To the Graduate Council:

I am submitting herewith a thesis written by Lauren Amber Rockhold entitled "Secular Change in External Femoral Measures from 1840 to 1970: A Biomechanical Interpretation." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Anthropology.

Richard L. Jantz, Major Professor

We have read this thesis and recommend its acceptance:

Accepted for the Council:

Associate Vice Chancellor and Dean of the Graduate School.

Secular Change in External Femoral Measures from 1840 to 1970: A Biomechanical Interpretation

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Abstract

The purpose of the present study is to examine secular change during the last century in the femur as expressed through external measures. New technologies have greatly impacted nutrition, healthcare, sanitation, activity levels and behavior. Secular changes in stature, body proportion, weight, childhood growth and development, age at menarche, and cranial measures have been documented for many modern industrialized human samples. These secular changes are attributed largely to environmental influences which allow individuals to reach a genetic potential that is environmentally plastic.

My results indicate a statistically significant increase in anterior-posterior elongation of the femoral midshaft from 1840 to the mid 1970's in black females (n = 156), white females (n = 249), black males (n = 202), and white males (n = 388) from the Terry collection and Forensic Data Bank. Additionally, these data demonstrate a statistically significant secular decrease in overall robustictity of the femur midshaft relative to maximum femur length, an increase in femur length and a decrease in many diaphyseal measures. The secular increase in anterior-posterior elongation of the femur midshaft is due to a non-significant change in the anterior posterior dimension of the midshaft accompanied by a significant decrease in the transverse dimension.

The results of this study indicate that a complex relationship exists between the diaphysis, total femur structure, and mechanical loading. The current findings

suggest the mediolateral dimension of the femoral midshaft may be more indicative of the level of mechanical loading than the anterior-posterior dimension. Additionally, anterior-posterior elongation of the femur midshaft in the current study appears to be related to a decrease loading and not to the type of loading (like running), as previously postulated. The non-significant change in the anterior-posterior midshaft is attributed to the critical significance of this dimension to overall femur morphology, including length, curvature, and anatomical significance as a muscle attachment site. The decrease in many femur measures is attributed to a reduction in mechanical loads as a consequence of the changing lifestyle initiated in the early 20th century.

Sex differences were also examined, with statistically significant differences apparent for all size variables. Sex differences were not noted for the subtrochanteric or midshaft shape indices in Whites, or for the subtrochanteric region in Blacks. Blacks were significant for sex differences in the shape of the midshaft at $p = 0.0029$. Difference between Black and White females and Black and White males were also examined for each of the femur variables. Results of the allometric analysis suggest that total subperiosteal area is increasing more slowly in relation to bone length in all groups. Finally, the interaction between age and the diaphyseal variables was explored. The results support some age related expansion of the diaphysis with no change in midshaft shape, supporting the hypothesis that bone shape is determined during growth and development and young adulthood while the skeleton is engaged in modeling. Different patterns of age- related periosteal expansion were noted for males and females.

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Chapter I

Introduction

Project Aims

The goal of the current research is to examine secular change in the femur during the last century. To date, there have been no research projects which have sought to examine secular change in femoral morphology, with the exception of Trotter and coworkers (1968), who noted secular change in the transverse diameter of the midshaft. In addition, this research adds to the data already reported on Native American and autopsy samples. According to previous studies, modern femora are relatively circular and no temporal trends have yet been identified. This project seeks to unite the morphological changes in recent femora with a biomechanical explanatory framework. Secondarily, this research seeks to understand the relationships among the femur variables as they relate to general femur structure, sex differences, and aging. Comparisons with previously proposed explanatory frameworks detailing comparisons between prehistoric subsistence strategies and recent humans will be evaluated in light of the current findings.

Anthropology and Biomechanical Studies

Within anthropology, research addressing the relationship of bone cross-sectional geometry and shape to meet the biomechanical needs of the organism is extensive. This area of inquiry details the locomotor demands on the skeleton and, in turn, how the skeleton may adapt to withstand peak strains in an effort to develop a functional interpretation of morphology. These studies focus primarily on midshaft cross-sectional geometric properties, given that the diaphysis of a long bone is responsive to the mechanical loads to which the whole bone is subjected. Some anthropological studies have charted morphological shifts in the genus *Homo*, noting a decrease in strength properties and robusticity of the long bones through the Pleistocene (Buxton, 1938; Ruff et al.,1994). Other investigations examining *Homo sapiens* have explored the relationship between bone cross-sectional geometric properties and the impact of different subsistence strategies (Cole, 1994; Ruff, 1994; Ruff, 1987, 1992; Ruff and Larsen, 1990; Bridges, 1989; Brock and Ruff, 1988; Ruff et al., 1984; Ruff and Hayes, 1983a, 1983b). Shifts in subsistence strategies are expressed through changing patterns of behavior which alter overall levels of mechanical stress, and hence, bone shape and size. Changes in diaphyseal size are interpreted as representative of the magnitude of mechanical loading, while specific diaphyseal shapes are indicative of the predominant direction of loading and thus specific activities (see, for example, Ruff, 1992). Many correlations between diaphyseal shape and specific behaviors have been attempted, but most actively by Ruff and coworkers (see below).

Early anthropological investigations recognized the differences in long bone diaphyseal shape present between prehistoric and modern peoples. Platynemia, first named by Busk in 1863, was used to describe the pronounced mediolateral flattening of the tibial diaphysis observed among the ancient inhabitants of Gibralter (Lovejoy et al., 1976). Buxton (1938), in his literature review of platynemia and platymeria (mediolateral flattening of the femur) noted that these conditions have been associated with activities such as mountain climbing or squatting, due to the interaction of the lower limb musculature interacting with bone.

In the late 1970's and early 1980's, biomechanically based investigations of bone morphology intensified, and engineering principles incorporating beam theory were routinely applied to long bones (for example see Lovejoy et al.,1976; Burr, 1980; Lovejoy and Barton, 1980; Bouvier, 1985). Beam theory, as applied to long bones, models the diaphysis as an engineering beam, where cross-sectional areas of bone are proportional to the axial rigidity (pure compression or tension) of a structure. Using a beam model, shape deviations from circularity indicate an increase in bending strength in the plane of elongation. The biomechanically based anthropological investigations primarily utilized computed tomography and direct sectioning of bone to more accurately assess internal cross-sectional geometry rather than employing external measures, which do not contribute information on medullary area, cortical area, or bone distribution.

Work by Ruff and colleagues comprises the majority of research addressing the biomechanical adaptations of long bones in physical anthropology (Ruff, 1995, 1992, 1987; Ruff et al.,1994; Trinkaus et al.,1994; Ruff et al., 1993; Ruff and Runestad, 1992; Ruff et al., 1991; Ruff and Larsen, 1990; Brock and Ruff, 1988; Ruff et al., 1984; Ruff and Hayes, 1983a, 1983b). In short, Ruff and coworkers have found the femoral diaphysis of hunter-gatherer groups to be anterior-posteriorly elongated relative to the medial-lateral dimension when compared to the relatively more circular femora of agricultural Native Americans and recent autopsy samples. Ruff has attributed anterior posterior elongation to high magnitude stresses in the anterior-posterior plane induced by activities such as running, carrying heavy loads or traversing long distances. Ruff and coworkers have also documented a reduction in postcranial robusticity throughout human evolution, attributing this to declining levels of mechanical use linked to an increase in brain size and technology (Ruff et al., 1993). No significant temporal changes in articular dimensions were noted, suggesting that mechanical sensitivity of articular and diaphyseal dimensions are different.

Sex differences have also been observed to decline from prehistoric to modern autopsy samples. In modern samples, there is virtually no diaphyseal shape difference or difference in bending strengths in the mid femur and tibia (Ruff, 1987). The decline in sex differences has been attributed to the activity roles of males and females becoming more similar. All work by Ruff and associates, with the exception of Ruff (1987) which incorporated external measures, has utilized direct sectioning of bone or computed tomography (Brock and Ruff, 1988) to access bone cross-sectional properties. Although precise and accurate, direct sectioning is destructive and computed tomography is expensive, and both are time intensive. Hence, these factors may explain why many of these investigations utilized very small sample sizes.

Research by Bridges (1985, 1989) and Cole (1995) on Native American samples is also of interest. Bridges (1985, 1989) used both external measures and computed tomography in her study of Middle Archaic and Mississipian Native Americans from the Tennessee River Valley, Alabama. Bridges reported that mechanical strength actually increased in the transition from hunting and gathering to agriculture, specifically in the bones of the lower limbs of males and upper limbs of females. However, as pointed out by Ruff (1992), though her samples experienced strength gains, the diaphyseal shapes were similar to reported values for other Native American agricultural groups, implying that the type of activities were similar to other agricultural groups. Bridges attributed the strength gains in the upper limbs of females to the rigors of corn grinding, while the increase in male lower limb strength was correlated to participation in warfare and game playing (such as the ball game). Bridges also suggested that some of the size variation present between her study and others may be due to a general decline in health and nutritional status in other samples not experienced by inhabitants of the Tennessee River Valley. A decline in health status would effect size and the amount of cortical bone, and thus the discrepancy between the Tennessee Valley and other areas may not be a result of an increase in mechanical loading.

Cole (1995) using external breadth measures analyzed the femur and tibia in a sample of Northern Plains Indians. Cole, unexpectedly, found little differentiation in bone dimensions and shape between subsistence traditions. In his analysis, Cole suggested that the relative homogeneity of the sample might indicate little change in overall activity patterns between subsistence strategies or possibly a strong genetic component to femur shape.

The allometric relationship between long bone length and cross-sectional geometry has also been the subject of anthropological research. Ruff (1984), using a sample of Native American and modern autopsy femora, found length to scale approximately isometrically with cross-sectional geometric properties of total cortical area, medullary area, and total subperiosteal area. However, Ruff and coworkers (1993) in a re-evaluation of Ruff (1984) argued that bone length should demonstrate positive allometry rather than isometry.

Ruff (1991) also examined the possible relationship of body weight to bone cross-sectional size and articular dimensions in the proximal femur. Ruff obtained current radiographs of the proximal femur, current body weight and recalled body weights for 80 females and males of White or Black ancestry. His results indicated that cross-sectional size is correlated to current body weight in contrast to articular dimensions, which were more highly correlated with recalled weight at 18. Ruff attributed these results to the ability of the diaphysis to alter size in response to mechanical loads throughout the lifecycle in contrast to articular structures.

In summary, the recognition of the form and function relationships between bone shape and behavior has long been a subject of inquiry in anthropology. Largely, this relationship has been of great importance due to the tremendous explanatory power an accurate and predictable assessment of morphology could provide if the relationship between bone shape and activity were clear. Overall, biomechanical investigations of human long bones have yielded varied results concerning the morphological consequences of the transition to agriculture. However, it is generally agreed in the anthropological literature that increases in anterior-posterior bending strength can be correlated with activities, such as running or long distance travel. Overall, there has been noted a temporal decrease in sex differences, and the midshaft of modern femora have been observed as comparatively more circular when compared to historically older remains.

Secular Change

Secular change, in the context of human biological characteristics, denotes non-genetic change over time in a characteristic or suite of features, such as stature or weight. Secular changes are attributed largely to environmental influences which allow individuals to reach a phenotypic potential that is environmentally plastic. During the last 150 years, new technologies have greatly impacted nutrition, healthcare, sanitation, activity levels and behavior. In tandem, secular changes in stature, weight, childhood growth and development, age at menarche, long bone lengths/dimensions, and cranial measures have been documented for many modern industrialized human samples (see for example Meadows Jantz, 1996; Greiner and Gordon, 1990,1992; Eveleth and Tanner,1990; Jantz and Moore-Jansen, 1988; Marshall, 1978; Van Wieringen, 1978; Trotter, 1969). Secular changes, negative or positive, or lack thereof, have also been documented and attributed to social history, socioeconomic status (SES) or rural/ urban status (see for example Price et al., 1987 on South Africa Blacks).

The potential for environmental influence on the phenotype is well illustrated by studies of growth and development and by research on migrating populations. Research has demonstrated that growth among infants during the first 6 months of life is remarkably similar due to the nutritional value of breast milk, even among infants of varying ethnic and socioeconomic (SES) backgrounds. Post weaning, however, growth patterns between high and low SES children become apparent, with infants of low SES status often lagging in growth. Although there is the ability for "catch-up" growth if environmental conditions are remedied, if negative status proceeds into early childhood differences become magnified and if conditions follow into middle childhood they can become permanent (Bogin, 1988).

Migration studies have documented changes in dimensions between primary populations of individuals residing in rural areas and first generation migrants to industrialized areas, often the United States. For example, Bogin (1995) found phenotypic changes in Mayan refugee children living in the United States in comparison to Mayan children living in Guatemala. Bogin found that the children raised in the United States were taller, heavier, and carried more fat and muscle than their counterparts in Guatemala. The noticeable differences in physical characteristics between migrants and non-migrants were attributed to relief from the chronic malnutrition and disease experienced by Mayan children raised in the United States.

Secular trends have also been documented for skeletal samples. Meadows Jantz (1996) noted secular change in bone lengths and proportional changes among long bones in a sample of skeletal remains dating from the mid 18^{th} century to present. Interestingly, Meadows Jantz reported that males were more susceptible to environmental fluctuations than females. Secular change in stature has also been investigated in the Terry Collection by Trotter and Gleser (1951). Trotter and coworkers (1968) noted a secular decrease in the transverse diameter of the femur in the Terry Collection, which in part provided the impetus for the present study.

In summary, the secular trends identified for industrialized nations, and specifically for the populations in the United States are based on the impact lifestyle has on overall health. Levels of overall health are expressed through the phenotype. Given the multitude of changes over the last 150 years in the United States, including changes in sanitation, medical care, nutrition and transportation, morphological secular trends are probable in an American sample.

Chapter II

Bone Structure and Bone Biomechanics

The Structure and Biology of Bone

Bone is highly specialized connective tissue composed of cellular and vascular networks residing within an ossified matrix of inorganic and organic materials. The skeletal system performs many crucial biological functions in mammals. The skeletal system not only acts as a scaffold to support musculature and protect organs, but plays an integral role in the production of blood cells, mineral storage and calcium metabolism, contributing to the proper function of cardiac and skeletal muscle, nerve function, and blood coagulation (Buckwalter et al.,1996a; Moore and Persaud, 1996; White, 1991; Steele and Bramblett, 1988).

The following section outlines bone morphology and construction and provides the background for discussion of bone biomechanics and activity related bone change.

Classification of Bones

Bones may be classified by a number of criteria; including shape, growth and development, cellular and material organization. The following review outlines these classifications and criteria in depth.

Shape

Bones classified by shape fall into 3 general categories: tubular or long, flat, and irregular or cuboidal (Buckwalter et al.,1996a; White, 1991). Tubular bones, like the femur and humerus, have thick tube shaped diaphyses with expanded metaphyses at either end. Like the name implies, a thin cortice and flat appearance characterize flat bones, such as the scapulae and neurocranial bones. Irregular bones, like the tarsals, carpals and vertebrae, have a relatively square and boxy shape. Despite differences in external form, the material composition of all bone is the same.

Growth

Bones classified by developmental criteria are designated as either endochondral or intramembranous, indicating the process by which they form and grow. Endochondral bone formation occurs within pre-existing cartilaginous models (e.g. long bones), while intramembranous ossification arises between membranes lined with osteoblastic (bone forming) cells.

The majority of bones grow though the process of endochondral ossification (Buckwalter et al.,1996a; Moore and Persaud, 1996; White, 1991; Steele and Bramblett, 1988). Long bones, for example, begin as cartilaginous models in the fetus with initial ossification centers forming in the diaphyseal region. From the primary ossification center, bone growth radiates towards the ends of the cartilage model. Secondary ossification sites are located in the epiphyses connected to the diaphysis via the epiphyseal plate. During mammalian growth, bone is deposited on the diaphyseal margin of the epiphyseal plate enabling the bone shaft to lengthen. Bone growth ceases when the epiphysis and diaphysis fuse at the site of the epiphyseal plate. Although most long bones develop from primary and secondary ossification centers, some endochondral bones, like the carpals, grow from a single site of ossification (White, 1991).

Intramembranous ossification requires no cartilaginous model, but forms within a membranous layer of undifferentiated mesenchymal cells (Buckwalter et al.,1996a; Moore and Persaud, 1996; White, 1991; Steele and Bramblett, 1988). The mesenchymal cells synthesize a loose organic matrix containing blood vessels, fibroblasts and pre-osteoblasts. As the pre-osteoblasts differentiate into mature bone formation cells, they begin to deposit spicules and islands of organic bone matrix within the membrane (Buckwalter et al.,1996a). Intramembranous ossification is the way in which flat bones, like the bones of the vault and pelvis form.

Cortical and Trabecular Bone

Bone is comprised of two organizational forms of tissue: cortical (compact) bone and trabecular (cancellous) bone. Though cortical and trabecular bone are comprised of the same material, the organization of material differs. Cortical bone is very dense and forms approximately 80% of the mature human skeleton, encompassing marrow and trabecular bone (Buckwalter et al.,1996a; White, 1991). Trabecular bone, on the other hand, is found primarily in-between bone plates and inside epiphyses. Trabecular bone is predictably, but loosely organized.

Woven and Lamellar Bone

Developmentally, there are two types of bone: woven (primary) and lamellar (secondary or mature) bone. Woven bone is composed of randomly and loosely organized/mineralized collagen fibrils and contains approximately four times the number of osteocytes as lamellar bone (Buckwalter et al.,1996a). Woven bone is associated with periods of rapid bone deposition and turnover, like periods of active growth or fracture repair. Woven bone has a lower mineral content than lamellar bone and is generally replaced by mature bone except at certain sites such as the alveoli and cranial sutures (Bouvier, 1989). With the exception of fracture repair and a few anatomical sites (such as the ear ossicles, cranial sutures among others), woven bone is rarely present in the normal human skeleton after 4 to 5 years of age (Buckwalter et al.,1996a). In contrast to woven bone, the organization of lamellar bone is very consistent. The collagen fibrils vary less in diameter and organization, lying in tightly organized parallel sheets with almost uniform mineralization (Buckwalter et al.,1996a). Primary lamellar bone is formed by modeling on periosteal and endosteal surfaces during growth, whereas secondary lamellar bone is composed of secondary osteons formed through the process of bone remodeling (Martin, 1991).

Biomechanically, due to its higher water content, cell composition and irregular patterning, woven bone is more flexible but weaker when compared to lamellar bone. Additionally, the random alignment of the collagen fibrils makes woven bone react in a similar fashion (more isotropically) when forces are applied from different angles. In contrast, lamellar bone behaves more anisotropically: its mechanical response varies with the placement of the applied force (Buckwalter et al., 1996a).

Mature Cortical Bone

Mature bone comprises the trabecular lamellae of cancellous bone, the circumferential lamellae, interstitial lamellae, and the lamellae of osteons in cortical bone (Figure 1). Each lamella consists of densely packed collagen fibrils running in different directions to adjacent lamellar structures. The organization of these structures contributes significantly to the strength of bone.

Osteons form the bulk of cortical bone (Buckwalter et al.,1996a). Osteons run longitudinally down the bone shaft and are formed from concentric lamellae surrounding a central canal, referred to as a *haversian* canal. The haversian canal

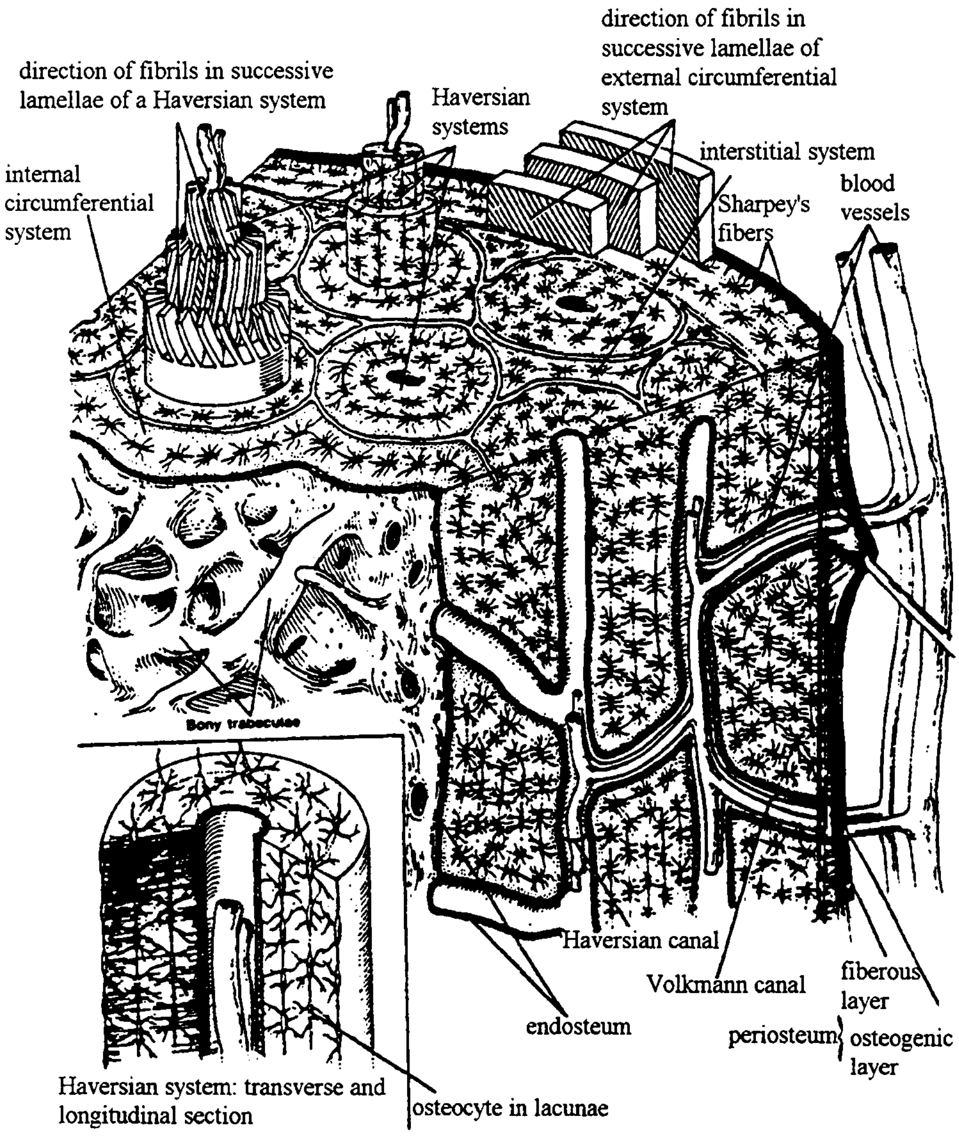


Figure 1: Schematic diagram of bone microstructure (modified from Buckwalter et al., 1996a).

contains blood vessels, lymph vessels and occasionally nerves. Canaliculi, the cell processes from osteocytes trapped within the bone matrix, connect to the haversian canal and adjacent osteocytes providing nutrients. Cement lines, comprised of a thin layer of organic matrix (similar to osteoid) demarcate the outer perimeter of osteons and create a sheath which runs the length of the osteon. Volkmann canals, running obliquely though the bone, create connections between haversian canals. The outer perimeter of cortical bone (near the periosteal surface) is comprised of circumferential lamellae, osteons which run at a right angle to the osteonal lamellae. The organization of vascular canals in bone ensures that no cell lies more than 300μm from a blood vessel (Buckwalter et al., 1996a).

The outside surfaces of bone are covered with periosteum, a highly vascularized connective tissue that contributes an important part of the blood and nerve supply to bone. The periosteum contributes many functions to bone maintenance. Cells within the inner layer of the periosteum are capable of becoming osteoblasts, while some of the periosteal fibers intertwine with tendons, providing attachment sites for muscles. Due to the osteogenic properties of the periosteum, throughout adult life, appositional formation of bone occurs on the periosteal surface of bone (Buckwalter et al.,1996a; Martin and Burr, 1989; Ruff and Hayes, 1988). In tandem, the bone cortices become progressively thinner due to continual resorption of the endosteal surface. Though endosteal resorption initiates later than periosteal apposition, it proceeds at a much faster rate. Over the life cycle, the process of periosteal apposition enlarges the outer dimensions of bones, though sex differences have been noted (Ruff and Hayes, 1988; Martin and Atkinson, 1977). However, external bone shape is should not be affected (Martin, 1991).

Bone Cells

Both modeling and remodeling of bone occur in response to biomechanical use and physiological needs. Bone modeling and remodeling take place though the combined action of osteoclasts (bone resorption cells) and osteoblasts (bone formation cells) while bone maintenance is facilitated by osteocytes.

Osteoclasts

Osteoclasts are large multinucleated bone resorption cells, which reach up to 100μ in diameter and contain up to 50 nuclei (Bouvier, 1989). Osteoclasts differentiate from hematopoietic stem cell precursors from the monocyte cell family found in marrow and circulating blood. Specific hormones and growth factors initiate the transformation of the undifferentiated cells into osteoclasts. Osteoclasts form by fusing together and creating large multinucleated cells and typically contain 3 to 20 nuclei with large numbers of mitochondria and lysosomes (Buckwalter et al.,1996a).

On trabeculae, osteoclasts create small resorbed depressions known as Howship's lacuna. In cortical bone, osteocytes create a "cutting cone", initiated with the brush border of the cells creating a seal between the cell and bone matrix (Ortner and Putschar, 1981). Osteocytes absorb bone by lowering the pH level (from 7 to 4) below which bone is soluble (Buckwalter et al.,1996a). Following the resorption of bone, the cells move on and the pH returns to normal.

Osteoblasts

Osteoblasts (bone formation cells) originate from undifferentiated mesenchymal cells that reside in bone canals, endosteum, periosteum, marrow, and circulating blood. The undifferentiated cells have an irregular form, a single nucleus, minimum cytoplasm, and few organelles. The cells remain in an undifferentiated state until they are stimulated by hormones or other factors to differentiate into osteoblasts (Buckwalter et al.,1996a; Bouvier, 1989).

Osteoblasts are cuboidal cells that contain large amounts of rough endoplasmic reticulum and, like their predecessors, have a single nucleus. On a bone surface undergoing modeling or remodeling, osteoblasts are found as a continuous layer secreting osteoid, the unmineralized collagen and proteoglycan protein bone matrix (Bouvier, 1989). In the process of bone remodeling, osteoblasts follow behind the osteoclasts and secrete osteoid, replacing old bone which was resorbed in the cutting cone.

Osteocytes

Osteocytes originate as osteoblasts, which during the process of bone formation differentiate into bone maintenance cells (Ortner and Putschar, 1981).

Differentiation occurs when they are trapped within the bone matrix during the secretion of osteoid (protein matrix).

In summary, bone is a highly vascularized connective tissue of which the organization and mechanical properties vary with growth and development and maturity. Although the organization of bone tissue differs though growth and development, the composition of the material is the same. The following section will combine these basic aspects of bone biology as they relate to biomechanics and functional bone change.

Bone Biomechanics

Throughout life, the skeleton adapts and modifies, within genetic constraints, according to behavioral (biomechanical, dietary) and physiological needs. Historically, the observation that there is interdependence between the form and function of bone is attributed to Julius Wolff (1870). Wolff's recognition of the mechanical environment as a determining factor in bone growth and shape dates back to Galileo, who noted the correlation between bone size, body weight and activity, and believed that bone form was closely related to its mechanical role supporting the body (Buckwalter et al.,1996b; Bouvier, 1985). However, Wolff's classic "Law of Bone Transformation", which predicts bone will be deposited and resorbed from the skeleton according to mathematical principles to accommodate the functional needs of the organism, has set the stage for the last 100 years of research exploring the dynamic nature of bone.

