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To the Graduate Council:

I am submitting herewith a thesis written by Sandra Cridlin entitled "Examination of Secular Change in the Vertical Head Diameter of the Human Femur in American Males and Females." I have examined the final electronic 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:

Michael H. Logan, William L. Seaver

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Vice Provost and
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Examination of Secular Change in the Vertical Head Diameter of the Human Femur in American Males and Females

A Thesis
Presented for the
Master of Arts
Degree
The University of Tennessee, Knoxville

Sandra Cridlin
May 2007

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Abstract

Secular changes in various aspects of the human skeleton can provide indications of environmental effects on growth and development. Temporal trends, as a reflection of fluctuations in health of a particular population over time, can provide evidence of how that population responds to episodic environmental transitions. Cohort comparisons of trends can reveal differing degrees of change experienced among groups within a single population or between different populations. The purpose of this study is to examine secular changes in the femoral maximum vertical head diameter of Americans male and females, and to investigate whether changes in head diameter size could be a corollary of decreased physical activity.

The maximum vertical head diameters of 19th Century and modern Americans were examined for secular changes utilizing a sample (n = 1,217) of measurements taken from the Robert J. Terry Anatomical Collection, the M. F. Ericksen Femur Collection, and the University of Tennessee Forensic Data Bank. Two cohorts categorized by sex were evaluated for normality and autocorrelation prior to performing additional statistical analyses. Statistical evaluation of a secular trend for the male sample was executed via an Autoregressive Integrated Moving Average (ARIMA) model of the average maximum vertical head diameter variable on the year-of-birth variable, and a subsequent regression analysis of lag first-differences on five year year-of-birth variable. The Hotelling's T-square test was

employed to test for differences among group head diameter size means for males in first fifty years of the study and the last fifty years of the study. For the female cohort, piecewise regression analysis was employed to examine the trend in this sample

Results of the ARIMA statistical analyses indicate that among American males the average maximum vertical head diameter of the femur appears to fluctuate in size over time. For the female sample, employment of the piecewise polynomial curve fitting in conjunction with the multiple regression indicate that female femoral head diameters were increasing in size until approximately 1910 when head diameters begin to rapidly decrease in size. The increase in average femoral head diameter was not statistically significant; however the decrease was determined to be statistically significant.

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Chapter I

Introduction and Literature Review

The examination and analysis of secular changes or trends that occur in human populations are important in skeletal biology and can be valuable in the subsequent application to forensic anthropology. For nearly a century, secular changes have been an ongoing subject of anthropological research examining growth, sexual maturation, stature, and cranial morphology. The identification of secular trends within a population offers insight as to how different aspects a particular population may be changing over time in response to their particular environment. Analyses have been conducted in both the living and the dead; the latter through the analysis of skeletal remains. While trends have been studied in living individuals through the use of anthropometric measurements, the utilization of osteological measurements obtained from skeletal materials can be as valuable and constructive for the identification of microevolutionary changes that occur over generations. As such, secular changes can be considered to be non-random variability with morphological and temporal directionality.

Temporal changes in several different aspects of skeletal morphology have been identified and documented, yet unequivocal specifics as to the nature of the proximate or ultimate causes of these transformations have not been totally ascertained and ultimately understood (Wescott and Jantz, 2005; Jantz, 2001; Jantz and Jantz, 2000; Jantz and Jantz, 1999; Trotter and Gleser, 1951). Similar

morphological changes occurring in various North American populations confirm the adaptive phenotypic plasticity of the skeleton due to various environmental factors possibly in addition to genetics, and that these changes can occur fairly rapidly (Jantz, 2005; Jantz, 2001; Jantz and Jantz, 2000;). Selection as a causative factor has been dismissed as it operates too slowly to account for secular trends (Malina, 1979).

Generational microevolutionary changes are typically regarded as the result of environmental conditions acting on growth and development, while longer temporal trends are typically deemed the result of a combination of both genetic and environmental factors (Jantz, 2001). Excluding genetics, various factors that have been deemed contributory for influencing or affecting growth-related morphological changes over time in humans include the socioeconomic level, nutritional status, education, and the health status of a given population.

Generally, the socioeconomic level of a population is thought to determine the access to and the quality of nutrition and health care. Because socioeconomic levels frequently vary within a population as a whole, not all groups within a population may have equal access to quality nutrition and health care. The comparison of secular changes among cohorts classified by sex and/or ethnicity can reveal this disparity within populations as the degree or extent of change can vary significantly by group. The cost and availability of quality nutrients can also be an issue resulting in higher socioeconomic status groups being better nourished than those in the lower socioeconomic strata. As such, the nutrient availability and

health status of a given population can be considered to be a reflection of that particular population's socioeconomic level.

Historically, improvements in environmental circumstances, including improved access to better-quality nutrition and health care, in most instances coincide with progressive industrialization and urbanization (Malina, 1979). According to Malina (1979), socioeconomic advancements associated with progress in industry and urbanization probably underlie environmental enrichments that can affect rates of growth and maturation, and these enrichments include improved health/medical services, better nutrition, reduced child mortality, and increased educational benefits. After a period of transition or reconstruction, the beginning of a positive secular trend in maturation and growth can thus be concurrent with improvements in nutrition, medicine, and hygienic practices that result from industrial, urban, and socioeconomic advances (Malina, 1979). Attained physical stature can be considered indicative of the health and welfare of children (Komlos and Baur, 2004). Differences and changes in stature as a reflection of growth have been utilized as a proxy ordinal measure for how well the human organism thrives in its socio-economic and epidemiological environment (Komlos, 2001).

Individuals in the United States have been shaped by an environment unlike that in which their ancestors lived, making the population as a whole unique in comparison to others. A survey of historical data revealed a substantial and rapid increase in the average physical stature of post-revolutionary eighteenth-century Americans occurred after physical stature had declined to some extent around the

mid-1700s (Komlos, 2001). By 1790, Americans were the tallest population in the world at that time as a consequence of better socioeconomic, nutritional, and epidemiological conditions (Komlos, 2001). Evidence of this positive trend in height continuing throughout the nineteenth to late twentieth centuries was observed from the analysis of American black and white males' and females' lower long bone lengths regressed on year of birth (Jantz and Jantz, 1999). Modern Americans have undergone notable changes in both stature and cranial dimensions for over the past 125 years (Wescott and Jantz, 2005; Jantz, 2001; Jantz and Jantz, 2000; Moore-Jansen, 1989; Smith et al., 1986; Hunter and Garn, 1969; Boas 1912).

From the eighteenth through the twentieth-century, Americans were considered the tallest population in the world (Komlos, 2001). Komlos and Baur (2004) assert that trends in the average physical stature for United States males and females have not maintained a rate equivalent to that observed in European trends, and that American male and female statures are falling behind the those of Western Europeans. At the middle of the nineteenth century, the height advantage of Americans reached 3-9cm, while increases in height since World War II consist of only a few centimeters (Komlos and Baur, 2004).

At the onset of the 21st century, Americans are as much as 2-6 cm shorter than Western and Northern Europeans with the Dutch, Norwegians, and Swedes being the tallest, followed by the Danes, British, West Germans, and East Germans (Komlos and Baur, 2004). There is also evidence of some stagnation of stature among American men, and that heights might have actually decreased among

females of the youngest adult birth cohort of the 1960s (Komlos and Baur, 2004; Zhang and Wang, 2004). Among males, income and education levels are indicated to have an association with stature as increases in height during recent decades have occurred among those with lower to middle economic status and remedial to upper educational accomplishments (Komlos and Baur, 2004). Disproportions in secular trends in regard to sex indicate that males may be more sensitive to the environment and therefore more skeletally plastic (Jantz and Jantz, 1999; Kuh et al., 1991). Komlos and Baur (2004) note that statures of American upper income groups have failed to keep up with the Western European averages in recent decades. Significant differences in health delivery, political systems, and socio-economic inequalities among Americans that would impact biological well-being may account for height disparities between Americans and Europeans (Komlos and Baur, 2004).

An overview of recent studies investigating secular changes in modern Americans indicates that current positive trends in stature are more likely to be observed today among adolescents than adults, and that those changes are in all likelihood associated with increases in Body Mass Index (BMI). The Body Mass Index is a relative measure of weight for height employed to assess weight levels or conditions in adults and children. In regard to adults, persons aged 20 years and over with a BMI of 25.1 – 26.9 are considered to be overweight, and those with a BMI of 27 and above are considered obese (Beers and Berkow, 1999). While the interpretation of BMI for children (also called BMI for age) is age and gender specific, nonetheless BMI can be a poor predictor of percentage body fat for an

individual child (Ellis et al., 1999; www.cdc.gov/nccdphp/dnpa/bmi/childrens_BMI/about_childrens_BMI.htm). Because significant associations between BMI and percentage body fat have been determined to be dependent on gender and ethnicity, these variables and the age of a child must be taken into consideration when trying to determine a measure of adiposity (Ellis et al., 1999).

Because 33% of the variation in body weight is accounted for by genetics (Beers and Berkow, 1999), the conditions of overweight and obesity are generally accepted as resulting from overnutrition in conjunction with diminished physical activity. A combination of both behavior and environment, obesity is a sornewhat recent phenomenon in modern America that is becoming endemic in this population. Research conducted by Zhang and Wang (2004) utilizing national representative NHANES data from 1971-1974, 1976-1980, 1988-1994, and 1999-2000 year surveys of 28,543 adults 20 - 60 years old found that the prevalence of obesity has doubled over the past three decades. While high frequencies of overweight and obesity have been recognized among low socioeconomic groups, a disproportionate increase in the prevalence of obesity among those of high socioeconomic status may suggest a weakened association between socioeconomic status and obesity for gender and most ethnic groups. This trend may suggest that social-environmental factors might have a more profound effect in influencing body weight status than socioeconomic status (Zhang and Wang, 2004).

Gordon-Larsen et al. (1997) assert that a significant proportion of adult obesity originates during the adolescent period. Between the 1970s and the 1990s, a

positive trend in stature and a threefold increase in male obesity and a fourfold increase in female obesity was observed among African American adolescents between 11 and 15 years of age with similar socioeconomic status from Philadelphia, Pennsylvania (Gordon-Larsen et al., 1997). Adolescents within the 1990 cohort were found to be taller at younger ages (11 and 12 years), and markedly heavier than the National Health and Nutrition Examination Surveys (NHANES) I reference standards (Gordon-Larsen et al., 1997). Thompson et al. (2002) note that increases in body mass and height of children from successive generations may be related to earlier maturation as the age of peak height velocity has decreased from the early to late 1900s in both males and females. When maturity and size were controlled, the fatness of children and adolescents aged 8 - 16 years was shown to have increased over the past 30 years. This positive trend in both stature and weight most likely indicates that those adolescents were able to reach their growth potential and morphological maturation sooner than adolescents of previous decade cohorts due to their particular environmental and nutritional circumstances. As such, the trends in height and weight would therefore also be associated with a positive trend in skeletal maturation. Klepinger (2001:788) asserts that while a positive trend in obesity is associated with a trend for accelerated skeletal maturation, the trend in obesity does not predict a "consistent direction or a quantitative correction for traditional standards" as positive trends in stature and earlier maturation are obscured by "increasing nonsecular intrapopulational variation."

Although positive trends in stature appear to be occurring primarily American adolescents, there is evidence that positive secular changes in both stature and weight are occurring among the offspring of immigrants and adult immigrants. The continued migration of other nationalities to America continues to change and expand the much varied ethnic and socioeconomic composition of this population, and overnutrition and the resulting overweight or obese conditions are not limited to individuals of European and African ancestry in the United States. Compared to Guatemalan Mayan children, Mayan children reared in the United States experienced stunted growth less frequently and were consistently taller with longer legs (Smith et al., 2003; Frutos, 2003). Because the gain in growth was so large and rapid, change due to genetics was determined not to be a causative factor; nor was selective migration as entire populations of some rural villages of Guatemala had been forced to emigrate (Smith et al., 2003). Smith et al. (2003) ascertained that among those Mayan American children that were found to be taller than Guatemalan Mayan children, the Mayan American children were also at a higher risk of being overweight relative to white American children.

Analysis of the stature and BMI of adult northern and southern Italian immigrants to the United States between 1908 – 1928 and 1960 – 1970 conducted by Danubio et al. (2005) revealed slight positive secular trends in stature, and notable increases in BMI among men and women within the 1960 – 1970 sample. For the latter sample, the Italian American males were more likely to be overweight and obese than females while the prevalence of obesity for both sexes was much

higher than frequencies reported from 1970 – 1980 for several European countries. The prevalence of obesity was found to be higher for Italian American males as compared to a contemporary American white male sample, and the percentage of obese Italian American males was deemed equivalent to the recorded assessment beginning in the 1980s for African Americans and Hispanics. The prevalence of obesity among Italian American females was found to be relatively equivalent to the contemporary white female sample (Danubio et al., 2005).

Modern Americans are considered to be one of the most affluent populations in the world exemplified by high average per capita incomes, and access to innovative technologies, advanced health care, as well as an abundance of resources and commodities. However, several features characteristic of biological well being have diminished. Positive trends in stature appear to be waning, the average life expectancy at birth has decreased, and Americans are rapidly become one of the most overweight populations with an increasing prevalence of obesity (Komlos and Baur, 2004; www.oecd.org). Statistics published on the website by the Organisation for Economic Co-operation and Development (OECD) indicate that in 1990, approximately 23 percent of Americans were considered obese, and by 2003, the proportion of those considered to be obese had increased to approximately 30 percent (www.oecd.org).

Societal changes in both the environment and the behavior of modern Americans underlie the current transformations in weight occurring in this population. Environmental factors including mass production of food and

government subsidized agriculture both make lower priced food possible; however affordability does not ensure nutritional quality or consumptive moderation. A multitude of food options, the convenience of pre-packaged and pre-cooked food, and increased portion sizes also promote the overconsumption of food and thus the excessive intake of energy or caloric and fat intake. Combined with caloric overconsumption, lowered energy expenditure as a consequence of sedentary lifestyles contributes to the likelihood of obesity among adults and children. Modern Americans overall have become less likely to engage in labor-intensive occupations, and increasing dependence on societal conveniences that include a heavy reliance on motorized transport and advanced technological developments effectively foster physical inactivity. The extent to which sedentism and obesity has affected possible changes in various aspects of the skeletal morphology of modern Americans is an area in need of investigation. The following section will address specific research regarding femoral morphology and secular changes.

The Human Femur and Secular Change

The femur has been perhaps the most studied of all the long bones in the human body (Krogman and Işcan, 1986). In a study of South African blacks and whites, Asala (2001) observed that the diameter of the femoral head may perhaps be the most sexually dimorphic part of the femur. The shape of the femoral head corresponds to the shape of the acetabulum, and is approximately two-thirds of a sphere with a slightly ellipsoidal contour that is greater in males than in females (Radin 1980; Kotani et al., 1975). Although the weight bearing portion of the

femoral head is nearly circular, there can be some difference between vertical and transverse diameters (Radin 1980; Kotani et al., 1975). Femoral head shape may be due to the biomechanical function of the joint as the subchondral bone of both the head and the acetabulum flattens under high load for maximum surface contact in the joint thereby diminishing the force per unit area (Radin 1980). Lieberman et al. (2001) found that in sheep the articular surface area is ontogenetically constrained and related to locomotor behavior at the species level and to body mass at the individual level. Statistical comparisons of exercised and sedentary (control) animals showed no increases in articular surface area in response to mechanical loading regardless of whether the sheep were juvenile, subadult, or adult (Lieberman et al., 2001).

Averaging about 160 degrees, the femoral neck-shaft angle in modern humans is larger at birth and decreases throughout skeletal growth to an average of about 135 degrees in an adult (Radin 1980). While it is not known how obesity in early childhood affects this particular angle (Anderson and Trinkaus, 1998), a significant reduction in the degree of femoral anteversion was observed in obese adolescents compared to those of normal weight (Galbraith et al., 1987). The axis of the head is normally parallel to that of the neck; however a slipped epiphysis or otherwise differential epiphyseal growth may cause retroversion of the head on the neck (Radin 1980). Following Wolff's law, variations in shape of the proximal femur may represent a physiological response to muscle forces when no pathology is present (Clark et al., 1987). Clark et al. (1987) observed that the center of the

femur head was generally closer to the shaft and more cephalad to the greater trochanter when the neck-shaft angle was more vertical, and the opposite was true when the neck-shaft angle was more horizontal. Because bone is dynamically remodeled throughout life, the bone mass, density, and (consequently) the geometry of the proximal femur may change with aging. Beck et al. (1992) observed in their study that white males were found to have a highly significant increase in neck width of 1 percent per decade, while white females did not show this change. However, according to Peacock et al. (1998), the dimensions and shape of the femur, which include the size of the femoral head and width of the femoral neck and shaft, do not change with age as these geometric variables are positively related to body size.

Ruff et al. (1991) found that changes in mechanical loading of the proximal femur are more likely to produce changes in cross-sectional diaphyseal geometry rather than changes in articular size. Femoral diaphyseal robusticity was observed to be highly correlated with present body weight, while head size was highly correlated with former body weight at 18 years of age. Although changes in mechanical loadings may not result in changes in articulation size, changes in the mechanical loadings of the articulations can have marked effects on the trabecular and subchondral bone structure of the articulation. As such, trabecular structure should have a higher correlation with present body weight, while femoral head size would be a reflection of early adulthood body weight. Based on these observations, femoral head breadth could be used to predict body weights for those persons in the

modern population that are not far above the mean for U.S. population weight. Heavier older adults would be associated with smaller femoral heads relative to their current weights. Testing of this hypothesis revealed that femoral head breadth was a poor predictor of body mass.

The value of femoral metric measures for the computation of stature and the assessment of sex for modern Americans has been widely accepted and appreciated by anthropologists for some time. However, the traditional standards consist of formulae derived from metric data collected from femora that were historic skeletal elements (Krogman and Işcan, 1986). The utility of osteometric measures of the femoral head for the determination of sex was recognized in the late nineteenth century (Stewart, 1979); however the classification of sex based on those measurements can be inherently tenuous as some measures can fall within an intermediate range of variation for both sexes (Krogman and Işcan, 1986). The necessity for modern population-specific standards derived from contemporary skeletal samples has been recognized (Frutos, 2003; Asala, 2002; Asala, 2001; Klepinger, 2001). Asala (2001) observed that the diameter of the femoral head may show variability according to race which would indicate the necessity for race-specific parameters for sexing from the femora of South Africans. The utility of this approach was demonstrated in a subsequent study in which the use of the vertical diameter of the femoral head proved more successful for the determination of sex in South African whites, while the transverse diameter was found to be more successful in South African blacks (Asala, 2002). Frutos (2003) identified the

importance of population-specific standards for the metric determination of sex from the minimum supero-inferior femoral neck diameter in a modern rural Guatemalan population; however unfavorable environmental factors affecting the growth of this population could explain some of the differences.

In addition to the use of femoral length for the calculation of stature estimates, observable and measurable differences in various aspects of femoral morphology and size have been employed to discriminate ethnicity and sex among individuals and populations. Regression equations for stature estimation can be computed from measurements of femoral length, and furthermore from the neck-shaft angle, neck length, vertical diameter of the head, and intertrochanteric apical axis as these measures have been determined to be significantly positively correlated with femur length (Prasad et al., 1996). A study of south Indian femora revealed strong positive correlations between the neck-shaft angle and the length of the femoral neck, and between the vertical diameter of the head and the maximum femoral length. Although sexual dimorphism was not suggested as a possible explanation, Isaac et al. (1997) observed that among individuals of short stature the femoral neck was oblique, the femoral length was shorter, and the neck-shaft angle, intertrochanteric apical axis length, length of the neck, and maximum vertical diameter of the head were all smaller than average (Isaac et al., 1997). Compared to white American females of the same age, Japanese women have been observed to have shorter femoral necks and smaller femoral neck angles (Nakamura et al., 1994), and significant differences in metric measurements of the femoral head, neck

and proximal shaft of white Americans and Hong Kong Chinese have also been identified (Hoaglund and Low, 1980). A study of the proximal femoral geometry of American white and black women revealed that, when matched for age, height, and weight, the black women had significantly smaller femoral head widths and head-neck axis lengths than the white women (Theobald et al., 1998). Gill (2001) found that American whites tend to have larger femora with larger head diameters than those of blacks and American Indians, and determined that femoral torsion and the shape of the proximal diaphysis can be useful in the determination of ancestry.

Research examining the increasing incidence of hip fracture among older adults identified that proximal femoral geometry can differ by ethnicity and sex (Gualdi-Russo, 1998; Mikhail et al., 1996). Hip axis length and femoral neck width have been found to be significantly shorter in black women than in white women, while the femoral neck-shaft angles between the two groups are not significantly different (Mikhail et al., 1996). Hip axis length is defined as the length along the femoral neck axis from below the lateral aspect of the greater trochanter, through the femoral neck, to the inner pelvic brim (Faulkner, 1993). Evidence of sexual dimorphism in the angular traits of the femur has been observed in Sardinian males and females in a study of the angular trait variation (Gualdi-Russo, 1998). Gualdi-Russo (1998) found that the collo-diaphyseal and torsion angles did not differ significantly between males and females, while the condylo-diaphyseal angle was significantly greater for females. Additionally, both the collo-diaphyseal and torsion angles were found to decrease with age in both sexes, and the reduction was

significant for females (Gualdi-Russo, 1998). Nilsson and Orbrant (1978) assert that poor childhood nutrition, consisting of food and vitamin deficiencies, during WWI may be an underlying cause in the secular increase of femur fracture in modern Swedish populations.

The identification of secular changes in several skeletal features and geometrical aspects of the femur can be informative in terms of how different morphological aspects of the femur may be changing over time within populations due to environmental factors. Research investigating secular trends specifically in the human femur has been predominantly focused on morphological changes in the length of this bone in regard to stature (Bruns et al., 2002; Jantz and Jantz, 1999; Price et al., 1987; Trotter and Gleser, 1951), and with changes in the femoral neck (Stojanowski and Seidemann, 1999; Anderson and Trinkaus, 1998; Duthie, Bruce, and Hutchison, 1998; Theobald et al., 1998; O'Neill et al., 1996; Reid et al., 1994; Nilsson and Orbrant, 1978). The attention and focus given to these topics is most likely a reflection of the continuing interest in stature as a measure of health, and in the increasing incidence of hip fracture among older adults. Conversely, current published research focused on specific features or aspects of the femur that may be contributory to some dimensional changes appears to be lacking.

