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Abstract

Over the past two centuries there have been documented secular changes in stature, weight, body proportions, and skeletal maturation rates in the United States. These changes along with a more sedentary lifestyle are likely reflected in femur morphology. Here we examine secular changes in diaphyseal cross-sectional size, shape, area, robusticity, and rigidity at midshaft and subtrochanteric of the femur using 395 adult White females and males from the United States born between the 1850s and the 1970s. The effect of secular change was controlled for an age effect. We also examine the relationship between femur length (proxy for stature) and femur head diameter (proxy for body weight) on measurements of diaphyseal size and biomechanical properties. The femur morphology of Americans born in the 20th century reflects the combination of changes in stature, body build, and activity levels. Both sexes show significant changes in femur midshaft shape due primarily to a decrease in the mediolateral diameter. There are no significant changes at subtrochanteric in size or biomechanical properties in either sex after controlling for age variation. The results suggest that the change in femur midshaft shape are primarily associated with a decrease in activity. The stability of the subtrochanteric

dimensions and femur anteroposterior diameter may reflect a combination of decreased activity with a corresponding increase in femur length (moment arm) and a decrease in body breadth.

Keywords

secular trend, mechanical loading, femur, sexual dimorphism, platymeric, pilastric

There is a significant body of literature demonstrating that long bones such as the femur respond to mechanical loading by altering diaphyseal geometry and structure (Pearson and Lieberman 2004). However, lower limb bone biomechanical structural properties (diaphyseal size, shape, robusticity, and strength) are affected by the interaction of numerous factors including mechanical usage, body mass, body shape, and bone length (Ruff 1984, Agostini and Ross 2011, Demes et al. 1991, Gruss 2007, Moore 2009, Meadows and Jantz 1995, 1999, Pearson and Lieberman 2004, Ruff and Larsen 2014, Wescott 2006, 2014). In many industrialized populations, especially the United States, there have been significant secular trends in biological variables such as stature, weight, body proportions, long bone lengths, and skeletal maturation primarily due to better nutrition and health (Fogel 2004, Wescott and Jantz 2005, Fredriks et al. 2000, Danubio and Sanna 2008, Driscoll 2010, Floud et al. 2011, Meadows and Jantz 1995, Meadows Jantz and Jantz 1999, Jantz and Meadows Jantz 2000, Wescott and Jantz 2005, Godina 2011, Harrington and Wescott 2015). There has also been a significant decrease in daily physical activity levels due to technological advances in transportation and in leisure-time activities resulting a more sedentary lifestyle. (Dollman et al. 2005, Nelson et al. 2006, Sandercock et al. 2010, Sigmundova et al. 2011, Jekauc et al. 2012, Scheffler and Hermanussen 2014). The combination of increased stature and body weight, changes in body proportions, earlier skeletal maturation, and a more sedentary life are likely to affect femur biomechanical properties such as diaphyseal dimensions, shape, and strength. While secular changes in long bone length and proportions is well documented in the United States, very little attention has been paid to how recent changes in activity levels, body weight, stature, and body proportions among Americans alter the magnitude and direction of forces on the femur, and therefore the structural properties of the American femur shaft. This study examines femur morphology of American Whites with birth dates between the 1850s and 1970s to investigate possible secular trends in femur diaphyseal cross-sectional size, shape, area, robusticity, and rigidity. The purpose is to examine if the recent dramatic environmental changes in the United States and associated trends in stature, body weight, body physique, maturation, and activity levels have also effected the morphology, size, and strength of the femur.

Previous Research of the Secular Change of Femur Morphology

The first study to examine changes in femur morphology among Americans was conducted by Trotter and colleagues (1968). They observed a positive trend in femur length and a negative trend in midshaft mediolateral (ML) breadth among individuals born between 1840 and 1940. Rockhold (1998) showed that coinciding with changes in femur length there has been a decrease in diaphyseal size relative to length and an increase in the midshaft shape or pilasteric index. In shape, Rockhold (1998) found that American femoral diaphyses have changed from nearly circular in diameter among individuals born in the early 19th century to oval (AP elongated) in individuals born in the late 20th century. Consistent with the findings of Trotter et al (1968), Rockhold (1998) found that the change in midshaft diaphyseal shape is primarily due to a decrease in the ML diameter and not an increase in the AP diameter, and she suggested that the ML diameter may be more sensitive to mechanical loads than the AP diameter. Harrington and Wescott (2015) also found that the most significant secular change in femur morphology is a decrease in ML diameter of the midshaft. Several other studies have examined the effect of obesity on femur morphology (Moore 2008, Agostini and Ross 2011, Moore and Schaefer 2011, Harrington and Wescott 2015), which has increased dramatically in the United States beginning in the 1960s but becoming more intense in the 1980s (Danubio and Sanna 2008). In general these studies have shown an increase in femur midshaft ML and medial condyle dimensions with increased body mass index. The difference between normal weight and obese individuals in midshaft diaphyseal dimensions is great enough that Agostini and Ross (2011) were able to correctly classify 88 and 77 percent of normal weight and overweight individuals, respectively, using the femur midshaft ML dimension.