Biomechanically, living bone can be regarded as a two-phase anisotropic composite material due to its mineral (hydroxyapatite crystals) and organic (collagen) components. The mineral component of bone lends compressive strength, while collagen provides tensile strength. The composite nature of living bone, with both brittle and flexible components, dictates that the material properties of each will be stronger in combination than alone. However, given the material properties of bone mineral, bone is approximately 1.5 times stronger in compression. The mechanical properties of bone are dictated by geometry, distribution of mass around the neutral axis, porosity and moisture content, which are affected by the health and maturity of the bone (Nordin and Frankel, 1989).

The ultimate shape of a bone represents a dynamic combination of nutrition, mechanical demands and genetics. While nutrition regulates the amount of potential bone material available, the mechanical demands determine the particular arrangement of bone tissue. Bone form represents the effect of length and morphology (like bone curvature) combined with the structural objectives of maintaining the integrity to meet functional demands. The stress and strain to which a bone is subjected at any time is (1) the sum of the baseline muscle tone of the associated muscle mass when the animal is stationary but not weight bearing, (2) the constant strain present when the animal is stationary and weight bearing (3) and the cyclic strain incurred when the animal is in motion, which varies with the type of gait and speed (Meade, 1989). The ability of a structure to withstand external loads is dependent on its construction to be able to withstand loads applied without developing strains which could damage it (Rubin, 1984).

Bone Modeling and Remodeling

During growth and development, the appendicular and most of the axial skeleton *models* according to the mechanical demands placed on it, emerging into adulthood architecturally adapted to meet functional demands (Frost, 1983). During adulthood and senescence the skeleton *remodels* in response to, or in the absence of, mechanical forces which results in the maintenance and/or net loss of bone. Interestingly, bones which form through intramembranous ossification grow and maintain their form, even though they are exposed to negligible mechanical stimuli during normal behavior (Carter, 1987).

Modeling

Modeling refers to the process by which bone mass is increased (Frost, 1983; Martin and Burr, 1989; Nigg and Grimston, 1994; Buckwalter et al.,1996b). Bone modeling involves both the resorption and formation of bone, but these may occur on different surfaces and are not linked at a given site. Thus, modeling can significantly alter bone shape. Modeling occurs throughout the period of growth and development, thickening and shaping cortical and trabecular bone in children and through minimodeling drifts which thicken cortical bone in adults (Nigg and Grimston, 1994; Frost, 1997b). The size and shape of a bone is in large part determined during growth: modeling sculpts the bone according to genetic constraints and the mechanical loading environment (Martin, 1991).

Modeling becomes inefficient in the cortical bones of adults (Nigg and Grimston, 1994; Frost, 1988). The transition to adulthood takes place following the cessation of skeletal growth (Buckwalter et al.,1996b), usually occurring gradually in the twenties. In adults, for example, since the modeling capabilities of bone are greatly reduced, mature individuals have an insufficient capacity to alter metaphyseal size in order to reduce joint stress and but instead acquire pathologic disorders such as osteoarthritis (Martin, 1991). However, continual periosteal deposition of cortical bone and gradual resorption of the endosteal surface of long bones has been observed in conjunction with adult aging. Periosteal expansion, which involves sole osteoblastic activity, could be interpreted as example of modeling (Buckwalter et al.,1996b). However, the phenomenon of periosteal expansion and endosteal resorption has also been interpreted as bone remodeling (see Parfitt, 1984).

Mechanically, the expansion of the diaphysis in conjunction with the enlarging internal dimensions of the bone has been understood as a physiological attempt to maintain bone strength in response to a decrease in bone mass experienced through adulthood (Burr, 1980). However, the relationship between expansion of the endosteal and periosteal surfaces has been found not to be directly compensatory (Parfitt, 1984). Periosteal apposition expansion proceeds at a linear rate from the third decade, thus it begins prior to significant endosteal loss and effects non-weight bearing bones (Parfitt, 1984). Additionally, the relationship between periosteal expansion and an increase in bone strength has only been noted for males (Martin and Adkinson, 1977; Burr and Martin, 1983; Ruff and Hayes, 1988). Further, some studies did not find periosteal expansion in aging females (Burr and Martin, 1983; Ruff and Hayes, 1988).

Remodeling

Bone *remodeling* is defined as the process by which bone mass is maintained or decreased and does not alter bone architecture (Frost, 1983; Martin, 1991; Nigg and Grimston, 1994). Bone remodeling occurs in cortical and trabecular bone as a "quantized, packaged form of bone turnover in multicellular units" (Frost, 1983; pp. 286) or a basic multicellular unit (BMU). The BMU involves the combined action of osteoblasts and osteoclasts and involves three phases: activation of the cell types, bone resorption and the bone formation, or ARF (*a*ctivation, *r*esorption, *f*ormation). The advancement of a remodeling front consists of osteoclasts creating a cutting cone (in cortical bone) or a howship's lacunae (on trabecular bone) followed by the secretion osteoid by osteoblasts. In remodeling, the action of osteoblasts and osteoclasts are coupled, in that bone formation and resorption are linked at a given site (Nigg and Grimston, 1994; Martin and Burr, 1989). In humans, the time it takes to complete the ARF sequence is called sigma (σ), usually 3-4 months in healthy individuals (Parfitt et al.,1996). Sigma, under certain pathological conditions, may extend beyond 12 – 24 months, causing a detrimental reduction in bone density.

Bone remodeling occurs on all bone surfaces throughout life. During the first year of life, bone turnover rates approach 100% but decline to about 10% per year in late childhood, continuing at about this rate or slower throughout life (Buckwalter et al.,1996b). Bone remodeling rates and efficiency are also sensitive to mechanical use. Bone remodeling proceeds as either a stochastic process which prevents mean bone age from exceeding an acceptable level or as a directed process (Parfitt et al.,1996). Directed (also known as adaptive) remodeling occurs in areas, which due to weight bearing activity, are in need of maintenance and repair. Remodeling occurring in response to loading is efficient and prompt, with little bone lost following the ARF sequence. In contrast, with stochastic (or generalized) remodeling in response to negative biomechanical stimuli, bone resorption proceeds at a higher rate than bone formation. With increasing activity, a decrease in generalized remodeling rates is observed with an increase in site specific adaptive remodeling. In adults, substantial skeletal changes in response to increased or decreased biomechanical loads are reflected in material properties, like density, rather than bone geometry (Martin, 1991).

Skeletal Adaptation to Strain

In order for bone to respond by modeling or remodeling, a signal must be sent and interpreted by bone cells causing the cells to activate. With regard to the mechanical adaptations of bone, experimental evidence supports that bone modifies in response to strain rather than stress. Strain is defined as the deformation in response to an external load, while stress is defined as the load or force per unit area (Currey, 1984). The main argument in support of adaptation to strain rather than stress is that peak functional strains are nearly identical in a wide variety of animals (Rubin and Lanyon, 1982; Biewener and Taylor, 1986; Martin and Burr, 1989). On the other hand, peak bone stresses vary widely in different animals and in different bones in the same animal, and these stresses are highly correlated with body mass (Biewener et al.,1983; Martin and Burr, 1989). Although stress and strain are directly related, skeletal adaptation appears engineered towards reducing bone strain to some acceptable level so that bone function will not compromise structural integrity.

Minimum Effective Strain

As a dynamic tissue, bone will attempt to keep strains within an "acceptable" level. First articulated by Frost, the level at which bone will construct an adaptive response is called the minimum effective strain or MES (a.k.a. mechanostat theory, see, for example, Frost, 1979, 1983, 1988, and 1997a,b). Strain smaller than the MES for modeling or remodeling do not incite adaptive or architectural responses. Following the introduction of MES, experimental evidence has mounted and approximate values for MES have been identified (see Frost,1997a for a review). There are three types of loading, trivial (below MES), physiologic (at or slightly above the MES), or pathologic (so far above MES, resulting in damage or fracture).

Due the shift in the mechanical properties of bone between immature and mature individuals, bone modeling will proceed at a much higher rate in young bone.

This is due to the decrease in mechanical compliance which occurs during maturation (adults have stiffer bones), changing the levels of achievable strains. Immature bone, due to the process of growth, is less mineralized and more flexible than adult bone. For this reason, fracture differences between children and adults have been extensively noted in the medical literature (e.g. Rockwood et al.,1984) and the adaptive response of growing and adult bone must be evaluated separately. Thus, bone architecture is determined by adulthood being dependent on the strain environment of growth and development – individuals emerge into maturity with a mechanically adapted skeleton.

The stain threshold necessary to initiate a modeling bone response is about 1000 microstrain (Frost, 1997b). The remodeling MES threshold, which reduces overall bone turnover and repairs microdamage, is near 50 – 100 microstrain (Frost, 1997a). In growing subjects, maximum voluntary bone strains range from about 2000 to 4000 microstrains, and in adults approximately 800 to 1300 microstrains (Frost, 1997a,b). Since the largest bone strains are dependent on muscle contractions multiplied by working against body weight, lever arms, and gravity, activities which increase muscular strength rather than repetitive or exercising to exhaustion (ex. running) will lead to higher bone strains, bone alteration and conservation (Frost, 1997a).

Strain Rate

Bone models and remodels in response to cyclic rather than static loads. Experimental evidence presented by Lanyon and Rubin (1984) using avian bone suggests that static loads caused bone change that was analogous to that of immobilized animals, with increased endosteal resorption and intracortical porosity. On the other hand, dynamic loads at equivalent peak strain magnitudes were found to increase net bone formation on the periosteal surface and prevent the increase in porosity seen in the statically loaded bone (see also Martin and Burr, 1989).

Experimental Evidence for Bone Adaptation

Experimental evidence unequivocally supports the ability of bone to modify in response to the loading environment. For example, Woo and associates (1981) found greater cortical thickness, cross-sectional area, and minimum and maximum area moments of inertia in a study of young growing pigs subjected to 12 months of daily 1hour runs on a treadmill when compared to sedentary controls. Goodship and colleagues (1979) surgically removed the ulna in skeletally immature swine. Following the osteotomy, peak strains in the overloaded radius were as high as 800 to 1100 microstrains. After three months, significant bone deposition on the radius and cross-sectional shape created strains comparable to the intact limb. Biewener and Bertram (1994) examined the limbs of growing chicks which were subjected to different mechanical loading environments. The authors found the exercised chicks demonstrated increases in total bone mass and cross-sectional geometry, while chicks deprived of any functional use (through sciatic denervation) showed reductions in bone mass and cortical area, even when compared to sedentary controls.

In humans, skeletal asymmetries have been observed between the dominant playing arm and opposite limb young tennis players by Jones and coworkers (1977) using radiographs. The authors noted significant increases of 34.9% (males) and 28.4% (females) in cortical breadth of the bone shafts of the dominant playing arms. The Jones et al., research is often cited due to the control of the research design, in that tennis preferentially employs one limb, thus the asymmetries observed in the study are unequivocally due to physical activity. Trinkaus and coworkers (1994) in a reevaluation of the Jones et al., (1977) data in combination with data from other recent human samples, found evidence of cortical expansion and endosteal contraction as a result of high mechanical use, supporting a causal relationship between increased loading and diaphyseal robusticity. However, the authors note that the subject's age in conjunction with the observed patterns of bone robusticity suggest that the level of bone change is related to the age at which activity is initiated. Higher levels of asymmetries were found in players which had begun to play tennis at earlier ages, in contrast to players which started later following late adolescence, which demonstrated much smaller values of asymmetry. Forwood and coworkers (1993) and Parfit (1994) also made the same observation as Trinkaus and coworkers (1994) of the Jones et al. (1977) research concerning age sensitive bone change. The results support a shift in the sensitivity and type of reaction different loads will produce in bone with increasing age.

Conversely, when the strain environment is reduced, bone resorption occurs in children and adults. Bone resorption has been documented in the case of weightlessness on space flights (Smith et al.,1977; Tilton et al.,1980) and prolonged bed rest (Issekutz et al.,1966; LeBlanc et al.,1990). These studies show a decrease in total volume of bone tissue with a decreased strain environment. In tandem, reductions in mechanical usage through the lifecycle also lead to significant deficiencies in total bone mass when compared to physically active controls, indicating that weight bearing activity is positively correlated with higher bone density and skeletal robusticity (see LeBlanc and Schneider, 1991). Additionally, there is mounting evidence that bone mass lost in adulthood cannot be recovered without medical intervention but that exercise will serve to reduce bone loss during aging (LeBlanc and Schneider, 1991).

Biomechanics and Bone Shape

The ability of bone to model in response to mechanical use has been substantiated. But, the question remains, how does bone model in response to strain? The way in which bones adapt to mechanical usage has been coined as SATMU, or structural adaptation to mechanical usage by Frost (1988). Frost outlines the principal structural adaptations of lamellar bones during growth and development in reaction to typical repeated loads, uniaxial (pure tension or compression), flexural, or a combination. Frost's observations are drawn from clinical examples and are well supported (see also Currey, 1984; Cowin et al.,1985). The following review is adapted from Frost (1988). For each number, a loading situation is given, followed by the predicted adaptive behavior of bone (Figure 2):

1. **The diaphysis loaded in uniaxial compression**: bone will be added to the periosteal surface, which will increase the outside diameter and cortical thickness approximately equally along all diameters.

2. **The trabeculum loaded in uniaxial compression**: the trabeculum will tend to thicken.

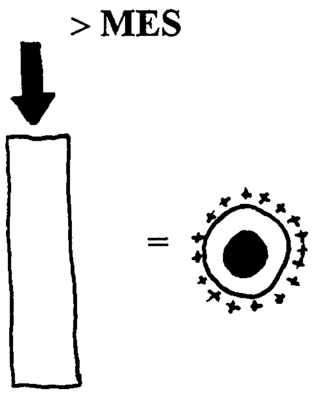
3. **The trabeculum loaded in uniaxial tension**: will also tend to thicken trabeculae.

4. **The diaphysis loaded in uniaxial compression and flexure**: bone will be added to the concave and resorbed form the site of convex tending flexure, straightening the bone.

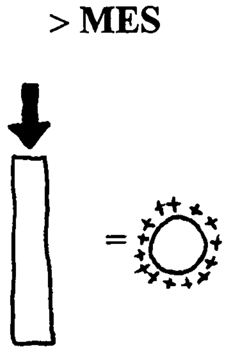
5. **The trabeculum loaded in compression and flexure**: the organization of trabeculae tend to parallel compressive stress. When this relationship is compromised it is restored by bone deposition in the concave areas and bone resorption in surface under convexity.

Frost's observations of the adaptive response of bone under tension and compression are related to the fact that peak compressive strains are almost always greater than peak tensile strains. Compressive strains in a long bone are usually higher because they are combined with bending strains with the neutral axis shifted (Martin and Burr, 1989).

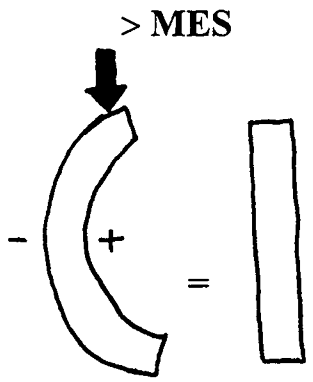
On first glance, Frost's SATMU predictions can be challenged on the observation that some bones (like the femur) are curved, and as some structural investigations suggest, need to be. Betram and Biewener (1988) suggest that bone curvature, while promoting bending, will result in a highly predictable strain pattern. They argue that predictable strain patterns are highly advantageous in structures



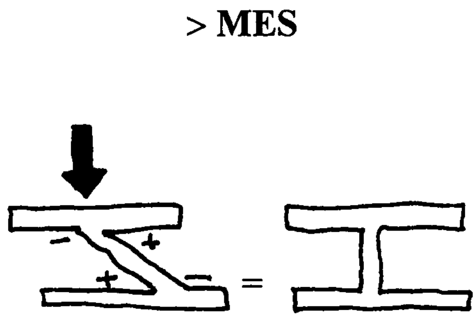
The diaphysis loaded in uniaxial compression.



The trabeculum loaded in uniaxial compression or tension.



The diaphysis loaded in uniaxial compression and flexure.



The trabeculum loaded in compression and flexure.

Figure 2: The predicted behavior of bone in response to different loading situations. A ' + ' indicates an area of bone formation, while a ' - ' designates an area of bone resorption. (Redrawn and modified from Frost, 1988).

which have a highly variable loading environment, providing an acceptable 'trade-off' for sacrificed strength.

Martin and Burr (1989) point out that the discrepancies between Frost's theory and bone curvature can be united on two important points. First, the strain threshold to initiate a modeling response must reach the MES threshold, and not all bending will exceed the threshold. Martin and Burr also suggest that misunderstandings stem from researchers failing to note that Frost's theory concerns load-induced changes in surface curvature, rather than absolute bone curvature. Thus mechanically adapted bone changes can happen anywhere locally on the bone where bone strains exceed the MES threshold.

In summary, during growth and development the skeleton models in response to the loading environment, adding to and sculpting the shapes of bones. During adulthood and senescence the skeleton remodels in response to the loading environment which leads to a maintenance or decrease in bone density. The level at which bone will manifest an adaptive response is termed the minimum effective strain, which differs for modeling and remodeling.

The Human Femur

The femur is the longest and heaviest bone in the human body, transmitting the weight of the body through the hip and the femoral head to the tibia when standing. Anatomically, the head of the femur projects superiomedially and slightly anterior when articulated to the pelvis via the acetabulum. In normal femora the angle between the neck and the shaft is between 115° to 140°, with the angle varying with age and sex (Moore and Agur, 1996). Anatomically, the femur is diagonally situated with the shaft angled medially, creating the characteristic valgus knee of humans.

The femoral diaphysis is characterized by a slight anterior-posterior longitudinal curvature of the diaphysis and an anterior cross-sectional circularity. The posterior portion of the shaft is defined by the linea aspera, a raised bony ridge which runs longitudinally down the diaphysis. The linea aspera is a muscle insertion site for the adductors of the thigh: adductor magnus, adductor longus and adductor brevis; and the origin of vastus lateralis and vastus medialis, muscles which extend the knee joint. Superiorly, the gluteal muscles insert on the posteriorly located greater trochanter and gluteal tuberosity. The lesser trochanter serves as the insertion point for the iliopsoas muscle, while the pectineus muscle inserts just inferiolaterally to the trochanter. The anterior portion of the shaft and spiral line provide the origin for the vastus intermedius muscle. The distal portion of the femur is the attachment site for the gastrocnemius and plantaris muscles. Laterally, the femur is bounded by the iliotibial tract (Agur, 1991).

The most diagnostic features of the femoral diaphysis are the linea aspera and pilaster, the beading which supports the linea aspera. Although the linea aspera is expressed in all femora due to its origin as a muscle attachment site, the pilaster is present in only 71% of Caucasian femora and is not necessarily correlated with the expression of the linea aspera (Hrdlicka, 1934 as cited in Aiello and Dean, 1990). Aiello and Dean (1990) report that in femora which have a greater degree of anterior posterior curvature the pilaster appears to compensate by straightening out the posterior aspect of the femoral shaft.

The understanding of how the characteristic morphology of the femur evolves as a result of development or activity is still relatively in its infancy. However, due to the benefit of a predictable model of femoral bone change in response to strain in clinical applications, there is a growing body of literature exploring femur shape, anatomy and behavioral strain consequences. For example, using finite element analysis and computer-aided optimization to simulate adaptive bone growth Mittlmeier and coworkers (1994) found that the characteristic shape of the femoral diaphysis could not be accounted for by standard loads - axial, torsion, or bending. Not until the action of the adductor muscles was added to the model was the characteristic shape of the diaphysis realized, with the tear drop shape of the linea aspera and pilaster. Pauwels (1980b) suggested that the significance of the linea aspera and the resulting large anterior-posterior dimension of the femur actually serves to predictably place stress in plane of maximum resistance, which is at a 40 degree angle with the linea aspera. Pauwels (1980a) also advanced an approach taking into consideration muscular action as a stabilizing force neutralizing or serving to reduce bone strains.

Bone strains during a one legged stance have been examined by Taylor and coworkers (1996) using finite element analysis. Taylor found that in the one legged stance the femur shaft is loaded in compression, not bending. The proximal femur has been recently examined using a curved beam model derived from dual-energy X-ray absorptiometry by Mourtada and coworkers (1996). The authors found peak stresses to be located at the femoral neck and in the middle intertrochanteric region, both of which correspond to common fracture sites in the elderly.

Sumner and Andriacchi (1996) assessed relationships between cross-sectional properties of the femur and humerus to bone length during growth and development to adulthood using an archaeological sample from Grasshopper Pueblo. The authors found that the increase in cross-sectional properties as function of bone length was greater in the femur than humerus for individuals 1 to 25 years. They attributed this to different mechanical loading histories of the femur and humerus due to the increase muscle strength of the lower body and strength gains during growth and development, which are greater for the lower extremity.

Moro and coworkers (1996) used DXA to analyze the mid-femoral diaphysis of 375 healthy 9 –26 year olds from 4 ethnic cohorts (Black, Asian, White, Hispanic). The authors found that cross-sectional properties correlated more highly with total body mass than sex, ethnicity, fat mass, or lean mass. Similarly, Kimura and Amtmann (1984) found cross-sectional properties which were associated with robusticity increased with larger body size. Frost (1997a) reports that obesity is correlated with higher levels of bone mass, however bed ridden obese individuals will experience the same bone loss due to inactivity as slender individuals.

Chapter III

Materials and Methods

Study Samples

The sample utilized for this study is derived from the Terry collection, housed at the Smithsonian Institution (n = 335), and the Forensic Data Bank at the University of Tennessee (n = 661). Individuals with birth dates prior to 1900 hail primarily from the Terry Collection.

Four subgroups were identified to analyze secular change: White females, Black females, White males and Black males. I am aware of the controversial nature of classification by ancestry and bureaucratic race assessments, but in a biological context, these classifications are of importance and reflect, to some degree, immediate relationships. Identification of subgroups are useful to describe secular trends, in that contrary trends have been identified for different populations (see for example Greiner and Gordon, 1990 and 1992, for an assessment of anthropometric change in male military personnel). Given that secular trends probably represent non-genetic modifications of the phenotype, socially constructed classifications which may be suggestive of possible different environmental conditions, can be useful for the identification of secular changes. Though labels of "Black" and "White" are curtained with social connotations and are entrenched in perceptions of skin color, these words were chosen over other population descriptors such as "European" or "African" which might contain more biological significance in some situations. These more specific terms, however, do not account for individuals who are socially categorized as "Black" or "White" but do not have direct African or European ancestry. Racial categories are inherently flawed. To accurately describe an individual's ancestry is to produce a long list of labels, labels which cannot easily be lumped into one inclusive category. For the current study labels of "Black" and "White" were chosen because they are more socially inclusive even though they are less biologically based. Secondarily, labels of "Black" and "White" were chosen because these are the categorical terms which characterize the majority of research literature to which this study contributes.

Terry Collection

The Terry collection is comprised of 1732 individuals of White and Black ancestry received by the Anatomy Department at Washington University Medical School, St. Louis, MO, between 1920 to 1960 (Meadows Jantz, 1996). Presently, this collection is housed at the Smithsonian Institution in Washington, D.C.. Dates of death for the Terry collection range from the late 1930's and extend into the 1960's, with age at death ranging from mid-twenties to nineties. The racial make-up of the "White" segment is primarily of Old Americans or Germanic groups which settled in the St. Louis area, while the "Black" individuals are of unknown variable Caucasian or European admixture (St. Hoyme and Iscan, 1989). Secular changes in this population have been investigated in stature and transverse diameter of the midshaft femur (Trotter and Glesser, 1951; Trotter et al.,1968).

Bicondylar femur measures for the Terry collection individuals used in this study were acquired through the Washington University Archives in St. Louis, as a subset from the original data set used by Trotter for her 1969 study on secular change of the transverse diameter of the femur. However, Trotter used maximum transverse diameter (rather than the transverse diameter measured perpendicular to the anterior-posterior dimension as used in the current study), which was incompatible with information available in the Forensic Data Bank. Drs. David Hunt, Smithsonian Institution, and Richard Jantz, University of Tennessee, generously provided midshaft measures for the Terry cases.

Forensic Data Bank

The Forensic Data Bank is a computerized database for use in skeletal identification research, housed at the University of Tennessee, Knoxville. Cases compiled in the Data Bank are submitted by practicing forensic and skeletal anthropologists worldwide and stem from forensic cases, anatomical collections, and donated skeletal materials. Submissions to the Data Bank follow a standardized recording form and data collection procedure as put forth in the Data Bank Collection Manual (Moore-Jansen, Ousley, and Jantz, 1994) for the contribution of vital statistics, metric, and non-metric observations. The Data Bank sample employed in this study roughly represents a cross-sectional, albeit very eclectic, sample of the United States population for the last 100 years.

Methodology

Inclusion in this study was determined by the availability of birth year statistics, sex and ancestry, and femur measures. For individuals assessed as positively identified and categorized as "1" (n = 913), personal identity is known. For individuals designated as "2" (n = 83), although personal identity is not known, soft tissue features were used to construct a biological profile. No individuals were included in the analysis which were profiled using diagnostic skeletal traits. Only individuals identified as "adult" or over 18 years of age were included in the analysis. Preference was given to measures from the left side. When left side measures were unavailable, bone measures from the right side were substituted. Table 1 presents number of observations by date of birth broken down into 10-year cohorts.

Femur measures

Nine femur measures (Figure 3), taken to the nearest millimeter, were included in this study. All femur measures were done in accordance with the guidelines presented in Moore-Jansen, Ousley, and Jantz (1994) after Martin (1957):

1. **Maximum femur length (MFL)**: The distance from the most superior point on the head of the femur to the most inferior point on the distal condyles.

2. **Bicondylar femur length (BFL)**: The distance from the most superior point on the head of the femur to a plane drawn along the inferior surfaces of the distal condyles.

3. **Epicondylar breadth (EPIBR)**: The distance between the two most laterally projecting points on the epicondyles.

4. **Maximum diameter of the femur head breadth (FH)**: The maximum diameter of the femur head measured on the border of the articular surface.

5. **Anterior-posterior subtrochanteric (APS)**: The anterior-posterior diameter of the proximal end of the diaphysis measured perpendicular to the transverse diameter at the point of the greatest lateral expansion of the femur below the lesser trochanter.

6. **Transverse subtrochanteric diameter of the femur (MLS)**: The transverse diameter of the proximal portion of the diaphysis at the point of its greatest lateral expansion below the base of the lesser trochanter. In cases where this cannot be determined (e.g. where the lateral surfaces remain parallel), this measurement is recorded within 2 – 5 cm below the lesser trochanter.

7. **Anterior-posterior midshaft (APM)**: The anterior-posterior diameter measured approximately at the midpoint of the diaphysis, at the highest elevation of the linea aspera. This measurement is taken perpendicular to the ventral surface.

8. **Mediolateral midshaft (MLM)**: The distance between the medial and lateral margins of the femur from one another measured perpendicular to and at the same level as the sagittal diameter.

9. **Midshaft circumference (CIR)**: The circumference is measured at the midshaft at the same level of the sagittal and transverse diameters.