Significant secular change in femur length for white and black males and females in the United States has been observed by Jantz and Jantz (1999). White males and black females were found to have significant change in shape over time in the femur, while black males and white females did not. In regard to stature, the

femur was determined not to be as positively allometric as the tibia and fibula (Jantz and Jantz, 1999). Bruns et al. (2002) found that since the Middle Ages, femoral curvature has significantly decreased over time in Northeastern Scottish populations, and that the early and late 20th century femora, which were similar in length, were longer than the medieval femora. Duthie, Bruce, and Hutchison (1998) examined a sample of 120 femora comprising 1900-1920 and 1980 cohorts from the University of Aberdeen anatomical collection for evidence of secular change. The authors found an overall increase in the femoral length as well as significant increases in the diameter of the femoral head, and in the length and width of the femoral neck. In a study of South African blacks with years of birth spanning1880-1884, 1890- 1894, and 1930-1934, Price et al. (1987) found a general decline in stature based on femoral and tibial maximum lengths; however it was not statistically significant. This decline was attributed to the social history of governmentally imposed economic subjugation causing a gradual decline in living standards for blacks in South Africa.

A comparative study of the femoral neck-shaft angles of prehistoric, early historic, and modern populations as a means of evaluating patterns of variation in the angle relative to the physical activity and mobility of foraging, agricultural, and urban populations respectively was presented by Anderson and Trinkaus (1998). The authors observed a significant increase in the mean neck-shaft angle (collodiaphyseal angle) with increasing sedentism and mechanization across populations. A significant correlation between economic level and degree of

decrease in the angle was found to reflect differential activity levels during ontogeny (Anderson and Trinkaus, 1998). For early modern Edo period and Modern period Japanese populations, Hiramoto (1998) identified a positive secular increase in the mean torsional angle of femora for males and females. This trend may be attributed to changes in sedentary habits or sitting postures over these time periods (Hiramoto, 1998). Reid et al. (1994) examined anteroposterior radiographs from 1950s and 1990s cohorts of white New Zealand females and found that mean lengths of the femoral neck and hip axis had significantly increased, with no change occurring in the mean width of the femoral neck (Reid et al., 1994). A similar study of the proximal femoral geometry of white women in the United Kingdom revealed significant increases in femoral neck length, but increases in hip axis length were not significant (O'Neill et al., 1996).

Because anthropometric measures of the femur can be instrumental in demographic assessments, the recognition of temporal trends is important since changes in morphology can potentially affect the utility of data utilized for demography. The continuing microevolution of the human femur and the subsequent discoveries of significant morphological differences underscore the potential need for the development of anthropometric standards that are not only population-specific but temporally-specific as well. Stojanowski and Seidemann (1999) tested the accuracy and reliability of employing the minimum supero-inferior femoral neck diameter as a sex predictor for modern skeletons by comparing the discriminant functions derived from the Hamann-Todd skeletal collection to modern

skeletal samples. Although no significant differences in the mean femoral neck diameters were observed between the pre-1900 Hamann-Todd sample and the modern sample, latter African-American males and white and black female groups exhibited significant differences in mean femoral neck diameters as the modern sample had larger diameters than those in the Hamann-Todd sample. The secular increase in mean neck diameter in the modern sample resulted in a decrease in the accuracy of the original discriminant function when this metric measure was employed for sex determination.

The primary objective of this study is to examine the head of the human femur for evidence of secular change in American males and females. Currently, research and interest in changes over time in regard to this particular portion of the femur for any population has been almost absent. The exception to this consists of a study conducted by Duthie, Bruce, and Hutchison (1998) in which a significant increase in the diameter of the femoral head was found among anatomical specimens from the University of Aberdeen. Discriminant functions computed from osteological measurements of the femoral head for sex estimation were derived from historic skeletal samples (Bass, 1994; Krogman and Işcan, 1986; Stewart, 1979), and these standards are routinely utilized for the assessment of sex for both historic and modern forensic skeletal remains. Anthropologists continue to rely on such established criteria derived from documented skeletons to construct estimates of ethnicity, sex, and stature for unidentified skeletal remains. Morphological changes over time can affect the accuracy of such standards. Because of the

composition of most anatomical reference collections several of these standards have already been found to be inappropriate in terms of their applicability to modern Americans (Ousley and Jantz, 1998; Ayers, Jantz, and Moore-Jansen, 1990; Ericksen 1982). The necessity of having a modern comparative skeletal reference sample in order to examine the extent that secular change is occurring in the United States has been identified (Ousley and Jantz, 1998), and the presence of significant trends could indicate that current methodologies utilized by anthropologists for the purpose of identification and demographic analysis may require modification.

Chapter II

Materials

For this study of secular change, the data utilized for analysis consisted of vertical head diameters (VHD) of human femora from the Terry Anatomical Collection, the M. F. Ericksen Femur Collection, and the University of Tennessee Forensic Databank. These three sources of data provided a combined total sample of *n=1,217* vertical head measures of femora from adult black and white males and females with birth years spanning the 1830s to 1980s. (See Table 1 below for the sample distribution).

The Robert J. Terry Anatomical Collection is currently housed at the Smithsonian Institution's National Museum of Natural History in Washington D. C.. The collection consists of the skeletal remains of 1,728 adult cadavers obtained from local hospitals and institutional morgues in St. Louis, Missouri during the

Table 1: Sample Sizes Classified by Cohort and Data Source (including totals).

	Terry Collection *n* =	M. F. Ericksen Collection *n* =	UT Forensic Databank *n* =	Total Sample Size *n* =
White males	55	89	362	506
Black males	58	3	134	195
White females	50	89	201	340
Black females	84	4	88	176
Total	247	185	785	1217

Total Males = 701 **Total Females = 516**

twentieth century (Hunt and Albanese, 2004). The decedents were mainly indigent individuals that were unclaimed by kin and subsequently donated to the collection. As such, the sample may not necessarily be representative of the upper socioeconomic population at that time; however it is still a valuable source of data. Femoral head measures from a sample of 247 individuals from this collection were included in this study. Of these individuals, ages range from approximately 20 to 102 years old, encompassing birth years from 1833 to 1943.

The M. F. Ericksen Femur Collection consists of proximal femora from 185 persons that were willed to the George Washington University Medical Center, and collected by Dr. M. F. Ericksen (Ericksen, 1982). This collection was donated to the University of Tennessee, Knoxville Department of Anthropology during the mid-1990s where it is still housed. Demographically, the collection is comprised of individuals with diverse vocations and varied socioeconomic backgrounds, making this sample somewhat more representative of the population at that time. However, the sample is ethnically disparate as black males and females are markedly under-represented in this collection. Ages of individuals in this collection range from 28 to 97 years old with birth years spanning approximately 1884 to 1949. All obtainable vertical femoral head diameter measurements from this sample were included in this study.

Vertical head diameter measures from the University of Tennessee Forensic Databank were obtained from Dr. Richard Jantz of the University of Tennessee and comprise a sample of 785 modern individuals for this study. Birth years for this

sample spans approximately from 1884 to 1985. Similar to the Terry Anatomical Collection, the demography of the Forensic Databank sample is not characteristic of the general population as most individuals comprising the collection are of a forensic nature, and therefore died of unnatural causes at young ages (Ousley and Jantz, 1998). Geographically, the distribution of the sample is also somewhat uneven (Ousley and Jantz, 1998). In addition to those osteometric measurements obtained from forensic casework, this sample also includes a portion of data obtained from individuals within the William M. Bass Donated Collection housed at the University of Tennessee, in Knoxville, Tennessee. Regardless of any intrinsic biases, the sample data of modern individuals that is available for analysis is invaluable due to the paucity of large reference samples that are temporally similar.

Chapter III

Methods

The maximum vertical diameter of the femoral head is one of several standard osteometric measurements taken from the human femur (Bass, 1995; Moore-Jansen et al., 1994; Buikstra and Ubelaker, 1994). Sliding calipers are used to take this measure with millimeters as the standard unit of measurement. The vertical femoral head diameter is measured by placing one arm of the caliper on the anatomical superior articular surface of the head and the other caliper arm on the inferior articular surface. The femur is then rotated slightly in a mediolateral plane until the maximum measure of the head is obtained (Bass, 1995; Moore-Jansen et al., 1994; Buikstra and Ubelaker, 1994).

Following the standard techniques described above, all Ericksen Collection femora (n=185) were measured by the author with Mitoyo digimatic sliding calipers. All measurements were rounded to the nearest millimeter, and the calipers were zeroed between each measurement in order to assure accuracy. Additionally, a random sample of approximately 30 femora was re-measured by the author throughout the data collection process in order to ensure consistency in technique and to assess intraobserver reliability.

The vertical head diameter data of Terry Collection femora employed for this study was obtained from three sources, with the majority of these data having been previously collected. These data were acquired from Dr. Richard L. Jantz of

the University of Tennessee, and consisted of femoral head measurements of Terry Collection individuals with early twentieth-century birth years that comprise a portion of data from the Forensic Databank, and an additional separate set of Terry Collection femoral head measurements. These two data sources comprised a sample of n=203 vertical head diameter measurements. An additional sample of n=44 vertical femoral head diameters from this collection were measured by the author.

Concerns associated with utilizing data collected by other persons include the accuracy and consistency of measurements. Obviously, inaccurate and inconsistent data utilized for analysis will yield like results. Because the objective of this analysis is to investigate evidence of secular trends in femoral head size, an additional issue of analytical relevance is the possibility that systematic measurement errors have the potential of indicating a trend that is false. In order to try to minimize this potential a random sample of n=59 femoral heads from the Terry Collection were re-measured by the author and subsequent error and accuracy rates were calculated. A re-measurement of 1 millimeter (mm) greater or less than the original measure was regarded as a measurement error. No re-measurements of 2 millimeters greater or less than the original measure occurred. The formula utilized to calculate the observer error rate is as follows: $T / W = E$ where T= the total number of femoral heads re-measured, W= the number of mismeasurements, and E= the observer error rate. The subsequent formula used to calculate the observer accuracy rate is as follows: $(T - W) / T * 100 = A$ where A= the accuracy rate. In addition, a statistical paired t-test was performed to determine if the re-

measurements are significantly different from the original measurements. (See the following *Results* chapter for the error and accuracy rates, and paired t-test results).

An advantage of the vertical femoral head diameter measure is that the procedure or technique utilized to obtain the measurement is not complicated to execute. The straightforward method of measurement should help to minimize the likelihood of mismeasurement error among observers. Additionally, measurement errors that may be present in the data obtained from the University of Tennessee Forensic Databank should be small in degree and random due to the number of persons contributing data to those records. Most contributors to the databank are proficient in obtaining specific osteometric measurements, and contributed data is reviewed to an extent prior to being appended to the database. As such, the degree of variability in the distribution of errors should be minimal and random, and therefore should not reflect a secular trend that is false.

The original data consisted of three separate sets of data that were initially combined to form one large dataset. Data within this comprehensive dataset were then partitioned by sex into two groups categorized by sex in order to facilitate further statistical analyses as the degree and rates of morphological change in response to environmental effects can potentially differ among the sexes. While changes in morphology in response to environmental pressures have been found to differ among ethnicities in addition to sex, the small sample size in terms of the duration of time for this particular dataset limited further analysis by sex and ethnicity.

Left femoral vertical head diameters were primarily utilized for analyses. Right vertical head diameter measures were substituted when necessary if the left femoral head measurement was unavailable or unobtainable. Although bilateral femoral head diameters in an individual occasionally differ from one another, the differences observed by the author during the collection of data have been minimal. Differences in diameter typically ranged between .5mm to 1 mm, with no apparent pattern or tendency of one particular side being larger than the other. In the instances where an actual year of birth was not available for an individual, an approximated year of birth was calculated by subtracting the estimated age at death for that individual from the year that individual died. Because there were a small number of individuals that required the above, the temporal scope of this study encompasses roughly 150 years, and averages were used in the analysis, an estimated year of birth that is within one to three years of the correct year should not largely affect the results of this study. (See Appendix 1, page 70, for the raw data used for this study categorized by sex cohort). (See Appendix 2, pages 105 - 106 for maximum head diameter averages categorized by sex cohort). Statistical analyses were executed using a combination of computer software programs consisting of Microsoft Excel ™ and NCSS statistical software (NCSS, Kaysville, Utah).

A. Tests for Normality and Descriptive Statistics

Each population sample was tested by sex cohort for normality or Gaussian distribution in order to assess whether the data was parametric or non-parametric in

distribution. The D'Agostino Omnibus test which combines tests for skewness and kurtosis was employed to test the normality of the data used in this study. Histograms and normal probability plots were also generated to visually assess the data distributions. In addition to these tests, general descriptive statistics for both sexes were obtained.

B. Serial Correlation and the Autoregressive Integrated Moving Average Model

Datasets comprised of values observed sequentially through time are regarded as time series data. The data employed for the examination of secular change can thus be considered time series data. Because patterns associated with changes over time are not always linear in nature and the variables are usually autocorrelated, statistical methods specifically for the assessment of time series data were warranted for this analysis. Typically, measurements that are close in time tend to also be closer or similar in value than measurements that are temporally far apart. Thus the data exhibit some sequential dependence that occurs more so than what would be expected to occur purely by chance alone. If the probability distribution is the same (the mean and variance are constant) for all starting values of time, the statistical process is deemed as stationary. A data series that exhibits a trend is not stationary because the values of the series are dependent on time (NCSS, Kaysville, Utah). A time series is referred to as a stochastic process if "future values can be described only by their probability distribution.... A stationary stochastic process is completely defined by its mean, variance, and autocorrelation function" (NCSS, Kaysville, Utah).

Serial correlation exists in the data if any observations or their residuals are determined to not be independent. The Durbin-Watson test can be employed to test for positive or negative first order serial correlation present in the data. For autocorrelated data, a regression analysis which uses the actual dependent values to asses the presence of trends is deemed inappropriate because of the serial correlation among those values. In order to remove the problem of serial correlation in the dependent variable, the lags and the difference between the lags and the actual values must be calculated, and the resulting *lag first-differences* variable rather than the original dependent variable should then be used in the regression model to examine trends in the data. With the serial correlation now removed, statistically significant results among the first differences would indicate that significant changes in size are occurring between five year intervals for this dataset.

For data that are sequentially dependent, a proper statistical model for the inherent dependence or autocorrelation must be found and then employed for analysis. Additionally, an appropriate statistical method for examining an underlying trend within the time series data must be used. For time series data presumed to have an underlying trend, the Box-Jenkins Autoregressive Integrated Moving Average (ARIMA) model utilizes the differences between successive observations or values rather than the actual values to compute a regressive model, thus the model is applied to a differenced series and not to the series itself. A function in the Box-Jenkins ARIMA method is to transform a non-stationary series into a stationary series. As a regressive method the ARIMA model provides tests of

significance and predicted values for the dependent variable. The ARIMA model has three parameters: "the order *p* of the autoregressive component, the order *d* of differencing... and the order *q* of the moving average component" (Maindonald and Braun, 2003:246).

For this study, the raw data were grouped by five year birth-year increments and then averages for each five year cohort were calculated using Microsoft Excel ™. The utilization of averages for the calculation of the model acts to reduce the serial correlation within the dataset. The average maximum femoral head diameters for each of the two groups categorized by sex were then imported directly into the NCSS statistical program (NCSS, Kaysville, Utah) in order to assess each dataset for autocorrelation, and to compute the appropriate Box-Jenkins ARIMA model. The averages for both datasets were plotted using scatterplots that include the underlying trends.

C. Least Squares Regression Analysis and Hotelling's T-square Test

Least squares regression was employed to describe and examine the presence of secular trends in the size of the vertical head diameter of the femur, and to provide tests of significance after the problem of serial correlation had been resolved. For the males in this study, the dependent variable *lag first-differences* was regressed on the independent variable *five year year-of-birth interval* as a general means of examining the overall trend of secular change over time. Results showing a negative regression slope or negative trend would indicate that the size of the vertical head diameter of the femur has decreased over time. Conversely, a

positive regression slope would signify that the vertical head diameter has increased over time. A slope of zero may indicate that little to no change has occurred, or it could signify that changes in diameter over a particular period of time have been entirely stochastic, and therefore no definitive trend is present.

A two-sample Hotelling's T-square test was performed on the male dataset in order to test the differences between the means of two groups comprised of those individuals with birth years in the first fifty years of the sample and those with birth years in the latter fifty years of the sample. While the significance test associated with the linear regression analysis of the lag first-differences on the year of birth interval tests for significant changes occurring between five year intervals, the two-sample Hotelling's T-square test tests for significant differences between the means of two specified groups. The overall sample of males was split into three specified groups. Group one consisted of the five-year birth year interval maximum femoral head diameter averages for those individuals born between the years of 1835 – 1884. Group two was comprised of the five-year birth year interval maximum femoral head diameter averages for those individuals born between the years of 1885 – 1934. Group three consisted of the five-year birth year interval maximum femoral head diameter averages for those individuals born between the years of 1935 – 1984. Group two was not included in the two-sample Hotelling's T-square analysis as the test was utilized to test for significant differences in the means over the period of 150 years. The two-sample Hotelling's T-square is the multivariate equivalent of the univariate Student's t-test. This particular test was chosen and

used specifically because it does not rely on distributional assumptions, and because it also includes and conducts a randomization test on the data.

For the males, an additional plot of the studentized residuals in a standardized control chart was utilized to identify potential outliers within this dataset because of the lack of outlier diagnostics in the ARIMA analysis. For the control chart, the underlying trend was removed by dividing the residuals (obtained from the linear regression of the maximum femoral head diameter averages on the five year year-of-birth cohorts) by the square root of the mean square error (obtained from the Box-Jenkins ARIMA analysis).

D. Randomization Test

A fundamental assumption made in statistical analyses is that the dataset represents a random sample of a population. Due to the origins of the collections from which the measurement data for this analysis was obtained it can be questioned that these data do not truly comprise a random sample of the entire population. Re-measurement of vertical femoral head diameters may act to alleviate false trends due to systematic mismeasurement errors during the collection of data. However, this particular endeavor does not rectify systematic biases that may be inherent in non-random assemblages that are utilized for the acquisition of data, such as anatomical and skeletal collections. As a result, it is necessary to evaluate these vertical head diameter measurement data for systematic biases through the implementation of a randomization test.

The randomization of data counteracts the effects systematic biases can have on statistical analyses. In general, a randomization test is an exact test that compares an observed test statistic with a data distribution generated by a random reordering of a dataset. The test is conditional on the observed data values and uses a resampling method to test the null hypothesis that groups come from the same distribution. Results of the randomization test can then be used to further support the results of other tests performed on the dataset. The two-sample Hotelling's T-square test which was discussed previously includes a randomization test within the output. The results from this randomization test will be utilized to evaluate the randomness of the male and female samples.

E. Piecewise Regression Analysis

Initial analysis and visual examination of the overall trend of the averages for the female dataset deemed it not necessary to perform an ARIMA analysis of the data. Rather, a piecewise regression method was utilized to analyze this female dataset. This type of regression has been used to investigate and identify thresholds in ecological analyses (Toms and Lesperance, 2003). A piecewise polynomial curve was fit to the female data in order to determine where the particular temporal change points occurred as exhibited by abrupt changes in the intercept and slope. Available as a feature in NCSS, this particular piecewise method provides an option of fitting two linear lines with a sharp demarcation denoting an abrupt change rather than fitting a traditional curve to the data. Once the temporal change points or "breakpoints" were determined from the piecewise polynomial analysis, an

additional indicator dummy or binomial variable was created in order to reflect a particular change point in the regression model. The new dataset contains the original dependent variable, but now includes two independent variables consisting of 1) the original year of birth interval and 2) the indicator/dummy variable. This linear model provides tests of significance for those changes in the intercept and slope prior to and after the pre-determined breakpoint using the *five year year-of-birth interval*, the *indicator* variable, and the interaction of these two variables as coefficients. These coefficients are regressed on the maximum vertical femoral head diameter averages in order to obtain the significance of the change as determined by the degree of the slope of the regression. In this instance, a "*0*" was utilized to categorize the years prior to the abrupt change, and a "*1*" was used to categorize those years after the change. The regression equation for this regression model is as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_1 X_2$$

where X_1 is the year-of-birth interval, X_2 is the dummy indicator variable, X_1X_2 is the interaction of the year-of-birth and the dummy variable, *beta2* is the change in the intercept, and *beta3* is the change in the slope. Thus, statistically significant changes prior to and after the change point can be determined.

F. Analysis of the Residuals

The adequacy of the regression models in this study were tested by implementing a Portmanteau Test on the residuals that were obtained from the regression analyses. This test is used to determine if there is any pattern left among

the residuals that may be modeled. If there is no pattern that can be modeled among the residuals the model can be considered adequate. The equation utilized for the calculation of this test is as follows:

$$Q = n(n+2) \sum (acf^2 / (n\text{-}trend)$$

where Q is distributed as a chi square, n = the number of observations in the time series sequence, *trend* = the sequence of the time series, and *acf* = the autocorrelations of the residuals. Significant p-values associated with particular Q values would be indicative of the presence of a pattern among the residuals.

Chapter IV

Results

As described in the previous chapter, measurement error and accuracy rates were calculated in order to assess the presence and extent of systematic measurement errors that have the potential of indicating a false trend. Fifty-nine Terry Collection vertical head diameters were re-measured and four head diameter measurements were found to differ within 1mm from the original measures. Of these four, two vertical head diameters were measured as 1mm higher than the original measure, and two diameters were measured 1mm less than the original measure. As such, there was no tendency of the author having taken measurements that were consistently greater than or less than the original which could produce a false trend. The calculated rate of error was found to be 14.75%, and the rate of accuracy was determined to be 93.2%. As seen below in Table 2, a (two-tailed) p-value of 1.0 indicates that there is no significant difference between the original sample of Terry Collection measurements that were obtained for analysis and the

Table 2: Paired Samples T-Test Results for Measurement Error

	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
				Lower	Upper			
Original Terry Measurement - Observer Re-measurement	0	0.26490	0.034783	-0.06965	0.06965	0	57	1

secondary sample re-measured by the author.

For this study, randomization tests were employed to evaluate whether the male and female data sets represent random samples, and were based on 10,000 Monte Carlo iterations. For the males, the results of the randomization test were not significant with a p-value of 0.4541 at a 0.05 Alpha level. Results of the randomization test for the female dataset were not significant with a p-value of 0.3849 at a 0.05 Alpha level. Since these results are not significant, the null hypothesis that the data are random fails to be rejected. Because the underlying assumption of randomness of the data does not appear to have been violated, the data can therefore be considered to be characteristic of a random population sample. (See Table 6, page 41, for the results of the randomization test for the male sample, and Table 45, page 132 for the results of the randomization test for the female sample).

A. Black and White Males

Results of the D'Agostino Omnibus test for the male sample indicate that the data are not normally distributed at a 5% critical value. Descriptive statistics for the male dataset are provided below in Table 3. Results of the Durbin-Watson test for

Table 3: Descriptive Statistics for Males

Statistic	Result	Statistic	Result
N	701	**Sum Weights**	701
Mean	48.4265	**Sum Observations**	33947
Std Deviation	2.5656	**Variance**	6.5821
Skewness	0.1293	**Kurtosis**	0.4213
Uncorrected SS	1648543	**Corrected SS**	4607.4665
Coeff Variation	5.2978	**Std Error Mean**	0.0969

positive serial correlation were found to be statistically significant at the 0.05 level (Durbin-Watson value = 1.4262, Pr. = 0.0478). (See Appendix 3, Table 13 and Figures 3-4, pages 107-108, for the results of the normality test, histogram, and normal probability plot for the male dataset). (See Appendix 4, Tables 15 – 18, and Figures 7-9 on pages 110-113 for the autocorrelation output and plots, and for the Durbin-Watson test results for the male sample).