With increasing sedentary lifestyles and increases in stature and body weight due to improved health and nutrition, there should be significant secular change in femur diaphyseal size, shape, robusticity, and rigidity among Americans over the past two centuries to reflect these changes. The results of biomechanical studies suggest that increases in stature may cause greater anteroposterior (AP) bending stress at the midshaft of the femur (Gruss 2007), while a more sedentary lifestyle would result in a decrease in the AP stress (Ruff 1987, Wescott 2006, Shaw and Stock 2011). Likewise, there should be a small decrease in the midshaft ML dimension due to a slight decrease in hip breadth and activity (Rockhold 1998, Driscoll 2010). Finally, there should also be a negative trend in femoral cross-sectional area and rigidity (Rockhold 1998, Ruff 2000).

Materials and Methods

The sample consists of 395 adult White females (n=147) and males (n=248) with birth dates ranging from 1856 to 1978 (Figure 1). Previous studies have shown that other ancestral groups in the United States follow similar but less pronounced trends as American Whites (Rockhold 1998, Meadows and Jantz 1995, Meadows Jantz and Jantz 1999). Therefore in this study only American Whites were examined. All 395 individuals have known age at death and the full set of measurements described below. While this limits sample size it allows for control of age effects and to standardize by body size. The sample was drawn from the Terry Collection (Hunt and Albanese 2005) and Forensic Data Bank (Ousley and Jantz 1997, Jantz and Ousley 2012), both of which include identified individuals with known demographic information. The Terry Collection consists of individuals born in the nineteenth and early twentieth centuries that died in the St. Louis, Missouri area. The Forensic Data Bank includes individuals born in the twentieth century from different parts of the United States and submitted by numerous forensic anthropologists.

Standard external bone measurements of femoral maximum length, head diameter, and AP and ML diameters of the diaphysis at subtrochanteric and midshaft were used in this study (Table 1). In addition, these measurements were used to calculate cross-sectional area, shape, robusticity, and torsional rigidity of the femur diaphyseal at subtrochanteric and midshaft locations (Table 2). These calculated variables provide information about the bone's size, strength, and resistance to bending in different directions. Diaphyseal shape serves to understand the direction of forces on the femur. A ratio greater than 1.0 indicates greater bending in the AP direction while a ratio less than 1.0 indicates greater bending forces in the ML direction. Cross-sectional area and robusticity are used to examine diaphyseal size relative to body size.

Torisional rigidity serves as an estimation of the bone's ability to resist torsional forces and therefore serves as a proxy for bone strength. To control for differences in long bone length and body mass between individuals, the cross-sectional properties were divided by either body mass or body mass times bone length where appropriate (Ruff 2008). Since body mass was not available for all individuals, it was calculated using femur head diameter in sex-specific formulae provided by Ruff et al. (1991) based on a sample from Baltimore, Maryland.

Secular change was evaluated by examining the linear relationship between year of birth and femur diaphyseal dimensions and biomechanical variables while controlling for the effect of age using partial correlation. When conducting cross-sectional studies of secular change it is necessary to control for age since individuals with earlier birth years are often older than individuals with more recent birth years. Furthermore, when using external dimensions it is possible that older individuals will have greater dimensions due to age-related periosteal expansion. In addition, regression with partial correlation was used to examine the effect of femur length (proxy for stature) and femur head diameter (proxy for body weight) on the biomechanical variable. This allows for a better understanding of whether changes in bone length or body weight are responsible for changes in diaphyseal biomechanical variables. Due to possible sex differences in size and response to environmental changes, each sex were examined separately.

Results

Similar to other studies there is a positive linear secular trend in femur length and no trend in femur head diameter for both sexes (Meadows and Jantz 1995, Meadows Jantz and Jantz 1999, Cridlin 2007) After controlling for age the only significant linear secular trend in both sexes is FMS, which is associated with a decrease for both sexes (significant in females only) in the midshaft ML dimension (MLM) and a slight positive increase in APM for males (Table 3, Figure 2). Diaphyseal area, robusticity, and torsional rigidity do not significantly change over the century examined for either sex. Femur subtrochanteric shape exhibits a slight but significant negative trend in females. There is a slight decrease in APS and an increase in MLS (Table 3) over the study period but the trend was not significant for either sex.