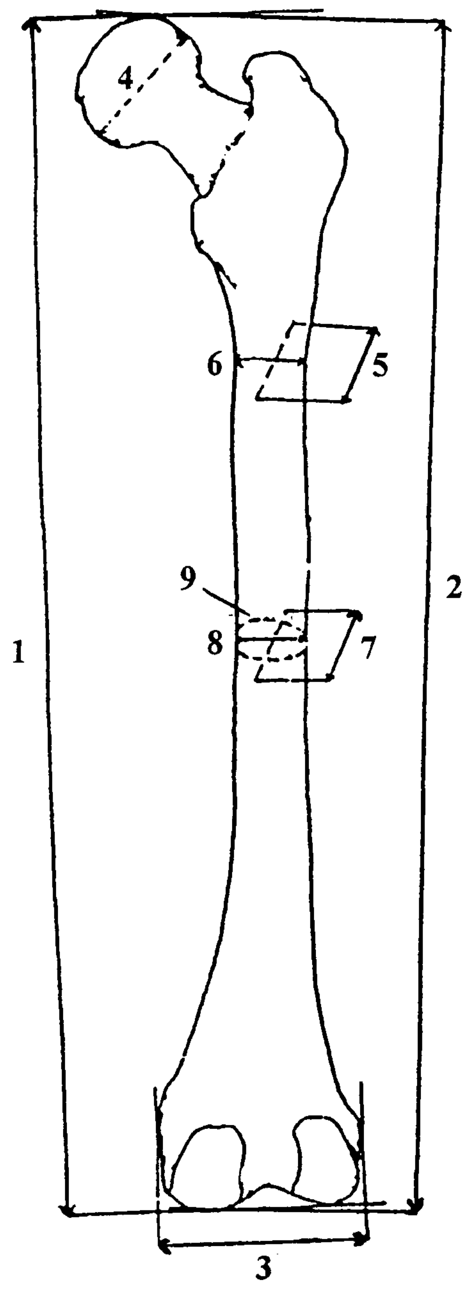


Figure 3: Graphic representation of femur measures used in this study. (modified from Moore-Jansen, Ousley, and Jantz, 1994). See text for number and measurement definitions.

Not all Terry collection or Data Bank cases included all measures, so specific comparisons are limited to cases for which the pertinent information was available and recorded.

Robusticity Index and Shape Ratios

Using the above femur measures, indices and ratios were computed to generate additional structural comparisons: an index of femoral robusticity, ratios representative of external subtrochanteric and midshaft diaphyseal shape, and an estimate of the total subperiosteal area of the midshaft for the allometric comparisons.

***Robusticity index* (BFLROB):**

$$BFLROB = (APM + MLM) \times 100/BFL$$

An index of robusticity was used to assess relative robusticity of the femoral midshaft relative to bicondylar femur length. Robusticity indices of shaft size and length have also been used by Demes and Jungers (1989) and Cole (1994) to describe the robusticity of long bones. Bicondylar femur length was chosen rather than maximum femur length because more cases were available and it more closely measures the length of the femur shaft.

Midshafts shape ratio **(MRATIO):**

$$MRATIO = APM/MLM$$

Femur midshaft cross-sectional shape comparisons are made through analysis of the anterior-posterior diameter and the distance between the medial-lateral margins at midshaft. Femur cross-sectional shape is expressed in a ratio of APM/MLM. A ratio of 1.0 indicates a bone is the same size in both the transverse and anterior-posterior planes, equally resistant to bending stresses in all directions. A ratio greater than 1.0 shows that the cross-sectional is more elongated in the sagittal plane, and likewise, a ratio of less than 1.0 indicates the bone is wider in the medial-lateral dimension. Ideally, ending strength of the bone is highest in the dimension that the bone is largest.

Although external dimensions are only approximations of cross-sectional properties, these measures are highly correlated with those derived by more precise means, such as CT scans and direct sectioning, and can be used to describe bone shape (Cole 1995, Ruff 1987, Jungers and Minns 1979, Rockhold n.d.). Rockhold (n.d.), using a sample of 131 Plains Native American midshaft femoral external measures and internally derived cross-sectional geometric properties (second moments of area about the x and y axes: Ix, Iy) found Pearson correlation coefficients of 0.873 and 0.870 between matched femoral external measures and internal properties. Additionally, the externally derived ratio of femur midshaft shape compared to the internally derived shape ratio (Ix/Iy) yielded a correlation coefficient of 0.82. Results of a two-tailed paired sample t – test on these data indicate that shape ratios derived from external measures (mean = 1.08) are somewhat smaller than ratios derived from internal properties (mean = 1.12) at $p = 0.001$. These results support the validity and use of external measures to describe femoral biomechanical relationships.

Subtrochanteric shape ratio **(SRATIO):**

$$SRATIO = APS/MLS$$

Shape comparisons of the subtrochanteric region of the femur were facilitated though the analysis of the ratio between the anterior-posterior and the medial-lateral diameters. Like the midshaft ratio, a value of 1.0 indicates that the distances measured in the sagittal and transverse planes are equal. A ratio greater than 1.0 indicates the subtrochanteric area is more elongated in the anterior-posterior plane and less than 1.0, more elongated in the medial-lateral dimension. Like midshaft shape, bending strength in the subtrochanteric region is highest in the dimension of greatest expansion.

Allometric analysis

To determine the relationship of cross-sectional area to femur length the allometric analysis was accomplished as follows. Cross-sectional external measures, APM and MLM, were translated into an elliptical model of total subperiosteal area (TA) of the midshaft femur:

$$TA = \pi\,(APM/2 \times MLM/2)$$

Using natural log transformed data (*ln*TA, *ln*BFL), the relationship of cross-sectional area to *ln*BFL was accomplished by reduced major axis regression analysis. BFL was chosen to test the allometric relationship between bone length and cross-sectional area because it more closely measures the length of the femur shaft than MFL. For this reason, BFL more closely resembles an engineering beam model of the femur, which has been proposed as more appropriate for structural comparisons by Ruff (1984) to model the allometric relationships of the femur. The value expected for isometry is 2.0. Values below 2.0 indicate BFL is increasing slower in relation to cross-sectional area. A value greater than 2.0 would indicate BFL is increasing faster than cross-sectional area.

Statistical analysis

These data were entered in to a Microsoft Excel 97 spreadsheet, then imported into the University of Tennessee mainframe computer for statistical analysis using SAS on the UNIX platform at the University of Tennessee, Knoxville. General descriptive statistics for each group by decade are presented in Appendix 1.

Initially, these data were correlated through a Pearson correlation coefficient matrix to assist in defining statistically significant relationships among the variables. Calculation of general secular trends was assessed through least squares regression analysis. Least squares regression was chosen because of the clear assignment of date of birth (DOB) as the independent variable. The null hypothesis was that there was no relationship between DOB and the femoral measures and indices. Cubic and polynomial regressions were also used to assess change over time, however, these methods did not increase the significance of the least squares regressions.

Secular trends in the femur variables were also plotted using the Lowess smoothing method. Lowess is a locally weighted robust nonparametric regression technique, which makes no a priori assumptions about the shape of the plotted regression line. The purpose of the Lowess regression curve is to summarize the middle of the distribution of Y for each value of X.

Due to the strong association many of the variables had with DOB, to examine the relationship between age and selected femur measures, a partial correlation coefficient (Kachigan, 1982) controlling for DOB was derived by:

$$r_{12*3} = \frac{r_{12} - r_{13}\, r_{23}}{\sqrt{(1-r_{13}^2)(1-r_{23}^2)}}$$

where r_{12} equals the Pearson correlation coefficient between the femur variables 1 and 2, r_{13} equals the correlation coefficient between variable 1 with DOB, and r_{23} is the correlation coefficient between variable 2 and DOB. Only cases which were complete for all three *r* values were included in the calculation.

T statistics for the partial correlation coefficients were derived by:

$$T = \frac{r_{12*3}}{\sqrt{(1 - r_{12*3}^2)}} * \sqrt{(n-3)}$$

where r_{12*3} is the partial correlation coefficient and *n* equals the number of observations. The null hypothesis was that there was no correlation between age and the femur variables. Corresponding two-tailed *p* values were generated for the *T* statistics from a student's *T* distribution.

Two-sample *t* -tests were run on these data to examine sex and sample differences. The null hypothesis was that the means were not significantly different between two groups (two-tailed test). *T* - tests were conducted between White males and females, Black males and females, Black and White females, and Black or White males.

To model the allometric relationship between total cross-sectional area and femur bicondylar length, reduced major axis regression was employed. Reduced major axis (RMA), unlike least squares regression, is not affected by the correlation coefficient of the reference sample. RMA is the ratio of the standard deviation of the y variable and x variable, thus the ratio of the variances will be the same irrespective if the data are highly correlated or not (Aiello, 1992). RMA regressions are recommended method of choice for examining biological allometric relationships (Ruff et al.,1993; Aiello, 1992).

Chapter IV

Results

Table 1 presents the mean date of birth and number of cases by group and decade. White females (n = 249) and White males (n =388) represent the largest number of cases by decade. Black males (n = 202) and Black females (n = 156) have fewer cases per decade. Birth dates range from 1839 to 1976.

Descriptive statistics for each variable, including sample size, mean, standard deviation, minimum value and maximum value for all decades combined are presented in Tables 2 (Black females), 3 (White females), 4 (Black Males), and 5 (White males). Descriptive statistics are presented broken down by decade for each group in Appendix 1. Predictably, age at death is greater for earlier birth dates, but as the tables demonstrate, a wide age range of adult ages is included for most decades. Age distribution plots for Black males and females, and White males and females are located in Appendix 2.

Secular Change

Tables 6 (Black females), 7 (White females), 8 (Black Males), and 9 (White males) present the results of the least squares regression of the femur variables

Table 1: Sample sizes by decade. Individuals with birth dates prior to 1900 Hail primarily from the Terry Collection.

	Females		*Males*	
Decade	*White*	*Black*	*White*	*Black*
1830 – 1839	0	1	1	1
1840 – 1849	7	6	5	7
1850 – 1859	21	14	33	21
1860 – 1869	20	14	27	19
1870 – 1879	14	8	20	12
1880 – 1889	10	11	11	12
1890 – 1899	12	13	13	10
1900 – 1909	9	19	13	28
1910 – 1919	23	21	22	27
1920 – 1929	23	6	48	15
1930 – 1939	17	5	56	14
1940 – 1949	19	9	50	14
1950 – 1959	37	17	55	10
1960 – 1969	27	5	24	10
1970 – 1979	10	4	10	3
TOTAL	249	156	388	202

Table 2: Summary statistics for Black females, all decades combined.

	Black Females				
Variable	*N*	*Mean*	*Std Dev*	*Minimum*	*Maximum*
MFL	82	446.10	25.78	386.00	525.00
BFL	147	436.27	23.98	381.00	520.00
EPIBR	72	73.96	3.89	66.00	87.00
FH	80	42.04	2.14	35.00	47.00
APS	81	25.69	2.08	22.00	31.00
MLS	81	28.78	2.33	24.00	35.00
APM	147	27.67	2.15	21.40	34.00
MLM	147	25.12	2.15	20.80	31.30
CIR	71	82.06	5.47	67.00	93.00
MINDEX	147	1.11	0.11	0.83	1.55
SINDEX	81	0.90	0.09	0.70	1.29
TA	147	546.81	70.69	395.84	764.30
BFLROBUST	145	12.13	0.81	10.17	14.68

Table 3: Summary statistics for White females, all decades combined.

	White Females				
Variable	*N*	*Mean*	*Std Dev*	*Minimum*	*Maximum*
MFL	150	436.57	22.35	385.00	514.00
BFL	222	428.62	23.52	369.00	505.00
EPIBR	136	74.60	3.61	66.00	83.00
FH	148	42.17	2.19	33.00	47.00
APS	156	25.34	2.11	19.00	32.00
MLS	156	28.58	2.15	23.00	33.00
APM	237	26.97	2.24	20.00	32.40
MLM	238	24.76	2.14	18.90	34.70
CIR	89	80.58	5.01	65.00	91.00
MINDEX	237	1.09	0.10	0.82	1.42
SINDEX	154	0.89	0.07	0.70	1.17
TA	237	525.98	74.04	329.87	833.95
BFLROBUST	221	12.12	0.86	9.88	14.01

Table 4: Summary statistics for Black males, all decades combined.

	Black Males				
Variable	*N*	*Mean*	*Std Dev*	*Minimum*	*Maximum*
MFL	114	484.35	26.68	414.00	542.00
BFL	194	474.71	27.21	408.00	562.00
EPIBR	109	83.92	4.33	72.00	95.00
FH	114	47.92	2.74	40.00	57.00
APS	112	28.63	2.40	22.00	34.00
MLS	112	32.72	2.45	26.00	40.00
APM	196	30.72	2.31	26.00	37.00
MLM	194	28.77	2.30	23.00	35.80
CIR	95	91.76	5.76	82.00	107.00
MINDEX	194	1.07	0.10	0.81	1.33
SINDEX	112	0.88	0.07	0.69	1.07
TA	194	695.10	85.34	523.86	984.10
BFLROBUST	191	12.56	0.82	10.75	15.24

Table 5: Summary statistics for White males, all decades combined.

	White Males				
Variable	*N*	*Mean*	*Std Dev*	*Minimum*	*Maximum*
MFL	258	474.14	23.67	403.00	563.00
BFL	354	466.10	24.97	391.00	561.00
EPIBR	245	85.26	4.45	75.00	99.00
FH	262	48.68	2.45	40.00	56.00
APS	272	29.04	2.52	23.00	39.00
MLS	272	32.42	2.75	21.00	48.00
APM	366	30.44	2.52	23.00	42.00
MLM	366	28.22	2.32	21.00	36.00
CIR	190	91.77	6.25	74.00	115.00
MINDEX	366	1.08	0.10	0.83	1.45
SINDEX	271	0.90	0.09	0.71	1.39
TA	366	676.20	91.53	379.35	1017.09
BFLROBUST	352	12.63	0.89	10.27	15.71

Table 6: Intercept, slope, F statistic, r^2 and p values for femur variables regressed on date of birth for Black Females.

	Black Females					
Variable	*Number*	*Intercept*	*Slope*	*F statistic*	r^2	*p value*
MFL	82	515.43	- 0.036	0.08	0.001	0.7745
BFL	147	221.72	0.113	4.18	0.028	0.0426*
EPIBR	72	114.89	- 0.212	1.02	0.014	0.3151
FH	80	92.05	- 0.026	6.23	0.074	0.0147*
APS	81	71.88	- 0.024	5.76	0.068	0.0187*
MLS	81	71.51	- 0.022	3.84	0.046	0.0537*
APM	147	34.18	- 0.003	0.46	0.003	0.4971
MLM	147	81.8	- 0.029	46.72	0.244	0.0001*
CIR	71	209.68	- 0.066	5.68	0.076	0.0199*
MRATIO	147	- 1.15	0.001	23.92	0.142	0.0001*
SRATIO	81	1.18	- 0.000	0.11	0.001	0.7439
TA	147	1907.85	- 0.716	21.58	0.130	0.0001*
BFL ROBUST	145	32.18	- 0.011	38.57	0.212	0.0001*

* statistically significant at $p < 0.05$.

Table 7: Intercept, slope, F statistic, r^2 and p values for femur variables regressed on date of birth for White Females.

	White Females					
Variable	*Number*	*Intercept*	*Slope*	*F statistic*	r^2	*p value*
MFL	150	508.81	- 0.037	0.19	0.001	0.6614
BFL	222	195.34	0.122	9.77	0.043	0.002*
EPIBR	136	124.75	- 0.026	3.41	0.025	0.0670
FH	148	76.23	- 0.018	4.63	0.031	0.033*
APS	156	88.62	- 0.033	19.25	0.111	0.0001*
MLS	156	67.83	- 0.020	7.24	0.045	0.0079*
APM	237	24.76	0.001	0.10	0.000	0.7552
MLM	238	68.29	- 0.023	50.32	0.176	0.0001*
CIR	89	196.79	- 0.059	5.56	0.060	0.0206*
MRATIO	237	- 0.95	0.001	45.88	0.163	0.0001*
SRATIO	154	2.01	- 0.001	4.38	0.028	0.0381*
TA	237	1414.12	- 0.464	15.30	0.061	0.0001*
BFL ROBUST	221	27.40	- 0.007	34.67	0.137	0.0001*

* statistically significant at $p < 0.05$.

Table 8: Intercept, slope, F statistic, r^2 and p values for femur variables regressed on date of birth for Black males.

	Black males					
Variable	*Number*	*Intercept*	*Slope*	*F statistic*	r^2	*p value*
MFL	114	252.39	0.120	1.01	0.009	0.3159
BFL	194	88.60	0.203	14.34	0.069	0.0002*
EPIBR	109	120.71	- 0.019	0.92	0.008	0.3407
FH	114	53.55	- 0.003	0.06	0.000	0.8139
APS	112	40.77	- 0.006	0.33	0.003	0.5668
MLS	112	71.76	- 0.020	3.37	0.030	0.0692
APM	196	22.74	0.004	0.79	0.004	0.3743
MLM	194	71.09	- 0.022	25.14	0.116	0.0001*
CIR	95	56.96	0.018	0.4	0.004	0.5279
MRATIO	194	- 0.80	0.001	24.84	0.115	0.0001*
SRATIO	112	0.12	0.000	1.34	0.012	0.2501
TA	194	1526.59	- 0.437	6.46	0.033	0.0118*
BFL ROBUST	191	30.00	- 0.009	34.65	0.155	0.0001*

* statistically significant at $p < 0.05$.

Table 9: Intercept, slope, F statistic, r^2 and p values for femur variables regressed on date of birth for White males.

	White males					
Variable	*Number*	*Intercept*	*Slope*	*F statistic*	r^2	*p value*
MFL	258	168.22	0.158	4.05	0.016	0.0451*
BFL	354	53.32	0.215	39.32	0.100	0.0001*
EPIBR	254	96.94	- 0.006	0.16	0.000	0.6933
FH	262	78.14	- 0.152	3.55	0.013	0.0607
APS	272	75.45	- 0.024	8.79	0.032	0.0033*
MLS	272	110.36	- 0.040	21.81	0.075	0.0001*
APM	366	18.62	0.006	2.95	0.008	0.0868
MLM	366	62.96	- 0.018	32.34	0.082	0.0001*
CIR	190	223.61	- 0.068	7.59	0.039	0.0064*
MRATIO	366	- 0.71	0.001	46.90	0.114	0.0001*
SRATIO	271	0.36	0.000	0.84	0.003	0.3616
TA	366	1205.06	- 0.276	4.48	0.012	0.0350*
BFL ROBUST	352	27.99	- 0.008	43.32	0.110	0.0001*

* statistically significant at $p < 0.05$.

regressed on DOB. Black females are statistically significant for secular change in BFL ($p = 0.04$), FH ($p = 0.0147$), APS ($p = 0.0187$), MLS ($p = 0.05$), MLM ($p = 0.0001$), CIR ($p = 0.01$), MRATIO ($p = 0.0001$), TA ($p = 0.0001$), and BFLROB ($p = 0.0001$). These changes illustrate the femur shaft becoming longer, in tandem with the midshaft changing shape, due to the decrease in the mediolateral dimension. The significant decrease of the anterior-posterior and mediolateral dimensions in the subtrochanteric region is not associated with any temporal change in diaphyseal shape in the subtrochanteric shape ratio. In addition, the femur head is significant for secular change, decreasing in maximum breadth. Total area and midshaft circumference also decrease, together with femoral robusticity over the represented time period. The increase in the midshaft shape ratio, which represents the anterior-posterior elongation of the midshaft, is a result of a decrease in the medio-lateral diameter and a non-significant change in the anterior-posterior dimension.

Like Black females, White females are statistically significant for secular change in BFL ($p = 0.002$), FH ($p = 0.03$), APS ($p = 0.0001$), MLS ($p = 0.0079$), MLM ($p = 0.0001$), CIR ($p = 0.02$), MRATIO ($p = 0.0001$), TA ($p = 0.0001$), and BFLROB ($p = 0.0001$). In addition, White females are also significant for change in SRATIO ($p = 0.038$). The pattern of secular change between White and Black females is similar, but White females are experiencing a faster rate of decrease in the anterior-posterior dimension that in the mediolateral, which results in a statistically significant mediolateral elongation of the subtrochanteric region.

The results of the femur variables regressed on date of birth for Black Males are presented in Table 8. Black males are significant for secular increase in BFL (p = 0.0002), and a decrease in MLM (p = 0.0001), TA (p = 0.01) and BFLROB (p = 0.0001). Black males are also significant for anterior-posterior elongation of the midshaft as reflected by the midshaft shape ratio (p = 0.0001) due to the temporal decrease in mediolateral dimension and the non-significant change in anterior-posterior size.

Results for White males are presented in Table 9. White males are significant for secular increase in MFL (p = 0.04) and BFL (p = 0.0001), but a secular decrease in APS (p = 0.003), MLS (p = 0.0001), MLM (p = 0.0001), CIR (p = 0.006), TA (p = 0.035), and BFLROB (p = 0.0001). White males, like all other groups are significant for an increase in the midshaft shape ratio (p = 0.0001), due to the decrease in the mediolateral dimension and non-significant change in anterior-posterior size.

Oddly, Black and White females and Black males are not significant for secular change in maximum femur length, although all are significant for an increase in bicondylar femur length. Given the similarity of these measures, two explanations are plausible. First, there may be an increase in diaphyseal length of the femur in conjunction with a decrease in the angle of the femoral neck, which would be reflected in bicondylar but possibly not maximum femur length. Alternatively, given the smaller sample size of maximum length due to fewer pre 1900 birth dates, this discrepancy may be a result of a less representative sample. To test these hypotheses, Pearson correlation coefficients were derived for maximum with bicondylar length, and femur lengths with date of birth using only cases which had both length measures represented (Table 10). The correlation coefficients and p values for bicondylar and maximum femur length to date of birth are nearly identical, suggesting that the non-significant status of maximum length for secular change is due to the small sample and comparatively restricted birth dates represented for max length.

Table 10: Pearson correlation coefficient of r_1 (MFL and BFL) r_2 (BFL and DOB) and r_3(MFL and DOB) and respective p values. Only cases for which both BFL and MFL were available were included in the analysis.

Group	*N*	r_1	r_2	r_3
Black Females	78	0.996	- 0.035	- 0.051
		$p = 0.0001$*	$p = 0.76$	$p = 0.65$
White Females	141	0.997	- 0.021	- 0.029
		$p = 0.0001$*	$p = 0.81$	$p = 0.73$
Black Males	112	0.996	0.113	0.096
		$p = 0.0001$*	$p = 0.24$	$p = 0.31$
White Males	249	0.996	0.131	0.131
		$p = 0.0001$*	$p = 0.04$*	$p = 0.04$*

* statistically significant at $p < 0.05$.

None of the groups reach statistical significance for secular change in epicondylar breadth or anterior-posterior midshaft diameter, and only females are significant for a temporal decrease in femoral head breadth. The subtrochanteric ratio was significantly correlated with date of birth indicating mediolateral elongation only in White females, despite significant decreases in the anterior-posterior and mediolateral subtrochanteric dimensions in Black females, White females, and White males.

Lowess Data Plots

Lowess plots were generated for each group for variables APM (Figure 4), MLM (Figure 5, 6, 7, 8), MRATIO (Figure 9), BFL (Figure 10) and BFLROB (Figure 11) on date of birth to illuminate fluctuations in these measures not detailed in the least squares regression line. Visual appraisal of APM in Black females (Figure 4), for which there was no secular change demonstrated in the least squares regression for any group, suggests a slight decrease in APM from 1840 to 1870 followed by a plateau to 1910. Following 1910 to 1970, a slight progressive decrease in APM is apparent. In White females, there is a relative plateau from 1840 to 1920, followed by a slight decrease in APM to 1950, with an increase to 1970. White males demonstrate a plateau to about 1885, followed by an increase in APM to about 1920 then decreasing to 1970. APM, in White males, ends in the 1970's at almost the same size as 1840. Black males demonstrate a sharp decrease in APM from 1840 to about 1885, followed by a sharp linear increase to the 1970's. However, Black males, like White males, demonstrate fluctuation throughout the last century, the beginning and ending points are virtually the same for the APM measures.

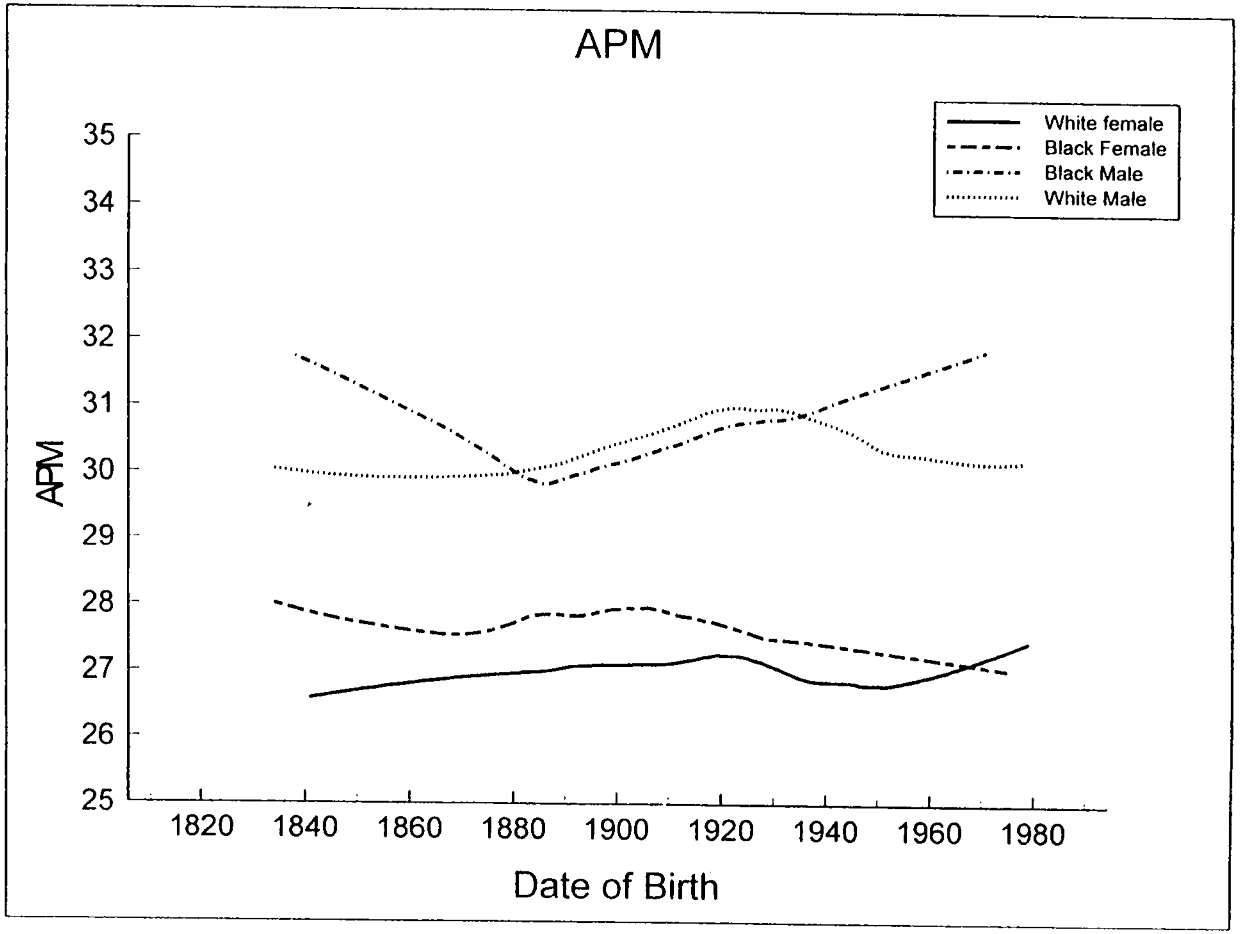


Figure 4: Lowess regression line for APM (midshaft anterior-posterior dimension).