As discussed in the previous chapter, the problem of serial correlation in the dependent variable must be dealt with prior to examining temporal trends in the data. Using NCSS, the lags and lag differences were calculated, and the resulting new *lag first-differences* dependent variable was input into the linear regression model to examine trends in the male dataset. The test of the hypothesis that the slope is zero for the regression of lag first-differences on five year birth-year interval was not significant, therefore the null hypothesis of the slope being equal to zero is accepted. This result indicates that there has been no significant positive or negative change in the first-differences of the maximum vertical head diameter of black and white male femora from one five year birth-year interval to the next at the 0.05 level over the past 150 years. The regression equation, level of significance, and results of the analysis of variance are as follows:

Linear regression of Lag First-differences on Year of Birth Intervals (Males):

Lag First-difference = -3.2415 + 0.0017 * YOB

F- statistic: 0.1446 T-value: 0.3803 Pr>F: 0.7067

r^2: 0.0053 Mean Square Error: 1.010823

(See Appendix 5, Tables 21-24 and Figure 10 on pages 114-115 for the linear regression results).

The Box-Jenkins Autoregressive Integrated Moving Average model (2,0,1) with order *2* as the autoregressive component (AR(1)), order *0* as the degree of differencing (AR(2)), and *1* as the moving average component (MA(1)) was found to be the model of best fit for the male dataset. Implementation of this model provided the maximum pseudo R-squared value of 18.922730, and all parameter estimates were determined to be significant. The statistically significant results of the model estimation are provided below in Table 4. This (2,0,1) ARIMA model produced predicted values that were quite close to the actual values which provides some evidence that the model is adequate. The similarity among the actual and predicted trends are visually apparent in the scatterplot of the plotted ARIMA forecasted values and maximum femoral head diameter averages which includes linear regression trend lines overlying the aforementioned plotted points. (See Appendix 6, Figure 11, page 116, for the scatterplot). For males, it appears that the average maximum femoral head diameter size fluctuates fairly regularly over time, increasing and then decreasing over intervals spanning approximately twenty-five years.

Table 4: ARIMA Model Estimation for Males

Parameter Name	Parameter Estimate	Standard Error	T-Value	Probability Level
AR(1)	1.178428	0.1735206	6.7913	0.000000
AR(2)	-0.4244916	0.1796314	-2.3631	0.018122
MA(1)	0.9417317	0.0371973	25.3172	0.000000

The portmanteau lack-of-fit test was utilized in order to determine if "white noise" was present among the residuals. This test assesses the significance of the autocorrelations up to a certain lag in order to determine if there is any pattern left in the residuals that may be modeled. Because the results of this test were not statistically significant , it can be assumed that the (2,0,1) model is adequate. (See Appendix 7, page 120, for the Portmanteau Test results.) The term "white noise" is used to describe a "sequence of errors for successive observations that consists of independent random values from a normal distribution with zero mean" (Upton and Cook, 2002). (See Appendix 7, pages 118-123, for the ARIMA results.)

As discussed in the previous chapter, the two-sample Hotelling's T-square test was employed to test for significant differences between the means of two specific groupings of the male dataset. Group one was comprised of the five-year birth year interval maximum femoral head diameter averages for those individuals born within the first fifty years of the sample (1835 – 1884), and group three consisted of the five-year birth year interval maximum femoral head diameter averages for those individuals born within the last fifty years of the sample (1935 – 1984). Group means and standard deviations are provided below in Table 5 and shows that the means of groups are fairly close. The difference between the two

Table 5: Group Means and Standard Deviations for Males

	Means		Standard Deviations	
Group	1	3	1	3
Average	48.56544	48.23826	1.104572	0.7740549
Count	10	10	10	10

Table 6: Two-Sample Hotelling's T-square Test Results for Males

Covariance Assumption	T2	DF1	DF2	Parametric Test Probability Level	Randomization Test Probability Level
Equal	0.588	1	18	0.453	0.4541
Unequal	0.588	1	16.1	0.4541	0.4541

The randomization test results are based on 10000 Monte Carlo samples.

group means was calculated as 0.3271848. Results of the two-sample Hotelling's T-square test shown above in Table 6 indicate that the differences between the two group means are not statistically significant; therefore, no significant increase or decrease in the size of the maximum vertical head diameter of the femur of black and white males has occurred over the past 150 years.

The underlying negative trend of decreasing femoral maximum vertical head diameters over time as indicated by the linear regression was removed prior to employing a standardized control chart (xbar chart) as an outlier diagnostic. As stated in the previous chapter, the underlying linear trend was removed by dividing the residuals (obtained from the linear regression of the maximum femoral head diameter averages on the five year year-of-birth cohorts) by the square root of the mean square error (obtained from the Box-Jenkins ARIMA analysis). These values were then plotted into a standardized xbar control chart. See Figure 1, on page 42 for the control chart for the black and white males.

One potential outlier was identified for the time interval encompassing the birth years1940 – 1944. In the control chart, the point identified as the potential outlier is designated by its value of -2.83497383884628 as it falls below the -2.5

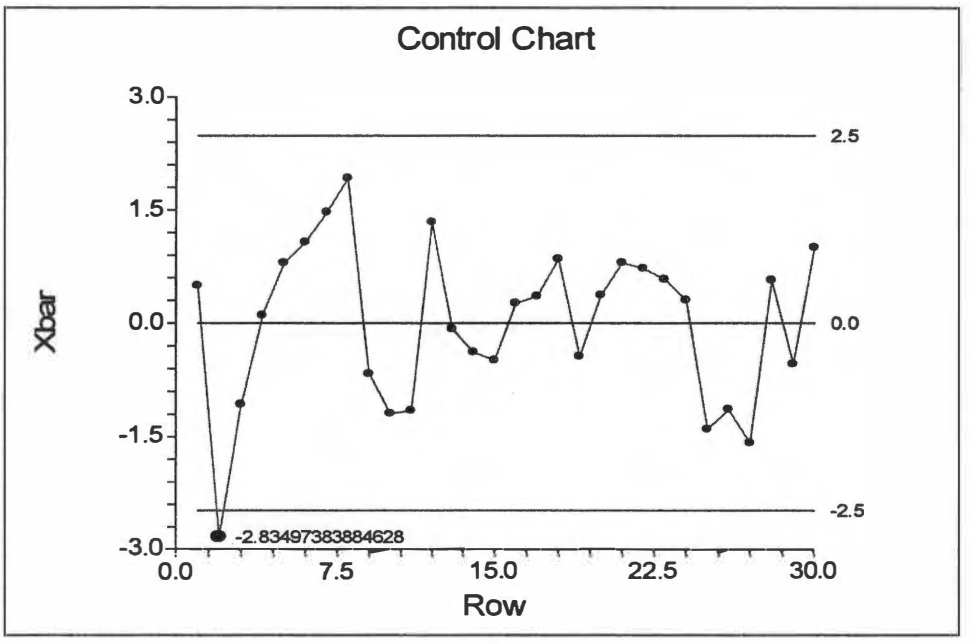

Figure 1. Control Chart for White and Black Males

line. This outlier could be due to sample size as the earlier and later birth-year cohort sample sizes were fairly small, or possibly due to measurement error.

B. Black and White Females

Results of the D'Agostino Omnibus test for the female sample indicate that the data are normally distributed at a 5% critical value. Descriptive statistics for the female dataset are provided in Table 7 on the following page. Results of the Durbin-Watson test for serial correlation for the female dataset indicate that the data are neither positively nor negatively autocorrelated. (See Appendix 3, Table 14 and Figures 5-6 on page 108-109 for the results of the normality test, histogram, and normal probability plot for the female dataset). (See Appendix 4, Tables 19-20, on

Table 7: Descriptive Statistics for Females

Statistic	Result	Statistic	Result
N	516	**Sum Weights**	516
Mean	42.1967	**Sum Observations**	21773.5
Std Deviation	2.2766	**Variance**	5.1831
Skewness	-0.0158	**Kurtosis**	0.4365
Uncorrected SS	921439.3	**Corrected SS**	2669.2844
Coeff Variation	5.3953	**Std Error Mean**	0.1002

page 113 for serial correlation and Durbin-Watson test results).

Because it was determined that the data were not serially correlated, the calculation and subsequent use of lags and lag first-differences for use in regression analyses was deemed unnecessary. Additionally, the fitting of a Box-Jenkins ARIMA model to the dataset as a method of examining changes over time was not warranted.

NCSS was employed to fit a piecewise polynomial curve to the female maximum vertical head diameter averages in order to examine the presence of particular temporal change points as exhibited by abrupt changes in the intercept and slope. Similar to a regression analysis, the maximum vertical head diameter averages comprised the dependent variable, and the independent variable consisted of the five year year-of-birth intervals. According to the output, the convergence criterion was met after the fourteenth iteration of the minimization phase, and an abrupt change in female average maximum head diameter was determined to begin in 1911. Visual examination of the Average = Linear – Linear piecewise polynomial plot shows that the average maximum vertical head diameter seems to

have steadily increased in size until approximately 1910 when diameter size abruptly begin to decrease. Because tests of significance are not provided in the piecewise polynomial analysis, multiple regression analysis must be employed in order to see if the patterns of change are significant. (See Appendix 8, Tables 32-38 and Figures 15-17, pages 124-130, for the piecewise polynomial analysis results).

Using the year 1911, as established by the piecewise analysis, an indicator or dummy binary variable was created and then added to the original dataset as an ancillary variable specifically used to represent the abrupt change in maximum head diameter in time. A "0" was used to indicate those five year year-of-birth intervals prior to and including the year 1911, and a "1" was utilized to categorize those intervals after the abrupt change. A multiple regression analysis was then performed to examine all the terms including interactions using the maximum vertical head diameter averages as the dependent variable with the original birth year intervals and new indicator variable as the independent variables for the model. Table 8 below provides the regression coefficients, standard errors, T-values, and probability levels for this model. Results of the multiple regression analysis

Table 8: Regression Equation Coefficients, Errors, and Significance Tests for Female Model

Independent Variable	Regression Coefficient b(i)	Standard Error Sb(i)	T-Value H0:B(i)=0	Probability Level
Intercept	19.8756	12.5821	1.58	0.1268
Dummy Variable	63.3929	19.1965	3.302	0.0029
5 Year Interval	0.0119	0.0067	1.772	0.0886
Interaction	-0.0332	0.01	-3.309	0.0028

indicate that female maximum femoral head diameters have been gradually increasing in size from one five-year birth year interval to the next between the years 1835 to 1914; however, this increase is not statistically significant at the 0.05 alpha level. Conversely, from 1915 – 1980 a statistically significant somewhat rapid decrease in female maximum femoral head diameters from one five-year birth year interval to the next is observable. The regression equation for this model is as follows:

Multiple regression of Maximum Vertical Head Diameter Averages (MVHDA) on Year of Birth Interval (Females):

MVHDA = 19.8756 + 63.3929 * Dummy Variable + 0.0119 * Five Year Interval

– 0.0332 * Dummy Variable * Five Year Interval

F- statistic: 4.610 r^2: 0.3562 Mean Square Error: 0.3151714

(See Appendix 9, tables 40 – 44 on pages 131 – 132 for multiple regression results).

As seen above, the proportion of the variation in the maximum vertical head diameter average that can be accounted for by variation in the five year year-of-birth interval is 0.3562, thus maximum vertical head diameter size does have some relationship to year of birth for the female group. A scatterplot of the maximum vertical head diameter averages plotted against year of birth was produced for the female group without overlying trend lines. This plot shows that the patterning of change between birth year intervals is fairly stochastic prior to the turn of the century but a decreasing trend in size can be observed to begin in approximately 1910. Upon further examination of the scatterplot, it appears that the maximum

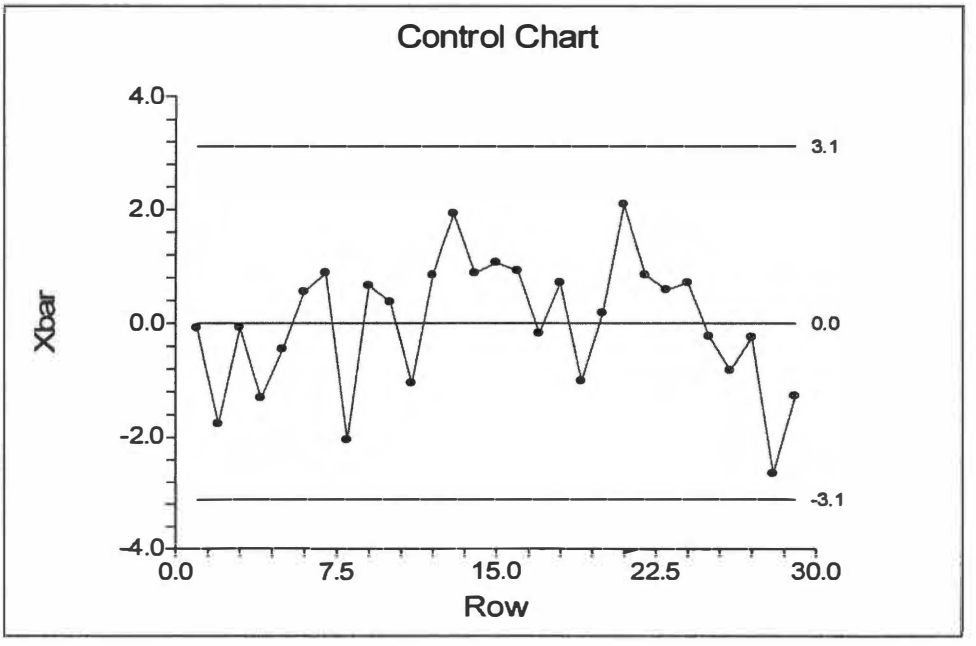

Figure 2: Control Chart for White and Black Females

head diameter average for the year 1975 may be a potential outlier. A control chart of the standardized residuals for the female dataset was constructed for use as an outlier diagnostic. As seen above in Figure 2, the control chart of the standardized residuals for the female dataset shows that this point is not out of the range of the data. (See Appendix 6, Figure 12, on page 117 for the scatterplot). Additionally, calculations on the residuals were performed in order to implement a Portmanteau test in order to determine if there is any remaining pattern that can be modeled. The associated statistically non-significant p-values from the results of this test indicate that the regression model for the female dataset is an adequate model. (See Appendix 8, Table 39, on page 127 for the Portmanteau Test results). (See Figures 17-18 on page 129 for the residual Autocorrelation plots).

Chapter V

Discussion

The femoral heads of n = 1217 black and white males and females representing historic and modern individuals were assessed statistically for secular changes in the size of the vertical diameter spanning the years 1830 through 1980. Tests for normality, randomization, and serial correlation were conducted on the time series data prior to performing additional statistical analyses. The results of these tests indicated that the male dataset used for this analysis was not normally distributed and had positive serial correlation, while the female dataset was normally distributed and was not serially correlated. Results of the randomization test were found to be statistically significant, and thus can be used to provide additional credence to significant findings of other statistical tests. In regard to measurement technique, the results of the paired t-test indicate that there was no significant difference between the measures taken by the author from those that were obtained from other sources for analyses.

Due to the presence of positive serial correlation in the male dataset, the Box-Jenkins Autoregressive Integrated Moving Average (ARIMA) method, a statistical approach to examining time series data, was used to create forecast and control models that would most accurately identify and fit the linear process of the data. This particular method was also utilized to transform the non-stationary series into a stationary series. With the underlying trend removed from the data, the

appropriate model was then identified and the parameters for the model were estimated. The ARIMA parameter estimates (2,0,1) was determined to be the model of best fit for the male dataset as all parameter estimates were found to be statistically significant at the 0.05 level. Because outlier diagnostics are not available as part of the ARIMA analysis, control charts were utilized to identify one potential outlier in the male dataset. The scatterplot of the male dataset indicates that male maximum femoral head diameters have been increasing and decreasing in size over twenty-five year intervals spanning the past 150 years.

The linear trend line shown in the aforementioned scatterplot implies that male femoral head diameters may be decreasing in size over time. This plot of the averages versus the five year year-of-birth interval, however, does not take the serial correlation that is present in the data into consideration. The slightly positive slope (0.0017) evidenced in the linear regression of the maximum vertical head diameter lag first-differences on the five year year-of-birth interval indicate that maximum femoral head diameters may be increasing somewhat over time; however the increase was not statistically significant (p-value = 0.7067). Additionally, the low r-square value (0.0053) indicates that the size of the diameter of the male femoral head does not have a strong relationship to year of birth.

The Hotelling's T-square test was employed to test for significant differences between the group mean maximum femoral head diameter for those individuals born within the first fifty years of the sample (1835 – 1884) and the group mean maximum femoral head diameter for those individuals born within the

last fifty years of the sample (1935 – 1984). Results of the Hotelling's T-square test indicate that the difference between the two group means is not statistically significant. (See Appendix 10, Table 46 on page 133, for a summary of the results found from the statistical analyses of the male dataset).

Because the female dataset was not serially correlated, employment of methods used to handle autocorrelated data such as the Box-Jenkins ARIMA method of analysis was deemed not necessary. Instead, a piecewise polynomial (linear – linear) curve fitting method was used to ascertain a particular temporal breakpoint which was indicative of an abrupt change in size over time. Results of the piecewise polynomial curve fitting analysis determined that the temporal breakpoint was 1911. A dummy variable representing this breakpoint was then created and used in a multiple regression analysis. For this portion of the analysis, the dependent variable *maximum vertical head diameter average* was regressed on the two independent variables *five year year-of-birth interval*, and the newly created *dummy* or *indicator* variable. Results of this two part analysis indicate that females have experienced a gradual increase in the average femoral head diameter size between the years 1835 and 1914; however this increase was not statistically significant at the 0.05 level (p-value = 0.0886). Beginning in 1915 through 1980, the average female vertical femoral head diameter appears to rapidly decrease in size and this decrease is statistically significant at the 0.05 level (p-value = 0.0029). The r-squared value of 0.3562 indicates that female maximum vertical head diameter sizes do have some relationship to year of birth, and this particular

relationship is stronger for females than for males. (See Appendix 10, Table 47 on page 133, for a summary of the results found from the statistical analyses of the female dataset).

The differences in the results of these analyses show that the rates, degrees, and modes of secular changes do differ among the sexes, and the significance of those changes varies as well. This study indicates that male maximum vertical head diameters have been fluctuating in size fairly regularly over time, while female maximum vertical head diameters have gradually increased in size until approximately 1910 when femoral head diameters, rather abruptly, begin to rapidly decrease in size. The incongruent patterns of change occurring in the femoral maximum vertical head diameter among males and females seen in this study seem to confirm that environmental factors that influence growth and development do differ among the sexes, and that males and females may differ in degrees of phenotypic plasticity in terms of this particular skeletal feature. It has been previously demonstrated that in terms of body morphology females are less affected by environmental factors than males, and that certain long bones of the skeleton are more plastic than others in relation to stature (Jantz and Jantz, 1999).

Because various environmental factors can precipitate phenotypic changes in humans, it is necessary to take a biocultural approach to the analyses of secular trends. The cultural environment in addition to the examination of the environmental history of a given population must be taken into consideration in conjunction with changes in morphology. The use of such an approach relevant for

identifing the morphological changes in addition to the contributing factors that may have precipitated those changes over time. Allometrically, the length of the femur should have a strong correlation to the size of femoral head. If secular increases in stature, partially due to increases in femoral lengths, are attributed to better environmental conditions, then increases in the maximum vertical diameter of the femoral head should also be indicative of better environmental conditions.

For males the expected changes in the size of the maximum vertical diameter of the femoral head to not appear to neatly coincide with significant changes in the cultural landscape that would have affected the economy, morbidity, nutrition, and degree of physical activity in that portion of the population. Femoral head diameters appear to continue to decrease in size after minor economic depressions that occurred in 1837 and 1893, but no reduction in size is apparent after the Great Depression in 1929 (http://kclibrary.nhmccd.edu/19thcentury.html). Surprisingly, femoral head diameters appear to decrease in size in those years prior to 1929 (1920 – 1925), and then subsequently increase in size over the decade 1925 – 1935 which encompasses this landmark event in American economic history.

Short-term negative effects on health as a result of epidemic disease are also not necessarily reflected in those patterns of change seen among male vertical head diameters. Femoral vertical head diameters continue to increase in size over the years 1840 – 1870 despite the environmental impacts of the Civil War (1861 – 1865) on health and nutrition, and the persistence of cholera that reached epidemic proportions twice over this period initially killing approximately 10 percent of the

population in 1849, and subsequently eradicating nearly 5 percent of the population in 1866 (Kohn, 2001). This positive trend in head diameter size continues through the first part of the post-Civil War period of reconstruction (1865 – 1877) which could be expected since environmental conditions began to improve during this time (Komlos, 2001; Jantz and Jantz, 1999). However, the average male femoral head diameter decreases in size from 1870 to 1880 which includes the latter portion of this period and is contemporaneous with the second industrial revolution (http://kclibrary.nhmccd.edu/19thcentury.html).

An increase in male femoral head diameter size beginning in1885 and continuing until 1890 temporally coincides with industrial mechanization and the advent of the 8 hour work day, but diameters subsequently decrease in size thereafter until 1905. From 1905 until 1935, the apparent increase in male femoral head diameter could be attributed to improvements in public health, nutrition, and technology. Another negative trend in femoral head diameter size can be observed to begin in 1935 and continues until 1965 despite those environmental improvements. While the discovery of penicillin may have additionally improved health over this thirty year span, the advent of World War II, and the widespread affordability and availability of automobiles, public transportation, televisions, and processed foodstuffs may be the reasons for this apparent reduction in diameter size over time (http://kclibrary.nhmccd.edu/19thcentury.html).

For females, the pattern of change in the femoral head diameter over time as evidenced in the piecewise polynomial curve and subsequent regression analysis is

fairly straightforward and therefore more easily explained than the pattern observed in the male sample. Additionally, the configuration of the trend seems to confirm that morphological changes due to environmental factors are less likely to occur among females than males. Female maximum vertical head diameter sizes increase in dimension until approximately 1910 when an abrupt change occurs and diameters begin to decrease. Prior to 1910, the comprehension of disease transmission slowly improved over time and as morbidity became more understood additional polices in regard to public health were instituted. Additionally, improvements and advancements continued to be made in industry, technology, and nutrition.