This study also examined the pattern of relationship between the diaphyseal measurements and biomechanical with FML and FHD (Table 4). In females, subtrocanteric AP and ML diameters and the biomechanical variables FMR, FMJ, and FMA significantly correlate with FHD but not FML. Also in females, femur AP midshaft diameter (APM) significantly correlates with FML but not FHD. Femur ML diameter and FMS, on the other hand, significantly correlates with both FML and FHD in females. None of the relationships are strong, explaining only between 3 and 22 percent of the variation. Males follow a similar but slightly different pattern with APD, FSR, FSA, APM, and midshaft biomechanical variables (FMR, FMJ, and FMA) significantly correlated with FML and FHD. MLS and MLM significantly correlated with FHD but not FML, and FMS significantly correlated with FML only. Like the females, the variation explained by FML and FHD ranged from 2 to 20 percent.

Discussion

Since the mid-1800s improvements in nutrition, healthcare, and sanitation along with greater sedentism due to technological advances have had a significant impact on the biology of modern Americans (Steckel 1995, Meadows Jantz and Jantz 1999). Stature has increased by approximately 0.6 cm per decade (Roche and Sun 2005). Body weight has also increased steadily over the last two centuries, but has become greatly accelerated in the last four decades. Since the 1960s there has been a four-fold increase in obesity (Ogden et al 2012). Unfortunately the birth years for individuals used in the current study only begin to capture the changes associated with obesity.

Shaft Cross-Sectional Properties

The femur morphology of modern Americans reflects a combination of changes in stature, body build, and activity levels that have taken place over the past century. Increases in femur length are most likely associated with dietary and healthcare improvements (Meadows and Jantz 1995, Meadows Jantz and Jantz 1999), but changes in diaphyseal size, shape, robusticity, and rigidity are usually thought to also be caused by changes in physical activity, especially terrestrial mobility, and post-adulthood weight (Ruff 1987, 2000, Stock and Pfeiffer 2001, Holt 2003, Stock 2006, Wescott 2006, 2014). The most dramatic change in femur cross-sectional morphology is in the shape of the femur midshaft (FMS). The trend in FMS is from a more circular diaphysis (APM/MLM ~ 1.0) in the 1850s to a more oval, AP elongated diaphysis (APM/MLM > 1.0) in more recent Americans in the United States. There is a complex relationship between femur morphology and mechanical loading, but it appears that ML dimensions of the femur midshaft may be more sensitive to the combination of decreased activity (mechanical loading) and changes in stature and body weight than the AP diameter in modern Americans. The change in FMS is largely due to a decrease in MLM (Figure 2). This finding is consistent with work by Trotter et al. (1968) and Rockhold (1998). Conventionally an AP elongated femur midshaft is thought to reflect an increase in terrestrial mobility (Ruff 1987). However, in modern Americans, the AP diameter seems to be primarily associated with the increased bone length and age. Gruss (2007) found that individuals with longer femora experience greater AP bending moments, but in this study only males showed a significant increase in the midshaft AP diameter. Shaw and Stock (2011) did not find a significant influence between femur length and midshaft diaphyseal shape. While traditional studies of femur midshaft shape have argued that cross-sectional an AP elongated midshaft reflects increased mobility and greater AP bending stress, this argument does not explain the changes observed in this and other studies of secular change among Americans. It is possible that the slight increase in AP diameter simply reflects the increase in femur length along with a decrease in activity. The ML diameter, on the other hand, seems to be best explained by reflect a decrease in activity or mechanical usage (Rockhold 1998, Wescott 2014).

Interestingly there is little change in femur robusticity, area, or rigidity when standardized by length and body mass. This suggests that the subtrochanteric and midshaft strength has not increased proportionality to changes in femur length. Again, this probably reflects the concurrent decrease in physical activity. Rockhold (1998) did find a significant negative relationship between femoral robusticity and year-of-birth using a larger sample size, suggesting that mechanical loading associated with activity has decreased. In this study, both midshaft torsional rigidity and area show a slight, but insignificant, decrease over time, but it is possible that the increased mechanical forces on the femur associated with a longer femur and increased weight have maintained the relative strength of the femur despite the decrease in activity.

This study also addressed whether femur length (proxy for stature) and femur head diameter (proxy for body weight) influence diaphyseal variables. Body weight had an influence on more variables than did bone length in both sexes, but femur length significantly influenced more variables for males than female. However, previous studies have also found a greater change in femur length among males (Meadows Jantz and Jantz 1999). Interestingly, femur midshaft shape was influenced by bone length (moment arm length) in both sexes as was the midshaft AP diameter. The relationship between APM and FML is not surprising since Gruss (2007) found that longer femora have greater AP bending forces at midshaft. The midshaft ML diameter was influence by both weight and stature in females but only femur head diameter in males. These results are consistent with other studies that have found that the ML diameter is affected more by body weight than the AP diameter (Demes et al. 1991, Ruff et al. 2006, Agostini and Ross 2011, Harrington and Wescott 2015). While the variation explained by body mass is small, the results suggest that standardizing for body mass does not remove it as a cause of variation as observed by Shaw and Stock (2011).