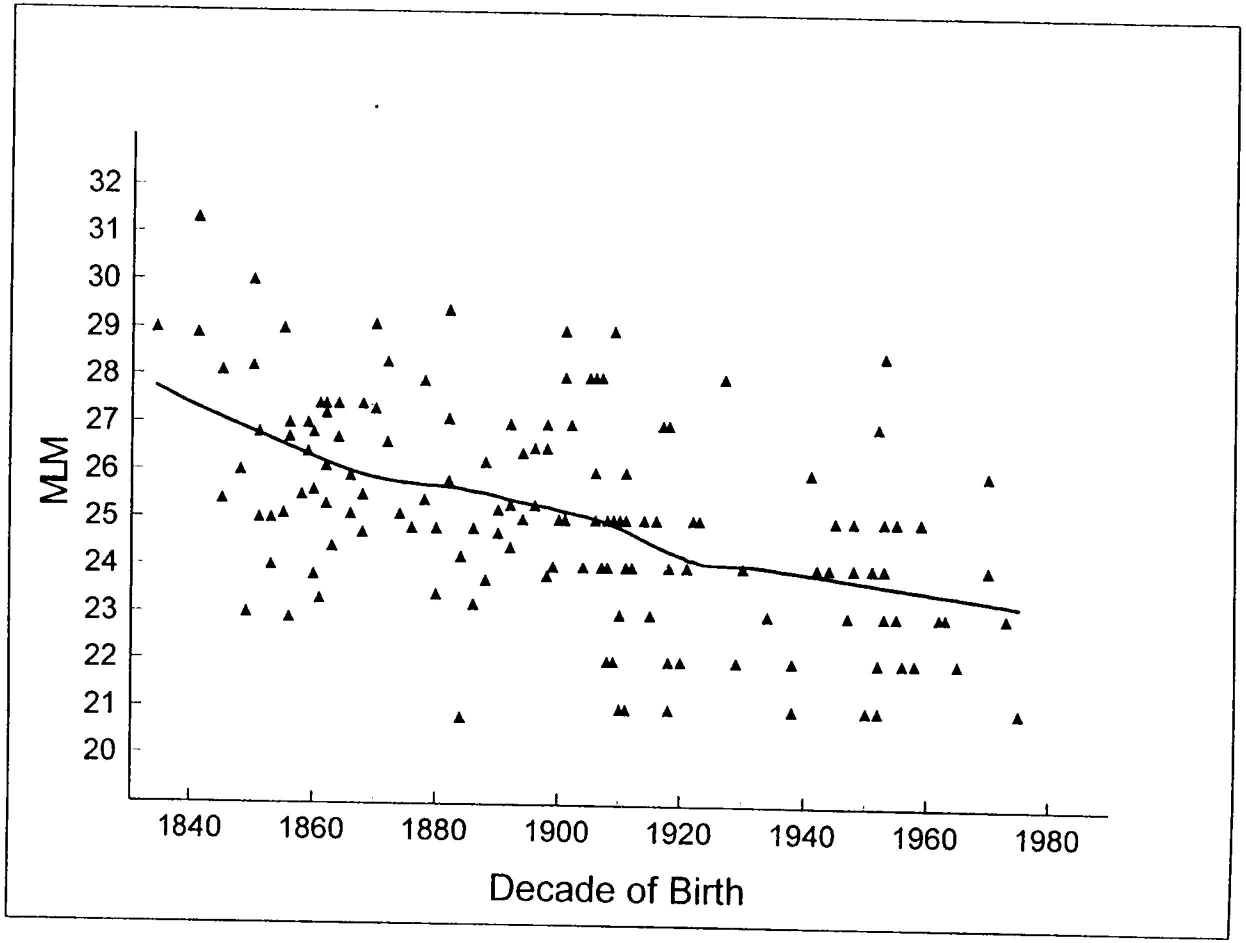


Figure 5: Lowess data plot for MLM for Black females (midshaft mediolateral dimension).

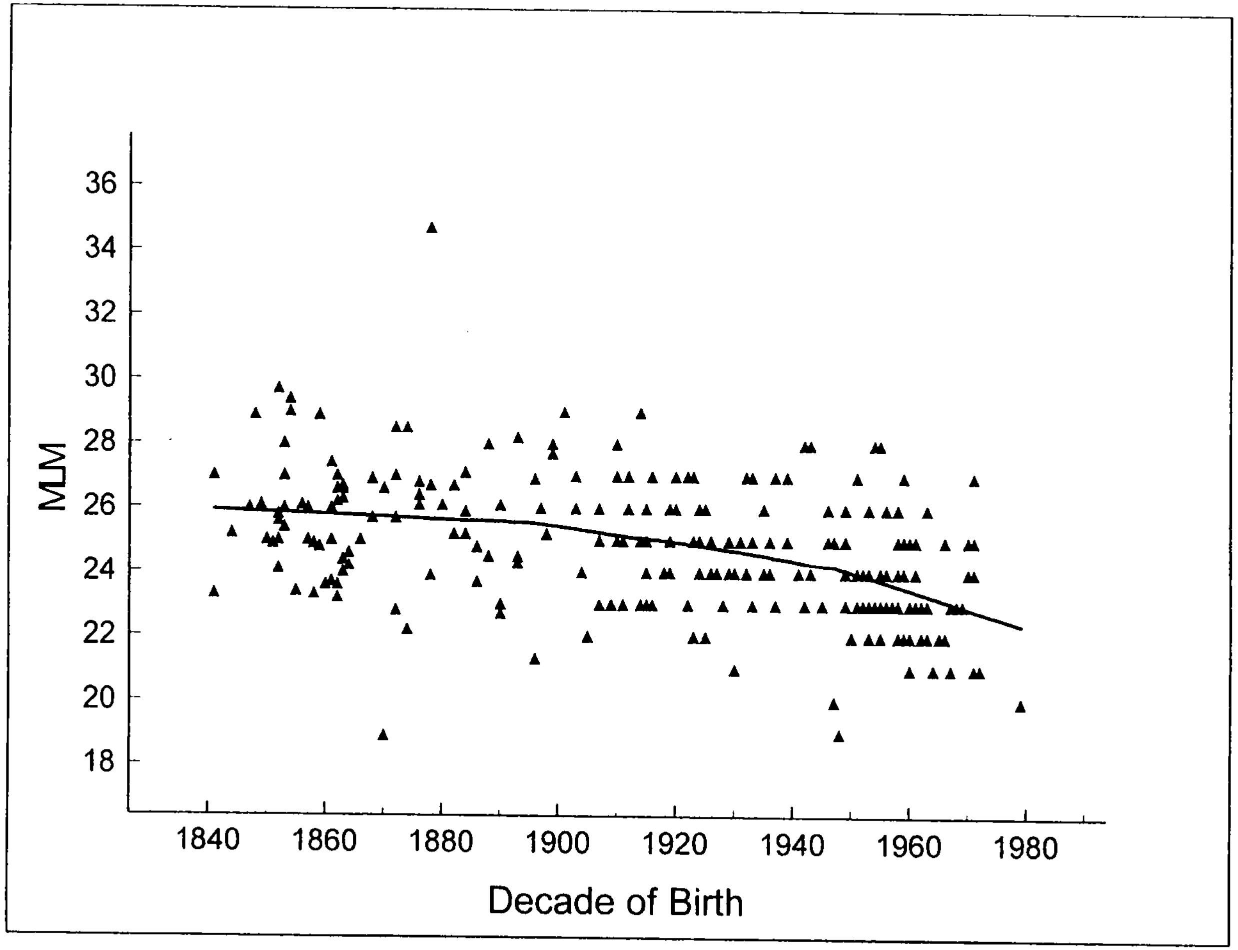


Figure 6: Lowess data plot for MLM for White females (midshaft mediolateral dimension).

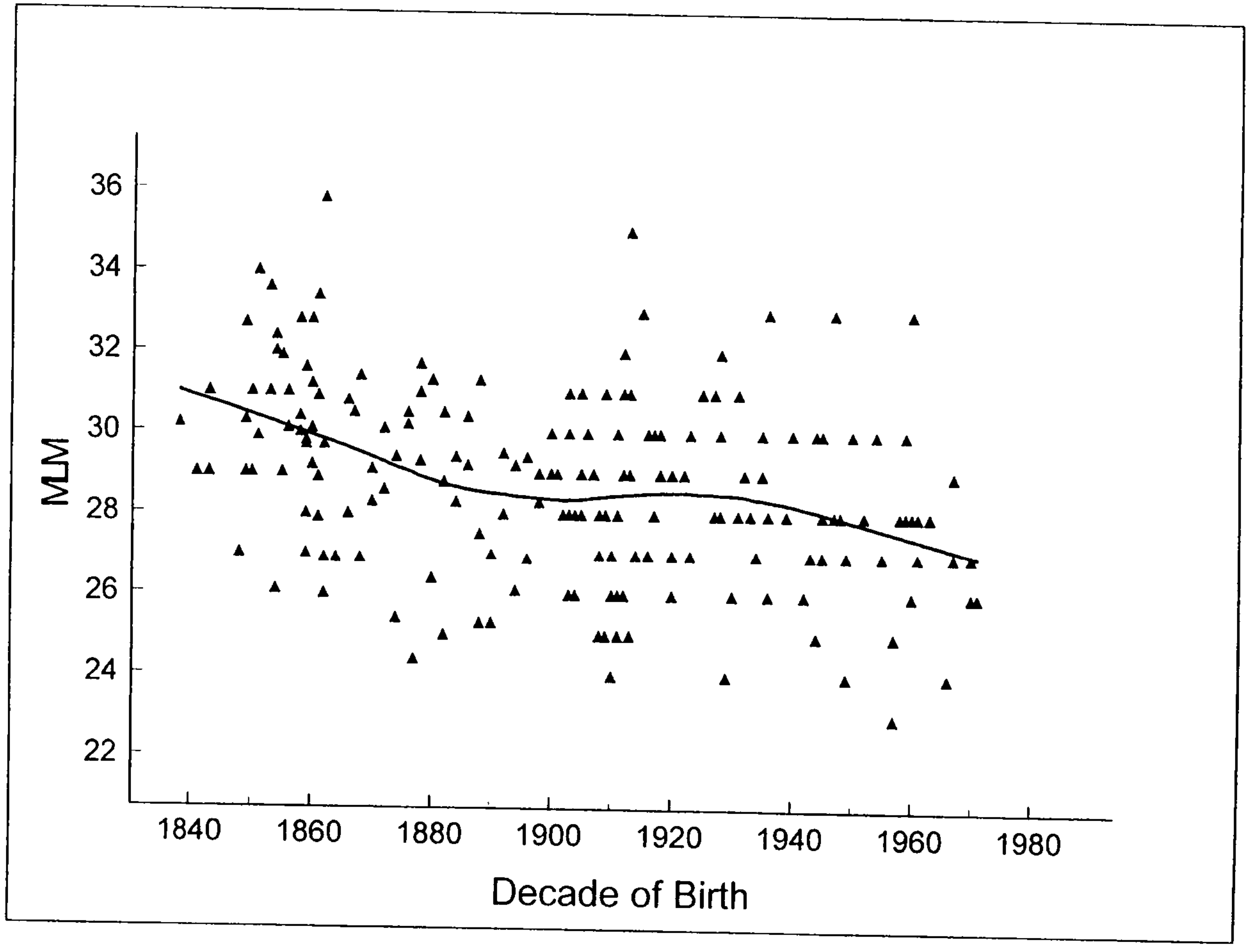


Figure 7: Lowess data plot for MLM for Black males (midshaft mediolateral dimension).

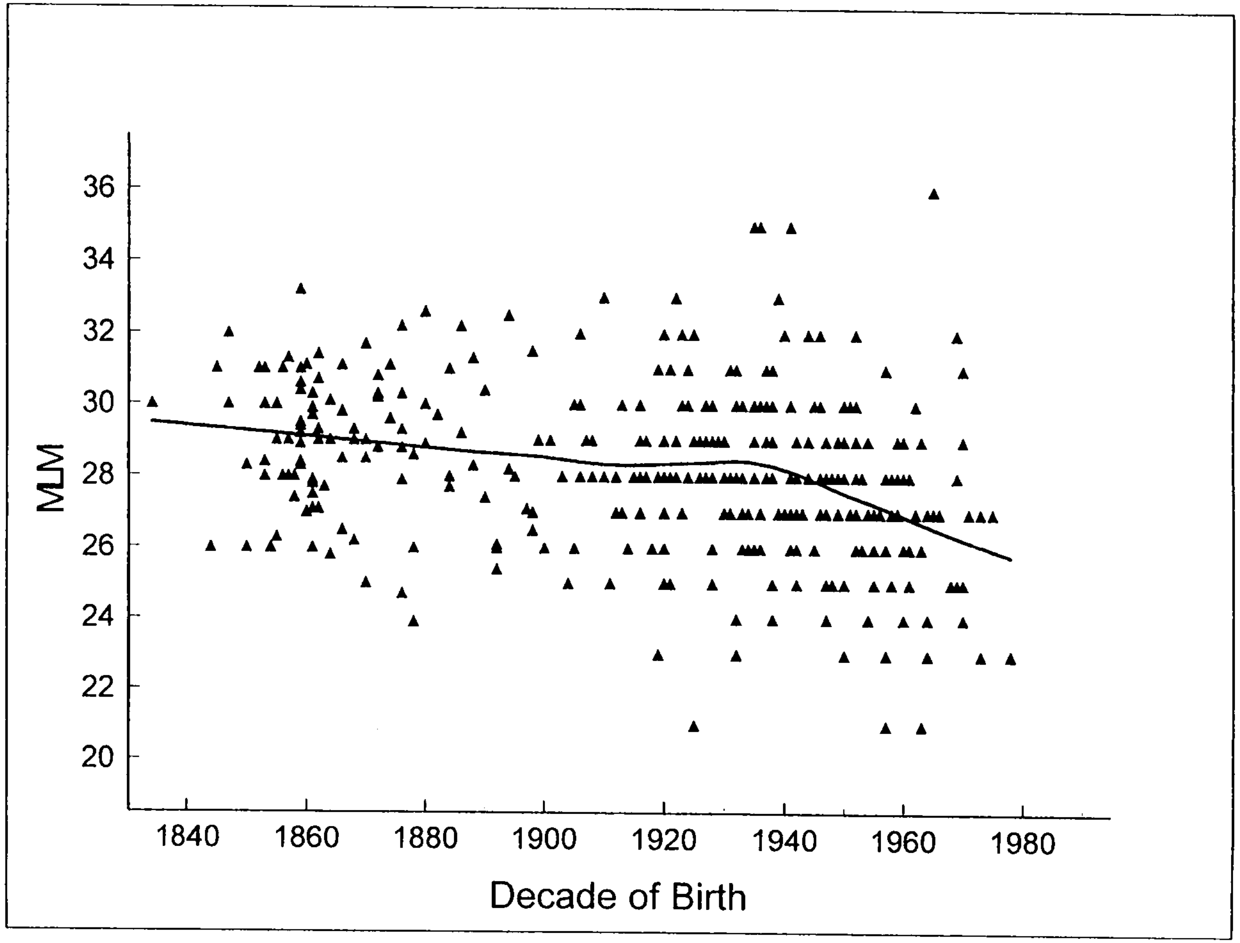


Figure 8: Lowess data plot for MLM for White males (midshaft mediolateral dimension).

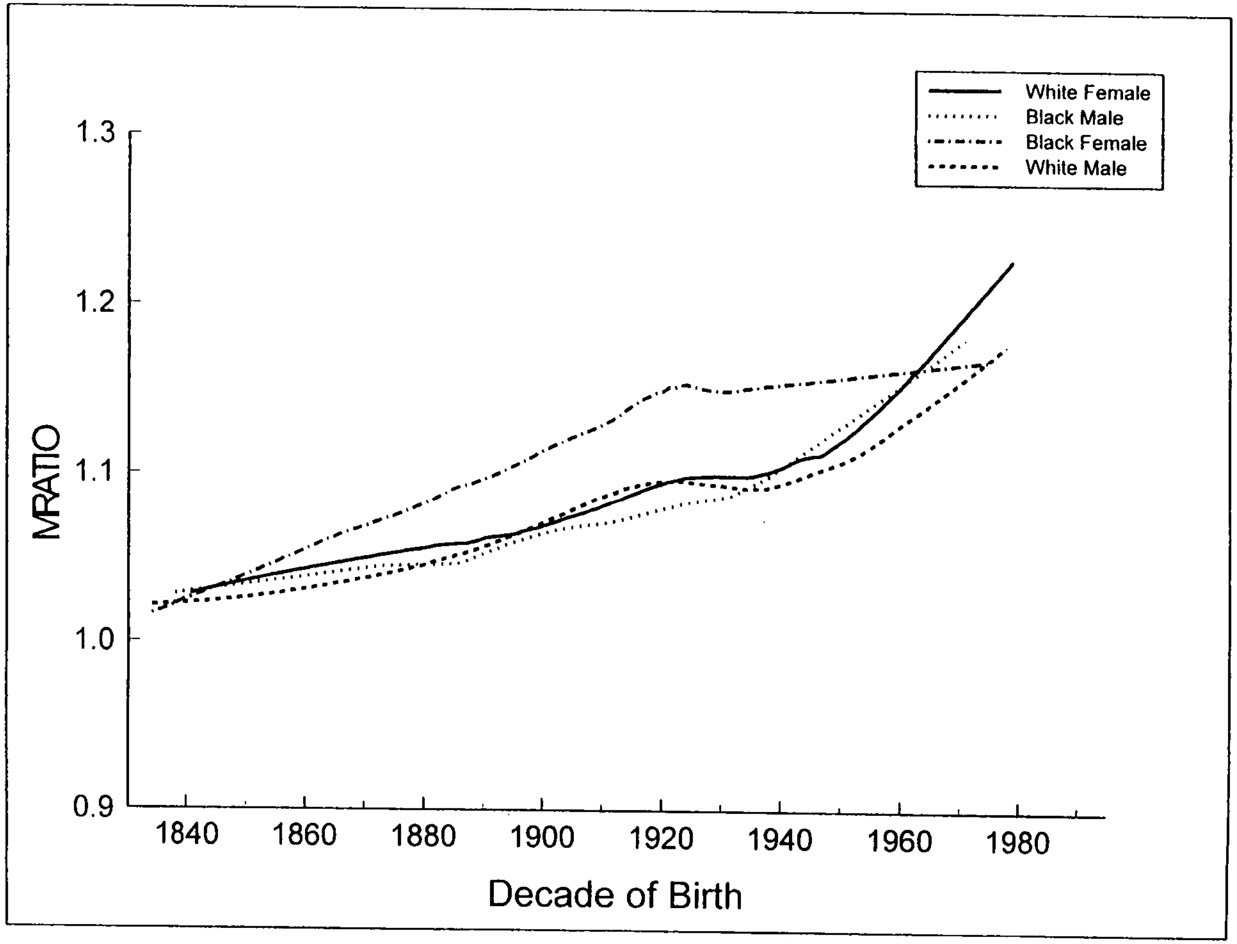


Figure 9: Lowess regression line for MRATIO (midshaft shape ratio).

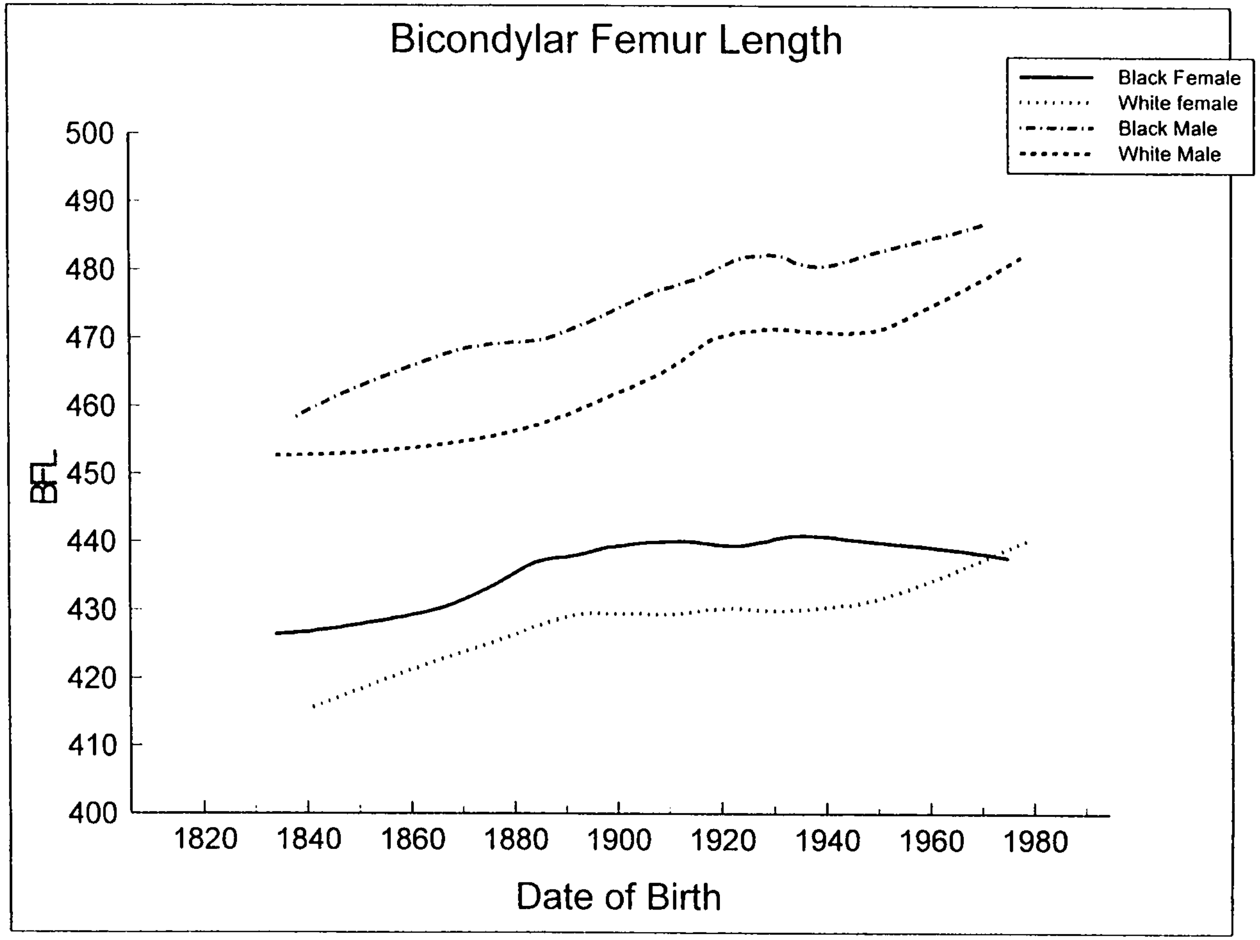


Figure 10: Lowess regression line for BFL (bicondylar femur length).

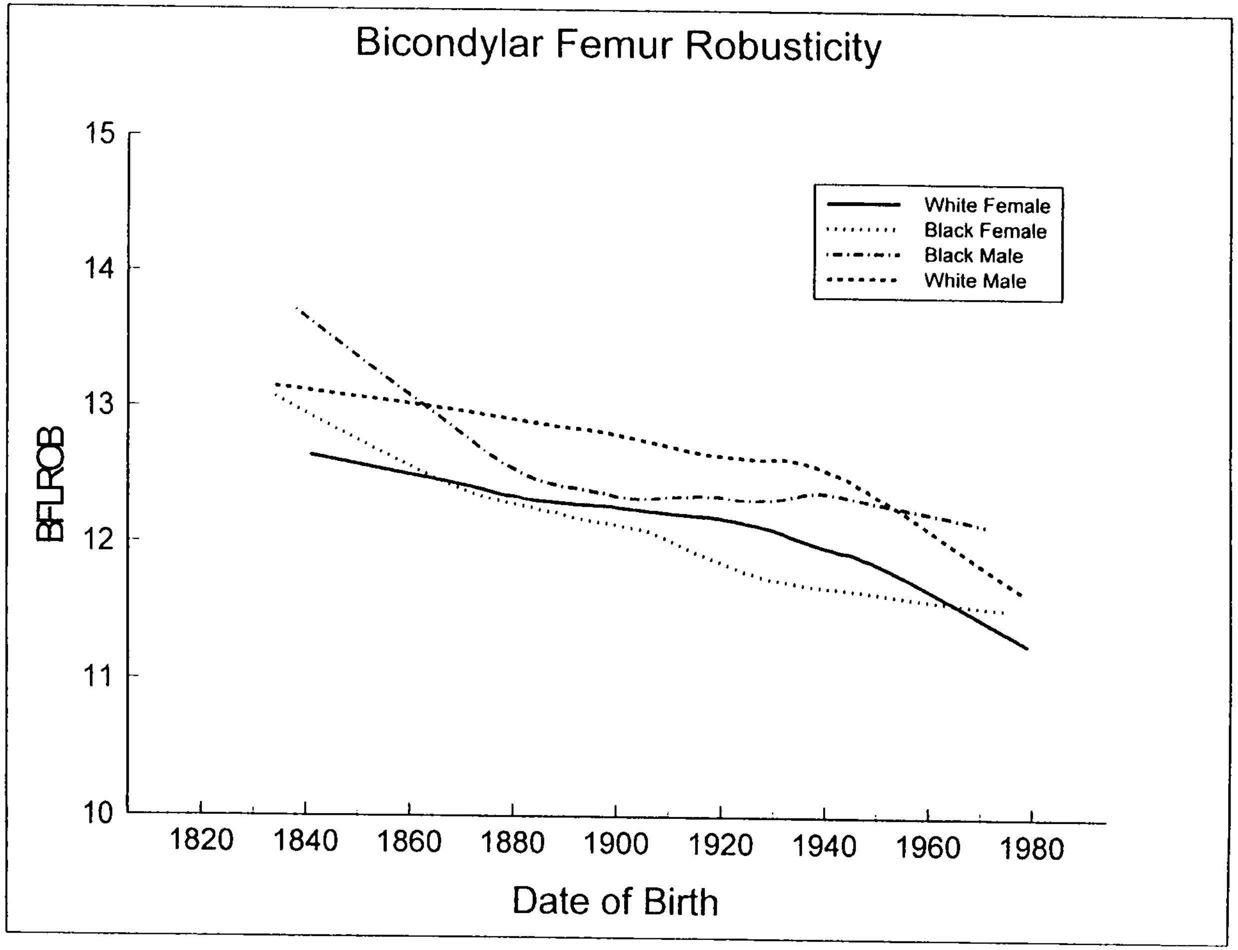


Figure 11: Lowess regression line for BFLROB (bicondylar femur robusticity).

The decrease in MLM, as shown in Figures 5 (Black females), 6 (White females), 7 (Black males), and 8 (White males) with the data points for each group presented, is much more linear and shows a more consistent pattern among the groups. Black females show a decline in MLM to about 1920, and then continue to decline to the 1970's, but not quite as steeply. White females display the opposite, with MLM showing a slow decrease from 1840 to 1940, followed by a sharp decrease to the 1970's. Black males demonstrate a decrease in MLM to about 1880, followed by a plateau till the late 1930's, and finally a linear decrease to the 1970's. White males demonstrate a slight decrease in MLM between 1840 and 1930, from which point, like Black males, MLM decreases sharply to the 1970's.

Changes in MRATIO are presented in Figure 9. Here, the groups demonstrate much similarity, with MRATIO increasing linearly from 1840 to about 1920, followed by a slight decrease or plateau to about 1930, culminating with a very sharp linear increase in MRATIO to the 1970's. Interestingly, Black females are more anterior-posteriorly elongated than the other groups in the mid 19th century due to a more pronounced increase in MRATIO from 1840 to the 1920's. However, although the subsequent increase in the ratio post 1920 in Black Females is akin to the other groups, it is not as steep, so that Black females cluster slightly below the other groups by the 1970's.