The occurrence of epidemics and the event of the Civil War do not appear to have had an effect on femoral head diameter; however, the production of one invention of significance – the automobile – does appear to temporally coincide with the change and subsequent decrease in female head diameter size. Between the years 1900 and 1909, automobiles became affordable and approximately 8,000 autos were produced (http://kclibrary.nhmccd.edu/19thcentury.html). In 1914, the first moving assembly line made it possible for the one-millionth Model T automobile to be produced in 1915 (http://kclibrary.nhmccd.edu/19thcentury.html). It could rationally be hypothesized that the secular change observed in the femoral head may partially be the result of diminished physical activity as the decrease in diameter size coincides temporally with technological and transportation advancements that have fostered more sedentary lifestyles among Americans. The continuing advancements in technology, health science, and industry, and

improvements in nutrition and education through the nineteenth and twentieth centuries are considered causative factors for the continuing increase of American stature through the mid-twentieth century (Komlos and Baur, 2004; Komlos, 2001; Jantz and Jantz, 1999).

If femoral head size is limited ontogenetically, and also related to locomotive behavior and body mass as maintained by Lieberman et al. (2001), early childhood physical activity and biomechanical loading in addition to other environmental influences can be contributory factors in the determination of femoral head size. Therefore, a lack of physical activity and subsequent reduction in loading could theoretically result in a smaller femoral head diameter. Statistics published by the Bureau of Transportation (2004) indicate that the percentage of Americans walking to work (4%) in 1985 has decreased to 3.1% in 1999, while the percentage of those that drive to work has increased from 86.5% to 87.7% within the same span of time. Statistics published by the United States Bureau of the Census (2006) show that the percentage of households with television sets has increased from 65% in 1955 to 98% in 2003. Additionally, the number of hours that a household is tuned into television has almost doubled from an average of 4.35 hours in 1950 to an average of 8.11 hours in 2005 (Nielsen Media Report, 2006).

While an increase in body mass, such as obesity, could result in greater loading of the femoral head, physical activity would most likely remain diminished. Currently the relative significancet of each of these factors in the final determination of individual femoral head size remains unknown. The apparent reduction in female

femoral head diameter and may also be a causative factor in the increasing prevalence of hip fractures among older adults as the femoral head and neck are important features considered in the examination of femoral hip geometry. Although current research examining secular trends in obesity has investigated television and modes of transportation in relation to diminished physical activity and increased food consumption, another possible causative factor for such trends in need of study concerns the recent advent of computer technology as ownership and time spent using them for a variety of purposes continues to escalate among children and adults.

It appears that secular changes in the maximum diameter of the femoral head do not necessarily follow the same patterns observed in studies of secular trends of stature. Additionally, while the prevalence of clinical obesity in both the United States and Britain continues to increase (Prentice and Jebb, 1995), the negative secular changes occurring in the femoral vertical head diameter of American females is contrary to what appears to be happening among the modern population of the United Kingdom where a significant secular increase in head diameters has been observed (Duthie, Bruce, and Hutchison, 1998). The exact mechanism behind these divergent trends has yet to be determined; however, it would not be unreasonable to speculate the disparity is a result of a combination of environmental differences and levels of physical activity among these populations. For the British, it has been hypothesized that a reduction in physical activity is responsible for the

growing obesity epidemic as the average per capita food consumption has decreased in recent decades (Prentice and Jebb, 1995).

Several researchers examining modern American youth and adults have documented various associations among the amount of television watched, increased caloric intake, decreased levels of physical activity with the increased incidence of obesity (Wiecha et al., 2006; Bowman, 2006; Gordon-Larsen et al., 2005; Jeffery and Utter, 2003; Roche and Sun , 2003; Crespo et al., 2001; Klesges et al., 1993). Among children and premenarcheal adolescent females in the United States, television has been implicated as a factor contributing to the likelihood of obesity as increases in time spent viewing television have been found to be associated with increases in caloric intake, and decreases in time engaged in physical activity (Wiecha et al., 2006; Jeffery and Utter, 2003; Crespo et al., 2001; Klesges et al., 1993). Additionally Klesges et al. (1993) identified that while watching television, metabolic rates significantly decreased beyond typical energy expenditure during rest. For adults, Bowman (2006) identified that watching television for two or more hours a day was associated with higher energy-rich food consumption and having a high Body Mass Index.

Chapter VI

Conclusion

Twentieth century Americans, in particular, comprise a unique population for which there are few, if any, comparisons, and the importance of identifying and documenting aspects of secular change in different areas of the skeleton should not be disregarded. Generally speaking, studies of secular changes and skeletal plasticity have shown that morphology is not constant over time, and such changes have the potential to complicate and compromise anthropometric and demographic analyses. Because secular change results in differing patterns of growth for specific human groups, after a number of generations pass current methodologies utilized by anthropologists for the purpose of identification and demographic analysis may require modification. The identification of a statistically significant negative trend in the size of the femoral vertical head diameters for American females and the fluctuations in the size of American male femoral head diameters underscore the necessity for the development and utilization of anthropometric standards that are both population and temporally specific.

Anthropologists rely on established criteria derived from documented skeletons to construct estimates of ethnicity, sex, and stature for unidentified skeletal remains and morphological changes over time can affect the accuracy of such standards. Several statistical formulae currently utilized for age, stature, and sex estimation from postcranial skeletal elements were originally derived from data

collected from historic anatomical collections (Krogman and Iscan, 1986). Likewise, assessments of ethnicity and sex based on qualitative morphological characteristics as well as discriminant functions utilizing metric measurements of the skull presently in use were developed from such skeletal collections (Krogman and Iscan, 1986). Because of the composition of these anatomical reference collections several of these standards have already been found to be inappropriate in terms of their applicability to modern Americans (Ousley and Jantz, 1998; Ayers, Jantz, and Moore-Jansen, 1990; Ericksen 1982). The subsequent necessity of having a modern comparative skeletal reference sample in order to examine the extent of secular change in the United States has been recognized and is currently being fulfilled with the development of the modern anatomical donated collections, and the University of Tennessee Forensic Databank.

This study has demonstrated that a significant decrease over time has occurred in the average maximum femoral vertical head diameter among American females, and that male femoral head diameter sizes have fluctuated over time. Additionally, this study has underscored the importance of applying a biocultural approach to the investigation of secular change in order to ascertain a broader view of the potential environmental factors that can influence such trends. While the documentation of these trends is important and valuable, as additional data become available another study which includes ethnicity should be conducted as differences among the sexes and ethnicities are known to exist. Unfortunately, this study required the grouping of the ethnicities as there was a lack of metric data with

consecutive birth years for the analysis. Based on the results of this study, research investigating the allometric relationship of the length of the femur and the head diameter over time should be conducted. Furthermore, additional research employing discriminant analyses should be considered in order to determine if the current standards used for the assessment of sex are in need of revision in order to be applicable to modern American females.

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Appendices

Appendix 1 – Raw Data Categorized by Cohort

Table 9: Maximum Vertical Head Diameter Measurements and Year of Birth for Female Sample

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
1	T-1212	White	1846	40
2	T-692	White	1846	44
3	T-639	White	1848	43
4	T-1559	White	1850	42
5	T-1432	White	1851	41
6	T-715	White	1851	43
7	T-686	White	1852	39
8	T-834R	White	1852	43
9x	T-837R	White	1852	43
10	T-206R	White	1853	45
11	T-327	White	1853	42
12	T-601	White	1854	42
13	T-1370	White	1855	43
14	T-1139	White	1857	41
15	T-1137R	White	1859	41
16	T-854	White	1859	45
17	T-689R	White	1860	41
18	T-925	White	1860	47
19	T-818R	White	1861	42
20	T-321R	White	1862	39
21	T-464	White	1862	44
22	T-728R	White	1862	41
23	T-96R	White	1862	46
24	T-749R	White	1863	42
25	T-1058	White	1864	42
26	T-117R	White	1864	41
27	T-191R	White	1864	42
28	T-611	White	1864	43
29	T-791	White	1864	42
30	T-39R	White	1865	43
31	T-678R	White	1865	41
32	T-947R	White	1866	41

(Table 9: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
33	T-1085R	White	1867	47
34	T-1502R	White	1867	48
35	T-319R	White	1867	38
36	T-71R	White	1867	45
37	T-175R	White	1868	44
38	T-580	White	1868	41
39	T-108R	White	1869	45
40	T-1094	White	1875	42
41	T-934	White	1875	43
42	T-543R	White	1876	41
43	T-1557	White	1877	45
44	803	White	1885	43
45	921	White	1885	44
46	922	White	1885	40
47	T-1016R	White	1885	41
48	T-1296R	White	1885	41
49	516	White	1886	44
50	T-951R	White	1886	42
51	808	White	1887	44
52	812	White	1887	46
53	919	White	1887	42
54	T-1123R	White	1887	37
55	T-710R	White	1887	48
56	902	White	1888	41
57	915	White	1889	43
58	402	White	1890	42
59	1115	White	1890	43
60	911	White	1891	45
61	424	White	1892	41
62	814	White	1892	41
63	T-554R	White	1892	41
64	T-847	White	1892	39
65	256	White	1893	43
66	901	White	1893	38
67	301	White	1894	46

(Table 9: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
68	254	White	1895	41
69	255	White	1895	43
70	907	White	1895	46
71	913	White	1895	45
72	258	White	1896	40
73	510	White	1896	42
74	905	White	1896	45
75	908	White	1896	43
76	313	White	1897	43
77	414	White	1897	45
78	417	White	1897	42
79	428	White	1897	44
80	903	White	1897	40
81	306	White	1898	44
82	518	White	1898	43
83	824	White	1898	43
84	459	White	1899	45
85	815	White	1899	41
86	251	White	1900	46
87	407	White	1900	46
88	904	White	1900	43
89	924	White	1900	43
90	1112	White	1900	44
91	420	White	1901	42
92	461	White	1901	46
93	916	White	1901	42
94	923	White	1901	42
95	517	White	1902	41
96	910	White	1902	44
97	449	White	1903	41
98	817	White	1903	41
99	1245	White	1903	46
100	316	White	1904	41
101	505	White	1904	43
102	658	White	1904	47
103	811	White	1904	42

(Table 9: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
104	254	White	1905	41
105	307	White	1905	37
106	326	White	1905	45
107	257	White	1906	41
108	813	White	1906	42
109	76	White	1907	46
110	252	White	1907	43
111	325	White	1907	46
112	411	White	1907	44
113	463	White	1907	42
114	465	White	1907	41
115	422	White	1908	45
116	515	White	1908	45
117	820	White	1908	44
118	989	White	1909	40
119	200	White	1910	44
120	410	White	1910	46
121	416	White	1910	43
122	457	White	1910	42
123	1555	White	1910	46
124	2015	White	1910	40
125	2079	White	1910	44
126	378	White	1911	40
127	452	White	1911	42
128	506	White	1911	42
129	1972	White	1911	39
130	1999	White	1911	37
131	331	White	1912	43
132	404	White	1912	44
133	2076	White	1912	45
134	2146	White	1912	45
135	305	White	1913	41
136	2092	White	1913	43
137	358	White	1914	44
138	1206	White	1914	42
139	1570	White	1914	45

(Table 9: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
140	2018	White	1914	43
141	450	White	1915	43
142	453	White	1915	46
143	455	White	1915	40
144	512	White	1915	42
145	1401	White	1915	41
146	1848	White	1915	42
147	2067	White	1915	43
148	409	White	1916	43
149	710	White	1916	42
150	717	White	1916	48
151	799	White	1916	39
152	1204	White	1916	45
153	1206	White	1916	43
154	2110	White	1916	41
155	818	White	1917	40
156	2053	White	1917	42
157	427	White	1918	44
158	454	White	1918	44
159	619	White	1918	48
160	706	White	1918	41
161	1107	White	1918	43
162	1114	White	1918	41
163	1122	White	1918	42
164	78	White	1919	40
165	312	White	1919	44
166	520	White	1919	42
167	543	White	1919	43
168	1119	White	1919	44
169	1880	White	1919	41
170	1960	White	1919	46
171	2034	White	1919	42
172	451	White	1920	42
173	460	White	1920	44
174	615	White	1921	43
175	616	White	1921	41

(Table 9: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
176	610	White	1922	46
177	1370	White	1922	41
178	1942	White	1922	41
179	1965	White	1922	42
180	184	White	1923	40
181	322	White	1923	39
182	397	White	1923	46
183	406	White	1923	41
184	462	White	1923	40
185	456	White	1924	44
186	458	White	1924	41
187	826	White	1924	42
188	1454	White	1924	41
189	2021	White	1924	42
190	80	White	1925	44
191	85	White	1925	43
192	519	White	1925	39
193	620	White	1925	47
194	2020	White	1925	40
195	2091	White	1925	43
196	2118	White	1925	45
197	720	White	1926	45
198	1364	White	1926	43
199	2108	White	1926	42
200	1202	White	1927	41
201	1950	White	1927	41
202	245	White	1928	38
203	621	White	1928	40
204	715	White	1928	43
205	1256	White	1929	46
206	1946	White	1929	42
207	1951	White	1929	43
208	2049	White	1929	42
209	2057	White	1929	48
210	2070	White	1929	39
211	710	White	1930	41

(Table 9: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
212	1371	White	1930	39
213	1992	White	1930	40
214	2036	White	1930	44
215	419	White	1931	40
216	2047	White	1931	42
217	2117	White	1931	41
218	539	White	1932	43
219	2101	White	1932	43
220	325	White	1933	41
221	447	White	1933	43
222	724	White	1933	39
223	1873	White	1933	41
224	2212	White	1933	42
225	284	White	1935	43
226	1084	White	1935	42
227	2098	White	1935	40
228	8	White	1936	44
229	573	White	1936	41
230	379	White	1937	44
231	535	White	1937	38
232	2022	White	1939	47
233	2030	White	1939	43
234	2075	White	1939	41
235	327	White	1940	42
236	2028	White	1940	48
237	1093	White	1941	42
238	1963	White	1941	44
239	2267	White	1941	41
240	1156	White	1942	44
241	1170	White	1942	44
242	1576	White	1942	42
243	14	White	1943	47
244	443	White	1943	43
245	2304	White	1943	42
246	2094	White	1944	42
247	2106	White	1944	42

(Table 9: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
248	1178	White	1945	43
249	685	White	1946	42
250	1243	White	1946	42
251	327	White	1947	40
252	328	White	1947	45
253	1246	White	1947	44
254	2307	White	1947	41
255	2288	White	1948	42
256	320	White	1949	45
257	554	White	1949	43
258	563	White	1949	44
259	1105	White	1949	43
260	1540	White	1949	41
261	1841	White	1950	43
262	657	White	1951	41
263	1404	White	1951	42
264	791	White	1952	44
265	334	White	1953	39
266	364	White	1953	40
267	792	White	1953	46
268	1251	White	1953	41
269	2069	White	1953	39
270	1100	White	1954	46
271	349	White	1955	43
272	365	White	1955	42
273	1408	White	1955	41
274	1982	White	1955	47
275	51	White	1956	42
276	395	White	1956	41
277	441	White	1956	44
278	501	White	1956	41
279	562	White	1956	46
280	2130	White	1956	43
281	391	White	1957	43
282	197	White	1958	39
283	345	White	1958	43

(Table 9: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
284	433	White	1958	33
285	478	White	1958	42
286	564	White	1958	41
287	789	White	1958	44
288	9	White	1959	42
289	419	White	1959	43
290	435	White	1959	43
291	1215	White	1959	41
292	1446	White	1959	45
293	194	White	1960	38
294	776	White	1960	46
295	793	White	1960	42
296	832	White	1960	40
297	1111	White	1960	42
298	1318	White	1960	39
299	808	White	1961	43
300	1145	White	1961	42
301	1458	White	1961	44
302	1932	White	1961	46
303	32	White	1962	40
304	673	White	1962	44
305	1209	White	1962	44
306	788	White	1963	41
307	809	White	1963	41
308	1097	White	1963	39
309	1101	White	1963	40
310	1090	White	1964	42
311	1922	White	1964	42
312	2089	White	1964	41
313	2331	White	1964	42
314	1088	White	1965	39
315	1838	White	1965	41
316	1955	White	1965	42
317	1975	White	1965	36
318	2218	White	1965	44
319	1214	White	1966	43

(Table 9: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
320	2286	White	1966	41
321	202	White	1967	44
322	1152	White	1967	41
323	1525	White	1967	46
324	2071	White	1967	40
325	1315	White	1968	42
326	1142	White	1969	41
327	841	White	1970	42
328	1236	White	1970	43
329	1508	White	1970	45
330	248	White	1971	43
331	1083	White	1971	42
332	1419	White	1971	43
333	1451	White	1971	40
334	1572	White	1971	41
335	826	White	1972	41
336	1870	White	1972	40
337	1506	White	1975	43
338	2283	White	1977	39
339	1161	White	1979	40
340	1296	White	1983	41
341	T-484	Black	1840	44
342	T-1483	Black	1841	42
343	T-63RR	Black	1842	41
344	T-43	Black	1843	42
345	T-1316R	Black	1845	42
346	T-1104	Black	1847	41
347	T-1203	Black	1848	37
348	T-78R	Black	1849	42
349	T-1338	Black	1850	40
350	T-761	Black	1850	47
351	T-1231	Black	1851	40
352	T-1078	Black	1852	40
353	T-661	Black	1853	44
354	T-1494	Black	1855	42
355	T-1461	Black	1856	38

(Table 9: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
356	T-532	Black	1857	42
357	T-160	Black	1858	43
358	T-1227	Black	1859	40
359	T-1501	Black	1859	40
360	T-390R	Black	1860	40
361	T-640	Black	1860	42
362	T-769	Black	1860	41
363	T-807R	Black	1860	39
364	T-40	Black	1861	40
365	T-90R	Black	1862	42
366	T-141R	Black	1863	44
367	T-528	Black	1863	43
368	T-538	Black	1863	43
369	T-930R	Black	1863	39
370	T-418R	Black	1864	42
371	T-100RR	Black	1865	37
372	T-101R	Black	1865	46
373	T-429R	Black	1865	42
374	T-653	Black	1865	42
375	T-819	Black	1865	41
376	T-163R	Black	1866	39
377	T-218R	Black	1867	48
378	T-544R	Black	1868	43
379	T-559	Black	1868	42
380	T-587	Black	1868	41
381	T-67R	Black	1868	42
382	T-86R	Black	1868	41
383	T-180R	Black	1869	40
384	T-526R	Black	1869	43
385	T-967R	Black	1870	42
386	T-105R	Black	1871	45
387	T-102R	Black	1872	41
388	T-38R	Black	1872	41
389	T-19R	Black	1873	45
390	T-120R	Black	1874	42
391	T-272	Black	1875	39

(Table 9: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
392	T-1145	Black	1877	39
393	T-65R	Black	1877	38
394	T-1063	Black	1878	38
395	T-603	Black	1879	44
396	T-48R	Black	1882	45
397	T-997R	Black	1882	42
398	T-1129	Black	1883	41
399	T-46R	Black	1883	42
400	T-93R	Black	1885	44
401	T-626R	Black	1887	43
402	T-24R	Black	1888	40
403	T-23R	Black	1889	37
404	T-454R	Black	1889	44
405	T-199R	Black	1890	39
406	T-241R	Black	1890	36
407	T-98R	Black	1890	46
408	T-228R	Black	1891	39
409	226	Black	1892	43
410	T-27R	Black	1892	44
411	T-208	Black	1893	39
412	T-51R	Black	1893	44
413	T-766	Black	1895	37
414	T-68R	Black	1896	40
415	T-32R	Black	1897	42
416	1001	Black	1898	43
417	T-1236	Black	1898	43
418	1074	Black	1899	43
419	T-60R	Black	1899	43
420	819	Black	1900	41
421	1349	Black	1900	43
422	T-1441	Black	1900	40
423	T-541	Black	1900	42
424	T-824	Black	1900	40
425	181	Black	1901	40
426	783	Black	1901	47
427	992	Black	1901	44

(Table 9: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
428	984	Black	1902	46
429	T-255	Black	1902	46
430	T-255	Black	1902	46
431	524	Black	1903	41
432	993	Black	1904	43
433	T-840	Black	1904	42
434	1333	Black	1905	41
435	T-1222	Black	1905	41
436	1021	Black	1906	44
437	1081	Black	1906	45
438	1337	Black	1906	40
439	1071	Black	1907	43
440	1357	Black	1907	43
441	1341	Black	1908	43
442	1347	Black	1908	44
443	1372	Black	1908	38
444	448	Black	1909	44
445	1196	Black	1909	43
446	1197	Black	1909	41
447	T-729R	Black	1909	42
448	1011	Black	1910	43
449	1080	Black	1910	40
450	1117	Black	1910	45
451	1334	Black	1910	41
452	1342	Black	1910	44
453	810	Black	1911	44
454	1005	Black	1911	41
455	1010	Black	1911	45
456	1363	Black	1911	35
457	1368	Black	1911	44
458	1353	Black	1912	41
459	1356	Black	1914	45
460	1374	Black	1914	44
461	1365	Black	1915	40
462	1195	Black	1916	44
463	1362	Black	1916	40

(Table 9: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
464	1191	Black	1917	45
465	1067	Black	1918	41
466	1198	Black	1918	41
467	1199	Black	1918	41
468	1361	Black	1918	42
469	715	Black	1920	40
470	1019	Black	1921	40
471	752	Black	1922	42
472	1366	Black	1923	44
473	711	Black	1925	38
474	1373	Black	1927	43
475	1669	Black	1929	41
476	2026	Black	1929	43
477	1000	Black	1930	41
478	468	Black	1931	40
479	1017	Black	1934	43
480	519	Black	1938	40
481	1320	Black	1938	41
482	578	Black	1941	43
483	2136	Black	1941	41
484	572	Black	1942	42
485	1876	Black	1943	41
486	216	Black	1944	47
487	368	Black	1944	41
488	768	Black	1945	41
489	668	Black	1947	42
490	577	Black	1948	42
491	588	Black	1948	41
492	1179	Black	1949	41
493	1385	Black	1950	39
494	1	Black	1951	40
495	110	Black	1952	42
496	192	Black	1952	42
497	178	Black	1953	39
498	582	Black	1953	45
499	586	Black	1953	45

(Table 9: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
500	1134	Black	1953	46
501	228	Black	1955	44
502	769	Black	1955	42
503	25	Black	1956	40
504	1591	Black	1956	43
505	1118	Black	1958	43
506	1270	Black	1959	41
507	1388	Black	1962	44
508	790	Black	1963	39
509	2164	Black	1963	39
510	845	Black	1965	39
511	1871	Black	1965	40
512	1575	Black	1969	42
513	1207	Black	1970	39
514	1210	Black	1970	39
515	1143	Black	1973	43
516	1219	Black	1975	39

Table 10: Maximum Vertical Head Diameter Measurements and Year of Birth for Male Sample

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
1	T-317	White	1841	46
2	T-428	White	1843	45
3	T-805	White	1843	46
4	T-502	White	1846	43
5	T-691	White	1847	49
6	T-832	White	1847	49
7	T-979	White	1847	49
8	T-1310	White	1849	48
9	T-498	White	1849	50
10	T-510	White	1849	49
11	T-750	White	1849	47
12	T-416	White	1850	46
13	T-485	White	1850	49
14	T-1062	White	1851	52
15	T-1111	White	1851	50
16	T-499	White	1851	47
17	T-501	White	1851	51
18	T-1073	White	1852	47
19	T-388	White	1852	50
20	T-396	White	1852	50
21	T-432	White	1852	47
22	T-531	White	1852	46
23	T-806	White	1852	51
24	T-1116	White	1853	46
25	T-262	White	1853	48
26	T-493	White	1853	51
27	T-633	White	1853	52
28	T-1107	White	1854	51
29	T-1495	White	1854	47
30	T-307	White	1854	49
31	T-378	White	1854	48
32	T-406	White	1854	49
33	T-436	White	1854	46
34	T-266	White	1855	51
35	T-439	White	1855	54

