 presents the descriptive statistics for male and female mean osteon size with right and left second metacarpals considered separately. Mean osteon sizes of the right second metacarpals for males and females were compared using a t-test. A p-value of 3.6×10^{-4} resulted (Table 4.1). When the left second metacarpal of males and females was compared using a t-test a p-value of 2.9×10^{-5} resulted (Table 4.1). Both t-tests used a significance level set at .05. Figure 4.7 is a whisker and box plot that compares the means of males and females when sides were combined and tested separately. These results show that when comparing males and females in either hand separately H_o2 can be rejected. This means that at a 95% confidence level there is a statistically significant difference in mean osteon size between male and female right second metacarpals, and between male and female left second metacarpals.

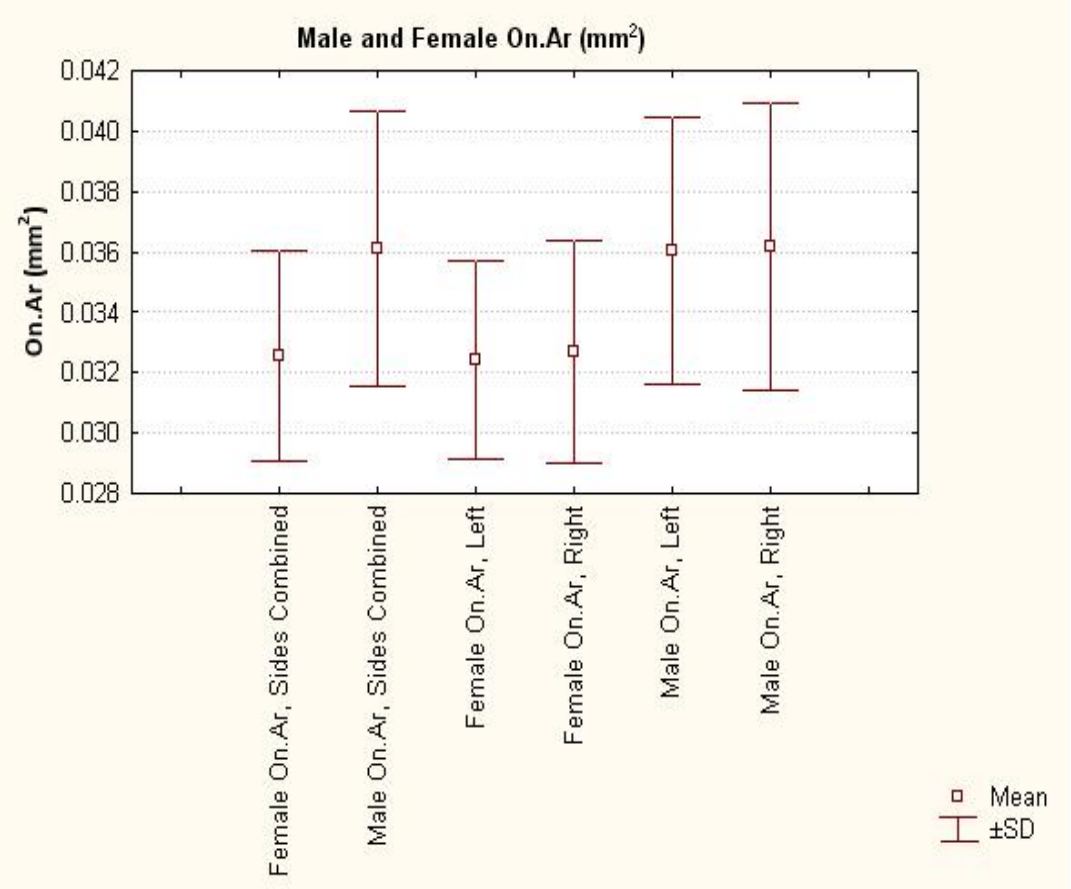

Figure 4.7 Male and Female On.Ar Mean osteon size for males and females combined and separately ± one standard deviation.

Left versus Right

Table 4.5 Descriptive Statistics for Right and Left On.Ar, Sexes Combined

	Right MC2 On.Ar (mm^2)	**Left MC2 On.Ar (mm^2)**
Mean	.035	.034
Standard Deviation	.005	.004
Range	.025-.049	.026-.047

Table 4.6 Descriptive Statistics for Left and Right On.Ar, Sexes Separate

	Right MC2 On.Ar (mm^2)	**Left MC2 On.Ar (mm^2)**
Males		
Mean	.036	.036
Standard Deviation	.005	.004
Range	.026-.049	.026-.047
Females		
Mean	.033	.032
Standard Deviation	.004	.003
Range	.025-.040	.026-.040

Descriptive statistics for mean osteon size from right and left second metacarpals with the sexes combined are listed in Table 4.5. H_o3 states that there is no statistically significant difference in mean osteon size between right and left second metacarpals. H_a3 states that there is a statistically significant difference. Mean osteon size for right and left second metacarpals with sexes combined was .034 mm^2 on the left side and .035 mm^2 on the right side. A t-test was used to compare these means with a significance level of .05. The resulting p-value is .676 (Table 4.1). This indicates that the null hypothesis H_o3 is not rejected. Therefore, with a 95% confidence level there is no statistically significant difference in mean osteon size between right and left second metacarpals when the sexes were tested together.