Bicondylar femur length (Figure 10) increases in Black and White females from about 1840 to 1890, at which time there is a plateau. In Black females this relative plateau remains till the 1970's, but in White females it only lasts until about

1940, increasing somewhat sharply from this point to the 1970's. Black and White males demonstrate a fairly linear increase in BFL from 1840 to about 1925, where Black males decrease slightly but then continue to increase to 1970. White males plateau from about 1920 to 1950, then increase sharply to the 1970's.

The Lowess plot for BFLROB on DOB is presented in Figure 11. Black females exhibit a fairly equal temporal linear decrease in robusticity for the time period represented. White females demonstrate a relatively moderate straight decrease in robusticity from 1840 to about 1925, which decreases sharply from 1925 to the 70's. Black males illustrate a sharp decrease in robusticity in the 40-year period from 1840 to 1880, followed by a plateau to 1940 and a very moderate decline to the 1970's. White males, like White females, show a modest but linear decrease in robusticity to about 1930, followed by a sharp decrease from 1930 to 1970.

The Lowess plots did not illuminate any significant fluctuations which can be individually interpreted or linked across groups to better understand secular change in the current sample. The plots did however, support the use of linear regression to describe secular change due to the general characteristics seen in the lines which, overall, were relatively linear.

Correlations: Femur Variables

Tables 11 (Black females), 12 (White females), 13 (Black males), and 14 (White males) present the Pearson correlation coefficients for femur variables.

Table 11: Pearson correlation coefficient matrix for Black females.

Variable	*BFL*	*EPIBR*	*FH*	*APS*	*MLS*	*APM*	*MLM*	*CIR*	*MRATIO*	*SRATIO*	*TA*	*BFLROB*
BFL	1	0.322*	0.427*	0.112	0.436*	0.396*	0.200*	0.447*	0.125	- 0.267*	0.375*	- 0.454*
EPIBR	0.322*	1	0.755*	0.349*	0.327*	0.210*	0.430*	0.420*	- 0.202*	0.019	0.411*	0.097
FH	0.427*	0.755*	1	0.373*	0.445*	0.296*	0.482*	0.473*	- 0.191	- 0.062	0.495*	0.104
APS	0.112	0.349*	0.373*	1	0.272*	0.689*	0.270*	0.653*	0.300*	0.608*	0.581*	0.482*
MLS	0.436*	0.327*	0.445*	0.272*	1	0.301*	0.545*	0.617*	- 0.249*	- 0.591*	0.548*	0.129
APM	0.396*	0.210	0.296*	0.689*	0.301*	1	0.238*	0.811*	0.563*	0.337*	0.764*	0.434*
MLM	0.200*	0.430*	0.482*	0.270*	0.545*	0.238*	1	0.666*	- 0.663*	- 0.231*	0.806*	0.592*
CIR	0.477*	0.420*	0.473*	0.653*	0.617*	0.811*	0.666*	1	0.042	0.061	0.919*	0.533*
MRATIO	0.125	- 0.202*	- 0.191	0.300*	- .249*	0.563*	- 0.663*	0.042	1	0.473*	-0.099	- 0.155
SRATIO	- 0.267*	0.019	- 0.062	0.608*	- 0.591*	0.337*	- 0.231*	0.061	0.473*	1	0.033	0.296*
TA	0.375*	0.411*	0.495*	0.581*	0.549*	0.764*	0.806*	0.919*	- 0.099	0.033	1	0.650*
BFLROB	- 0.454*	0.097	0.104	0.482*	0.129	0.434*	0.592*	0.533*	- 0.155	0.296*	0.650*	1

*statistically significant at $p < 0.05$

Table 12: Pearson correlation coefficient matrix for White females.

Variable	*BFL*	*EPIBR*	*FH*	*APS*	*MLS*	*APM*	*MLM*	*CIR*	*MRATIO*	*SRATIO*	*TA*	*BRFROB*
BFL	1	0.369*	0.442*	0.151	0.116	0.453*	0.165*	0.208*	0.252*	0.058	0.37*	-0.401*
EPIBR	0.369*	1	0.693*	0.385*	0.377*	0.337*	0.381*	0.371*	-0.053	0.04	0.427*	0.15
FH	0.442*	0.693*	1	0.358*	0.438*	0.269*	0.419*	0.324*	-0.125	-0.029	0.405*	0.116
APS	0.151	0.385*	0.358*	1	0.506*	0.551*	0.465*	0.619*	0.091	0.57*	0.607*	0.509*
MLS	0.116	0.377*	0.438*	0.506*	1	0.367*	0.516*	0.511*	-0.113	-0.424*	0.522*	0.45*
APM	0.453*	0.337*	0.269*	0.551*	0.367*	1	0.376*	0.81*	0.531*	0.248*	0.818*	0.479*
MLM	0.165*	0.381*	0.419*	0.465*	0.516*	0.376*	1	0.686*	-0.577*	0.02	0.838*	0.677*
CIR	0.208*	0.371*	0.324*	0.619*	0.511*	0.81*	0.686*	1	0.072	0.145	0.914*	0.675*
MRATIO	0.252*	-0.053	-0.125	0.091	-0.113	0.531*	-0.577*	0.072	1	0.191*	-0.045	-0.201*
SRATIO	0.058	0.04	0.029	0.57*	-0.424*	0.248*	0.02	0.145	0.191*	1	0.165*	0.112
TA	0.37*	0.427*	0.405*	0.607*	0.522*	0.818*	0.838*	0.914*	-0.045	0.165	1	0.697*
BFLROB	-0.401*	0.15	0.116	0.509*	0.45*	0.479*	0.677*	0.675*	-0.201*	0.112	0.697*	1

*statistically significant at $p < 0.05$

Table 13: Pearson correlation coefficient matrix for Black males.

Variable	*BFL*	*EPIBR*	*FH*	*APS*	*MLS*	*APM*	*MLM*	*CIR*	*MRATIO*	*SRATIO*	*TA*	*BRFROB*
BFL	1	0.441*	0.555*	0.374*	0.345*	0.462*	0.171*	0.534*	0.216*	0.066	0.399*	-0.513*
EPIBR	0.411*	1	0.786*	0.513*	0.495*	0.41*	0.569*	0.613*	-0.138	0.059	0.617*	0.205*
FH	0.555*	0.786*	1	0.528*	0.499*	0.411*	0.577*	0.615*	-0.118	0.086	0.648*	0.132
APS	0.374*	0.513*	0.528*	1	0.443*	0.532*	0.532*	0.696*	0.019	0.605*	0.692*	0.359*
MLS	0.345*	0.495*	0.499*	0.443*	1	0.249*	0.628*	0.557*	-0.326*	-0.442*	0.558*	0.229*
APM	0.462*	0.41*	0.441*	0.532*	0.249*	1	0.242*	0.788*	0.573*	0.314*	0.772*	0.326*
MLM	0.171*	0.569*	0.577*	0.532*	0.628*	0.242*	1	0.689*	-0.651*	-0.036	0.801*	0.583*
CIR	0.534*	0.613*	0.615*	0.696*	0.557*	0.788*	0.689*	1	0.036	0.197*	0.934*	0.547*
MRATIO	0.216*	-0.138	-0.118	0.019	-0.326*	0.573*	-0.651*	0.036	1	0.317*	-0.073	-0.232*
SRATIO	0.066	0.059	0.086	0.605*	-0.442*	0.314*	-0.036	0.197*	0.317*	1	0.187*	0.147
TA	0.399*	0.617*	0.648*	0.692*	0.558*	0.772*	0.801*	0.934*	-0.073	0.187*	1	0.578*
BFLROB	-0.513*	0.205*	0.132	0.359*	0.229*	0.326*	0.583*	0.547*	-0.232*	0.147	0.578*	1

*statistically significant at $p < 0.05$

Table 14: Pearson correlation coefficient matrix for White males.

Variable	*BFL*	*EPIBR*	*FH*	*APS*	*MLS*	*APM*	*MLM*	*CIR*	*MRATIO*	*SRATIO*	*TA*	*BRFROB*
BFL	1	0.443*	0.419*	0.246*	0.229*	0.351*	0.147*	0.33*	0.179*	0.01	0.313*	-0.477*
EPIBR	0.443*	1	0.686*	0.368*	0.396*	0.479*	0.428*	0.566*	0.03	-0.026	0.535*	0.198*
FH	0.419*	0.686*	1	0.316*	0.354*	0.424*	0.393*	0.486*	0.006	-0.029	0.481*	0.162*
APS	0.246*	0.368*	0.316*	1	0.354*	0.54*	0.33*	0.538*	0.181*	0.58*	0.512*	0.33*
MLS	0.229*	0.396*	0.354*	0.354*	1	0.385*	0.574*	0.613*	-0.211*	-0.542*	0.563*	0.372*
APM	0.351*	0.479*	0.424*	0.54*	0.385*	1	0.346*	0.838*	0.561*	0.127*	0.825*	0.494*
MLM	0.147*	0.428*	0.393*	0.33*	0.574*	0.346*	1	0.716*	-0.577*	-0.216*	0.812*	0.619*
CIR	0.33*	0.566*	0.486*	0.538*	0.613*	0.838*	0.716*	1	0.07	-0.067	0.927*	0.671*
MRATIO	0.179*	0.03	0.006	0.181*	-0.211*	0.561*	-0.577*	0.07	1	0.342*	0.001	-0.107*
SRATIO	0.01	-0.026	-0.029	0.58*	-0.542*	0.127*	-0.216*	-0.067	0.342*	1	-0.047	-0.039
TA	0.313*	0.535*	0.481*	0.512*	0.563*	0.825*	0.812*	0.927*	0.001	-0.047	1	0.68*
BFLROB	-0.477*	0.198*	0.162*	0.33*	0.372*	0.494*	0.619*	0.671*	-0.107*	-0.039	0.68*	1

*statistically significant at $p < 0.05$

Bicondylar Femur Length

Bicondylar femur length correlates significantly with all of the size variables. Additionally, in White females and males bicondylar length correlates significantly with midshaft shape ratio but not the subtrochanteric ratio. In Black females, this relationship is reversed, with bicondylar femur length significantly correlated with the subtrochanteric shape ratio. With regard to the size variables, bicondylar length is most highly correlated with articular dimensions and the anterior-posterior midshaft measure across groups.

Epicondylar and Femoral Head Breadth

Epicondylar and femoral head breadth are both correlated significantly with all size variables, but not with shape ratios except in Black Females, which demonstrate a significant correlation between epicondylar breadth and midshaft shape. Of all the size variables, epicondylar and femoral head breadth are most highly correlated with each other at 0.693 to 0.786. Epicondylar and femoral head breadth had the lowest correlations with femoral robusticity, with either low or non-significant coefficient values. In Black males, epicondylar and femoral head breadth are exceptionally correlated with all femur measures.

Diaphyseal Measures

The anterior-posterior subtrochanteric dimension is significantly correlated with all size variables, but is most highly with midshaft circumference, total subperiosteal area, and midshaft anterior-posterior measures. Generally, anterior-posterior subtrochanteric is also significantly correlated with femoral robusticity, but not with midshaft shape. The mediolateral subtrochanteric dimension, like the anterior-posterior measure, is correlated significantly with all size variables, but especially midshaft circumference, total area, and mediolateral midshaft. With the exception of Black females, the mediolateral dimension is significantly correlated with femoral robusticity. Anterior-posterior and mediolateral midshaft, like the subtrochanteric measures are highly correlated with circumference and total area across groups. Anterior-posterior midshaft presents consistently higher correlations with bicondylar length than mediolateral midshaft dimensions across groups, with correlations on average twice that for anterior-posterior than mediolateral midshaft and bicondylar length.

Predictably, midshaft circumference and total area are most highly correlated with each other, having correlation coefficients in excess of 0.9 across the samples. Additionally, circumference and total area are highly correlated with all size variables and femoral robusticity, but most highly with midshaft measures. Total area and circumference are not significantly correlated with midshaft shape and only significant with subtrochanteric shape in Black males.

Sex and Group Differences

To facilitate comparisons of sex differences between the present sample (all decades combined) and other research, two-sample t – tests were conducted. Sex differences between Black females and males are presented in Table 15, and between White females and males in Table 16. Results of the t – test show statistically significant sex differences at $p < 0.0001$ for all size variables between males and females, reflecting the obvious, that males are generally larger than females. Interestingly, sex differences were not significant between White females and males for the diaphyseal shape indices, SRATIO or MRATIO. Between Black females and males, sex differences in SRATIO were not significant. Black males and females were significant for shape differences in MRATIO ($p = 0.0029$), with females demonstrating higher values for anterior-posterior elongation of the midshaft.

T-tests between Black and White females are presented in Table 17. Black females demonstrate longer femora, a larger anterior-posterior dimension at midshaft and larger values for total midshaft area. No statistical differences were detected in the shape ratios or femoral robusticity. Results of the *t*-tests between Black and White males (Table 18) demonstrate general size differences exist in femur length, epicondylar and femoral head breadths, mediolateral size at midshaft and total area. Though Black males have generally larger length measures, white males demonstrate lager values for epicondylar and femoral head breadths. Black and White males also exhibit significant differences in subtrochanteric shape, with White males demonstrating higher values signifying comparatively greater anterior-posterior elongation. Midshaft shape and femoral robusticity were not significantly different between the male groups.

Table 15: Independent sample *t*-test for sex differences assuming equal variances for Black Females and Black Males.

Variable	*T statistic*	*P value*
MFL	- 10.0331	0.0001*
BFL	- 13.5932	0.0001*
EPIBR	- 15.7451	0.0001*
FH	- 16.0614	0.0001*
APS	- 8.8916	0.0001*
MLS	- 11.2798	0.0001*
APM	- 12.4566	0.0001*
MLM	- 14.9287	0.0001*
CIR	- 10.9964	0.0001*
MRATIO	2.9952	0.006*
SRATIO	1.6451	0.2032
TA	- 17.0881	0.0001*
BFLROB	- 4.7721	0.0001*

* statistically significant at $p < 0.05$.

Table 16: Independent sample *t*-test for sex differences assuming equal variances for White Females and White Males.

Variable	*T statistic*	*P value*
MFL	- 15.7779	0.0001*
BFL	- 17.9270	0.0001*
EPIBR	- 23.8925	0.0001*
FH	- 26.8550	0.0001*
APS	- 15.4633	0.0001*
MLS	- 14.9884	0.0001*
APM	- 17.2777	0.0001*
MLM	- 18.4302	0.0001*
CIR	- 14.8058	0.0001*
MRATIO	- 1.2271	0.4406
SRATIO	- 1.2178	0.448
TA	- 21.1736	0.0001*
BFLROB	- 6.7038	0.0001*

* statistically significant at $p < 0.05$.

Table 17: Independent sample *t*-test for group differences assuming equal variances for Black and White females.

Variable	*T statistic*	*P value*
MFL	2.931	0.0072*
BFL	3.0325	0.0052*
EPIBR	- 1.1921	0.4692
FH	- 0.4353	0.6638
APS	1.225	0.4436
MLS	0.6368	0.5249
APM	3.0296	0.0052*
MLM	1.6138	0.2148
CIR	1.7739	0.1560
MRATIO	1.2119	0..4526
SRATIO	0.6809	0.4966
TA	2.7252	0.0134*
BFLROB	0.1268	0.8992

* statistically significant at $p < 0.05$

Table 18: Independent sample *t*-test for group differences assuming equal variances for Black and White males.

Variable	*T statistic*	*P value*
MFL	3.6724	0.0006*
BFL	3.7385	0.0004*
EPIBR	- 2.6428	0.0172*
FH	- 2.6629	0.0162*
APS	- 1.4420	0.3002
MLS	0.9971	0.6388
APM	1.2764	0.4046
MLM	2.7062	0.0140*
CIR	- 0.0206	0.9836
MRATIO	- 1.2018	0.4600
SRATIO	- 2.3175	0.0420*
TA	2.3792	0.0354*
BFLROB	- 0.8352	0.8080

* statistically significant at $p < 0.05$.

Allometric Analysis

Table 19 presents the results of the RMA regression of lnBFL and lnTA. All groups have slopes higher than 2.0, the value expected for isometry, indicating cross-sectional area is increasing more slowly than bicondylar femur length (BF = 2.567, WF = 2.35, BM = 2.106, WM = 2.425).

Table 19: Results of RMA regressions for *ln*BFL and *ln*TA. The slope value expected for isometry is 2.0. Values greater than 2.0 indicate that TA is increasing more slowly than BFL.

Group	*N*	*Intercept*	*Slope*
White Females	221	- 9.29298	2.56711
Black Females	145	- 7.99362	2.35191
White Males	352	- 8.38823	2.42544
Black Males	191	- 6.43892	2.10628
All Females	366	- 8.74214	2.47576
All Males	543	- 7.57609	2.29239
Male & Female	909	- 9.36851	2.25819

Effect of Age at Death

Due to concern and conflicting data concerning diaphyseal expansion caused by periosteal bone apposition past the third decade, partial correlation coefficients were derived for age and diaphyseal variables controlling for date of birth. The results

Table 20: Pearson correlation coefficient (*r*), partial correlation, and *T* statistic of partial correlation coefficient for femur variables and age at death controlling for date of birth in Black Females.

Variable	*N*	*r*	*T statistic*	*Partial correlation*
BFL	140	-0.228*	- 1.89	-0.159
APS	73	0.383*	2.84	0.321*
MLS	73	0.088	0.04	0.005
APM	141	0.041	0.11	0.009
MLM	141	0.410*	0.53	0.045
CIR	65	0.425*	3.18	0.374*
SRATIO	73	0.254*	2.26	0.261*
MRATIO	141	-0.305*	- 1.19	-0.101
TA	141	0.298*	0.47	0.040
BFLROB	139	0.474*	2.41	0.202*

* statistically significant at $p < 0.05$.

Table 21: Pearson correlation coefficient (*r*), partial correlation, and *T* statistic of partial correlation coefficient for femur variables and age at death controlling for date of birth in White Females.

Variable	*N*	*r*	*T statistic*	*Partial correlation*
BFL	207	-0.243*	- 1.67	- 0.116
APS	140	0.450*	3.61	0.295*
MLS	140	0.268*	1.84	0.155
APM	221	0.056	2.52	0.168*
MLM	222	0.408*	1.40	0.094
CIR	84	0.320*	2.52	0.270*
SRATIO	138	0.192*	0.78	0.067
MRATIO	221	-0.327*	0.95	0.064
TA	221	0.282*	2.30	0.154*
BFLROB	206	0.449*	4.04	0.273*

* statistically significant at $p < 0.05$.

Table 22: Pearson correlation coefficient (*r*), partial correlation, and *T* statistic of partial correlation coefficient for femur variables and age at death controlling for date of birth in Black Males.

Variable	*N*	*r*	*T statistic*	*Partial correlation*
BFL	186	- 0.167	0.19	0.014
APS	104	0.446*	5.00	0.446*
MLS	104	0.292*	2.83	0.271*
APM	188	0.205*	4.74	0.329*
MLM	186	0.392*	3.26	0.234*
CIR	90	0.425*	4.46	0.431*
SRATIO	104	0.196*	2.30	0.223*
MRATIO	186	-0.168	1.14	0.084
TA	186	0.379*	5.10	0.353*
BFLROB	183	0.508*	5.46	0.377*

* statistically significant at $p < 0.05$.

Table 23: Pearson correlation coefficient (*r*), partial correlation, and *T* statistic of partial correlation coefficient for femur variables and age at death controlling for date of birth in White Males.

Variable	*N*	*r*	*T statistic*	*Partial correlation*
BFL	330	- 0.223*	0.65	0.036
APS	246	0.271*	3.73	0.233*
MLS	246	0.294*	2.27	0.144*
APM	340	0.031	3.42	0.183*
MLM	340	0.280*	3.22	0.173*
CIR	176	0.234*	2.31	0.173*
SRATIO	245	0.002	1.36	0.087
MRATIO	340	-0.227*	1.18	0.064
TA	340	0.187	3.22	0.173*
BFLROB	328	0.329*	2.31	0.127*

* statistically significant at $p < 0.05$.

are presented in Tables 20 (Black females), 21 (White females), 22 (Black males), 23 (White males). Controlling for date of birth, the Pearson correlation coefficients are, on average less than the first order correlation coefficients. Overall, the correlations are highest between age and APS or CIR, followed by APM, MLM, and MLS, supporting some expansion of the periosteal envelope with aging. The partial correlation coefficients do not correlate significantly with bicondylar femur length, which supports the contention that long bone length is not affected by age. None of the groups present significant partial correlation coefficients between age and the midshaft shape ratio, suggesting that periosteal apposition will not alter midshaft bone shape. In contrast, though the significant correlations exist between SRATIO and age for Black males and Black females at $r = 0.223$, $r = 0.261$, they do not for Whites ($r = 0.067$ and $r = 0.087$). In addition, Black males have the highest overall partial correlation coefficients between age and the given diaphyseal variables.

Females demonstrate significant correlations with age and anterior-posterior subtrochanteric dimension, circumference, and robusticity. Additionally, White females are significant for age related change in anterior-posterior midshaft and total subperiosteal area, while Black females have significant correlations between age and the subtrochanteric shape ratio. Interestingly, females do not demonstrate statistical significance between age and the transverse diameter of midshaft, unlike males. Males, in general, demonstrate higher correlations with age and significant correlations with age for more of the femur variables in general, suggesting that sex specific patterns do exist.

Chapter V

Discussion

Secular Decrease in Femur Measures

The decrease in most femur measures and femoral midshaft robusticity is best explained by a decrease in mechanical usage and thus muscle strength in modern people. The general acquisition of bone tissue during bone modeling is dependent on achieving strains which exceed the minimum effective strain threshold. Physical activity has been demonstrated to lead to bone hypertrophy (Jones, 1977) through elevated strain levels due to increased muscular strength and local bone deformation (Frost, 1997a). Black and White females demonstrate very similar patterns of decrease in the femur variables, both groups show a decline in femoral head breadth, anterior-posterior and mediolateral subtrochanteric diameters, mediolateral midshaft diameter, midshaft circumference, total midshaft subperiosteal area, and robusticity. Black and White males also show a very similar pattern, with secular decrease noted for mediolateral midshaft diameter, midshaft circumference, total subperiosteal area, and robusticity. Additionally, White males are also significant for a decrease in anterior-posterior and mediolateral subtrochanteric diameters. Given that the midshaft of a bone is representative of the bone strains to which the whole bone is subjected (Bienwener and Taylor, 1986), the decrease mediolateral midshaft diameter, circumference, and total area support a decline in mechanical loading. However, the decrease in circumference and total subperiosteal area are a result of the secular decline in the mediolateral dimension at midshaft. The decreases in the anterior-posterior and mediolateral subtrochanteric dimensions in females and White males may also be interpreted as a decline in mechanical loading.

The decrease in femur measures is also mirrored in the secular decline in femoral robusticity (BFLROB) across groups, a measure of the robusticity of the femur midshaft to bicondylar femur length. In the time period represented, 1940 to the 1970's the combination of an increase in bicondylar femur length and decrease in the mediolateral midshaft dimension amplifies the decline in robusticity. Alternatively, this may also be a reflection of the allometric relationship between length and total subperiosteal area, given that a longer femur will have a proportionally smaller cross-section than a shorter bone.

In support of a mechanical hypothesis, historically, the 20th century has introduced many transportation alternatives to physical activity, in addition to many daily activities which do not require physical movement. Given the widespread introduction of Ford's Model T in 1908 and the subsequent increases in output due to the advances in mass production (with 2 million Model T's produced in 1920) the automobile introduced Americans to a new way of life (Womack et al., 1990).

Intuitively, paralleling changes in skeletal morphology are probable in the U.S. population. Further evidence of a temporal difference in fracture rates among Canadian youth has also been interpreted as representing a decline in general activity levels in industrialized counties by Parfitt (1994). Though fracture rates among adolescents have declined (studies compared were from the 1950's and 1980's), Parfitt's suggests that this decline is due to a reduction in physical activity resulting in a lower risk of activity related injuries and not to stronger bones. Although the Lowess plots did not demonstrate any clear decreases occurring in the early part of the century, this may be due to the small sample sizes represented in each decade and the inherent variability they contain. The overall very linear decrease in femur measures from 1840 to 1970, nonetheless, is difficult to interpret since most transportation initiatives and lifestyle changes were initiated in the early 20th century. The linear decrease in measures during the later part of the 19th century leaves us with the question of what biomechanical factors were changing in this time period. Still, although the relationship between changing lifestyles and femur measures remains speculative, due to the great changes in leisure activities and transportation during the last century, it remains highly probable.

Increase in MRATIO

The model proposed by Ruff and colleagues (see, for example, Ruff, 1995, 1992, 1987; Ruff et al., 1994; Trinkaus et al., 1994; Ruff et al., 1993; Ruff and Runestad, 1992; Ruff et al., 1991; Ruff and Larsen, 1990; Brock and Ruff, 1988; Ruff et al., 1984; Ruff and Hayes, 1983a, 1983b), which interprets diaphyseal cross-sectional shape wholly as a consequence of the *type* of mechanical use (such as running or long distance travel), falls short in explaining the morphological trends present in the current study. The problem in the present study arises from examining secular change in the femur, implying that there must be another explanation for high midshaft anterior-posterior indices. The modern American population from which the sample was drawn has experienced rapid changes in lifeways since 1840, but the changes have presumably not increased the type (e.g. more running, carrying heavy loads) or level of activity. Instead, the lifestyle changes would have obviously promoted a decrease. The results of the current study suggest other factors are also involved which determine cross-sectional bone shape.

Although the decrease in many femur measures can be explained through lower activity levels, the secular decrease in midshaft mediolateral dimension across groups in combination with the non-significant change in the anterior-posterior dimension remains more difficult to explain. Trotter and coworkers (1968) also documented the decrease in transverse diameter of the midshaft for a larger sample of the Terry Collection. Additionally, Rockhold and Jantz (1996) also noted a decrease in the mediolateral diameter of the femur in a post-1890 sample. The increase in anterior-posterior elongation (or decrease in MLM) as reflected in the midshaft shape ratio is especially challenging to explain, given that it is a much more specific response than overall general size fluctuations. Given that anterior-posterior elongation has been associated with the types of mechanical use which would increase anterior-posterior bending loads (hypothesized as more running etc.), the data presented here for a modern sample runs contrary to a specific behavioral mechanical interpretation.

As stated earlier in this thesis, bone form represents the effects of length and morphology (like bone curvature) combined with the structural objectives of maintaining the integrity to meet functional demands. The stress and strain the femur is subjected to at any time is (1) the sum of the baseline muscle tone of the associated muscle mass when an animal is not moving, (2) the constant strain present when the animal is stationary and weight bearing, (3) and the strain incurred when the animal is moving (Meade, 1989). In addition, the ability of a structure to withstand external loads is dependent on the structure's construction to be able to withstand the loads applied to it without developing damaging strains (Rubin, 1984).