(Table 10: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
36	T-497	White	1855	48
37	T-974	White	1855	47
38	T-552	White	1856	48
39	T-665	White	1856	47
40	T-758	White	1857	47
41	T-264	White	1858	47
42	T-938	White	1858	49
43	T-338	White	1860	48
44	T-931	White	1864	49
45	T-459	White	1866	51
46	T-1087	White	1870	55
47	T-1371	White	1872	50
48	T-768	White	1876	46
49	T-525	White	1879	50
50	T-614	White	1879	52
51	T-756	White	1882	51
52	T-828	White	1883	50
53	425	White	1884	44
54	1218	White	1885	47
55	401	White	1887	50
56	T-924	White	1888	46
57	314	White	1891	52
58	825	White	1891	51
59	2010	White	1892	51
60	504	White	1894	51
61	906	White	1894	48
62	400	White	1895	52
63	T-1126	White	1895	50
64	912	White	1896	48
65	809	White	1897	51
66	822	White	1897	52
67	1022	White	1897	47
68	804	White	1898	45
69	1005	White	1898	51
70	1124	White	1898	47
71	271	White	1899	50

(Table 10: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
72	1123	White	1899	47
73	521	White	1900	55
74	801	White	1900	47
75	806	White	1900	41
76	925	White	1900	48
77	1113	White	1900	47
78	250	White	1901	48
79	329	White	1901	51
80	405	White	1901	53
81	421	White	1901	51
82	802	White	1901	44
83	909	White	1901	51
84	927	White	1901	45
85	1023	White	1901	47
86	1019	White	1902	50
87	1203	White	1902	50
88	2123	White	1902	46
89	508	White	1903	48
90	523	White	1903	48
91	784	White	1903	49
92	2038	White	1903	48
93	107	White	1904	50
94	319	White	1904	51
95	1217	White	1904	52
96	423	White	1905	46
97	511	White	1905	48
98	797	White	1905	48
99	1148	White	1905	44
100	1214	White	1905	48
101	2016	White	1905	51
102	50	White	1906	48
103	259	White	1906	49
104	525	White	1906	53
105	785	White	1906	50
106	805	White	1906	52
107	502	White	1907	47

(Table 10: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
108	665	White	1907	49
109	273	White	1908	48
110	664	White	1908	48
111	1006	White	1908	47
112	1128	White	1908	50
113	2027	White	1908	48
114	1215	White	1909	46
115	1222	White	1909	52
116	2043	White	1909	48
117	40	White	1910	46
118	82	White	1910	52
119	302	White	1910	46
120	1014	White	1910	43
121	1208	White	1910	49
122	285	White	1911	49
123	2128	White	1911	57
124	794	White	1912	52
125	807	White	1912	48
126	920	White	1912	51
127	1989	White	1912	47
128	174	White	1913	48
129	235	White	1913	45
130	1109	White	1913	51
131	1213	White	1913	47
132	2055	White	1913	49
133	42	White	1914	50
134	403	White	1914	49
135	503	White	1914	48
136	1103	White	1914	52
137	1843	White	1914	49
138	1994	White	1914	51
139	2113	White	1914	50
140	2143	White	1914	47
141	311	White	1915	47
142	413	White	1915	46
143	509	White	1915	51

(Table 10: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
144	821	White	1915	47
145	1997	White	1915	48
146	43	White	1916	53
147	293	White	1916	44
148	308	White	1916	53
149	810	White	1916	47
150	1010	White	1916	45
151	1332	White	1916	49
152	77	White	1917	54
153	408	White	1917	50
154	418	White	1917	50
155	816	White	1917	55
156	1375	White	1917	49
157	2033	White	1917	48
158	234	White	1918	49
159	624	White	1918	49
160	914	White	1918	49
161	1021	White	1918	47
162	1983	White	1918	52
163	54	White	1919	48
164	296	White	1919	50
165	618	White	1919	48
166	795	White	1919	46
167	1908	White	1919	48
168	2042	White	1919	50
169	47	White	1920	45
170	237	White	1920	48
171	544	White	1920	48
172	612	White	1920	51
173	802	White	1920	49
174	918	White	1920	53
175	1111	White	1920	48
176	1135	White	1920	46
177	1218	White	1920	51
178	1272	White	1920	49
179	1480	White	1920	50

(Table 10: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
180	1901	White	1920	49
181	2007	White	1920	44
182	2064	White	1920	47
183	2115	White	1920	50
184	2140	White	1920	50
185	323	White	1921	52
186	514	White	1921	46
187	593	White	1921	50
188	796	White	1921	47
189	2009	White	1921	49
190	2074	White	1921	49
191	2104	White	1921	44
192	415	White	1922	49
193	979	White	1922	49
194	980	White	1922	52
195	1017	White	1922	50
196	1941	White	1922	52
197	926	White	1923	46
198	1103	White	1923	55
199	1330	White	1923	49
200	1331	White	1923	48
201	1479	White	1923	46
202	1943	White	1923	52
203	105	White	1924	51
204	394	White	1924	51
205	1482	White	1924	46
206	1528	White	1924	45
207	2006	White	1924	48
208	2138	White	1924	54
209	201	White	1925	51
210	412	White	1925	46
211	501	White	1925	47
212	1911	White	1925	51
213	1940	White	1925	46
214	196	White	1926	50
215	389	White	1926	49

(Table 10: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
216	604	White	1926	48
217	1121	White	1926	50
218	1991	White	1926	49
219	2014	White	1926	46
220	473	White	1927	49
221	484	White	1927	50
222	513	White	1927	50
223	1224	White	1927	51
224	1244	White	1927	50
225	1944	White	1927	49
226	314	White	1928	49
227	431	White	1928	50
228	647	White	1928	47
229	649	White	1928	45
230	1483	White	1928	45
231	2058	White	1928	47
232	2077	White	1928	49
233	1026	White	1929	44
234	1905	White	1929	48
235	2087	White	1929	49
236	86	White	1930	53
237	661	White	1930	51
238	781	White	1930	49
239	800	White	1930	51
240	2013	White	1930	46
241	2072	White	1930	52
242	340	White	1931	46
243	704	White	1931	48
244	1840	White	1931	49
245	1904	White	1931	50
246	2045	White	1931	46
247	2054	White	1931	48
248	2081	White	1931	47
249	2083	White	1931	43
250	2135	White	1931	50
251	30	White	1932	50

(Table 10: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
252	381	White	1932	46
253	507	White	1932	51
254	645	White	1932	49
255	823	White	1932	48
256	1907	White	1932	47
257	44	White	1933	52
258	292	White	1933	49
259	502	White	1933	49
260	644	White	1933	47
261	648	White	1933	52
262	1872	White	1933	54
263	1887	White	1933	46
264	2048	White	1933	48
265	2086	White	1933	52
266	2121	White	1933	51
267	1162	White	1934	48
268	1217	White	1934	45
269	1220	White	1934	51
270	1952	White	1934	51
271	2357	White	1934	46
272	15	White	1935	50
273	81	White	1935	49
274	98	White	1935	47
275	276	White	1935	47
276	697	White	1935	53
277	1091	White	1935	50
278	1262	White	1935	49
279	1948	White	1935	48
280	2114	White	1935	50
281	2144	White	1935	48
282	56	White	1936	55
283	398	White	1936	49
284	1087	White	1936	49
285	1232	White	1936	51
286	1263	White	1936	54
287	198 8	White	1936	51

(Table 10: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
288	2096	White	1936	49
289	2100	White	1936	47
290	2109	White	1936	49
291	439	White	1937	46
292	827	White	1937	51
293	1249	White	1937	51
294	1258	White	1937	50
295	1267	White	1937	48
296	2003	White	1937	46
297	2032	White	1937	54
298	2090	White	1937	52
299	2120	White	1937	48
300	70	White	1938	50
301	191	White	1938	50
302	399	White	1938	49
303	801	White	1938	51
304	1259	White	1938	45
305	1261	White	1938	45
306	1276	White	1938	48
307	2005	White	1938	49
308	2031	White	1938	47
309	2137	White	1938	46
310	2145	White	1938	47
311	488	White	1939	53
312	714	White	1939	48
313	1521	White	1939	48
314	2004	White	1939	50
315	2024	White	1939	49
316	2059	White	1939	50
317	2085	White	1939	47
318	2133	White	1939	47
319	646	White	1940	49
320	1252	White	1940	50
321	1447	White	1940	45
322	1925	White	1940	50
323	2029	White	1940	54

(Table 10: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
324	2097	White	1940	53
325	498	White	1941	47
326	833	White	1941	46
327	1254	White	1941	47
328	1269	White	1941	47
329	1405	White	1941	46
330	2039	White	1941	46
331	2046	White	1941	49
332	2062	White	1941	51
333	2078	White	1941	47
334	2102	White	1941	50
335	176	White	1942	48
336	266	White	1942	55
337	705	White	1942	50
338	787	White	1942	48
339	1113	White	1942	49
340	1842	White	1942	47
341	2044	White	1942	46
342	2080	White	1942	47
343	692	White	1943	50
344	1889	White	1943	48
345	2111	White	1943	44
346	2112	White	1943	49
347	2127	White	1943	55
348	T-1602	White	1943	50
349	199	White	1944	52
350	426	White	1944	50
351	1278	White	1944	45
352	1586	White	1944	51
353	2025	White	1944	48
354	52	White	1945	50
355	83	White	1945	49
356	177	White	1945	50
357	688	White	1945	50
358	2056	White	1945	50
359	116	White	1946	51

(Table 10: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
360	701	White	1946	54
361	1138	White	1946	49
362	1172	White	1946	48
363	1205	White	1946	47
364	1266	White	1946	46
365	2099	White	1946	50
366	3	White	1947	49
367	45	White	1947	44
368	189	White	1947	55
369	401	White	1947	53
370	725	White	1947	49
371	1107	White	1947	48
372	1292	White	1947	53
373	84	White	1948	45
374	772	White	1948	46
375	1125	White	1948	51
376	1255	White	1948	47
377	1949	White	1948	52
378	2008	White	1948	48
379	485	White	1949	47
380	507	White	1949	47
381	656	White	1949	48
382	1431	White	1949	50
383	1588	White	1949	50
384	1738	White	1949	48
385	2116	White	1949	47
386	2162	White	1949	48
387	370	White	1950	45
388	733	White	1950	47
389	770	White	1950	47
390	1122	White	1950	52
391	1211	White	1950	50
392	1882	White	1950	49
393	1978	White	1950	47
394	1996	White	1950	43
395	2066	White	1950	50

(Table 10: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
396	79	White	1951	44
397	344	White	1951	45
398	493	White	1951	52
399	553	White	1951	51
400	819	White	1951	48
401	1877	White	1951	52
402	2301	White	1951	45
403	326	White	1952	49
404	387	White	1952	50
405	406	White	1952	48
406	761	White	1952	54
407	1110	White	1952	50
408	1257	White	1952	49
409	1268	White	1952	46
410	1280	White	1952	50
411	1329	White	1952	49
412	1993	White	1952	41
413	2012	White	1952	49
414	2017	White	1952	52
415	2051	White	1952	44
416	823	White	1953	50
417	1265	White	1953	48
418	1321	White	1953	51
419	1927	White	1953	50
420	2122	White	1953	50
421	2232	White	1953	50
422	2287	White	1953	49
423	402	White	1954	50
424	548	White	1954	47
425	730	White	1954	50
426	1953	White	1954	47
427	34	White	1955	46
428	689	White	1955	47
429	1116	White	1955	43
430	1133	White	1955	47
431	1201	White	1955	49

(Table 10: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
432	1274	White	1955	47
433	2217	White	1955	45
434	2356	White	1955	48
435	806	White	1956	49
436	197 9	White	1956	47
437	2131	White	1956	47
438	693	White	1957	50
439	1186	White	1957	51
440	1275	White	1957	49
441	1478	White	1957	43
442	1531	White	1957	51
443	1939	White	1957	47
444	2126	White	1957	46
445	376	White	1958	50
446	506	White	1958	46
447	1420	White	1958	48
448	1677	White	1958	43
449	2284	White	1958	47
450	114	White	1959	49
451	207	White	1959	48
452	423	White	1959	48
453	1212	White	1959	48
454	1923	White	1959	50
455	67	White	1960	48
456	188	White	1960	45
457	446	White	1960	48
458	1445	White	1960	46
459	1933	White	1960	52
460	2061	White	1960	49
461	2068	White	1960	49
462	2103	White	1960	44
463	21	White	1961	49
464	1146	White	1961	47
465	1271	White	1961	47
466	2129	White	1961	41
467	1248	White	1962	48

(Table 10: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
468	1481	White	1962	52
469	2095	White	1962	44
470	2289	White	1962	47
471	763	White	1963	48
472	1089	White	1963	49
473	1888	White	1963	48
474	760	White	1964	45
475	1086	White	1964	46
476	1577	White	1964	48
477	1962	White	1964	44
478	2035	White	1964	47
479	1104	White	1965	50
480	1279	White	1965	45
481	1228	White	1966	45
482	1571	White	1967	51
483	1976	White	1967	47
484	844	White	1968	49
485	1893	White	1968	48
486	1924	White	1968	48
487	2309	White	1968	46
488	1108	White	1969	46
489	1203	White	1969	47
490	1416	White	1969	51
491	1140	White	1970	55
492	1200	White	1970	47
493	1229	White	1970	47
494	1307	White	1970	50
495	1417	White	1970	49
496	1449	White	1970	49
497	1400	White	1971	52
498	1230	White	1973	50
499	1241	White	1973	46
500	1427	White	1975	49
501	1884	White	1975	46
502	1551	White	1976	48
503	1421	White	1978	47

(Table 10: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
504	2219	White	1979	49
505	2223	White	1982	48
506	1981	White	1983	50
507	T-1394	Black	1837	49
508	T-438	Black	1840	51
509	T-703	Black	1841	47
510	T-1200	Black	1842	46
511	T-998	Black	1842	44
512	T-1117	Black	1848	45
513	T-560	Black	1848	42
514	T-1349	Black	1849	48
515	T-278	Black	1849	53
516	T-796	Black	1849	49
517	T-1115	Black	1850	50
518	T-503	Black	1851	48
519	T-1490	Black	1853	54
520	T-790	Black	1853	46
521	T-609	Black	1854	47
522	T-773	Black	1854	48
523	T-993	Black	1854	45
524	T-1240	Black	1856	49
525	T-1445	Black	1856	51
526	T-1012	Black	1858	56
527	T-1108	Black	1858	47
528	T-1144	Black	1858	52
529	T-340	Black	1859	49
530	T-700	Black	1859	47
531	T-958	Black	1859	47
532	T-1395	Black	1860	50
533	T-445	Black	1860	49
534	T-461	Black	1860	48
535	T-467	Black	1860	52
536	T-500	Black	1860	51
537	T-1280	Black	1862	48
538	T-1128	Black	1868	47
539	T-618	Black	1869	51

(Table 10: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
540	T-1245	Black	1871	46
541	T-757	Black	1871	48
542	T-1224	Black	1873	51
543	T-1277	Black	1875	47
544	T-143	Black	1878	45
545	T-811	Black	1879	48
546	T-1281	Black	1881	50
547	T-771	Black	1881	46
548	T-1002	Black	1882	45
549	T-724	Black	1887	47
550	T-698	Black	1889	48
551	T-1035	Black	1890	48
552	T-684	Black	1893	49
553	T-425	Black	1894	48
554	T-549	Black	1894	48
555	T-565	Black	1896	45
556	T-619	Black	1896	48
557	T-1489	Black	1897	46
558	T-1285	Black	1898	48
559	990	Black	1900	48
560	999	Black	1900	46
561	T-1397	Black	1900	46
562	T-782	Black	1900	46
563	991	Black	1901	50
564	1351	Black	1901	47
565	1008	Black	1902	49
566	1072	Black	1902	45
567	T-1131	Black	1902	49
568	659	Black	1903	47
569	771	Black	1903	49
570	994	Black	1903	48
571	1002	Black	1903	48
572	1352	Black	1903	49
573	1662	Black	1903	48
574	1175	Black	1904	47
575	1346	Black	1904	45

(Table 10: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
576	1359	Black	1904	51
577	T-222	Black	1904	48
578	T-595	Black	1904	46
579	988	Black	1905	46
580	1077	Black	1905	45
581	1348	Black	1905	52
582	1345	Black	1906	48
583	1343	Black	1907	45
584	540	Black	1908	48
585	660	Black	1908	52
586	983	Black	1908	47
587	1340	Black	1908	42
588	522	Black	1909	46
589	843	Black	1909	46
590	847	Black	1909	48
591	1007	Black	1909	47
592	2060	Black	1909	50
593	1012	Black	1910	42
594	1069	Black	1910	44
595	1335	Black	1910	47
596	782	Black	1911	53
597	997	Black	1911	48
598	998	Black	1911	46
599	1336	Black	1911	50
600	1355	Black	1911	45
601	31	Black	1912	45
602	592	Black	1912	51
603	1194	Black	1912	48
604	1328	Black	1912	50
605	1339	Black	1912	48
606	109	Black	1913	57
607	513	Black	1913	49
608	1338	Black	1913	48
609	1358	Black	1913	49
610	1350	Black	1914	48
611	1354	Black	1915	51

(Table 10: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
612	1193	Black	1916	47
613	1247	Black	1916	49
614	T-30R	Black	1916	47
615	523	Black	1917	46
616	1192	Black	1917	47
617	324	Black	1918	48.5
618	1360	Black	1918	47
619	329	Black	1919	47
620	38	Black	1920	50
621	591	Black	1920	51
622	995	Black	1920	47
623	1114	Black	1920	48
624	1213	Black	1922	47
625	1450	Black	1922	50
626	786	Black	1923	54
627	2063	Black	1925	52
628	1022	Black	1927	43
629	2216	Black	1927	47
630	1014	Black	1928	49
631	1367	Black	1928	44
632	1406	Black	1928	50
633	1020	Black	1929	45
634	1277	Black	1930	49
635	2214	Black	1930	49
636	2002	Black	1931	48
637	1407	Black	1932	45
638	1264	Black	1933	44
639	1660	Black	1933	47
640	411	Black	1934	49
641	1205	Black	1934	49
642	16	Black	1935	51
643	1180	Black	1935	49
644	542	Black	1936	47
645	1150	Black	1936	44
646	1439	Black	1938	50
647	713	Black	1939	49

(Table 10: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
648	1095	Black	1939	48
649	1181	Black	1939	45
650	2084	Black	1940	49
651	1124	Black	1942	48
652	516	Black	1943	51
653	1527	Black	1943	50
654	849	Black	1944	48
655	1231	Black	1944	46
656	1839	Black	1944	53
657	547	Black	1945	47
658	716	Black	1945	52
659	1260	Black	1945	43
660	1402	Black	1947	47
661	1430	Black	1947	50
662	2011	Black	1947	47
663	2285	Black	1947	48
664	1308	Black	1948	47
665	1879	Black	1948	52
666	525	Black	1949	46
667	2050	Black	1950	50
668	2019	Black	1951	48
669	1220	Black	1952	46
670	1403	Black	1952	48
671	682	Black	1954	54
672	2224	Black	1954	47
673	1476	Black	1955	47
674	2105	Black	1955	49
675	1273	Black	1957	43
676	1399	Black	1957	40
677	759	Black	1958	49
678	2300	Black	1958	48
679	580	Black	1959	45
680	848	Black	1959	50
681	587	Black	1960	48
682	1325	Black	1960	51
683	1398	Black	1960	48

(Table 10: Continued)

Observation	ID Number	Ethnicity	Year of Birth	Maximum Vertical Head Diameter
684	1587	Black	1960	44
685	482	Black	1961	50
686	726	Black	1961	48
687	1092	Black	1961	49
688	1182	Black	1963	48
689	1526	Black	1963	46
690	2213	Black	1963	49
691	2134	Black	1965	44
692	1123	Black	1966	45
693	1522	Black	1966	46
694	1995	Black	1967	49
695	1523	Black	1969	47
696	1581	Black	1969	43
697	1132	Black	1970	47
698	1310	Black	1970	48
699	1126	Black	1971	47
700	1548	Black	1971	46
701	1737	Black	1975	48

Appendix 2 – Maximum Femoral Head Diameter Averages

Table 11: Maximum Vertical Head Diameter Average Measures by Five Year Year-of-Birth Interval for Males

5 Year Year-of-Birth Interval	Average Vertical Head Diameter	*n*
1835	49	1
1840	46	7
1845	48	13
1850	49	29
1855	49	17
1860	49	8
1865	50	3
1870	50	5
1875	48	6
1880	48	6
1885	48	5
1890	50	9
1895	48	15
1900	48	43
1905	48	35
1910	49	42
1915	49	37
1920	49	47
1925	48	34
1930	49	44
1935	49	55
1940	49	42
1945	49	43
1950	49	46
1955	47	36
1960	47	34
1965	47	18
1970	49	13
1975	48	6
1980	49	2
	Total male sample size =	701

Table 12: Maximum Vertical Head Diameter Average Measures by Five Year Year-of-Birth Interval for Females

5 Year Year-of-Birth Interval	Average Vertical Head Diameter	*n*
1840	42	4
1845	41	7
1850	42	4 1
1855	42	0 1
1860	42	24
1865	43	24
1870	43	6
1875	41	9
1880	43	4
1885	42	19
1890	42	18
1895	43	25
1900	43	32
1905	43	29
1910	43	35
1915	43	39
1920	42	22
1925	42	25
1930	41	17
1935	42	12
1940	43	19
1945	42	18
1950	42	18
1955	42	28
1960	42	24
1965	41	16
1970	42	13
1975	40	4
1980	41	1
	Total Female sample size =	516

Appendix 3 – Normality Test Results

Table 13: D'Agostino Normality Test Results for Male Sample

Test Name	Test Value	Prob Level	5% Critical Value	Decision -5%
Shapiro-Wilk W	0.984728	1.08E-06		Reject normality
Anderson-Darling	4.67081	1.44E-11		Reject normality
Martinez-Iglewicz	1.028235		1.011735	Reject normality
Kolmogorov-Smirnov	9.10E-02		0.034	Reject normality
D'Agostino Skewness	1.403605	0.160436	1.96	Can't reject normality
D'Agostino Kurtosis	2.0192	0.04347	1.96	Reject normality
D'Agostino Omnibus	6.0471	0.048627	5.991	Reject normality