Table 4.6 presents the descriptive statistics for the means of right and left second metacarpals with the sexes tested separately. As can be seen in Table 4.3 the mean osteon size in females was .032 mm^2 in the right second metacarpal and .033 mm^2 in the left second metacarpal. In both the right and left second metacarpals, the mean osteon size for males was .036 mm^2**.** A significance level of .05 was used for all the following t-tests. In

males when right and left mean osteon size was compared using a t-test, the resulting p-value was 0.858 (Table 4.1). Right and left means for females were compared using a t-test with a resulting p-value of 0.696 (Table 4.1). Figure 4.8 is a whisker and box plot that compares the means for right and left second metacarpals with males and females tested together and separate. When comparing right and left second metacarpals in females and males separately, their p-values allow for a failure to reject H_o3, meaning there is no statistically significant difference between right and left second metacarpals in either males or females with a 95% confidence level.

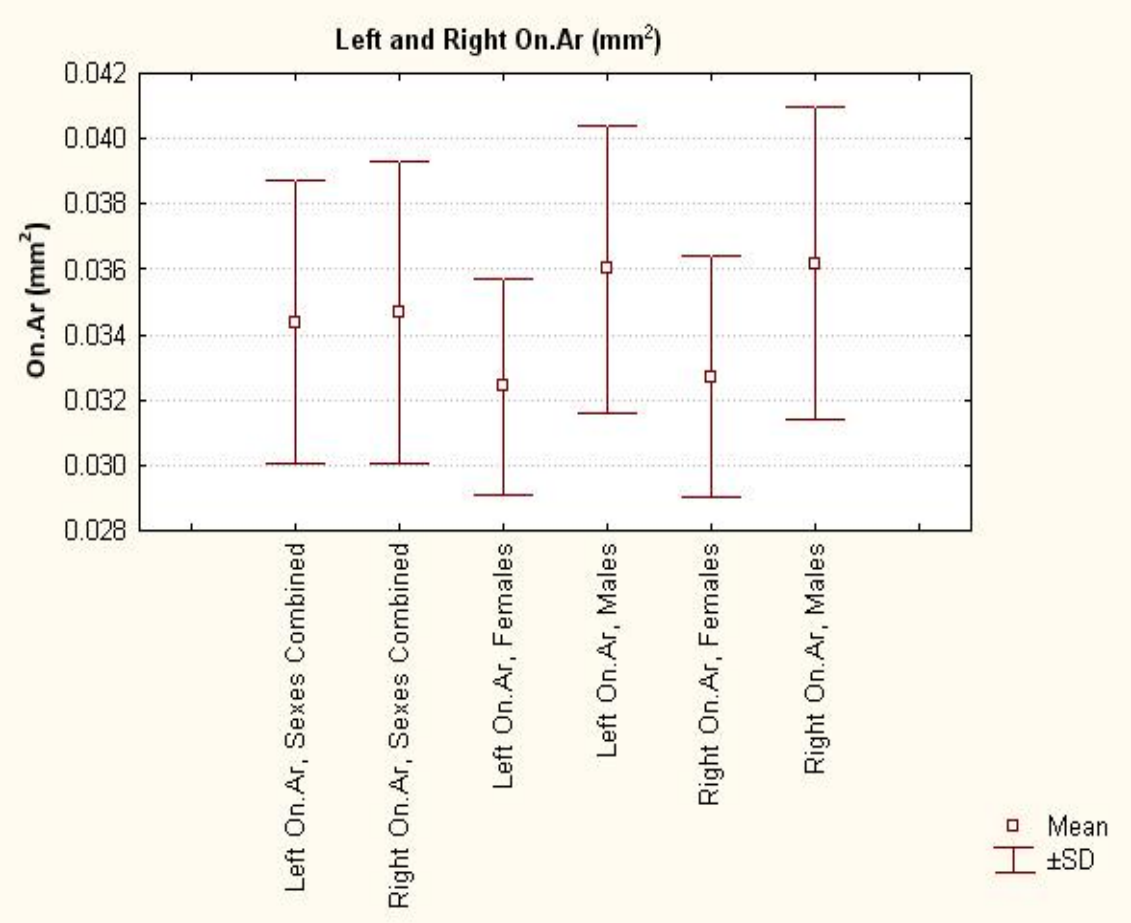

Figure 4.8 Left and Right On.Ar Mean osteon size for left and right second metacarpals with males and females combined and separate ± one standard deviation.