In the present sample, where a secular increase in bone length is concurrent with a decrease in many measures, strain reduction may be accommodated by maintaining the anterior-posterior dimension of the midshaft to compensate for the relatively longer, medio-laterally thinner femur shafts due to lower levels of overall mechanical loading. Given that peak strains occur at the midshaft of a long bone, and are representative of stresses to which the whole bone is subjected (Bienwener and Taylor, 1986), the secular shape change in the femur midshaft could represent an adaptation to meet functional demands. The decrease in robusticity in the sample presumably reflects a decline in mechanical usage, but cross-sectional shape may represent the femur's adaptation to the mechanical and structurally induced stress still present (locomotion, associated musculature - extensors and flexors of the thigh). This hypothesis may be related to the importance of the linea aspera (measured as part of APM), as advanced by Pauwels(1980), is to predictably placing stress in a particular area. Pauwels suggested the area was at a 40° angle from the sagittal plane, in the true area of greatest bending rigidity (which cannot, unfortunately, be measured in the present sample). Ruff and Hayes (1983) using femora from the Pecos Pueblo noted that the plane of greatest bending rigidity as measured through cross-sectional geometric properties at midshaft was located at an angle to the sagittal plane, oriented anterior-lateral to posterior-medial (Figure 6, pp. 370), as Pauwels suggested. The non-significant alteration in APM may suggest the significance of the linea aspera and pilaster in contributing to predictably placed strains. Given that the anterior-posterior midshaft dimension does not exhibit secular change in the current sample, I suggest that this femoral dimension is the indicator of overall levels of mechanical loading and that the anterior-posterior dimension is less sensitive possibly due to its anatomical and mechanical significance to overall femur structural integrity.

Bone curvature, although not measured in the current study may also contain significant information to understanding femoral diaphyseal morphology. Bertram and Biewener (1988) suggest that bone curvature may serve to place strains predictably in bones with highly variable loading patterns. The authors point out that bending represents a stable system because the increase in loads alter the magnitude of stress, but not the placement, distribution, or type. Frost (1983) points out that bone loaded in bending (when modeling) will produce a drift which will subtract bone from the site of tension (convexity) and add bone to the site of compression (concavity), in essence, to straighten the bone. In combination with the observation that human femora which exhibit marked anterior posterior curvature of the midshaft also have a more developed pilaster and elongation in the sagittal plane (Aiello and Dean 1990), bone curvature could play an integral role in diaphyseal morphology, meriting it as a topic for further research. Correspondingly, all structural relationships (length, angle of the femoral neck, curvature, etc.) could, theoretically, alter the strain relationships in the diaphysis.

It is also important to note that there is a possibility that femoral morphology represents the interaction of strain relationships present during growth and development. Therefore measurement of strain in adult femora may not represent the strain relationships which formed the shape of the bone if the bone has successfully decreased strains below the minimun effective strain threshold through modeling.

Regardless, given the lack of information concerning *in vivo* bone strains in humans and clinical information on the consequences of specific loading regimens and bone shape (see also Bouvier, 1985; Mikie and Carter, 1995), the conclusions drawn by previous researchers linking bone shape in archaeological populations to specific activities, although thought provoking, is premature. Similarly, the conclusions advanced in the present study are also largely speculation, but they suggest alternative reasons for anterior-posterior elongation of the midshaft and while introduce a more realistic level of complexity. In addition, current information concerning bone modeling during growth and development suggests that bone shape is a consequence of childhood and young adulthood during bone modeling. Further, activities which involve repetitive actions, no matter how exhaustive (such as running), may not produce bending loads high enough to exceed the MES threshold for modeling no matter how often they are applied. This lies in contrast to activities which produce large muscles, like weight lifting, which by the creation of stronger muscles produce large bending loads (Frost, 1997a). Endurance exercises do not produce larger muscles but more mitochondria in the muscle tissue leading to increased efficiency in oxygen utilization that enhances performance.

Articular Dimensions

Articular dimensions, epicondylar and femoral head breadth, exhibited a markedly different pattern of secular change and correlation when compared to the diaphyseal variables. Although femoral head breadth was significant for secular change in females (BF $p = 0.0147$, WF $p = 0.033$), it was not significant for change in males. Epicondylar breadth did not reach significant levels of secular change in any group. In the correlation analysis, epicondylar and femoral head breadth correlated most highly to each other, with r values ranging from 0.686 to 0.786. The correlation coefficients with size variables were significant, but much lower, supporting the idea that articular variables are influenced by different factors than bone length or the diaphysis. According to Poss (1984) the epiphyses of long bones are adapted to provide the largest possible weight bearing surface, and do not adaptively remodel during life despite the plasticity seen in the diaphysis due to aging (periosteal expansion) and exercise (shift type and rate of remodeling). The development of and final form of articular dimensions has been closely linked to total body mass (Ruff and Runestad, 1992), possibly indicating that in tandem with other changes in femoral morphology seen in the current study, body mass has not shown a similar secular change. Diaphyseal bone acquisition has also been closely linked to body mass during growth and development (Moro et al., 1996), but the results of this study suggest diaphyseal dimensions are affected by additional variables not experienced by articular dimensions. In females, the secular decrease in femoral head breadth remains unexplained.

Sex and Group Differences

Predictably, both Whites and Black demonstrated statistically significant sex differences in size variables, with males consistently larger than females. Sex differences in subtrochanteric shape ratio were negligible in all groups, while significant sex differences in midshaft shape ratio were apparent between Black males and females, with females demonstrating higher indices. These results are in agreement with published data on sex differences in recent samples by Ruff (1987). Ruff's research indicated low or negligible differences in diaphyseal shape in recent autopsy samples, but large sex differences in Native American femora. Ruff using external breadth measures, reported greatest sex differences in midshaft shape in hunter-gatherers from 7 to 15% between males and females, in agriculturists from 3 to 6% and 0 to 1% in industrial samples.

Differences between Black and White females did not exhibit any striking discrepancies. Aside from femur length, anterior-posterior midshaft and midshaft total area, Black and White females did not demonstrate any other statistically significant differences among the femur measures. Between Black and White males, statistical differences were noted with Black males having on average longer femora, higher midshaft mediolateral dimensions and larger total midshaft areas. White males demonstrated larger epicondylar and femoral head breadths.

The differences found in this study, with Blacks having on average longer femora, are not surprising. According to Krogman (1970) and Hamill et al. (1973) American Blacks have proportionally longer limbs and shorter trunks than Whites of matched stature when income, education and other environmental variables are controlled. The differences between Blacks and Whites in midshaft dimensions and total area may represent a size discrepancy related to longer femora or inheritance, or on the other hand, it may be suggestive of higher levels of mechanical loads. Given the non-significant secular change in APM across groups, the difference between females appear attributable to a general size discrepancy which is not due to differences in mechanical loading. Conversely, the difference between Black and White males in MLM, which is significant for secular change in both groups due to a decline in mechanical loading, may suggestive that Black males are experiencing higher loads. The significant difference in articular dimensions (EPIBR and FH) which indicates that White males are, on average, larger than Black males in these dimensions, may suggest differences in body mass during growth and development and young adulthood. Given that size of articular dimensions is closely linked to body mass (see previous section), the results presented here suggest that White males may be, on average, heavier than Black males.

Allometric Analysis

The results of the allometric analysis indicate that midshaft subperiosteal area is increasing more slowly than bicondylar femur length. Rephrased, this means that proportionally, longer femora have smaller total subperiosteal area than shorter femora. This result counters Ruff's (1984) claim that bone length should scale isometrically with cross-sectional area, but agrees with Ruff et al. (1993) in noting positive allometry of bone length to area. The results of the current study do however suggest that Black males scale closest to isometry with a RMA regression slope of 2.106, with a value of 2.0 expected for isometry.

Effects of Aging

Due to concern about periosteal expansion past the third decade, the interaction between aging and diaphyseal dimensions was explored. The highest partial correlation coefficients were between age and or midshaft circumference across groups. The correlation between age and midshaft circumference follows the prediction that the periosteal dimensions of long bones enlarge with age. Interestingly, the subtrochanteric anterior-posterior dimension was correlated higher with age than the other femur variables (BF = 0.321, WF = 0.321, WM = 0.446, WM

= 0.233), with the exception of midshaft circumference. Males in general exhibited the highest correlations between age and the femur variables, with statistically significant values for all diaphyseal measures, total subperiosteal area, circumference and robusticity. However, only black males were significant for age related change in the subtrochanteric shape ratio.

The midshaft shape ratio was not correlated with age in any group (BF = -0.101, WF = 0.064, WM = 0.084, WM = 0.064), supporting the contention that midshaft bone shape does not changed with age, although size does as a result of the osteogenic properties of the periosteum. During adult aging, bone reaction to activity or lack thereof is through bone remodeling, resulting in changes in density rather than external architecture. But, contrary to this, subtrochanteric shape ratio was significantly correlated with age in Blacks and not Whites (BF = 0.261, BM = 0.223 versus WF = 0.067, WM = 0.087). The increase in the midshaft anterior-posterior dimension and comparatively negligible change in the subtrochanteric mediolateral dimension in Black individuals makes this shape change apparent and unexplained, meriting further investigation.

The overall conclusion of the correlation between age and the femur variables is that males and females exhibit different patterns of age related expansion. Males appear to have more age related expansion, which due to endosteal expansion would have a mechanically compensatory effect with aging by changing the distribution of bone material around the neutral axis, increasing the area moments of inertia. This same protective benefit would be greatly reduced in females, however the specific reasons for this discrepancy are not yet known. The results of the current study are in agreement with Ruff and Hayes (1988), which also reported sex specific responses of the periosteal envelope with aging, with males exhibiting significantly more periosteal expansion than females. As suggested by Ruff and Hayes, sex differences in mechanical compensation with aging may be a contributing factor to higher fracture rates among elderly women.

Chapter VI

Conclusions

The sample on which the present study is based is admittedly very diverse; the individuals represented in the 20th century Data Bank hail from across the United States and have emerged primarily from forensic contexts, while the 19th century individuals represented in the Terry anatomical collection represent a more geographically localized sample. It is, however, the eclectic nature of the samples that makes the emergent secular trends, which demonstrate remarkable similarity across groups, of great interest.

My results suggest there has been significant secular change in the femur in the time period represented, from 1840 to the 1970's in Blacks and Whites. To summarize, across groups there has been an increase in bicondylar femur length and an increase in anterior-posterior elongation of the femoral midshaft. In tandem, during this time period, femora demonstrate a secular decrease in subtrochanteric diaphyseal variables, the mediolateral dimension at midshaft, midshaft circumference, midshaft total area, and femur robusticity. Secular elongation in the anterior-posterior plane at midshaft is facilitated by the non-significant change in the anterior-posterior dimension coupled with a significant decrease in the mediolateral diameter. The secular decrease in the diaphyseal variable is attributed to lower levels of mechanical loading of the femur during growth and development and young adulthood when the skeleton is engaged in modeling, which determines external bone architecture. The non-significant change in the anterior-posterior dimension at midshaft is attributed to the possible more critical role of this dimension to overall femoral integrity and anatomical significance of the linea aspera. Thus, fluctuations in the mediolateral dimension at midshaft are taken are more indicative of the level of mechanical loading in this modern sample.

With the exception of a secular decrease noted in the femoral head breadth of females, no secular changes in articular dimensions (epicondylar or femoral head breadth) were noted. The lack of secular changes in these femoral components suggests that their size may be dependent different variables than diaphyseal dimensions.

Sex differences in the current sample yielded similar results to other published accounts of the amount of dimorphism in 20^{th} century populations. Males were, on average, larger than females for all size dimensions, but not significantly different in diaphyseal shape which is in agreement with Ruff (1987). Comparisons of the same sex by ancestry indicated that Blacks, on average, have longer femora. This result is not surprising given that Blacks and Whites matched for environmental variables have been found to have longer limb bones and shorter torsos than Whites of the same stature (Krogman, 1970; Hamill et al., 1973). White males were found to have larger articular dimensions which may suggest White males are heavier than Black males during the early decades of life, however this is not testable in the current sample.

The results of the allometric analysis suggest that total midshaft subperiosteal area is increasing more slowly than bicondylar femur length, meaning that proportionally longer femora have smaller cross-sectional areas than shorter femora. This lies in agreement with Ruff et al. (1993) who also reported similar results for human femora.

Subperiosteal expansion of the external dimension of bones with aging has been found in the current study to occur, but differ in pattern between males and females. Males demonstrate age related expansion of all diaphyseal variables, but females only exhibit significant correlation with age and the anterior-posterior subtrochanteric dimension, midshaft circumference, and anterior-posterior midshaft diameter (White females only). Neither bicondylar femur length nor the midshaft shape ratio correlates significantly with age, suggesting that midshaft external bone shape is not effected by periosteal apposition. However, age was significantly correlated with the subtrochanteric shape ration in Black males and White females which is not explained. Overall, males appear to have more age-related periosteal apposition, which due to endosteal expansion would have a mechanically compensatory effect with aging by changing the distribution of bone material around the neutral axis, increasing the area moments of inertia. This same protective benefit would be greatly reduced in females, however the specific reasons for this discrepancy are not yet known. The results of the current study are in agreement with Ruff and Hayes (1988), which also reported sex specific responses of the periosteal envelope with aging, with males exhibiting significantly more periosteal expansion than females. As suggested by Ruff and Hayes, sex differences in mechanical compensation with aging may be a contributing factor to higher fracture rates among elderly women.

Directions for future research

A major limitation of this thesis is the lack of internal cross-sectional dimensions and bone density information for the present sample, which would undoubtedly contribute to a much fuller picture of the skeletal morphology and bone health of recent modern populations. Additionally, more information needs to be gathered on the known strain relationships present in modern growing bones and their morphological consequences in to adulthood. Once these relationships are clarified, functional interpretation of morphology from unknown contexts will be more informative. However, if indeed the proposal that mechanical use is declining in modern peoples is valid, this could have a significant impact on bone health and quality of life as people age. Research which contributes to this picture, from a public health standpoint, will serve to improve the awareness of physical activity during growth and young adulthood given its crucial role in promoting adult bone health.

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Appendices

Appendix I

Appendix 1: Descriptive statistics by decade of birth for Black Females, White Females, Black Males, and White Males.

------------------------ DECADE=1830 RACE=B SEX=F ------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	1	95.0000000	.	95.0000000	95.0000000
MFL	0	.	.	.	.
BFL	1	441.0000000	.	441.0000000	441.0000000
EPIBR	0	.	.	.	.
FH	0	.	.	.	.
APS	0	.	.	.	.
MLS	0	.	.	.	.
APM	1	29.0000000	.	29.0000000	29.0000000
MLM	1	29.0000000	.	29.0000000	29.0000000
CIR	0	.	.	.	.
MRATIO	1	1.0000000	.	1.0000000	1.0000000
SRATIO	0	.	.	.	.
TA	1	660.5199000	.	660.5199000	660.5199000
BFLROB	1	13.1519300	.	13.1519300	13.1519300

Appendix 1: Descriptive statistics by decade of birth (Continued).

------------------------ DECADE=1830 RACE=B SEX=M -------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	1	98.0000000	.	98.0000000	98.0000000
MFL	0	.	.	.	.
BFL	1	463.0000000	.	463.0000000	463.0000000
EPIBR	0	.	.	.	.
FH	0	.	.	.	.
APS	0	.	.	.	.
MLS	0	.	.	.	.
APM	1	31.7000000	.	31.7000000	31.7000000
MLM	1	30.2000000	.	30.2000000	30.2000000
CIR	0	.	.	.	.
MRATIO	1	1.0496690	.	1.0496690	1.0496690
SRATIO	0	.	.	.	.
TA	1	751.8931000	.	751.8931000	751.8931000
BFLROB	1	13.3693300	.	13.3693300	13.3693300

Appendix 1: Descriptive statistics by decade of birth (Continued).

---------------------- DECADE=1830 RACE=W SEX=M ----------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	1	75.0000000	.	75.0000000	75.0000000
MFL	0	.	.	.	.
BFL	1	467.0000000	.	467.0000000	467.0000000
EPIBR	0	.	.	.	.
FH	0	.	.	.	.
APS	0	.	.	.	.
MLS	0	.	.	.	.
APM	1	29.0000000	.	29.0000000	29.0000000
MLM	1	30.0000000	.	30.0000000	30.0000000
CIR	0	.	.	.	.
MRATIO	1	0.9666670	.	0.9666670	0.9666670
SRATIO	0	.	.	.	.
TA	1	683.2964000	.	683.2964000	683.2964000
BFLROB	1	12.6338300	.	12.6338300	12.6338300

Appendix 1: Descriptive statistics by decade of birth (Continued).

------------------------ DECADE=1840 RACE=B SEX=F ------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	6	88.5000000	5.0497525	85.0000000	95.0000000
MFL	0	.	.	.	.
BFL	6	427.6666667	26.0819222	399.0000000	462.0000000
EPIBR	0	.	.	.	.
FH	0	.	.	.	.
APS	0	.	.	.	.
MLS	0	.	.	.	.
APM	6	27.9000000	2.6092144	26.0000000	33.0000000
MLM	6	27.1166667	2.9253490	23.0000000	31.3000000
CIR	0	.	.	.	.
MRATIO	6	1.0378342	0.1319354	0.8306710	1.1739130
SRATIO	0	.	.	.	.
TA	6	594.7205167	90.1346297	487.7323000	749.0342000
BFLROB	6	12.8790733	0.8662775	11.6883100	14.1324200

Appendix 1: Descriptive statistics by decade of birth (Continued).

---------------------- DECADE=1840 RACE=B SEX=M ----------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	7	85.0000000	5.2915026	76.0000000	91.0000000
MFL	0	.	.	.	.
BFL	7	442.2857143	12.9963365	422.0000000	458.0000000
EPIBR	0	.	.	.	.
FH	0	.	.	.	.
APS	0	.	.	.	.
MLS	0	.	.	.	.
APM	7	30.4714286	2.6587681	27.0000000	35.0000000
MLM	7	29.7142857	1.8169834	27.0000000	32.7000000
CIR	0	.	.	.	.
MRATIO	7	1.0295189	0.1235729	0.9310340	1.2962960
SRATIO	0	.	.	.	.
TA	7	710.7573000	70.8008537	614.9668000	806.4311000
BFLROB	7	13.6065914	0.5212861	12.8821000	14.1189400

Appendix 1: Descriptive statistics by decade of birth (Continued).

------------------------ DECADE=1840 RACE=W SEX=F ------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	7	83.5714286	7.3225028	71.0000000	94.0000000
MFL	0	.	.	.	.
BFL	7	425.7857143	37.8394163	375.5000000	471.0000000
EPIBR	0	.	.	.	.
FH	0	.	.	.	.
APS	0	.	.	.	.
MLS	0	.	.	.	.
APM	7	26.7285714	2.7016750	23.9000000	30.3000000
MLM	7	26.0714286	1.6987390	23.3000000	28.9000000
CIR	0	.	.	.	.
MRATIO	7	1.0250447	0.0761562	0.9259260	1.1538460
SRATIO	0	.	.	.	.
TA	7	549.3894000	84.1043317	437.3647000	687.7496000
BFLROB	7	12.4399129	0.9003437	11.4035100	13.8482000

Appendix 1: Descriptive statistics by decade of birth (Continued).

---------------------- DECADE=1840 RACE=W SEX=M ----------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	5	84.6000000	1.8165902	82.0000000	87.0000000
MFL	0	.	.	.	.
BFL	5	464.6000000	9.5026312	453.0000000	477.0000000
EPIBR	0	.	.	.	.
FH	0	.	.	.	.
APS	0	.	.	.	.
MLS	0	.	.	.	.
APM	5	31.6000000	2.7018512	28.0000000	35.0000000
MLM	5	29.8000000	2.2803509	26.0000000	32.0000000
CIR	0	.	.	.	.
MRATIO	5	1.0671526	0.1408745	0.9333330	1.2692310
SRATIO	0	.	.	.	.
TA	5	738.7455000	77.1003298	659.7345000	852.1570000
BFLROB	5	13.2226000	0.7754718	12.1593300	14.1935500

Appendix 1: Descriptive statistics by decade of birth (Continued).

---------------------- DECADE=1850 RACE=B SEX=F ----------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	14	78.6428571	5.4576290	71.0000000	91.0000000
MFL	0	.	.	.	.
BFL	14	423.7857143	19.7685787	387.0000000	461.0000000
EPIBR	0	.	.	.	.
FH	0	.	.	.	.
APS	0	.	.	.	.
MLS	0	.	.	.	.
APM	14	27.8642857	2.0996729	23.0000000	31.0000000
MLM	14	26.3285714	1.9273052	22.9000000	30.0000000
CIR	0	.	.	.	.
MRATIO	14	1.0621979	0.1000387	0.9200000	1.3056770
SRATIO	0	.	.	.	.
TA	14	577.0578357	69.5212247	451.6039000	730.4203000
BFLROB	14	12.7905964	0.5482912	11.5473400	13.5786800

Appendix 1: Descriptive statistics by decade of birth (Continued).

DECADE=1850 RACE=B SEX=M

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	21	75.9523810	4.5219044	67.0000000	83.0000000
MFL	0	.	.	.	.
BFL	21	467.8571429	31.3963146	428.0000000	547.0000000
EPIBR	0	.	.	.	.
FH	0	.	.	.	.
APS	0	.	.	.	.
MLS	0	.	.	.	.
APM	21	31.4761905	1.6455713	28.0000000	34.1000000
MLM	21	30.4904762	2.0149205	26.1000000	34.0000000
CIR	0	.	.	.	.
MRATIO	21	1.0364698	0.0844296	0.8536590	1.2037040
SRATIO	0	.	.	.	.
TA	21	753.9564238	66.1505614	604.7173000	889.3220000
BFLROB	21	13.2816038	0.7840271	12.0658100	15.2424900

Appendix 1: Descriptive statistics by decade of birth (Continued).

---------------------- DECADE=1850 RACE=W SEX=F ----------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	21	79.6666667	7.1227336	66.0000000	91.0000000
MFL	0	.	.	.	.
BFL	21	418.6904762	17.4517021	373.0000000	451.5000000
EPIBR	0	.	.	.	.
FH	0	.	.	.	.
APS	0	.	.	.	.
MLS	1	31.2000000	.	31.2000000	31.2000000
APM	21	26.5809524	1.5406554	24.4000000	29.4000000
MLM	21	26.0619048	1.9061679	23.3000000	29.7000000
CIR	0	.	.	.	.
MRATIO	21	1.0229300	0.0655982	0.8249160	1.1630900
SRATIO	0	.	.	.	.
TA	21	545.1796571	62.8754268	448.4309000	678.8668000
BFLROB	21	12.5773090	0.5715894	11.5473400	13.6111100

Appendix 1: Descriptive statistics by decade of birth (Continued).

------------------------ DECADE=1850 RACE=W SEX=M ------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	33	76.4242424	4.1157495	71.0000000	85.0000000
MFL	0	.	.	.	.
BFL	33	452.7575758	18.6128825	401.0000000	489.0000000
EPIBR	0	.	.	.	.
FH	0	.	.	.	.
APS	0	.	.	.	.
MLS	0	.	.	.	.
APM	33	30.1393939	2.2970007	26.6000000	35.0000000
MLM	33	29.1909091	1.6061140	26.0000000	33.2000000
CIR	0	.	.	.	.
MRATIO	33	1.0355173	0.0963816	0.8692810	1.2307690
SRATIO	0	.	.	.	.
TA	33	691.0468545	67.1909623	592.1902000	896.9875000
BFLROB	33	13.1157612	0.6314479	11.7521400	14.5689700

Appendix 1: Descriptive statistics by decade of birth (Continued).

---------------------- DECADE=1860 RACE=B SEX=F ----------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	17	74.3529412	9.4666598	61.0000000	97.0000000
MFL	0	.	.	.	.
BFL	17	430.4117647	16.4280964	399.0000000	457.0000000
EPIBR	0	.	.	.	.
FH	0	.	.	.	.
APS	0	.	.	.	.
MLS	0	.	.	.	.
APM	17	26.8529412	2.1723022	23.6000000	31.7000000
MLM	17	25.8823529	1.3295842	23.3000000	27.4000000
CIR	0	.	.	.	.
MRATIO	17	1.0401089	0.0984748	0.8805970	1.1718750
SRATIO	0	.	.	.	.
TA	17	545.8826765	53.3480160	469.1812000	682.1811000
BFLROB	17	12.2686476	0.7444554	11.0383700	13.5240300

Appendix 1: Descriptive statistics by decade of birth (Continued).

DECADE=1860 RACE=B SEX=M

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	19	69.1578947	5.7180334	60.0000000	80.0000000
MFL	0	.	.	.	.
BFL	19	471.2105263	24.1972885	415.0000000	514.0000000
EPIBR	0	.	.	.	.
FH	0	.	.	.	.
APS	0	.	.	.	.
MLS	0	.	.	.	.
APM	19	30.9578947	2.5934353	27.8000000	36.7000000
MLM	19	29.9052632	2.5162745	26.0000000	35.8000000
CIR	0	.	.	.	.
MRATIO	19	1.0417551	0.1223496	0.8750000	1.3269230
SRATIO	0	.	.	.	.
TA	19	727.4671895	91.1647676	606.3509000	984.1039000
BFLROB	19	12.9284047	0.7012037	11.5320900	14.1883800

Appendix 1: Descriptive statistics by decade of birth (Continued).

------------------------ DECADE=1860 RACE=W SEX=F ------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	20	77.8000000	9.2201153	61.0000000	90.0000000
MFL	0	.	.	.	.
BFL	20	415.1500000	22.4880670	383.0000000	470.0000000
EPIBR	0	.	.	.	.
FH	0	.	.	.	.
APS	0	.	.	.	.
MLS	0	.	.	.	.
APM	20	27.0345000	2.4499871	22.2000000	32.4000000
MLM	20	25.3350000	1.3526874	23.2000000	27.4000000
CIR	0	.	.	.	.
MRATIO	20	1.0696990	0.1086811	0.8345860	1.2742620
SRATIO	0	.	.	.	.
TA	20	538.1158700	59.5741205	463.7933000	679.4322000
BFLROB	20	12.6364795	0.7794071	11.2127700	14.0076100

Appendix 1: Descriptive statistics by decade of birth (Continued).

----------------------- DECADE=1860 RACE=W SEX=M -----------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	27	68.1481481	5.3973192	54.0000000	80.0000000
MFL	0	.	.	.	.
BFL	27	451.9629630	30.0467347	401.0000000	507.0000000
EPIBR	0	.	.	.	.
FH	0	.	.	.	.
APS	0	.	.	.	.
MLS	0	.	.	.	.
APM	27	29.4481481	2.3702272	25.8000000	33.9000000
MLM	27	28.6925926	1.6657006	25.8000000	31.4000000
CIR	0	.	.	.	.
MRATIO	27	1.0277501	0.0796028	0.8837210	1.2301890
SRATIO	0	.	.	.	.
TA	27	664.8389630	76.9476254	532.9241000	806.0541000
BFLROB	27	12.8873304	0.6794167	11.7437000	14.1396500

Appendix 1: Descriptive statistics by decade of birth (Continued).

DECADE=1870 RACE=B SEX=F

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	8	64.7500000	9.0198194	49.0000000	75.0000000
MFL	0	.	.	.	.
BFL	8	435.0000000	26.0384331	404.0000000	485.0000000
EPIBR	0	.	.	.	.
FH	0	.	.	.	.
APS	0	.	.	.	.
MLS	0	.	.	.	.
APM	8	28.8500000	1.4152234	26.8000000	31.0000000
MLM	8	26.8125000	1.5986043	24.8000000	29.1000000
CIR	0	.	.	.	.
MRATIO	8	1.0767394	0.0226729	1.0424030	1.1169350
SRATIO	0	.	.	.	.
TA	8	609.0065750	65.1777674	528.3216000	708.5077000
BFLROB	8	12.8146550	0.6661618	11.7449700	13.9130400

Appendix 1: Descriptive statistics by decade of birth (Continued).