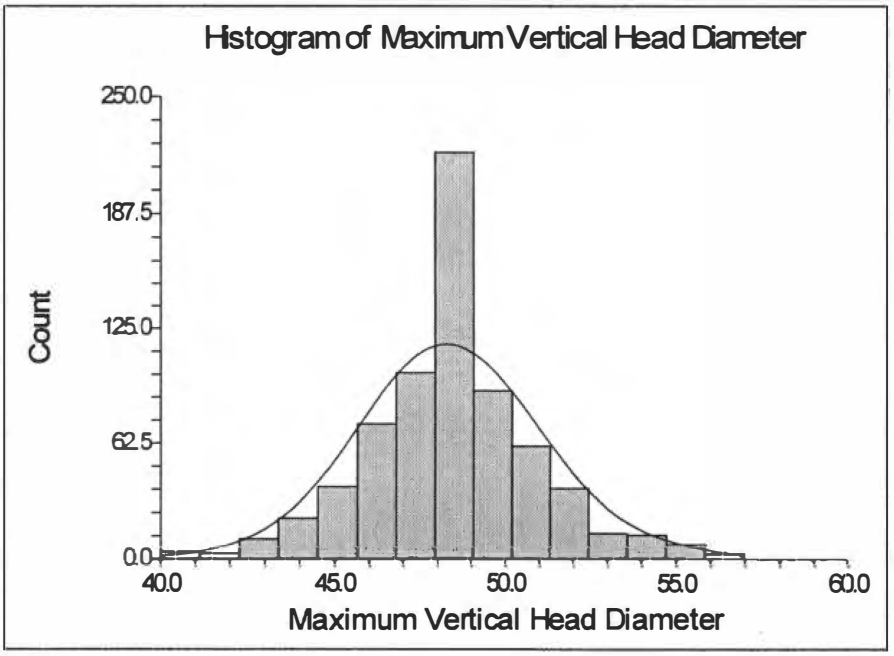

Figure 3: Histogram of Male Maximum Vertical Head Diameter Averages with Normality Curve

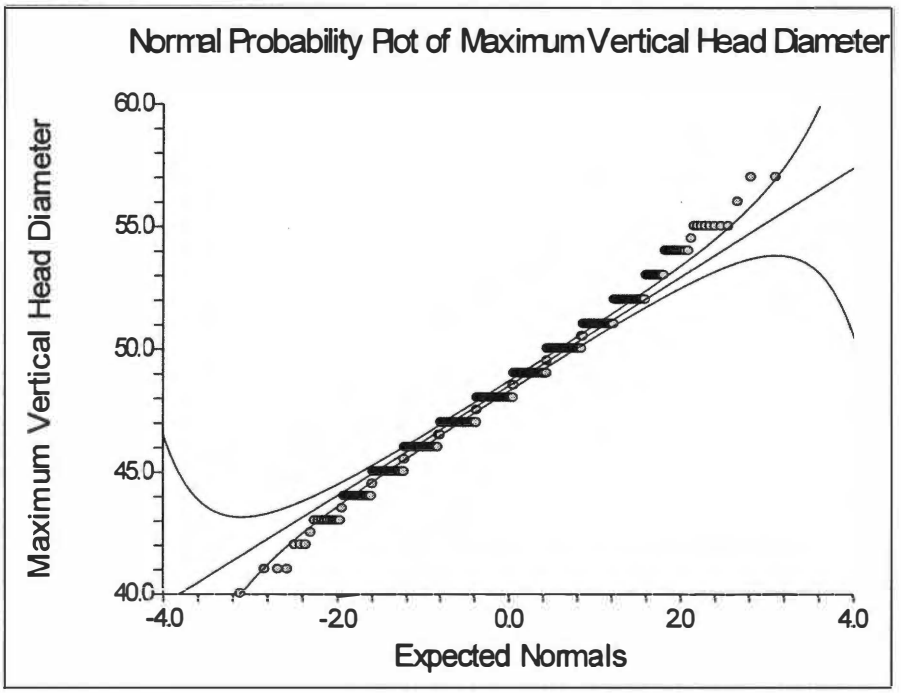

Figure 4: Normal Probability Plot of Male Maximum Vertical Head Diameter Averages

Table 14: D'Agostino Normality Test Results for Female Sample

Test Name	Test Value	Prob Level	5% Critical Value	Decision -5%
Shapiro-Wilk W	0.979823	1.45E-06		Reject normality
Anderson-Darling	4.347021	8.64E-11		Reject normality
Martinez-Iglewicz	0.985469		1.017039	Can't reject normality
Kolmogorov-Smirnov	0.104194		0.04	Reject normality
D'Agostino Skewness	-0.14829	0.882114	1.96	Can't reject normality
D'Agostino Kurtosis	1.8194	0.068846	1.96	Can't reject normality
D'Agostino Omnibus	3.3323	0.188971	5.991	Can't reject normality

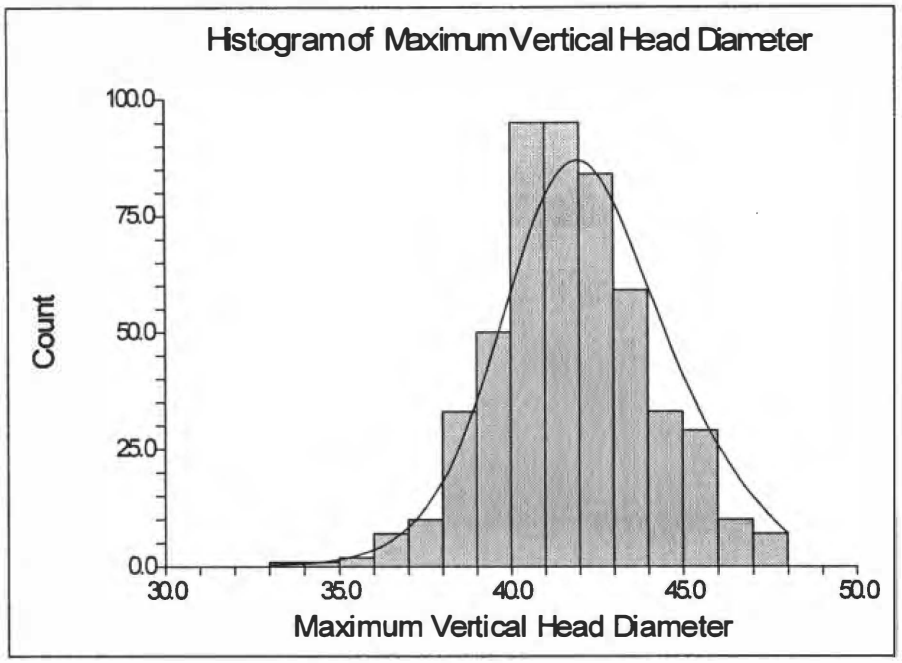

Figure 5: Histogram of Female Maximum Vertical Head Diameter Averages with Normality Curve

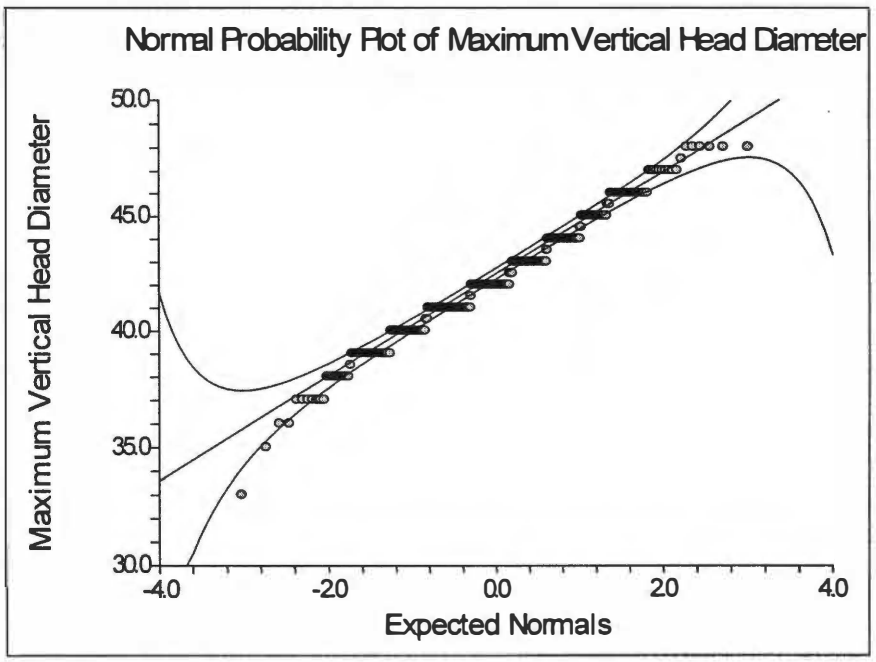

Figure 6: Normal Probability Plot of Female Maximum Vertical Head Diameter Averages

Appendix 4 – Autocorrelation Reports

Table 15: Autocorrelations of Male Averages (0,0,12,1,0)

Lag	Correlation	Lag	Correlation	Lag	Correlation	Lag	Correlation
1	0.284783	8	0.055041	15	0.060449	22	-0.004486
2	0.031012	9	-0.021376	16	0.168592	23	0.16154
3	-0.279095	10	-0.054103	17	0.037427	24	0.121942
4	-0.138371	11	0.033755	18	-0.110219	25	0.1158
5	-0.223025	12	0.089747	19	-0.29186	26	-0.040642
6	-0.125934	13	0.009582	20	-0.213795	27	0.04884
7	-0.00306	14	0.033503	21	-0.187131		
Significant if |Correlation|> 0.365148							

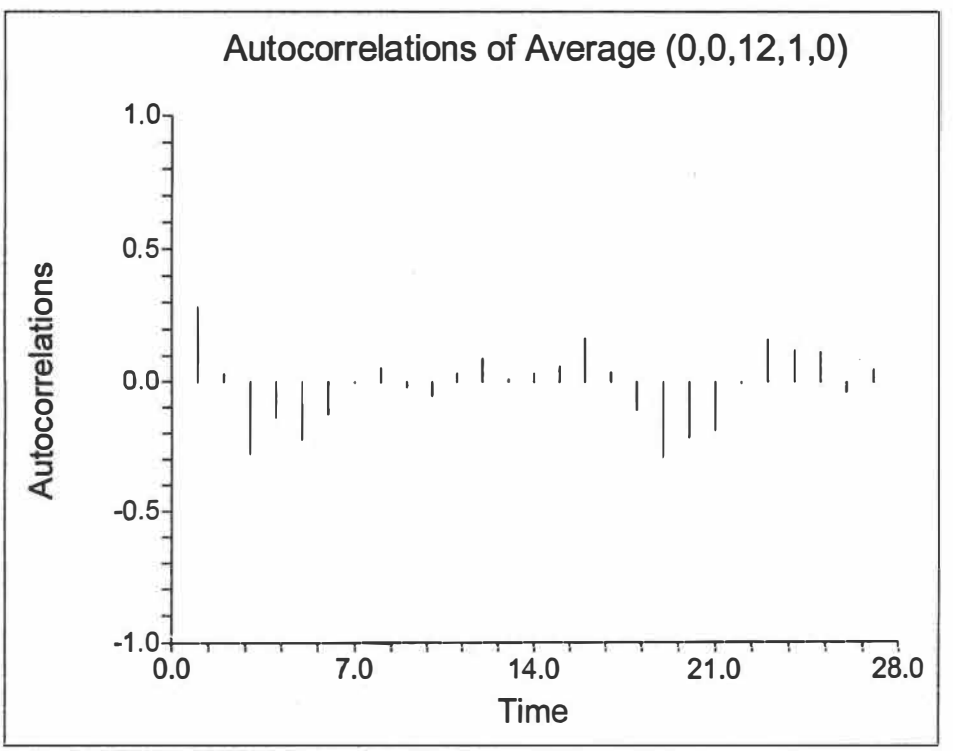

Figure 7: Autocorrelation of Male Averages Plot

Table 16: Partial Autocorrelations of Male Averages (0,0,12,1,0)

Lag	Correlation	Lag	Correlation	Lag	Correlation	Lag	Correlation
1	0.284783	8	-0.083382	15	0.052154	22	-0.044437
2	-0.05451	9	-0.126437	16	0.150586	23	0.061106
3	-0.297854	10	-0.057785	17	0.018972	24	-0.177952
4	0.029527	11	0.026141	18	-0.121578	25	0.033514
5	-0.206135	12	0.022284	19	-0.195229	26	-0.085977
6	-0.113817	13	-0.082335	20	-0.0633	27	0.016796
7	0.054784	14	0.050364	21	-0.129739		

Significant if |Correlation|> 0.365148

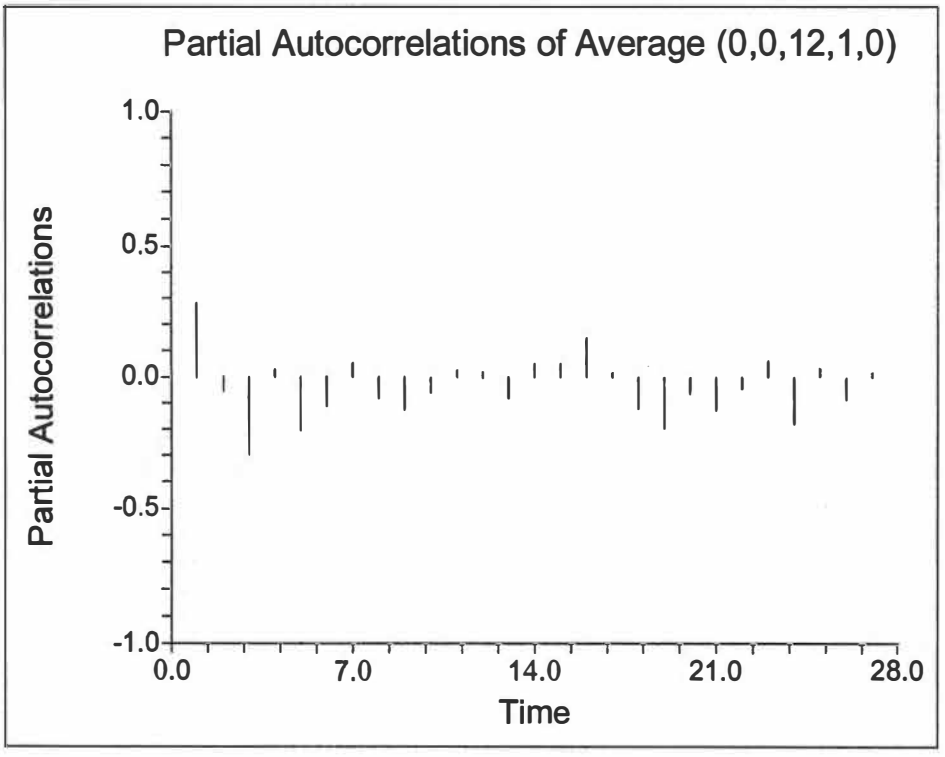

Figure 8: Partial Autocorrelation of Male Averages Plot

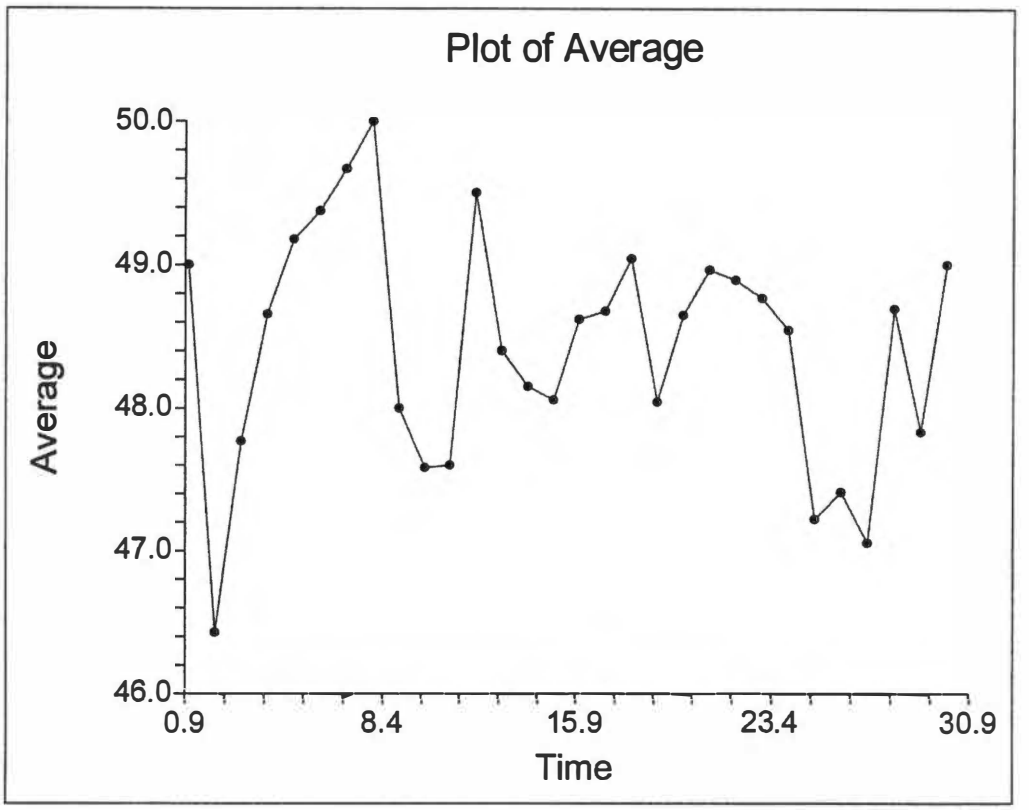

Figure 9: Data Plot of Male Averages

Table 17: Serial Correlation of Residuals for Males

Lag	Serial Correlation	Lag	Serial Correlation	Lag	Serial Correlation
1	0.2678	9	-0.0035	17	0.0455
2	-0.0084	10	-0.0502	18	-0.0969
3	-0.3378	11	0.0289	19	-0.2959
4	-0.1807	12	0.1018	20	-0.2037
5	-0.2506	13	0.0142	21	-0.1596
6	-0.1296	14	0.0339	22	0.0398
7	0.0082	15	0.056	23	0.2001
8	0.082	16	0.1728	24	0.1511

Above serial correlations significant if their absolute values are greater than 0.365148

Table 18: Durbin-Watson Test for Serial Correlation for Males

Parameter	Value	Did the Test Reject H0: Rho(1) = 0?
Durbin-Watson Value	1.4262	
Prob. Level: Positive Serial Correlation	0.0478	Yes
Prob. Level: Negative Serial Correlation	0.9388	No

Table 19: Serial Correlation of Residuals for Females

Lag	Serial Correlation	Lag	Serial Correlation	Lag	Serial Correlation
1	-0.0847	9	0.2957	17	0.1412
2	-0.0954	10	-0.1879	18	0.0538
3	0.157	11	0.1335	19	-0.1587
4	-0.2256	12	0.0314	20	0.1778
5	-0.3731	13	-0.239	21	-0.0134
6	0.1093	14	0.0083	22	-0.0674
7	-0.208	15	0.0746	23	0.0025
8	0.0894	16	-0.1541	24	0.0823

Above serial correlations significant if their absolute values are greater than 0.371391

Table 20: Durbin-Watson Test for Serial Correlation for Females

Parameter	Value	Did the Test Reject H0: Rho(1) = 0?
Durbin-Watson Value	2.1351	
Prob. Level: Positive Serial Correlation	0.4806	No
Prob. Level: Negative Serial Correlation	0.3721	No

Appendix 5 – Linear Regression Report

Table 21: Run Summary

Statistic	Result	Statistic	Result
Dependent Variable	Lag Difference	**Rows Processed**	54
Independent Variable	Five Year Interval	**Rows Used in Estimation**	29
Frequency Variable	None	**Rows with X Missing**	24
Weight Variable	None	**Rows with Freq Missing**	0
Intercept	-3.2415	**Rows Prediction Only**	1
Slope	0.0017	**Sum of Frequencies**	29
R-Squared	0.0053	**Sum of Weights**	29
Correlation	0.073	**Coefficient of Variation**	
Mean Square Error	1.010823	**Square Root of MSE**	1.005397

Table 22: Descriptive Statistics

Parameter Variable	Dependent Lag Difference	Independent Five Year Interval
Count	29	29
Mean	0	1910
Standard Deviation	0.9899	42.5735
Minimum	-2.5714	1840
Maximum	1.9	1980

Table 23: Regression Estimation

Parameter	Intercept B(0)	Slope B(1)
Regression Coefficients	-3.2415	0.0017
Lower 95% Confidence Limit	-20.7358	-0.0075
Upper 95% Confidence Limit	14.2529	0.0109
Standard Error	8.5262	0.0045
Standardized Coefficient	0	0.073
T Value	-0.3802	0.3803
Prob Level (T Test)	0.7068	0.7067
Reject H0 (Alpha = 0.0500)	No	No
Power (Alpha = 0.0500)	0.0656	0.0656
Regression of Y on X	-3.2415	0.0017
Inverse Regression from X on Y	-608.484	0.3186
Orthogonal Regression of Y and X	-3.2432	0.0017

Table 24: Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power-5%
Intercept	1	1.53E-32	1.53E-32			
Slope	1	0.146167	0.146167	0.1446	0.7067	0.0656
Error	27	27.29222	1.010823			
Adj. Total	28	27.43839	0.979943			
Total	29	27.43839				
s = Square Root(1.010823) = 1.005397						