CHAPTER FIVE: DISCUSSION AND CONCLUSION

The purpose of this research was to determine if there are any statistically significant changes in mean osteon size in the second metacarpal associated with age, sex, or handedness. As discussed in Chapter Two, previous studies analyzing mean osteon size and age in bones other than the metacarpal produced varying results with some concluding there is a change in mean osteon size, while others report no age related change (Landeros and Frost, 1964; Currey, 1964; Hattner et al., 1965; Takahashi et al., 1965; Jowsey, 1966; Black et al., 1974; Burr et al., 1990; Yoshino et al., 1994; Pfeiffer, 1998). Burr et al. (1990) found a difference in mean osteon size between males and females. van Ores et al. (2008) suggest mechanical stress may relate to a decrease mean osteon size. Therefore, smaller osteon sizes might be predicted in the dominant hand. The results of this study are discussed in this chapter.

Discussion

Age

When the Belleville sample is considered together (males and females combined), no correlation was found between mean osteon size and age (r = -.002). These results are consistent with studies on the rib and femur by Hattner et al. (1965), Takahashi et al. (1965), Jowsey (1966), and Pfeiffer (1998). Further when males and females were tested separately, neither group showed any age associated changes in mean osteon size (males r-value = .025, females r-value = -.037). Therefore, at a 95% confidence level $H_0 1$, which states that there is no statistically significant change in mean osteon size as age increases,

cannot be rejected. The results of this study suggest that diminished tissue and cell activity with age does not affect osteon size (Frost, 1963).

Sex

Mean osteon size was found to be greater in males than in females by an average of .004 mm^2. A statistically significant relationship at a 95% confidence level was found when comparing mean osteon size of males and females. The model by van Ores et al. (2008) predicts smaller osteon size with greater mechanical loading. If the hands of males were experiencing higher mechanical forces than those of females, then the results of this study do not support the conclusions of the van Ores et al. (2008) study (Jimenez, 1994; Lazenby 1994). It is entirely possible that the overall larger size of metacarpals in males compared to females is the reason for larger osteons in males. This same pattern can be seen in other bones of the body, for example, the femur has a larger mean osteon size than in the rib because it is a larger bone. One other possibility is that the overall larger size of the bone is better able to compensate for increased mechanical strain, leaving osteon size unaffected. These results may also suggest that mean osteon size might have the potential for distinguishing males from females.

Handedness

As noted, the van Ores et al. (2008) study predicts the inverse relationship between mechanical strain and mean osteon size. According to their model increased mechanical strain decreases osteoclast activity, which would produce smaller osteons in the dominant hand. The St. Thomas cemetery sample shows no difference in mean osteon size between the right and left second metacarpals of males and females at a 95% confidence level. There are several possible explanations for this. First, it is possible that there were equal levels of mechanical strain experienced by both hands in the St. Thomas

sample. Secondly, it is possible that the van Ores et al. (2008) model does not accurately depict the relationship between mechanical strain and osteon size.

Conclusion

The statistical results from this study allow for a number of conclusions. First, there is no age associated differences in mean osteon size in the second metacarpal, whether the sexes are combined or tested separately. Second, there is a statistically significant difference in mean osteon size between males and females with a difference of about .004 mm^2. Third, when sexes were combined and tested separately, there is no statistically significant difference in mean osteon size between right and left second metacarpals. This study concludes that the differences in mean osteon size seen between males and females from the St. Thomas population could be attributed to the sexes undergoing such different levels of mechanical strain that it affected the overall size of the bone, thereby affecting osteon size, or that the strain affected osteon size directly.

While age and sex of all individuals included in this study were known, occupation and handedness were not. Future studies of mean osteon size in the bones of the hand would benefit from knowing handedness and occupation of the individual. By knowing these variables, metacarpals can be further analyzed for differences between right handed and left handed individuals, and what affect certain kinds of occupations can have on osteon size.

In this study 50 osteons per slide were sampled for the point-count method. Other studies have used 100, or even all osteons available (Landeros and Frost, 1964; Takahashi et al., 1965; Burr et al., 1990). Since a cross-section of bone has the potential to have hundreds of osteons only sampling 50 may not provide reproducible results. To

correct for this possible variability in results future research on mean osteon size should include all osteons that fit the criteria for being included.

Although no correlation has been found between age and mean osteon size in the second metacarpal, this does not mean that this relationship does not exist in other bones in the body. It is possible that, as found in studies by Landeros and Frost (1964), Currey (1964), Black et al. (1974), Burr et al. (1990), and Yoshino et al. (1994), there actually is an age related change in mean osteon size in other bones of the body such as the rib, femur, tibia and humerus.

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