---------------------- DECADE=1870 RACE=B SEX=M ----------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	12	55.9166667	11.4927513	21.0000000	66.0000000
MFL	0	.	.	.	.
BFL	12	467.0000000	11.7782542	445.0000000	487.0000000
EPIBR	0	.	.	.	.
FH	0	.	.	.	.
APS	0	.	.	.	.
MLS	0	.	.	.	.
APM	12	29.7500000	1.3721251	27.5000000	31.6000000
MLM	12	29.0000000	2.1578609	24.4000000	31.7000000
CIR	0	.	.	.	.
MRATIO	12	1.0311588	0.0902492	0.9114750	1.2049180
SRATIO	0	.	.	.	.
TA	12	677.8123500	61.5143963	563.4132000	757.2024000
BFLROB	12	12.5835917	0.5677905	11.5957400	13.5777800

Appendix 1: Descriptive statistics by decade of birth (Continued).

---------------------- DECADE=1870 RACE=W SEX=F ----------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	14	65.0714286	10.9717419	45.0000000	86.0000000
MFL	1	514.0000000	.	514.0000000	514.0000000
BFL	14	435.4285714	34.1528561	391.0000000	505.0000000
EPIBR	1	80.0000000	.	80.0000000	80.0000000
FH	1	45.0000000	.	45.0000000	45.0000000
APS	1	28.0000000	.	28.0000000	28.0000000
MLS	1	33.0000000	.	33.0000000	33.0000000
APM	14	27.2857143	2.8465518	22.6000000	32.0000000
MLM	14	26.0571429	3.6203940	18.9000000	34.7000000
CIR	0	.	.	.	.
MRATIO	14	1.0541097	0.0801060	0.8818440	1.1957670
SRATIO	0	.	.	.	.
TA	14	564.4723857	128.1142715	335.4750000	833.9515000
BFLROB	14	12.2357029	0.8603682	10.6138100	13.6218700

Appendix 1: Descriptive statistics by decade of birth (Continued).

------------------------ DECADE=1870 RACE=W SEX=M ------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	20	57.5500000	4.1482400	51.0000000	67.0000000
MFL	1	437.0000000	.	437.0000000	437.0000000
BFL	20	454.4500000	27.8160783	394.0000000	501.0000000
EPIBR	1	79.0000000	.	79.0000000	79.0000000
FH	1	46.0000000	.	46.0000000	46.0000000
APS	1	29.0000000	.	29.0000000	29.0000000
MLS	1	36.0000000	.	36.0000000	36.0000000
APM	20	29.3600000	2.5980560	25.2000000	34.3000000
MLM	20	28.8500000	2.3270718	23.9000000	32.2000000
CIR	0	.	.	.	.
MRATIO	20	1.0197810	0.0738691	0.8689660	1.1600000
SRATIO	0	.	.	.	.
TA	20	668.1994850	102.1880701	486.1693000	867.4409000
BFLROB	20	12.8413795	1.0998841	10.9274200	14.4883700

Appendix 1: Descriptive statistics by decade of birth (Continued).

---------------------- DECADE=1880 RACE=B SEX=F ----------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	11	54.4545455	11.2014609	35.0000000	72.0000000
MFL	0	.	.	.	.
BFL	11	435.1818182	23.2457230	406.0000000	476.0000000
EPIBR	0	.	.	.	.
FH	0	.	.	.	.
APS	0	.	.	.	.
MLS	0	.	.	.	.
APM	11	26.9181818	2.7378160	23.7000000	33.1000000
MLM	11	24.8545455	2.2686400	20.8000000	29.4000000
CIR	0	.	.	.	.
MRATIO	11	1.0880003	0.1157798	0.9045800	1.2974140
SRATIO	0	.	.	.	.
TA	11	527.1778091	89.1684556	403.5062000	764.3024000
BFLROB	11	11.8994009	0.7414232	10.9322000	13.1302500

Appendix 1: Descriptive statistics by decade of birth (Continued).

DECADE=1880 RACE=B SEX=M

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	12	46.5833333	4.3995523	40.0000000	55.0000000
MFL	0	.	.	.	.
BFL	12	472.5833333	37.3666315	418.0000000	562.0000000
EPIBR	0	.	.	.	.
FH	0	.	.	.	.
APS	0	.	.	.	.
MLS	0	.	.	.	.
APM	12	30.4000000	2.6792129	26.5000000	35.3000000
MLM	12	28.6166667	2.1837555	25.0000000	31.3000000
CIR	0	.	.	.	.
MRATIO	12	1.0652790	0.0938968	0.9013610	1.2310610
SRATIO	0	.	.	.	.
TA	12	685.1290000	96.4396185	550.4149000	867.7786000
BFLROB	12	12.5151933	0.7311977	10.7489900	13.5962900

Appendix 1: Descriptive statistics by decade of birth (Continued).

------------------------ DECADE=1880 RACE=W SEX=F ------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	10	64.0000000	8.7559504	52.0000000	76.0000000
MFL	0	.	.	.	.
BFL	10	430.9000000	16.0239404	397.0000000	450.0000000
EPIBR	0	.	.	.	.
FH	0	.	.	.	.
APS	0	.	.	.	.
MLS	0	.	.	.	.
APM	10	26.9200000	2.3044884	22.5000000	30.5000000
MLM	10	25.7200000	1.2994016	23.7000000	28.0000000
CIR	0	.	.	.	.
MRATIO	10	1.0458008	0.0590308	0.9493670	1.1423220
SRATIO	0	.	.	.	.
TA	10	545.4448800	69.2140806	418.8136000	639.5890000
BFLROB	10	12.2245340	0.8055738	10.9738700	13.3812900

Appendix 1: Descriptive statistics by decade of birth (Continued).

------------------------ DECADE=1880 RACE=W SEX=M ------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	10	46.6000000	3.1340425	41.0000000	52.0000000
MFL	1	459.0000000	.	459.0000000	459.0000000
BFL	11	459.1818182	13.3777291	436.0000000	486.0000000
EPIBR	1	99.0000000	.	99.0000000	99.0000000
FH	1	56.0000000	.	56.0000000	56.0000000
APS	1	31.0000000	.	31.0000000	31.0000000
MLS	1	38.0000000	.	38.0000000	38.0000000
APM	11	30.4636364	2.5835142	27.0000000	36.0000000
MLM	11	29.9000000	1.6822604	27.7000000	32.6000000
CIR	0	.	.	.	.
MRATIO	11	1.0233820	0.1185190	0.8385090	1.2000000
SRATIO	1	0.8157890	.	0.8157890	0.8157890
TA	11	714.1925455	58.4084358	629.8108000	848.2300000
BFLROB	11	13.1608855	0.7591269	11.9873200	14.4736800

Appendix 1: Descriptive statistics by decade of birth (Continued).

DECADE=1890 RACE=B SEX=F

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	13	41.1538462	13.8494654	32.0000000	85.0000000
MFL	3	462.3333333	3.5118846	459.0000000	466.0000000
BFL	13	443.0769231	27.5301699	381.0000000	478.0000000
EPIBR	2	75.0000000	4.2426407	72.0000000	78.0000000
FH	3	43.0000000	0	43.0000000	43.0000000
APS	3	28.6666667	0.5773503	28.0000000	29.0000000
MLS	3	30.6666667	3.0550505	28.0000000	34.0000000
APM	13	28.5000000	2.6739484	21.4000000	31.0000000
MLM	13	25.4692308	1.1070867	23.8000000	27.0000000
CIR	3	88.3333333	4.5092498	84.0000000	93.0000000
MRATIO	13	1.1204444	0.1120131	0.8458500	1.2983190
SRATIO	3	0.9398693	0.0771050	0.8529410	1.0000000
TA	13	570.4032692	62.2513296	425.2303000	657.3783000
BFLROB	13	12.2005623	0.6409437	10.7740600	13.1116400

Appendix 1: Descriptive statistics by decade of birth (Continued).

---------------------- DECADE=1890 RACE=B SEX=M ----------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	10	37.1000000	3.7844712	31.0000000	42.0000000
MFL	0	.	.	.	.
BFL	10	468.2000000	19.5664111	440.0000000	506.0000000
EPIBR	0	.	.	.	.
FH	0	.	.	.	.
APS	0	.	.	.	.
MLS	0	.	.	.	.
APM	10	28.8800000	1.6883917	27.2000000	32.4000000
MLM	10	27.8700000	1.4787758	25.3000000	29.5000000
CIR	0	.	.	.	.
MRATIO	10	1.0376046	0.0596636	0.9387760	1.1107140
SRATIO	0	.	.	.	.
TA	10	632.9476700	60.4025487	554.3890000	750.6836000
BFLROB	10	12.1283100	0.5224057	11.2447300	12.7056300

Appendix 1: Descriptive statistics by decade of birth (Continued).

DECADE=1890 RACE=W SEX=F

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	12	59.7500000	9.9373035	44.0000000	84.0000000
MFL	2	445.0000000	19.7989899	431.0000000	459.0000000
BFL	12	420.5000000	28.9497998	369.0000000	477.0000000
EPIBR	2	80.5000000	2.1213203	79.0000000	82.0000000
FH	2	44.5000000	0.7071068	44.0000000	45.0000000
APS	2	27.0000000	0	27.0000000	27.0000000
MLS	2	29.5000000	0.7071068	29.0000000	30.0000000
APM	12	26.4583333	2.4773367	22.3000000	30.0000000
MLM	12	25.3250000	2.2328640	21.3000000	28.2000000
CIR	0	.	.	.	.
MRATIO	12	1.0497163	0.1130515	0.8687940	1.2863440
SRATIO	2	0.9155170	0.0219444	0.9000000	0.9310340
TA	12	527.4779833	74.7588919	373.0563000	637.7433000
BFLROB	12	12.3258867	0.6590534	10.8805000	13.4434000

Appendix 1: Descriptive statistics by decade of birth (Continued).

DECADE=1890 RACE=W SEX=M

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	12	50.9166667	22.2116199	28.0000000	101.0000000
MFL	4	467.2500000	17.7834192	447.0000000	485.0000000
BFL	13	452.3076923	27.1857334	391.0000000	481.0000000
EPIBR	4	86.2500000	4.7169906	83.0000000	93.0000000
FH	4	50.2500000	1.7078251	48.0000000	52.0000000
APS	4	30.0000000	0.8164966	29.0000000	31.0000000
MLS	4	32.7500000	2.2173558	31.0000000	36.0000000
APM	13	29.6769231	1.8534445	26.4000000	33.0000000
MLM	13	28.0846154	2.1984260	25.4000000	32.5000000
CIR	2	91.5000000	2.1213203	90.0000000	93.0000000
MRATIO	13	1.0635216	0.1135268	0.8584620	1.2030650
SRATIO	4	0.9178988	0.0378704	0.8611110	0.9375000
TA	13	653.7732846	53.7415167	549.4646000	725.7079000
BFLROB	13	12.8090469	0.8726114	11.4008600	14.4497600

Appendix 1: Descriptive statistics by decade of birth (Continued).

---------------------- DECADE=1900 RACE=B SEX=F ----------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	17	41.2352941	20.1386737	22.0000000	86.0000000
MFL	18	441.1666667	25.5923932	396.0000000	494.0000000
BFL	18	435.7222222	24.1583150	395.0000000	488.0000000
EPIBR	18	75.5000000	4.5665021	69.0000000	87.0000000
FH	18	42.8888889	2.2199335	38.0000000	47.0000000
APS	19	26.5263158	1.9541529	24.0000000	30.0000000
MLS	19	30.0000000	2.5819889	25.0000000	35.0000000
APM	19	28.2105263	1.4367768	26.0000000	31.0000000
MLM	19	25.7368421	2.1561825	22.0000000	29.0000000
CIR	18	84.6666667	3.7100817	79.0000000	91.0000000
MRATIO	19	1.1041067	0.1164802	0.9310340	1.3636360
SRATIO	19	0.8880032	0.0731013	0.7428570	1.0000000
TA	19	569.9510632	52.4299045	466.5265000	660.5199000
BFLROB	18	12.4760039	0.8000347	11.4583300	14.6835400

Appendix 1: Descriptive statistics by decade of birth (Continued).

------------------------ DECADE=1900 RACE=B SEX=M ------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	28	41.7142857	22.0384464	21.0000000	85.0000000
MFL	27	479.1851852	27.6252909	429.0000000	539.0000000
BFL	26	474.7307692	26.9110501	426.0000000	530.0000000
EPIBR	26	84.0384615	4.0445595	75.0000000	90.0000000
FH	27	47.6296296	2.3394304	42.0000000	52.0000000
APS	26	28.6538462	2.0187582	24.0000000	33.0000000
MLS	26	33.1153846	2.2149839	29.0000000	39.0000000
APM	27	30.3703704	2.2727169	27.0000000	35.0000000
MLM	26	28.4230769	1.7475257	25.0000000	31.0000000
CIR	26	90.8461538	4.4514475	83.0000000	99.0000000
MRATIO	26	1.0679089	0.1050279	0.8709680	1.2222220
SRATIO	26	0.8672877	0.0638677	0.7647060	1.0000000
TA	26	674.5966231	61.4388015	549.7787000	824.6681000
BFLROB	26	12.3805777	0.6942419	10.7547200	13.9072800

Appendix 1: Descriptive statistics by decade of birth (Continued).

---------------------- DECADE=1900 RACE=W SEX=F ----------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	8	55.3750000	17.5575584	27.0000000	79.0000000
MFL	9	441.8888889	25.8042847	394.0000000	482.0000000
BFL	9	437.6666667	25.4656632	390.0000000	477.0000000
EPIBR	9	74.8888889	4.9356976	68.0000000	83.0000000
FH	9	43.3333333	2.8284271	40.0000000	47.0000000
APS	9	25.6666667	2.0615528	21.0000000	28.0000000
MLS	9	28.5555556	2.0682789	26.0000000	31.0000000
APM	9	26.8888889	2.0883273	23.0000000	30.0000000
MLM	9	25.0000000	2.2360680	22.0000000	29.0000000
CIR	3	81.3333333	5.8594653	77.0000000	88.0000000
MRATIO	9	1.0805503	0.1003429	0.8965520	1.2608700
SRATIO	9	0.9009391	0.0742618	0.7741940	1.0000000
TA	9	529.0965778	70.8786370	397.4115000	636.1725000
BFLROB	9	11.8838633	0.9594974	10.5603400	12.8205100

Appendix 1: Descriptive statistics by decade of birth (Continued).

DECADE=1900 RACE=W SEX=M

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	13	70.6153846	14.7565718	29.0000000	87.0000000
MFL	12	469.4166667	20.6945682	435.0000000	506.0000000
BFL	12	466.2500000	20.6138744	432.0000000	502.0000000
EPIBR	13	85.3846154	2.8733970	79.0000000	89.0000000
FH	12	48.5000000	1.8340219	44.0000000	51.0000000
APS	13	30.0000000	2.1213203	27.0000000	34.0000000
MLS	13	32.9230769	2.5968423	29.0000000	38.0000000
APM	13	31.4615385	2.8465003	26.0000000	36.0000000
MLM	13	28.3846154	1.8946619	25.0000000	32.0000000
CIR	8	96.2500000	7.1264096	85.0000000	110.0000000
MRATIO	13	1.1088756	0.0787422	1.0000000	1.2800000
SRATIO	13	0.9137765	0.0647263	0.8181820	1.0689660
TA	13	704.0188308	100.8757917	530.9292000	904.7787000
BFLROB	12	12.9029067	1.0071941	10.5577700	14.3763200

Appendix 1: Descriptive statistics by decade of birth (Continued).

DECADE=1910 RACE=B SEX=F

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	20	29.1000000	11.3920563	19.0000000	65.0000000
MFL	21	447.8571429	28.0611577	386.0000000	491.0000000
BFL	21	442.2380952	27.9640926	381.0000000	487.0000000
EPIBR	19	73.3157895	3.7867111	66.0000000	80.0000000
FH	20	42.0500000	2.4596748	35.0000000	45.0000000
APS	20	25.3000000	1.8666040	22.0000000	28.0000000
MLS	20	28.0500000	2.2118104	25.0000000	33.0000000
APM	20	27.6500000	2.4553915	24.0000000	32.0000000
MLM	20	24.1500000	1.8144160	21.0000000	27.0000000
CIR	20	80.3500000	5.9407159	67.0000000	90.0000000
MRATIO	20	1.1488067	0.1072520	0.9259260	1.3043480
SRATIO	20	0.9057568	0.0796482	0.6969700	1.0800000
TA	20	525.4313700	68.0861636	395.8407000	628.3185000
BFLROB	20	11.7188680	0.6381829	10.1731600	13.0864200

Appendix 1: Descriptive statistics by decade of birth (Continued).

------------------------- DECADE=1910 RACE=B SEX=M -------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	25	39.4800000	21.9414372	18.0000000	80.0000000
MFL	25	487.4000000	28.8934825	436.0000000	542.0000000
BFL	25	483.2800000	27.9382056	433.0000000	537.0000000
EPIBR	24	84.2916667	4.2270266	74.0000000	95.0000000
FH	25	48.2800000	3.1026870	42.0000000	57.0000000
APS	25	28.5600000	3.0697448	24.0000000	34.0000000
MLS	25	32.7600000	2.7580186	29.0000000	40.0000000
APM	25	30.8000000	2.4324199	27.0000000	35.0000000
MLM	25	28.6000000	2.7386128	24.0000000	35.0000000
CIR	23	91.6086957	7.1778645	82.0000000	107.0000000
MRATIO	25	1.0814284	0.0821517	0.9000000	1.2400000
SRATIO	25	0.8732158	0.0793963	0.7272730	1.0312500
TA	25	694.9517240	109.5620291	527.7876000	962.1128000
BFLROB	25	12.3064352	0.9117132	10.9533500	14.3176700

Appendix 1: Descriptive statistics by decade of birth (Continued).

----------------------- DECADE=1910 RACE=W SEX=F -----------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	22	62.4545455	16.5089507	30.0000000	89.0000000
MFL	22	433.0000000	25.1509727	385.0000000	481.0000000
BFL	21	428.3333333	24.9145205	382.0000000	479.0000000
EPIBR	21	74.4285714	3.5152728	67.0000000	82.0000000
FH	22	42.2727273	2.1421355	37.0000000	46.0000000
APS	23	26.7826087	2.3150991	22.0000000	32.0000000
MLS	23	29.1739130	2.2289862	26.0000000	33.0000000
APM	22	27.8181818	1.8932553	25.0000000	32.0000000
MLM	22	25.2272727	1.7709782	23.0000000	29.0000000
CIR	11	83.1818182	4.0204025	78.0000000	91.0000000
MRATIO	22	1.1051917	0.0715725	0.9259260	1.1851850
SRATIO	23	0.9196804	0.0673952	0.8064520	1.0714290
TA	22	552.4919273	67.4048131	451.6039000	703.7168000
BFLROB	21	12.4381776	0.7521402	11.2734900	13.9860100

Appendix 1: Descriptive statistics by decade of birth (Continued).

DECADE=1910 RACE=W SEX=M

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	20	62.0000000	13.2386993	32.0000000	79.0000000
MFL	19	472.1578947	27.3541855	421.0000000	515.0000000
BFL	20	469.8500000	27.5437929	417.0000000	510.0000000
EPIBR	19	86.1052632	4.7713815	79.0000000	97.0000000
FH	20	48.8500000	2.6011131	44.0000000	54.0000000
APS	22	28.7272727	2.8314865	25.0000000	36.0000000
MLS	22	32.7727273	2.4286351	29.0000000	39.0000000
APM	21	30.7142857	2.5326440	26.0000000	35.0000000
MLM	21	27.9523810	2.1089379	23.0000000	33.0000000
CIR	13	90.9230769	7.2394928	81.0000000	104.0000000
MRATIO	21	1.1025590	0.0999819	0.8965520	1.3043480
SRATIO	22	0.8780660	0.0775790	0.7777780	1.0588240
TA	21	675.7416143	89.0692911	530.1438000	881.2167000
BFLROB	20	12.5242650	0.8323755	11.1764700	14.3884900

Appendix 1: Descriptive statistics by decade of birth (Continued).

---------------------- DECADE=1920 RACE=B SEX=F ----------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	6	52.3333333	14.2781885	38.0000000	66.0000000
MFL	6	447.3333333	26.7781005	397.0000000	475.0000000
BFL	6	442.6666667	26.0281898	395.0000000	471.0000000
EPIBR	5	73.2000000	3.8340579	69.0000000	78.0000000
FH	6	42.0000000	1.6733201	40.0000000	44.0000000
APS	6	24.8333333	2.1369761	22.0000000	28.0000000
MLS	6	28.3333333	2.0655911	26.0000000	31.0000000
APM	6	27.5000000	1.9748418	25.0000000	31.0000000
MLM	6	24.3333333	2.2509257	22.0000000	28.0000000
CIR	6	81.5000000	5.6480085	76.0000000	92.0000000
MRATIO	6	1.1329078	0.0571292	1.0800000	1.2272730
SRATIO	6	0.8786972	0.0798451	0.7857140	1.0000000
TA	6	528.0493833	85.6057551	431.9690000	681.7256000
BFLROB	6	11.7182567	0.7692679	10.9131400	13.0242800

Appendix 1: Descriptive statistics by decade of birth (Continued).

DECADE=1920 RACE=B SEX=M

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	14	51.2142857	18.3268553	18.0000000	71.0000000
MFL	14	475.9285714	24.8641363	414.0000000	517.0000000
BFL	13	470.3076923	25.5028907	408.0000000	515.0000000
EPIBR	14	84.0714286	5.4131505	74.0000000	92.0000000
FH	15	48.3333333	3.4364988	43.0000000	54.0000000
APS	14	29.0714286	2.7586029	25.0000000	34.0000000
MLS	14	33.2857143	2.1989008	30.0000000	39.0000000
APM	14	29.6428571	2.3731557	26.0000000	34.0000000
MLM	13	28.6153846	2.2560460	24.0000000	32.0000000
CIR	12	91.5833333	5.5178773	83.0000000	101.0000000
MRATIO	13	1.0460941	0.1136642	0.8125000	1.2692310
SRATIO	14	0.8749464	0.0821750	0.7647060	1.0333330
TA	13	669.2800846	78.7358125	527.7876000	827.8097000
BFLROB	13	12.4309977	0.7159824	11.4563100	13.7254900

Appendix 1: Descriptive statistics by decade of birth (Continued).

---------------------- DECADE=1920 RACE=W SEX=F ----------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	22	53.2272727	11.5012704	33.0000000	71.0000000
MFL	20	433.6000000	20.2390971	387.0000000	463.0000000
BFL	20	430.0500000	20.3093834	380.0000000	457.0000000
EPIBR	19	75.6315789	2.9478905	70.0000000	81.0000000
FH	20	42.0000000	2.0519567	38.0000000	46.0000000
APS	22	25.6363636	2.4984844	19.0000000	30.0000000
MLS	22	28.5909091	1.9188064	25.0000000	31.0000000
APM	22	27.0000000	2.7255406	21.0000000	31.0000000
MLM	22	24.7272727	1.6670995	22.0000000	27.0000000
CIR	13	82.3076923	4.6257363	73.0000000	89.0000000
MRATIO	22	1.0943933	0.1122339	0.8800000	1.2500000
SRATIO	22	0.8975246	0.0750769	0.7037040	1.0000000
TA	22	525.4313773	71.3558696	379.3473000	633.0309000
BFLROB	20	12.0662425	0.9645986	10.5769200	13.9473700

Appendix 1: Descriptive statistics by decade of birth (Continued).

DECADE=1920 RACE=W SEX=M

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	46	60.3043478	11.9049375	28.0000000	74.0000000
MFL	46	473.5869565	26.1623785	420.0000000	563.0000000
BFL	46	470.9347826	26.2173837	419.0000000	561.0000000
EPIBR	46	84.0652174	3.9350402	77.0000000	98.0000000
FH	46	48.6521739	2.1930941	45.0000000	55.0000000
APS	47	29.7872340	2.3859751	23.0000000	36.0000000
MLS	47	33.4255319	3.7401737	21.0000000	48.0000000
APM	47	31.0851064	2.7570446	25.0000000	42.0000000
MLM	47	28.5319149	2.1654507	21.0000000	33.0000000
CIR	37	93.5675676	6.6897124	74.0000000	113.0000000
MRATIO	47	1.0931301	0.1016448	0.9285710	1.4482760
SRATIO	47	0.8993469	0.1050708	0.7083330	1.3333330
TA	47	698.2189787	92.2584537	412.3340000	956.6150000
BFLROB	46	12.6948563	1.0214599	10.5747100	15.7142900

Appendix 1: Descriptive statistics by decade of birth (Continued).

---------------------- DECADE=1930 RACE=B SEX=F ----------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	5	34.4000000	14.6389890	18.0000000	55.0000000
MFL	4	440.0000000	16.1864141	421.0000000	460.0000000
BFL	4	434.7500000	17.0758114	415.0000000	456.0000000
EPIBR	5	71.8000000	3.7013511	66.0000000	75.0000000
FH	5	41.0000000	1.2247449	40.0000000	43.0000000
APS	5	26.0000000	3.1622777	23.0000000	31.0000000
MLS	5	27.6000000	2.3021729	24.0000000	30.0000000
APM	4	28.5000000	3.6968455	26.0000000	34.0000000
MLM	4	22.5000000	1.2909944	21.0000000	24.0000000
CIR	3	82.6666667	6.3508530	79.0000000	90.0000000
MRATIO	4	1.2716510	0.1971589	1.1250000	1.5454550
SRATIO	5	0.9532704	0.1942414	0.8214290	1.2916670
TA	4	502.8511750	62.2081871	445.3208000	587.4778000
BFLROB	4	11.7647400	1.2499919	10.7456100	13.4939800

Appendix 1: Descriptive statistics by decade of birth (Continued).

------------------------ DECADE=1930 RACE=B SEX=M ------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	12	51.3333333	9.4516313	36.0000000	66.0000000
MFL	13	495.3076923	25.7532672	453.0000000	530.0000000
BFL	13	491.6153846	25.4608800	451.0000000	528.0000000
EPIBR	13	84.0000000	3.4880749	79.0000000	91.0000000
FH	13	47.6923077	2.2130151	44.0000000	51.0000000
APS	13	29.3076923	1.3155870	27.0000000	32.0000000
MLS	13	33.2307692	2.0064000	30.0000000	37.0000000
APM	13	31.9230769	2.1779784	29.0000000	37.0000000
MLM	13	28.4615385	1.9839096	26.0000000	33.0000000
CIR	9	96.0000000	5.1720402	89.0000000	105.0000000
MRATIO	13	1.1258218	0.0997520	0.9666670	1.2758620
SRATIO	13	0.8849581	0.0673683	0.7777780	1.0000000
TA	13	713.9873538	74.1840709	612.6106000	855.2986000
BFLROB	12	12.2612600	0.7369876	10.9848500	13.2075500

Appendix 1: Descriptive statistics by decade of birth (Continued).

------------------------ DECADE=1930 RACE=W SEX=F ------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	17	42.4705882	9.3214648	25.0000000	57.0000000
MFL	14	437.1428571	26.5789308	403.0000000	507.0000000
BFL	13	433.3846154	26.9707819	399.0000000	503.0000000
EPIBR	12	73.8333333	2.7579087	70.0000000	78.0000000
FH	14	41.6428571	1.9057461	38.0000000	44.0000000
APS	15	25.8000000	1.8205180	22.0000000	29.0000000
MLS	15	28.8000000	2.3964259	24.0000000	33.0000000
APM	16	27.3750000	2.7049338	20.0000000	32.0000000
MLM	16	24.8125000	1.7211914	21.0000000	27.0000000
CIR	7	81.7142857	8.3409489	65.0000000	90.0000000
MRATIO	16	1.1031609	0.0814817	0.9523810	1.2173910
SRATIO	15	0.8988118	0.0655749	0.8000000	1.0384620
TA	16	535.8379063	79.9320377	329.8672000	678.5840000
BFLROB	13	12.1309429	1.0727750	9.8795180	13.8173300

Appendix 1: Descriptive statistics by decade of birth (Continued).