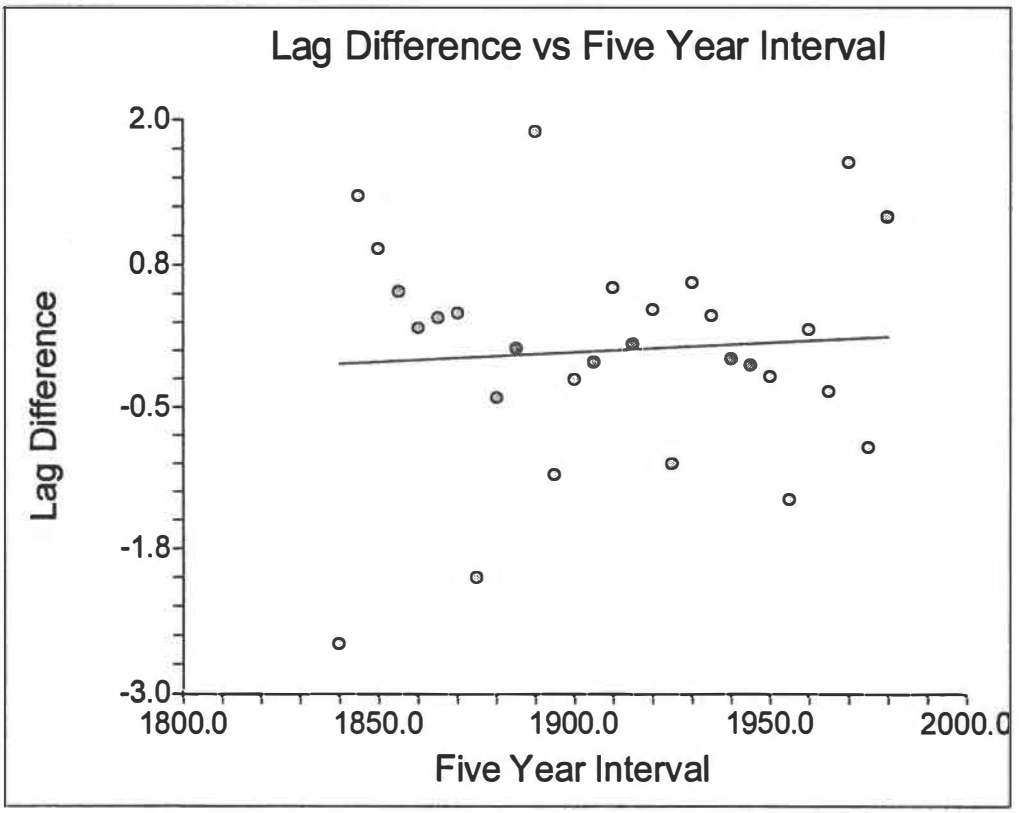

Figure 10: Linear Regression Plot

Appendix 6 – Scatterplots

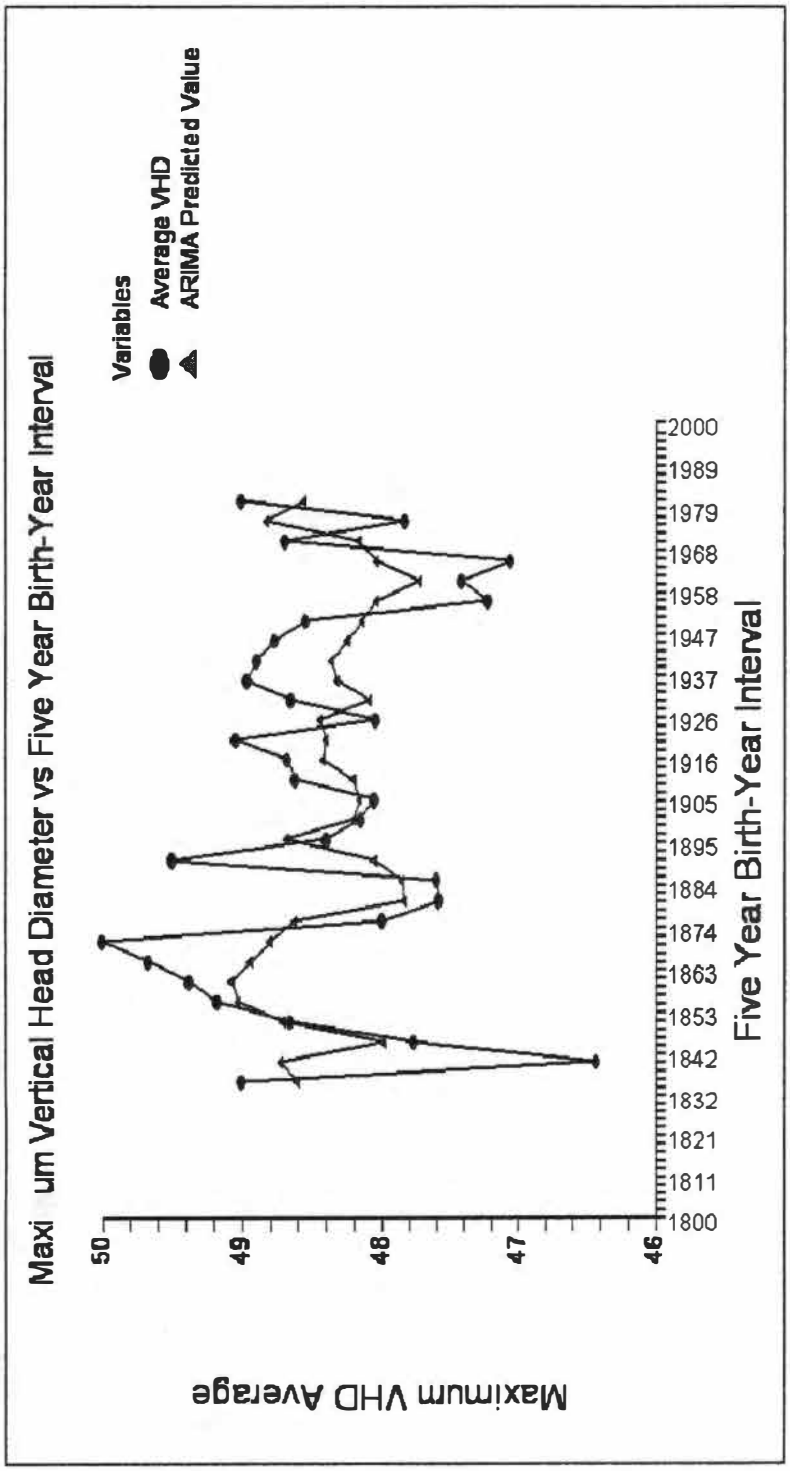

Figure 11: Scatterplot of Male Averages

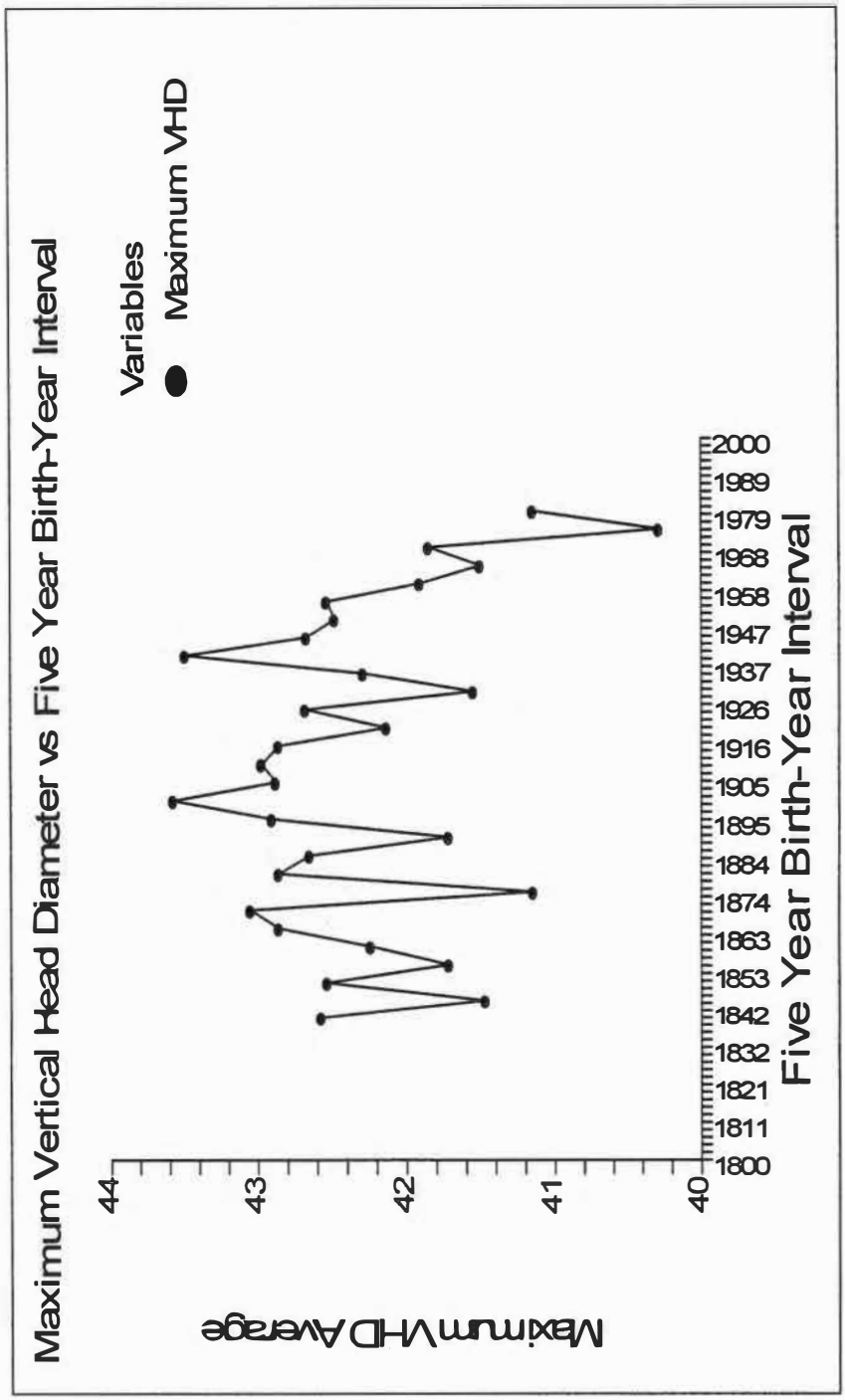

Figure 12: Scatterplot of Female Averages

Appendix 7 – Autoregressive Integrated Moving Average (ARIMA) Report

Table 25: Minimization Phase

Itn No.	Error Sum of Squares	Lambda	AR(1)	AR(2)	MA(1)
0	19.79687	0.1	0.1	0.1	0.1
1	18.01275	0.1	0.105903	-1.92E-02	-0.16003
2	17.8913	0.04	0.324342	-4.43E-02	2.06E-02
3	17.59583	0.016	0.600143	-0.16453	0.285652
4	1.90E+09	0.0064	1.464376	-0.46522	1.159632
5	17.2324	0.064	0.725278	-0.26064	0.406529
6	16.36202	0.0256	1.101802	-0.39247	0.798529
7	16.02843	0.01024	1.180074	-0.44603	0.898859
8	15.96193	0.004096	1.178066	-0.4294	0.921055
9	15.93283	0.001638	1.179628	-0.4251	0.933583
10	15.9261	6.55E-04	1.178944	-0.42417	0.939469
11	15.92627	2.62E-04	1.178312	-0.42404	0.94236
12	15.92626	2.62E-03	1.178316	-0.42404	0.942352
13	15.92621	0.026214	1.178352	-0.42413	0.942281
14	15.92587	0.262144	1.178428	-0.42449	0.941732
15	15.92704	0.104858	1.178166	-0.42433	0.943369
16	15.92631	1.048576	1.17821	-0.42467	0.942602
17	15.92591	10.48576	1.178347	-0.42458	0.941889
18	15.92588	104.8576	1.178418	-0.4245	0.941749
19	15.92587	1048.576	1.178427	-0.42449	0.941733
20	15.92587	10485.76	1.178428	-0.42449	0.941732
21	15.92587	104857.6	1.178428	-0.42449	0.941732
22	15.92587	1048576	1.178428	-0.42449	0.941732
23	15.92587	1.05E+07	1.178428	-0.42449	0.941732
24	15.92587	1.05E+08	1.178428	-0.42449	0.941732
25	15.92587	1.05E+09	1.178428	-0.42449	0.941732
26	15.92587	1.05E+10	1.178428	-0.42449	0.941732
27	15.92587	1.05E+11	1.178428	-0.42449	0.941732
28	15.92587	1.05E+12	1.178428	-0.42449	0.941732

Normal convergence.

Table 26: Model Description

Statistic	Result	
Series		Average VHD-MEAN
Model	Regular(2,0,1)	Seasonal(No seasonal parameters)
Mean		48.42582
Observations		30
Iterations		28
Pseudo R-Squared		18.92273
Residual Sum of Squares		15.92587
Mean Square Error		0.589847
Root Mean Square		0.768015

Table 27: Model Estimation

Parameter	Parameter Estimate	Standard Error	T-Value	Prob Level
AR(1)	1.178428	0.173521	6.7913	0.000000
AR(2)	-0.42449	0.179631	-2.3631	0.018122
MA(1)	0.941732	0.037197	25.3172	0.000000

Table 28: Asymptotic Correlation Matrix of Parameters

	AR(1)	AR(2)	MA(1)
AR(1)	1	-0.82061	0.01808
AR(2)	-0.82061	1	0.123231
MA(1)	0.01808	0.123231	1

Table 29: Portmanteau Test of Average Vertical Head Diameter-Mean

Lag	DF	Portmanteau Test Value	Prob Level	p-value	Decision (0.05)
4	1	2.26	0.132747	0.688045	Adequate Model
5	2	3.2	0.202178	0.669612	Adequate Model
6	3	3.59	0.308798	0.73145	Adequate Model
7	4	3.6	0.462896	0.824566	Adequate Model
8	5	3.75	0.586253	0.879123	Adequate Model
9	6	3.83	0.699706	0.922258	Adequate Model
10	7	4.11	0.766737	0.942131	Adequate Model
11	8	4.12	0.846002	0.966228	Adequate Model
12	9	4.37	0.885451	0.975808	Adequate Model
13	10	4.5	0.921965	0.984612	Adequate Model
14	11	4.5	0.952911	0.991618	Adequate Model
15	12	4.67	0.968014	0.99455	Adequate Model
16	13	5.42	0.96465	0.993213	Adequate Model
17	14	5.57	0.976103	0.995618	Adequate Model
18	15	5.9	0.981332	0.996575	Adequate Model
19	16	9.4	0.895803	0.966131	Adequate Model
20	17	9.69	0.916248	0.973511	Adequate Model
21	18	12.18	0.837908	0.934685	Adequate Model
22	19	12.37	0.869261	0.949287	Adequate Model
23	20	15.64	0.738445	0.870077	Adequate Model
24	21	16.05	0.766797	0.886238	Adequate Model
25	22	20.27	0.56627	0.732621	Adequate Model
26	23	21.74	0.535763	0.702632	Adequate Model
27	24	29.93	0.186956	0.317137	Adequate Model

Table 30: Forecast of Average Vertical Head Diameter

Row	Date	Actual	Residual	Forecast	Lower 95% Limit	Upper 95% Limit
1	1	49	0.4	48.6	47.1	50.2
2	2	46.4	-2.3	48.7	47.2	50.3
3	3	47.8	-0.2	48	46.4	49.5
4	4	48.7	-0.1	48.7	47.2	50.3
5	5	49.2	0.1	49	47.5	50.6
6	6	49.4	0.3	49.1	47.5	50.6
7	7	49.7	0.7	48.9	47.4	50.5
8	8	50	1.2	48.8	47.3	50.3
9	9	48	-0.6	48.6	47.1	50.2
10	10	47.6	-0.3	47.8	46.3	49.4
11	11	47.6	-0.3	47.9	46.3	49.4
12	12	49.5	1.4	48.1	46.5	49.6
13	13	48.4	-0.3	48.7	47.1	50.2
14	14	48.2	-0.1	48.2	46.7	49.8
15	15	48.1	-0.1	48.2	46.6	49.7
16	16	48.6	0.4	48.2	46.7	49.8
17	17	48.7	0.3	48.4	46.9	50
18	18	49	0.6	48.4	46.9	49.9
19	19	48	-0.4	48.4	46.9	50
20	20	48.6	0.6	48.1	46.5	49.6
21	21	49	0.6	48.3	46.8	49.9
22	22	48.9	0.5	48.4	46.8	49.9
23	23	48.8	0.5	48.2	46.7	49.8
24	24	48.5	0.4	48.1	46.6	49.7
25	25	47.2	-0.8	48	46.5	49.6
26	26	47.4	-0.3	47.7	46.2	49.3
27	27	47.1	-1	48	46.5	49.6
28	28	48.7	0.5	48.2	46.6	49.7
29	29	47.8	-1	48.8	47.3	50.4
30	30	49	0.4	48.6	47	50.1
31	31			48.9	47.4	50.5
32	32			48.8	47.2	50.3
33	33			48.6	47	50.2
34	34			48.5	46.9	50.2
35	35			48.4	46.8	50.1
36	36			48.4	46.7	50.1
37	37			48.4	46.7	50.1
38	38			48.4	46.7	50.1
39	39			48.4	46.7	50.1
40	40			48.4	46.7	50.1
41	41			48.4	46.7	50.1
42	42			48.4	46.7	50.1
43	43			48.4	46.7	50.1
44	44			48.4	46.7	50.1
45	45			48.4	46.7	50.1

(Table 30: Continued)

Row	Date	Actual	Residual	Forecast	Lower 95% Limit	Upper 95% Limit
46	46			48.4	46.7	50.1
47	47			48.4	46.7	50.1
48	48			48.4	46.7	50.1
49	49			48.4	46.7	50.1
50	50			48.4	46.7	50.1
51	51			48.4	46.7	50.1
52	52			48.4	46.7	50.1
53	53			48.4	46.7	50.1
54	54			48.4	46.7	50.1

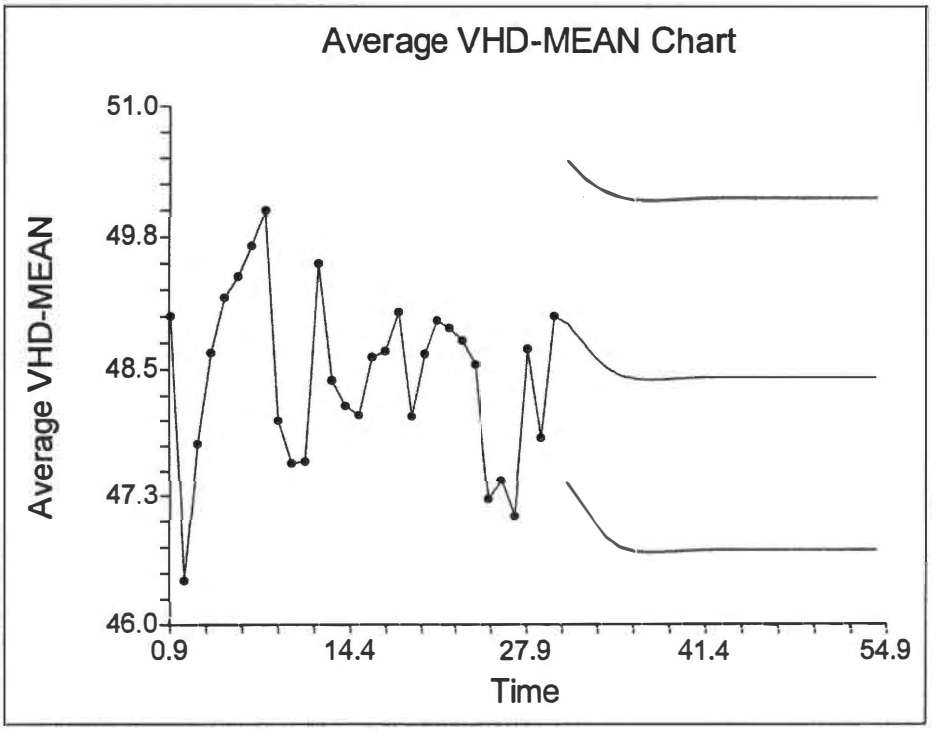

Figure 13: Forecast and Data Plot

Table 31: Autocorrelations of Residuals of Average Vertical Head Diameter-Mean

Lag	Correlation	Lag	Correlation	Lag	Correlation	Lag	Correlation
1	-0.05589	8	0.058296	15	-0.05187	22	-0.03987
2	0.106777	9	-0.04231	16	0.104605	23	0.154538
3	-0.20199	10	-0.07675	17	-0.04523	24	0.050411
4	0.092379	11	0.013343	18	-0.06407	25	0.148209
5	-0.15622	12	0.068204	19	-0.20032	26	-0.07841
6	-0.09957	13	-0.04813	20	-0.05413	27	0.159981
7	-0.01178	14	-0.00325	21	-0.15284		

Significant if |Correlation|> 0.365148

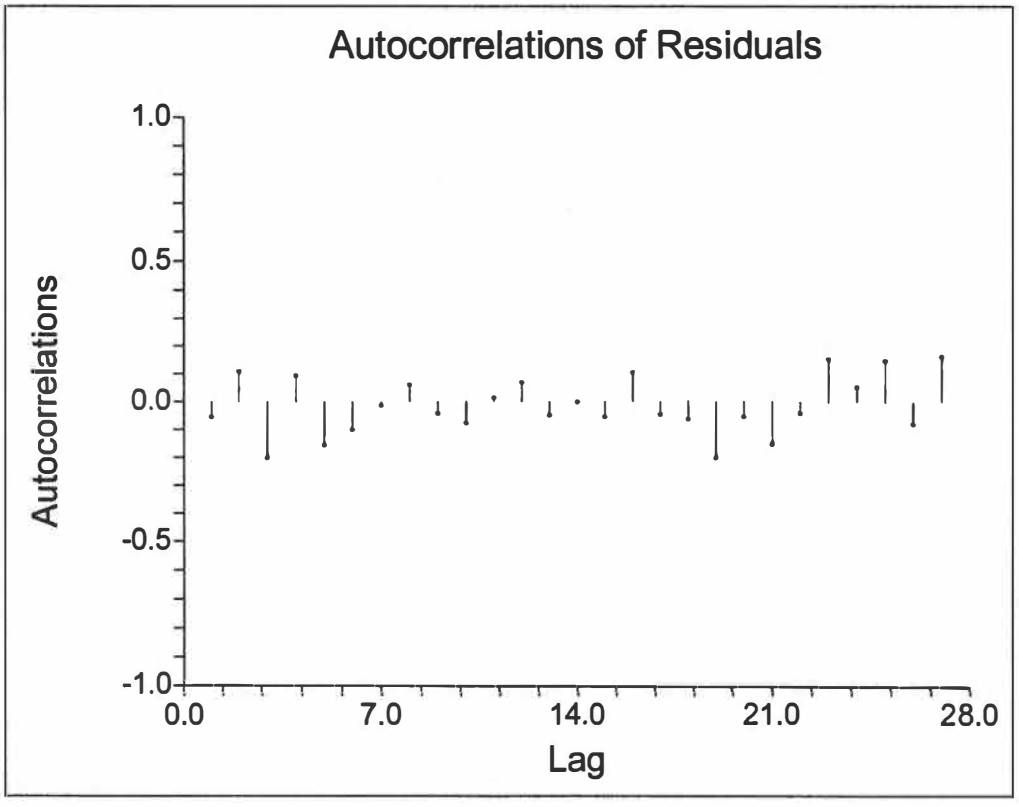

Figure 14: Autocorrelation Plot

Appendix 8 – Piecewise Polynomial Curve Fitting Results

Table 32: Minimization Phase

Itn No.	Error Sum Lambda	Lambda	A	B	C	D
0	45.26035	0.00004	2.464286	2.05E-02	0	1910
1	8.549057	0.000016	43.65346	-5.54E-04	-1.64E-02	1910
2	7.889566	6.4E-06	49.8369	-3.79E-03	-1.65E-02	1909.511
3	7.87941	2.56E-06	51.44427	-4.63E-03	-1.66E-02	1911.403
4	7.879376	1.02E-06	51.70869	-4.77E-03	-1.66E-02	1911.728
5	7.879375	0.04096	51.70848	-4.77E-03	-1.66E-02	1911.729
6	7.879375	0.016384	51.70831	-4.77E-03	-1.66E-02	1911.729
7	7.879375	0.065536	51.70822	-4.77E-03	-1.66E-02	1911.73
8	7.879375	0.026214	51.70816	-4.77E-03	-1.66E-02	1911.73
9	7.879375	0.104858	51.70813	-4.77E-03	-1.66E-02	1911.73
10	7.879375	0.41943	51.70811	-4.77E-03	-1.66E-02	1911.73
11	7.879375	0.167772	51.7081	-4.77E-03	-1.66E-02	1911.73
12	7.879375	0.671089	51.7081	-4.77E-03	-1.66E-02	1911.73
13	7.879375	0.268435	51.7081	-4.77E-03	-1.66E-02	1911.73
14	7.879375	1.073742	51.70809	-4.77E-03	-1.66E-02	1911.73

Convergence criterion met.