DECADE=1930 RACE=W SEX=M

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	50	48.4400000	8.5741900	30.0000000	63.0000000
MFL	52	474.0000000	23.4110750	423.0000000	531.0000000
BFL	52	470.7115385	22.7633491	422.0000000	528.0000000
EPIBR	52	85.8461538	4.4075898	77.0000000	99.0000000
FH	55	49.2363636	2.3330447	45.0000000	55.0000000
APS	55	29.2000000	2.0673834	24.0000000	36.0000000
MLS	55	32.6727273	2.3258176	28.0000000	39.0000000
APM	53	30.7169811	2.4208816	26.0000000	37.0000000
MLM	53	28.5283019	2.5465193	23.0000000	35.0000000
CIR	37	92.3243243	5.2390312	81.0000000	104.0000000
MRATIO	53	1.0817441	0.0948931	0.8857140	1.3333330
SRATIO	55	0.8979007	0.0889984	0.7714290	1.1379310
TA	53	690.4094528	101.4739070	510.5088000	1017.09
BFLROB	51	12.5685925	0.7552692	10.9207700	13.9810400

Appendix 1: Descriptive statistics by decade of birth (Continued).

---------------------- DECADE=1940 RACE=B SEX=F ----------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	8	35.3750000	4.0686080	27.0000000	40.0000000
MFL	8	451.7500000	30.4337688	394.0000000	491.0000000
BFL	7	441.5714286	28.4538055	388.0000000	469.0000000
EPIBR	6	74.1666667	1.8348479	72.0000000	77.0000000
FH	8	42.3750000	1.9955307	41.0000000	47.0000000
APS	7	25.2857143	0.4879500	25.0000000	26.0000000
MLS	7	29.8571429	1.4638501	28.0000000	32.0000000
APM	7	26.5714286	1.2724180	25.0000000	28.0000000
MLM	7	24.4285714	0.9759001	23.0000000	26.0000000
CIR	4	86.2500000	6.1305247	80.0000000	92.0000000
MRATIO	7	1.0894076	0.0724427	1.0000000	1.2173910
SRATIO	7	0.8486256	0.0449684	0.8064520	0.9285710
TA	7	509.7234143	30.4824735	471.2389000	551.3495000
BFLROB	7	11.5854186	0.7091642	10.6609800	12.6288700

Appendix 1: Descriptive statistics by decade of birth (Continued).

------------------------ DECADE=1940 RACE=B SEX=M ------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	14	37.7142857	12.7546587	20.0000000	54.0000000
MFL	13	482.6153846	22.9257441	444.0000000	520.0000000
BFL	13	479.6153846	22.7286107	440.0000000	517.0000000
EPIBR	11	83.1818182	4.8128616	77.0000000	90.0000000
FH	12	47.9166667	2.5030285	43.0000000	52.0000000
APS	12	28.1666667	3.0100841	22.0000000	34.0000000
MLS	12	32.2500000	2.0504988	29.0000000	36.0000000
APM	13	30.7692308	2.4884348	27.0000000	36.0000000
MLM	13	27.9230769	2.3965788	24.0000000	33.0000000
CIR	9	91.0000000	7.1763500	85.0000000	103.0000000
MRATIO	13	1.1058278	0.0904933	0.9642860	1.2592590
SRATIO	12	0.8754651	0.0990789	0.6875000	1.0303030
TA	13	677.0132154	100.1000030	546.6371000	881.2167000
BFLROB	12	12.3483925	0.7583121	11.2224400	13.5555600

Appendix 1: Descriptive statistics by decade of birth (Continued).

DECADE=1940 RACE=W SEX=F

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	13	34.8461538	8.5911403	21.0000000	48.0000000
MFL	19	433.1578947	18.6167880	404.0000000	476.0000000
BFL	16	427.3750000	19.2210822	399.0000000	473.0000000
EPIBR	15	74.3333333	3.0394235	69.0000000	79.0000000
FH	16	43.2500000	1.6931233	40.0000000	47.0000000
APS	16	24.4375000	1.4127397	22.0000000	28.0000000
MLS	16	28.2500000	1.8439089	25.0000000	31.0000000
APM	17	26.1176471	1.4950900	23.0000000	28.0000000
MLM	17	24.2352941	2.3326329	19.0000000	28.0000000
CIR	7	78.1428571	3.0783422	74.0000000	82.0000000
MRATIO	17	1.0870056	0.1220773	0.9200000	1.4210530
SRATIO	16	0.8681120	0.0705340	0.7666670	1.0000000
TA	17	497.5266471	59.2963465	376.9911000	593.7610000
BFLROB	16	11.8615100	0.7531493	10.3594100	13.0325800

Appendix 1: Descriptive statistics by decade of birth (Continued).

DECADE=1940 RACE=W SEX=M

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	44	39.2272727	9.1393950	19.0000000	56.0000000
MFL	42	473.5476190	22.0334584	427.0000000	526.0000000
BFL	38	470.7894737	21.8275277	421.0000000	524.0000000
EPIBR	38	86.0789474	4.4319575	79.0000000	97.0000000
FH	42	48.5952381	2.5380953	44.0000000	55.0000000
APS	44	28.9772727	2.3574586	24.0000000	36.0000000
MLS	44	32.5454545	2.5376655	25.0000000	38.0000000
APM	40	30.9250000	2.1766535	26.0000000	35.0000000
MLM	40	27.9750000	2.2012526	24.0000000	35.0000000
CIR	30	91.3333333	4.9503280	81.0000000	100.0000000
MRATIO	40	1.1092688	0.0857333	0.9285710	1.2500000
SRATIO	44	0.8936158	0.0789795	0.7142860	1.1250000
TA	40	681.0383925	85.9152216	490.0885000	907.1349000
BFLROB	37	12.6145859	0.8025603	11.0647200	14.0271500

Appendix 1: Descriptive statistics by decade of birth (Continued).

------------------------ DECADE=1950 RACE=B SEX=F ------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	13	27.7692308	5.5400639	19.0000000	37.0000000
MFL	14	450.7142857	29.7978537	410.0000000	525.0000000
BFL	14	443.9285714	27.4631621	402.0000000	520.0000000
EPIBR	11	73.8181818	3.3111382	69.0000000	79.0000000
FH	13	41.7692308	1.8776690	39.0000000	45.0000000
APS	14	25.7142857	2.3014568	22.0000000	30.0000000
MLS	14	28.2857143	1.9778999	25.0000000	31.0000000
APM	14	27.6571429	1.6402224	25.0000000	30.0000000
MLM	14	23.7500000	2.2079402	21.0000000	28.5000000
CIR	10	79.9000000	4.4833024	73.0000000	87.0000000
MRATIO	14	1.1711612	0.0991447	0.9859650	1.3181820
SRATIO	14	0.9128768	0.1009035	0.7931030	1.1153850
TA	14	516.9182143	66.3547265	412.3340000	636.1725000
BFLROB	13	11.6341777	0.6201990	10.6728500	13.0414700

Appendix 1: Descriptive statistics by decade of birth (Continued).

---------------------- DECADE=1950 RACE=B SEX=M ----------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	10	31.6000000	8.1676870	19.0000000	43.0000000
MFL	9	472.3333333	28.9395923	429.0000000	511.0000000
BFL	9	468.0000000	28.4736720	422.0000000	510.0000000
EPIBR	9	84.4444444	5.1505124	76.0000000	92.0000000
FH	9	46.8888889	4.0756731	40.0000000	54.0000000
APS	10	28.6000000	2.3664319	24.0000000	32.0000000
MLS	10	31.6000000	2.9888682	26.0000000	35.0000000
APM	10	31.7000000	2.6267851	29.0000000	37.0000000
MLM	10	27.7000000	2.2632327	23.0000000	30.0000000
CIR	6	90.1666667	5.2694086	82.0000000	98.0000000
MRATIO	10	1.1482933	0.0965033	1.0000000	1.2800000
SRATIO	10	0.9091824	0.0819870	0.8235290	1.0714290
TA	10	691.7001700	98.3850715	523.8606000	871.7920000
BFLROB	9	12.6901289	0.8101090	11.7043100	13.8828600

Appendix 1: Descriptive statistics by decade of birth (Continued).

------------------------ DECADE=1950 RACE=W SEX=F ------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	32	26.6875000	7.0547970	18.0000000	39.0000000
MFL	30	436.9333333	18.8788028	398.0000000	480.0000000
BFL	29	433.5862069	19.1283582	395.0000000	477.0000000
EPIBR	29	75.2758621	3.6926235	68.0000000	82.0000000
FH	30	42.0000000	2.5461262	33.0000000	46.0000000
APS	35	24.9428571	1.7140056	22.0000000	29.0000000
MLS	34	28.7941176	1.8874291	25.0000000	33.0000000
APM	35	26.9428571	2.1135815	23.0000000	31.0000000
MLM	35	24.0000000	1.7656860	22.0000000	28.0000000
CIR	18	79.7777778	4.3596486	74.0000000	88.0000000
MRATIO	35	1.1259695	0.0938365	0.9285710	1.3181820
SRATIO	34	0.8677375	0.0569524	0.7586210	1.0384620
TA	35	508.9380086	64.9493955	415.4756000	657.3783000
BFLROB	29	11.8340483	0.7128040	10.3671700	13.4663300

Appendix 1: Descriptive statistics by decade of birth (Continued).

------------------------ DECADE=1950 RACE=W SEX=M ------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	48	31.8125000	7.7450224	19.0000000	47.0000000
MFL	48	474.3541667	23.5818986	403.0000000	516.0000000
BFL	44	471.0000000	23.5372046	400.0000000	510.0000000
EPIBR	41	84.5609756	4.0252253	75.0000000	90.0000000
FH	47	48.2978723	2.6450519	40.0000000	54.0000000
APS	51	28.5784314	2.8396700	23.0000000	38.0000000
MLS	51	31.2941176	2.3689164	24.0000000	36.0000000
APM	49	30.2244898	2.6868918	23.0000000	36.0000000
MLM	49	27.1836735	2.0683475	21.0000000	32.0000000
CIR	34	90.7058824	5.9519766	80.0000000	103.0000000
MRATIO	49	1.1145158	0.0933983	0.9259260	1.4000000
SRATIO	51	0.9164750	0.0968348	0.7187500	1.1481480
TA	49	647.4085265	90.2294216	379.3473000	879.6459000
BFLROB	44	12.2564027	0.7721204	10.7142900	14.7500000

Appendix 1: Descriptive statistics by decade of birth (Continued).

DECADE=1960 RACE=B SEX=F

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	5	22.2000000	3.9623226	18.0000000	26.0000000
MFL	4	424.2500000	6.6520673	416.0000000	431.0000000
BFL	3	418.3333333	5.0332230	413.0000000	423.0000000
EPIBR	3	73.0000000	7.0000000	68.0000000	81.0000000
FH	3	40.6666667	2.8867513	39.0000000	44.0000000
APS	3	24.0000000	1.0000000	23.0000000	25.0000000
MLS	3	27.0000000	2.0000000	25.0000000	29.0000000
APM	3	25.6666667	1.1547005	25.0000000	27.0000000
MLM	3	22.6666667	0.5773503	22.0000000	23.0000000
CIR	3	77.3333333	1.5275252	76.0000000	79.0000000
MRATIO	3	1.1324113	0.0436125	1.0869570	1.1739130
SRATIO	3	0.8939973	0.1035431	0.7931030	1.0000000
TA	3	457.1017333	28.2852618	431.9690000	487.7323000
BFLROB	3	11.5521100	0.2353489	11.3801500	11.8203300

Appendix 1: Descriptive statistics by decade of birth (Continued).

DECADE=1960 RACE=B SEX=M

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	8	26.2500000	3.4121631	21.0000000	32.0000000
MFL	10	493.7000000	21.0662975	471.0000000	539.0000000
BFL	10	490.6000000	21.6753829	468.0000000	535.0000000
EPIBR	9	84.1111111	2.4720662	80.0000000	89.0000000
FH	10	48.6000000	1.6465452	45.0000000	51.0000000
APS	9	28.1111111	1.6914819	26.0000000	30.0000000
MLS	9	31.8888889	2.9767618	28.0000000	37.0000000
APM	9	31.5555556	1.3333333	30.0000000	34.0000000
MLM	9	27.7777778	2.4381231	24.0000000	33.0000000
CIR	7	93.0000000	4.2031734	88.0000000	99.0000000
MRATIO	9	1.1427769	0.1008291	1.0000000	1.3333330
SRATIO	9	0.8848652	0.0542268	0.8108110	1.0000000
TA	9	688.9687222	74.6952305	603.1858000	855.2986000
BFLROB	9	12.0882178	0.4953734	11.5234400	12.8898100

Appendix 1: Descriptive statistics by decade of birth (Continued).

DECADE=1960 RACE=W SEX=F

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	24	23.7500000	3.8813937	18.0000000	30.0000000
MFL	24	436.1666667	23.1209799	387.0000000	474.0000000
BFL	22	435.1363636	21.9768178	385.0000000	473.0000000
EPIBR	20	72.8000000	4.0987803	66.0000000	79.0000000
FH	25	41.5200000	2.0840665	38.0000000	46.0000000
APS	23	24.3043478	1.7171536	21.0000000	28.0000000
MLS	23	27.7826087	1.3127529	26.0000000	30.0000000
APM	23	26.8260870	2.3091158	23.0000000	31.0000000
MLM	24	22.7500000	1.4218787	21.0000000	26.0000000
CIR	21	79.4285714	4.9352956	72.0000000	91.0000000
MRATIO	23	1.1819115	0.1009331	1.0000000	1.3636360
SRATIO	23	0.8755082	0.0587641	0.7777780	1.0000000
TA	23	480.0831696	61.3695369	379.3473000	633.0309000
BFLROB	21	11.4767167	0.8346326	10.3837500	13.9705900

Appendix 1: Descriptive statistics by decade of birth (Continued).

DECADE=1960 RACE=W SEX=M

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	23	24.6956522	5.0581598	19.0000000	35.0000000
MFL	23	478.9565217	23.8203089	441.0000000	533.0000000
BFL	23	475.6086957	23.6830187	440.0000000	528.0000000
EPIBR	22	84.5000000	4.6675169	76.0000000	95.0000000
FH	24	47.6250000	2.0602343	45.0000000	52.0000000
APS	24	28.2708333	2.9450739	24.0000000	39.0000000
MLS	24	31.7708333	1.9109477	28.0000000	36.0000000
APM	23	29.8260870	2.5875958	27.0000000	40.0000000
MLM	23	26.9130435	3.1029757	21.0000000	36.0000000
CIR	19	89.3157895	7.6452791	76.0000000	115.0000000
MRATIO	23	1.1170010	0.1105573	0.8333330	1.2857140
SRATIO	24	0.8929448	0.1162425	0.7878790	1.3928570
TA	23	633.1333913	113.4014857	445.3208000	1005.31
BFLROB	23	11.9369030	0.9047943	10.3448300	13.8075300

Appendix 1: Descriptive statistics by decade of birth (Continued).

---------------------- DECADE=1970 RACE=B SEX=F ----------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	4	20.0000000	3.4641016	18.0000000	23.0000000
MFL	4	445.5000000	12.6095202	429.0000000	458.0000000
BFL	4	440.2500000	11.9826263	425.0000000	454.0000000
EPIBR	3	74.0000000	3.6055513	71.0000000	78.0000000
FH	4	40.0000000	2.0000000	39.0000000	43.0000000
APS	4	24.2500000	1.7078251	22.0000000	26.0000000
MLS	4	28.5000000	1.7320508	27.0000000	30.0000000
APM	4	27.2500000	1.5000000	25.0000000	28.0000000
MLM	4	23.5000000	2.0816660	21.0000000	26.0000000
CIR	4	79.2500000	5.5000000	72.0000000	84.0000000
MRATIO	4	1.1659700	0.1185795	1.0769230	1.3333330
SRATIO	4	0.8518520	0.0570579	0.8000000	0.9259260
TA	4	503.2438750	56.8076398	451.6039000	571.7699000
BFLROB	4	11.5273725	0.5401799	11.0609500	12.3006800

Appendix 1: Descriptive statistics by decade of birth (Continued).

----------------------- DECADE=1970 RACE=B SEX=M -----------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	2	19.5000000	2.1213203	18.0000000	21.0000000
MFL	3	508.3333333	7.2341781	500.0000000	513.0000000
BFL	3	505.6666667	7.0945989	498.0000000	512.0000000
EPIBR	3	79.3333333	7.5055535	72.0000000	87.0000000
FH	3	47.3333333	0.5773503	47.0000000	48.0000000
APS	3	27.6666667	0.5773503	27.0000000	28.0000000
MLS	3	32.3333333	2.8867513	29.0000000	34.0000000
APM	3	31.6666667	3.0550505	29.0000000	35.0000000
MLM	3	26.3333333	0.5773503	26.0000000	27.0000000
CIR	3	91.3333333	6.0277138	85.0000000	97.0000000
MRATIO	3	1.2013297	0.0907923	1.1153850	1.2962960
SRATIO	3	0.8610547	0.0916544	0.7941180	0.9655170
TA	3	655.8074667	77.5558607	592.1902000	742.2013000
BFLROB	3	11.4685967	0.6598452	11.0441800	12.2288000

Appendix 1: Descriptive statistics by decade of birth (Continued).

----------------------- DECADE=1970 RACE=W SEX=F -----------------------

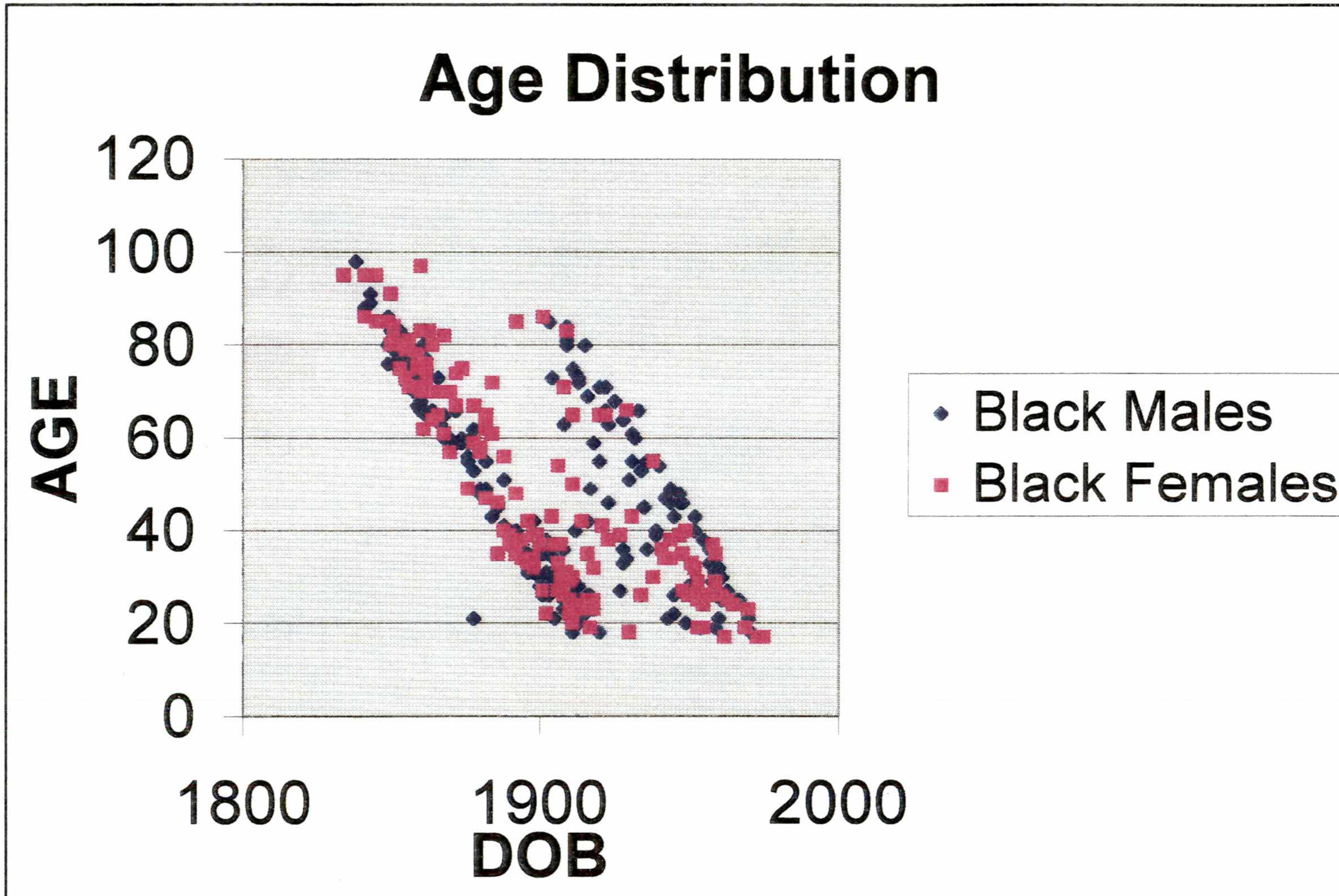
Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	10	19.8000000	2.5733679	18.0000000	24.0000000
MFL	9	442.2222222	16.5512672	413.0000000	473.0000000
BFL	8	434.1250000	11.7039371	410.0000000	446.0000000
EPIBR	8	73.8750000	2.1001701	70.0000000	77.0000000
FH	9	41.5555556	1.3333333	40.0000000	43.0000000
APS	10	25.0000000	2.4037009	21.0000000	28.0000000
MLS	10	27.7000000	4.0565448	23.0000000	33.0000000
APM	9	27.4444444	2.0069324	25.0000000	31.0000000
MLM	9	23.4444444	2.2973415	20.0000000	27.0000000
CIR	9	80.0000000	5.3150729	72.0000000	88.0000000
MRATIO	9	1.1795208	0.1291780	0.9259260	1.3809520
SRATIO	10	0.9154944	0.1310430	0.7666670	1.1666670
TA	9	505.7964111	64.9771803	408.4070000	608.6836000
BFLROB	8	11.5816600	0.7032440	10.3837500	12.2969800

Appendix 1: Descriptive statistics by decade of birth (Continued).

--------------------- DECADE=1970 RACE=W SEX=M ---------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
AGE	10	19.5000000	2.0682789	18.0000000	24.0000000
MFL	10	485.3000000	20.2047849	460.0000000	520.0000000
BFL	9	484.5555556	19.4493645	459.0000000	516.0000000
EPIBR	8	86.5000000	6.9897885	76.0000000	99.0000000
FH	10	49.2000000	2.7406406	46.0000000	55.0000000
APS	10	27.9000000	2.9981476	24.0000000	34.0000000
MLS	10	30.7000000	2.3593784	27.0000000	36.0000000
APM	10	31.0000000	2.1602469	29.0000000	36.0000000
MLM	10	26.0000000	2.6666667	23.0000000	31.0000000
CIR	10	90.3000000	6.5157928	84.0000000	105.0000000
MRATIO	10	1.1977842	0.0790379	1.0344830	1.3043480
SRATIO	10	0.9089451	0.0699980	0.8000000	1.0370370
TA	10	636.0939800	105.9828283	523.8606000	876.5044000
BFLROB	9	11.8347322	0.8499755	10.2713200	13.0604300

Appendix II


Age Distribution
AGE
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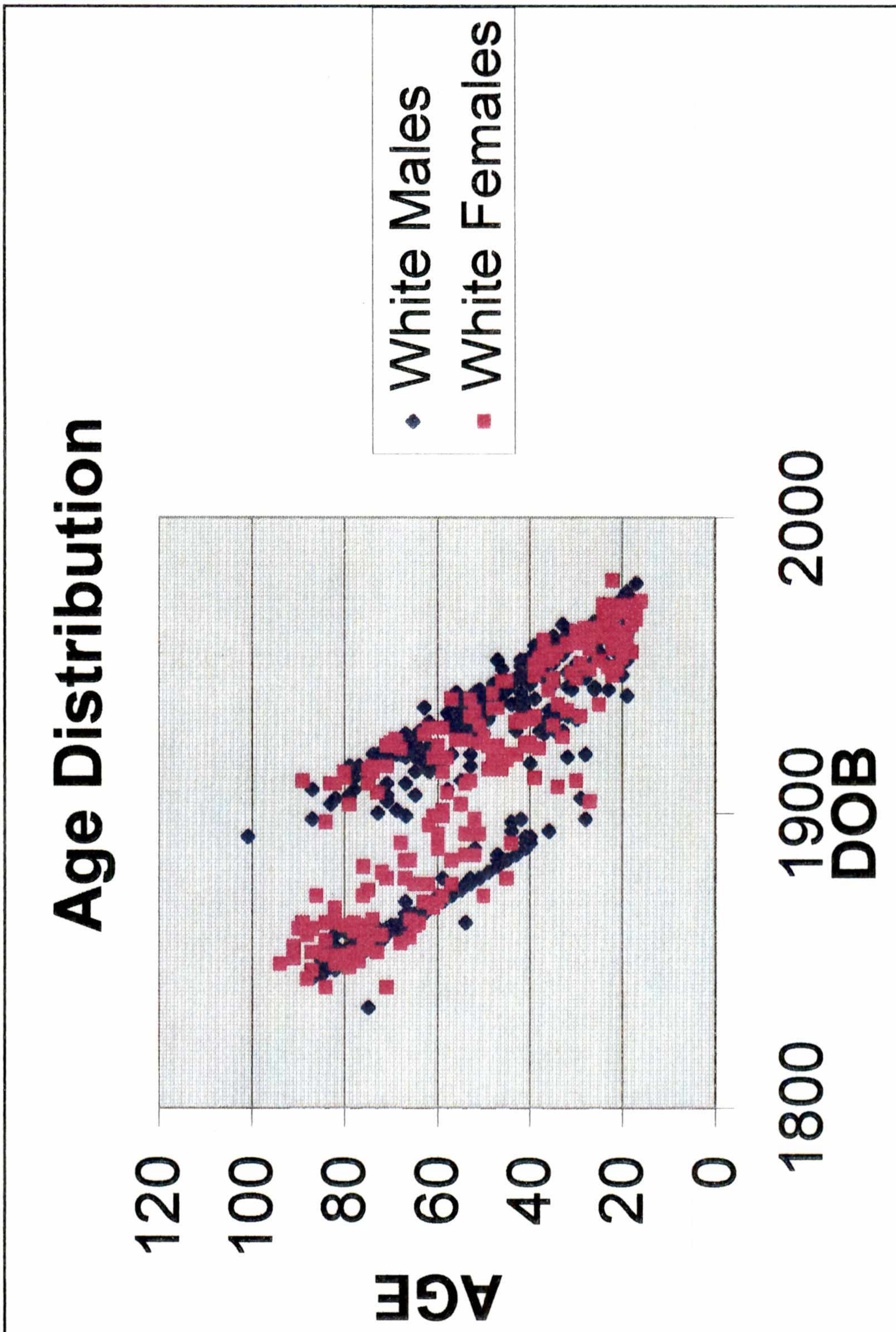
100
80
60
40
20
0
1800
1900
2000
DOB
Black Males
Black Females


Age Distribution
AGE
120
100
80
60
40
20
0
1800
1900
2000
DOB
White Males
White Females

VITA

Lauren Amber Rockhold was born in Santa Barbara on June 10 1971, but soon moved to Santa Cruz, where she spent her formative years. Ms. Rockhold graduated with a Bachelor of Arts in Anthropology from the University of California at Santa Cruz in the spring of 1993. One year later, she showed up on the doorsteps of the Anthropology Department at the University of Tennessee at Knoxville to eagerly pursue her graduate studies. After four fun-filled years, Lauren completed her Master's degree in Anthropology. After a short break, she will be continuing onward towards the doctoral degree.