Table 33: Parameter Estimation

Parameter Name	Parameter Estimate	Asymptotic Standard Error	Lower 95% C.L.	Upper 95% C.L.
A	51.70809	10.25676	30.5839	72.83229
B	-4.77E-03	5.34E-03	-1.58E-02	6.24E-03
C	-1.66E-02	5.10E-03	-2.71E-02	-6.09E-03
D	1911.73	13.71354	1883.486	1939.974

Table 34: Model Estimation

Dependent Variable	Independent Variable	Model	R-squared	Iterations
Average	X5_Years	Average=Linear-Linear (X5_Years)	0.356182	14

Estimated Model = (51.70809)+(-4.765228E-03)*(X5_Years)+((X5_Years)-(1911.73))*(-1.658945E-02)*SIGN((X5_Years)-(1911.73))

Table 35: Common Model

J =	a1 =	b1 =	a2 =	b2 =
1911.73	19.99355	1.18E-02	83.42264	-2.14E-02
	if X5_Years<=J Average = a1 + b1(X5_Years)		if X5_Years>J then Average = a2 + b2(X5_Years)	

Table 36: Analysis of Variance

Source	DF	Sum of Squares	Mean Square
Mean	1	51167.85	51167.85
Model	4	51172.21	12793.05
Model (Adjusted)	3	4.359146	1.453049
Error	25	7.879375	0.315175
Total (Adjusted)	28	12.23852	
Total	29	51180.09	

Table 37: Asymptotic Correlation Matrix of Parameters

	A	B	C	D
A	1	-0.99979	-0.22735	0.884274
B	-0.99979	1	0.210139	-0.88385
C	-0.22735	0.210139	1	-0.20065
D	0.884274	-0.88385	-0.20065	1

Table 38: Predicted Values and Residuals

Row No.	Years	Average	Predicted Value	Lower 95.0% Value	Upper 95.0% Value	Residual
1	1840	42.25	41.75011	40.46331	43.03692	0.499888
2	1845	41.28571	41.80923	40.54613	43.07233	-0.52352
3	1850	42.21429	41.86835	40.62573	43.11098	0.345931
4	1855	41.5	41.92747	40.70193	43.15302	-0.42748
5	1860	41.95833	41.9866	40.7746	43.19859	-2.83E-02
6	1865	42.5	42.04572	40.84362	43.24781	0.454282
7	1870	42.66667	42.10484	40.90889	43.30079	0.561828
8	1875	41	42.16396	40.97036	43.35756	-1.16396
9	1880	42.5	42.22308	41.02801	43.41815	0.276919
10	1885	42.31579	42.2822	41.08184	43.48256	3.36E-02
11	1890	41.5	42.34132	41.13192	43.55073	-0.84132
12	1895	42.54	42.40044	41.17832	43.62257	0.139556
13	1900	43.125	42.45956	41.22115	43.69798	0.665435
14	1905	42.51724	42.51869	41.26056	43.77681	-1.44E-03
15	1910	42.6	42.57781	41.2967	43.85891	2.22E-02
16	1915	42.5	42.52843	41.30367	43.7532	-0.02844
17	1920	41.86364	42.42166	41.12527	43.71806	-0.55803
18	1925	42.34	42.31489	41.04792	43.58186	2.51E-02
19	1930	41.35294	42.20811	40.96562	43.45061	-0.85517
20	1935	42	42.10134	40.87809	43.3246	-0.10134
21	1940	43.05263	41.99457	40.78506	43.20408	1.058063
22	1945	42.33333	41.88779	40.68635	43.08924	0.445539
23	1950	42.16667	41.78102	40.58185	42.98019	0.385645
24	1955	42.21429	41.67425	40.47152	42.87697	0.540038
25	1960	41.66667	41.56747	40.35542	42.77953	0.099192
26	1965	41.3125	41.4607	40.23367	42.68773	-0.1482
27	1970	41.61538	41.35393	40.10648	42.60138	0.261457
28	1975	40.25	41.24715	39.97411	42.5202	-0.99715
29	1980	41	41.14038	39.83687	42.44389	-0.14038

Table 39: Portmanteau Test

Residuals	acf	acf squared	Cumulative Sum	*Q*	p-value
0.267518	-0.01153	4.75E-06	4.75E-06	0.00427	0.947900
-0.76575	-0.04392	7.14E-05	7.62E-05	0.068502	0.966329
0.348964	0.271444	0.002834	0.00291	2.616198	0.454657
-0.43825	-0.11581	0.000536	0.003447	3.098509	0.541478
0.083918	-0.26277	0.002877	0.006324	5.685003	0.338086
0.602062	0.190434	0.001577	0.0079	7.102489	0.311473
0.58126	-0.14721	0.000985	0.008885	7.98804	0.333650
-1.24654	0.067742	0.000219	0.009104	8.184494	0.415659
0.59573	0.27725	0.003843	0.012947	11.63968	0.234393
0.31915	-0.18527	0.001806	0.014754	13.26371	0.209299
-0.62664	0.076614	0.000326	0.01508	13.55686	0.258490
0.587598	-0.01417	1.18E-05	0.015092	13.56748	0.329176
1.053391	-0.2861	0.005116	0.020207	18.16647	0.151301
0.157351	-0.04365	0.000127	0.020334	18.28068	0.194295
0.231844	0.015874	1.80E-05	0.020352	18.29686	0.247381
0.165912	-0.21182	0.003451	0.023804	21.39962	0.163656
-0.44096	0.081148	0.000549	0.024353	21.89294	0.188871
0.214651	0.023714	5.11E-05	0.024404	21.9389	0.234709
-0.76597	-0.2109	0.004448	0.028852	25.93761	0.131937
0.084856	0.108198	0.001301	0.030152	27.10699	0.132281
1.143478	-0.02726	9.29E-05	0.030245	27.19053	0.164635
0.101776	-0.10948	0.001712	0.031957	28.72973	0.152740
-0.10209	-0.02652	0.000117	0.032075	28.8351	0.185839
0.042037	0.075023	0.001126	0.0332	29.84711	0.189871
-0.46664	-0.04562	0.00052	0.033721	30.31494	0.212713
-0.67433	0.080024	0.002135	0.035855	32.23397	0.185498
-0.17775					
-1.51492					
-0.44221					

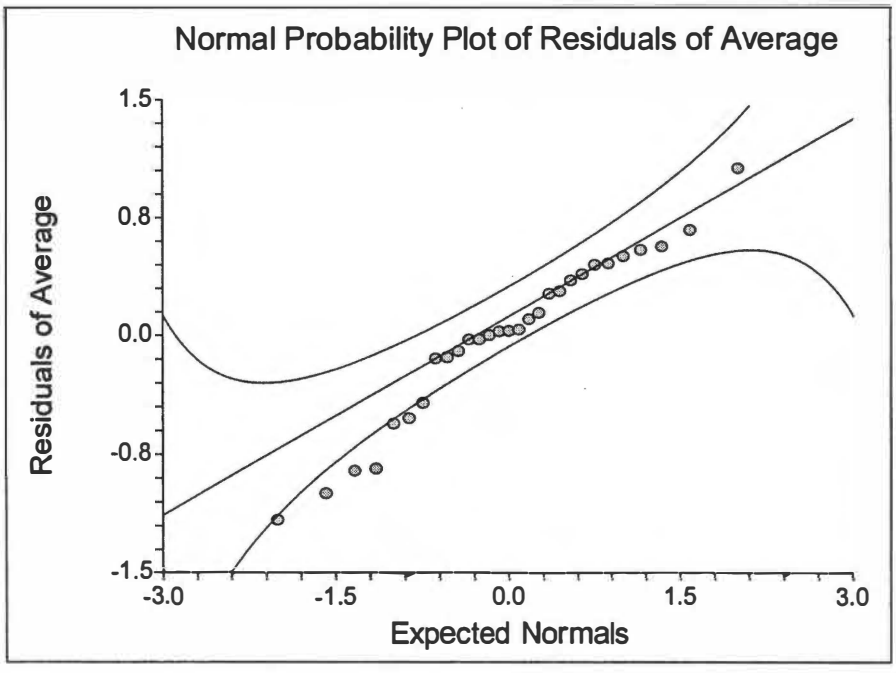

Figure 15: Normal Probability Plot of Residuals for Female Sample

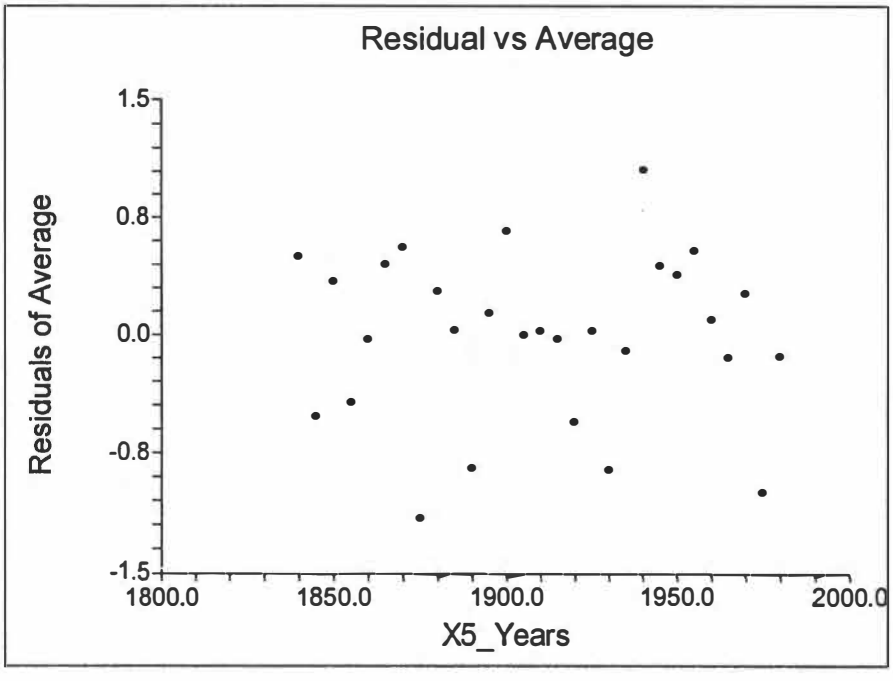

Figure 16: Plot of Residuals

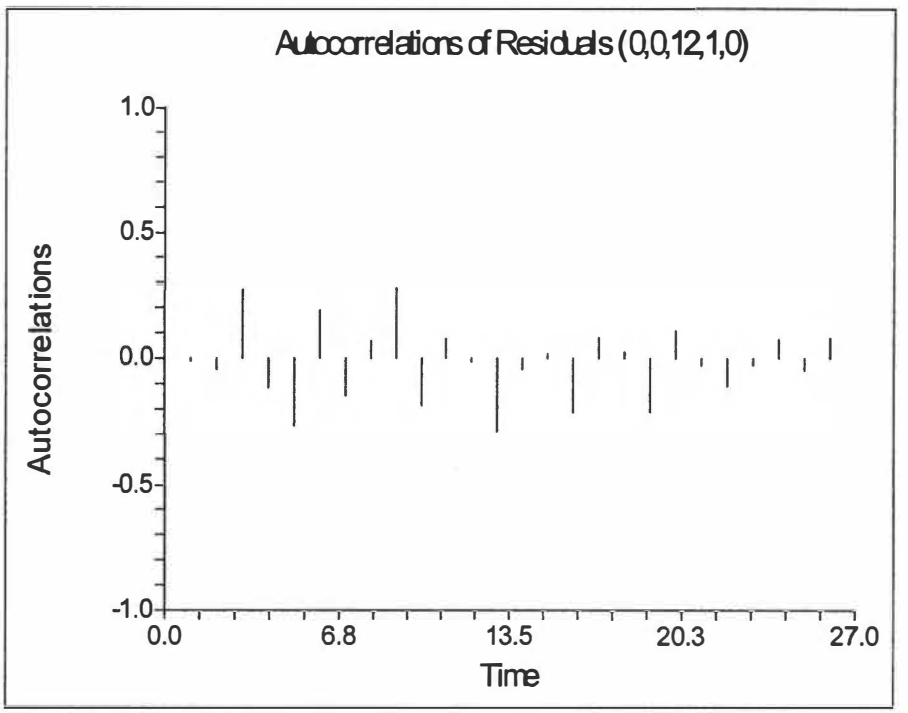

Figure 17: Autocorrelations of Residuals

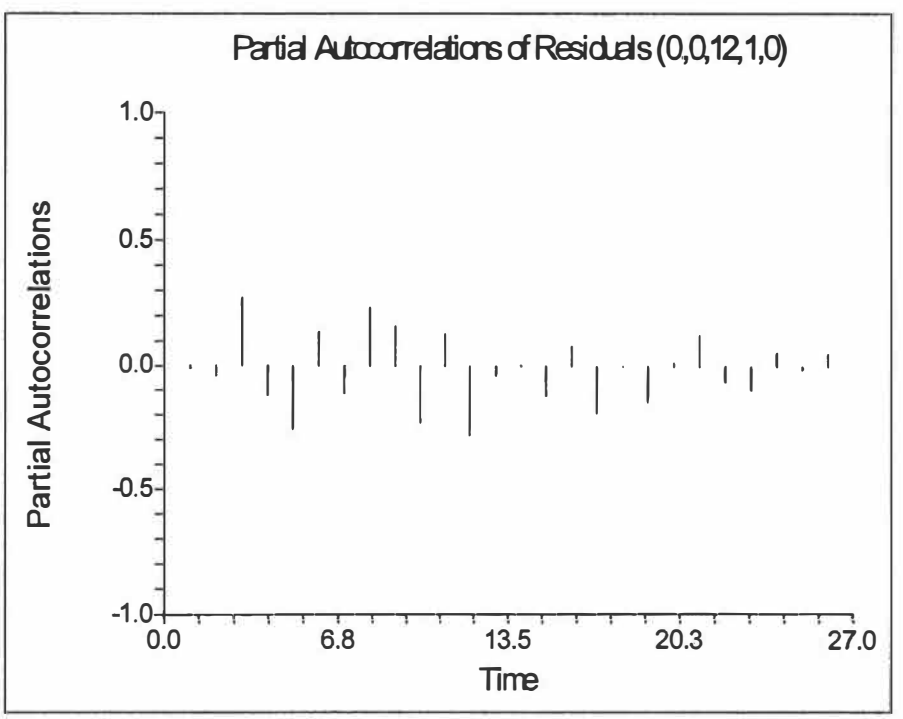

Figure 18: Partial Autocorrelations of Residuals

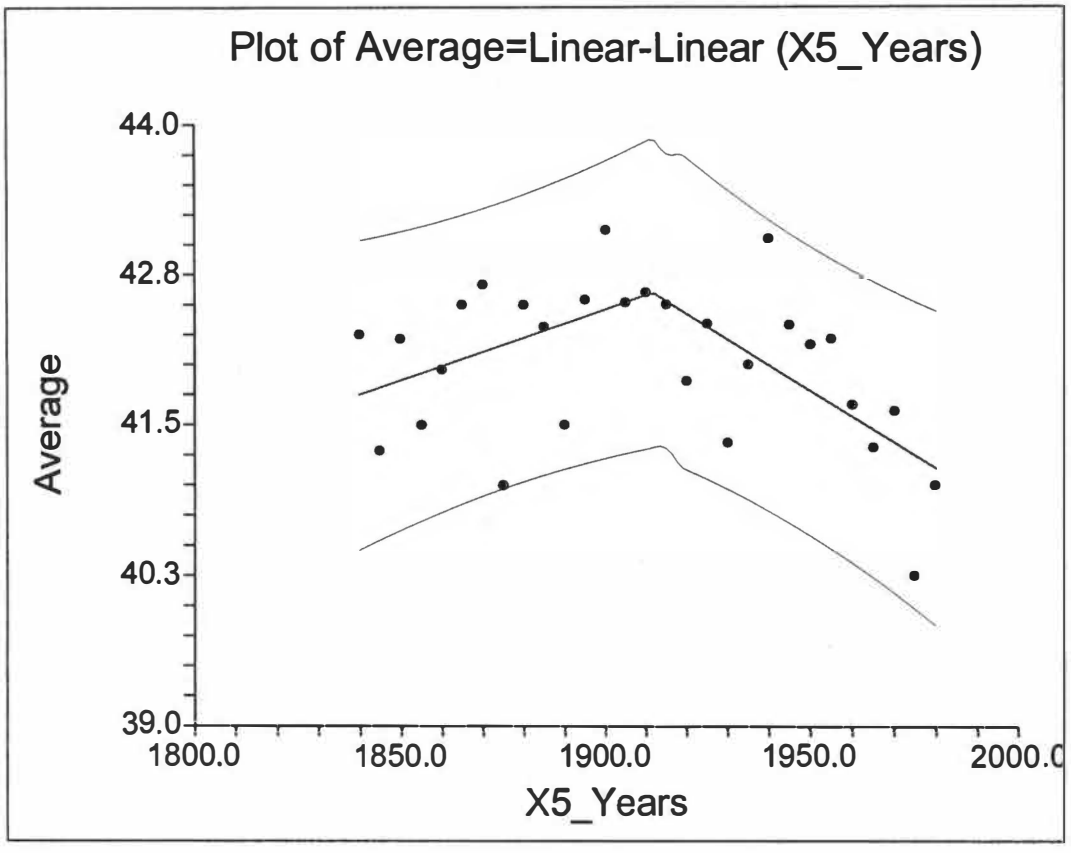

Figure 19: Plot of Linear-Linear Polynomial Curve

Appendix 9 – Multiple Regression Report

Table 40: Run Summary

Parameter	Value	Parameter	Value
Dependent Variable	Maximum VHD	Rows Processed	29
Number Ind. Variables	3	Rows Filtered Out	0
Weight Variable	None	Rows with X's Missing	0
R2	0.3562	Rows with Weight Missing	0
Adj R2	0.2789	Rows with Y Missing	0
Coefficient of Variation	0.0134	Rows Used in Estimation	29
Mean Square Error	0.315171	Sum of Weights	29
Square Root of MSE	0.561401	Completion Status	Normal Completion
Ave Abs Pct Error	0.958		

Table 41: Descriptive Statistics

Variable	Count	Mean	Standard Deviation	Minimum	Maximum
Dummy	29	0.482759	0.508548	0	1
Five Year Interval	29	1910	42.57347	1840	1980
Dummy * Five Year Interval	29	940.1724	990.499	0	1980
Maximum VHD	29	42.00486	0.661128	40.25	43.125

Table 42: Regression Equation

Independent Variable	Regression Coefficient b(i)	Standard Error Sb(i)	T-Value to test H0:B(i)=0	Prob Level	Reject H0 at 5%?	Power of Test at 5%
Intercept	19.8756	12.5821	1.58	0.1268	No	0.3299
Dummy Variable	63.3929	19.1965	3.302	0.0029	Yes	0.8875
Five Year Interval	0.0119	0.0067	1.772	0.0886	No	0.399
Dummy Var. * Five Year Interval	-0.0332	0.01	-3.309	0.0028	Yes	0.8887

Table 43: Regression Coefficients

Independent Variable	Regression Coefficient	Standard Error	Lower 95% C.L.	Upper 95%C.L.	Standardizd Coefficient
Intercept	19.8756	12.5821	-6.0378	45.789	0
Dummy Variable	63.3929	19.1965	23.8569	102.9289	48.7626
Five Year Interval	0.0119	0.0067	-0.0019	0.0257	0.7655
Dummy Var. * Five Year Interval	-0.0332	0.01	-0.0538	-0.0125	-49.6856

Note: The T-Value used to calculate these confidence limits was 2.060.

Table 44: Analysis of Variance

Model Term	DF	R2	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power -5%
Intercept	1		51167.85	51167.85			
Model	3	0.3562	4.359235	1.453078	4.61	0.0106	0.8339
Dummy_Variable	1	0.2808	3.43702	3.43702	10.905	0.0029	0.8875
X5_Years	1	0.0808	0.989206	0.989206	3.139	0.0886	0.399
Dummy_Var. * X5_Years	1	0.282	3.451183	3.451183	10.95	0.0028	0.8887
Error	25	0.6438	7.879285	0.315171			
Total(Adjusted)	28	1	12.23852	0.43709			

Table 45: Randomization Test Results

Variable	T2 or |Student's T|	Parametric Test Prob Level	Randomization Test Prob Level
All (T2)	0.779	0.3897	0.3957
Average	0.883	0.3897	0.3957

The randomization test results are based on 10000 Monte Carlo samples.
These individual t-test significance levels should only be used when the overall T2 value is significant.

Appendix 10 – Summary of Results Obtained from Statistical Analyses

Brief Summary of Results for Male Dataset

N	701
Mean	48.4265
Standard Deviation	2.5656
D'Agostino Omnibus	Reject Normality Test value = 6.0471 Prob Level = 0.048627
Randomization Test	0.4541
Durbin-Watson Test for Serial Correlation	Positive serial correlation present Test value = 0.0478
Time Series Analysis	Box-Jenkins ARIMA Model (2,0,1)
Linear Regression Equation for Lag First-differences (LFD)	LFD = -3.2415 + 0.0017 * YOB F statistic = 0.1446 T value = 0.3803 Pr>F = 0.7067 r^2 = 0.0053

Brief Summary of Results for Female Dataset

N	516
Mean	42.1967
Standard Deviation	2.2766
D'Agostino Omnibus	Cannot Reject Normality Test value = 3.3323 Prob Level = 0.188971
Randomization Test	0.3957
Durbin-Watson Test for Serial Correlation	No serial correlation present
Time Series Analysis	Piecewise Regression Model

Multiple Regression Model

MVHDA = 19.8756 + 63.3929 * Dummy Variable + 0.0119 * YOB - 0.0332 * Dummy Variable * YOB

F statistic = 4.610

r^2 = 0.3562

Vita

Sandra Cridlin was born in Taipei, Taiwan on September 6, 1971. She was raised in Richmond, VA and attended elementary school and junior high school at Warwick Christian School in Richmond. She graduated valedictorian from Commonwealth Christian High School in 1989. She attended Virginia Commonwealth University and received a Bachelor of Science degree in Anthropology and Sociology (Anthropology concentration) in 1994. After this, she worked as an archaeological technician, later as an EMT, and lastly as a forensic autopsy technician prior to returning to school for a graduate degree. She received a Master of Arts in anthropology with a minor in statistics in 2007.

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