Femur Head to Estimate Body Weight

Rockhold (1998) observed a small positive relationship between femoral head size and year of birth in females but not males. Later, Cridlin (2007) using more appropriate statistics found no significant positive or negative trend in the maximum vertical diameter of the femoral head over the past 150 years in either blacks or whites. However, while there appears to be no significant change in femoral head diameter among Americans, there has been a documented increase in body weight. The change in weight is due to both changes in stature and adiposity (Cole 2003, Danubio and Sanna 2008). In this study, however, most of the increase in weight is associated with the trend in height since the obesity epidemic did not start in the United States until the 1960s or later. Ruff et al. (1991) argued that diaphyeal cross-sectional size more closely reflects mechanical loading due to weight near the time of death. The femoral head diameter, on the other hand, most likely reflects lean body mass at 18 years of age (Ruff et al. 1991, Auerbach and Ruff 2004).

Perspectives

A confounding variable in the current study is that we focused only on linear relationships between diaphyseal variables and year-of-birth. However, several studies have demonstrated that the trends in femur length, morphology, and head diameter are not necessarily linear (Rockhold 1998, Meadows Jantz and Jantz 1999, Cridlin 2007, Wescott 2014). Rockhold (1998), for example, found that APM in white males increased until approximately 1920 and then slowly decreased from 1920 to 1970. Future studies should examine the relationship between length and biomechanical properties.

In addition, future studies should examine individuals born after 1960 to observe how changes in adiposity and further decreases in physical activity, especially in childhood, affect diaphyseal variables. It is possible that the increase in body weight associated with the obesity epidemic may reverse the trend in FMS by increasing the midshaft ML loading (Harrington and Wescott 2015).

Finally, most research examining long bone diaphyeal cross-sectional geometry have focused on changes associated with increased activity and control for body mass and moment arm length. The results of this study suggest that changes in single measures such as FMS may indicate changes in activity patterns and levels, but they cannot be used alone to determine the cause. Therefore, diaphyseal shape and other biomechanical variables should be used with caution when interpreting behavior from skeletal remains (Wescott 2014).

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Literature Cited

Agostini, G.M., and A.H. Ross. 2011. The effect of weight on the femur: a cross-sectional analysis. *J. Forensic Sci.* 56(2):339-343.

Auerbach B.M., and C.B. Ruff. 2004. Human body mass estimation: a comparison of "morphometric" and "mechanical" methods. *Am. J. Phys. Anthropol*. 125:331-342.

Cole, T.J. 2003. The secular trend in human physical growth: a biological view. *Econom. Hum. Biol.* 1:161-168.

Cridlin, S. 2007. *Examination of Secular Change in the Vertical Head Diameter of the Human Femur in American Males and Females*. Dissertation, University of Tennessee, Knoxville, Department of Anthropology.

Danubio M.E., and E. Sanna. 2008. Secular changes in human biological variables in western countries: an updated review and synthesis. *J. Anthropol. Sci.* 86:91-112.

Demes, B., W.L. Jungers, and K. Selpien. 1991. Body size, locomotion, and long bone cross-sectional geometry in Indriid primates. *Am. J. Phys. Anthropol.* 86:537-547.

Dollman J., K. Norton, L. Norton. 2005. Evidence of secular trends in children's physical activity behaviour. *Br. J. Sports Med*. 39:892-897.

Driscoll, K.R.D. 2010. *Secular Change of the Modern Human Bony Pelvis: Examining Morphology in the United States Using Metric and Geometric Morphometry*. Dissertation, University of Tennessee, Knoxville, Department of Anthropology.

Floud, R., R.W, Fogel, B. Harris, et al. 2011. *The Changing Body: Health, Nutrition, and Human Development in the Western World since 1700*. Cambridge, UK: Cambridge University Press.

Fogel, R.W. 2004. *The Escape from Hunger and Premature death, 1700-2100: Europe, America, and the Third World*. Cambridge Studies in Population, Economy, and Society in the Past. Cambridge, UK: Cambridge University Press.

Fredriks, A.M., S. van Buuren, R.J.F. Burgmeijer, et al. 2000. Continued positive secular growth change in the Netherlands 1955-1997. *Pediatric Res.* 47:316-323.

Godina, E.Z. 2011. Secular trends in some Russian populations. *Anthropol. Az.* 68:367-377.

Gruss, L.T. 2007. Limb length and locomotor biomechanics in the genus *Homo*: an experimental study. *Am. J. Phys. Anthropol.* 134(1):106-116.

Harrington, K.I. and D.J. Wescott. 2015. Size and shape differences in the distal femur and proximal tibia between normal weight and obese American whites. *J. Forensic Sci*. 60(S1):S32-S38.

Holt, B.M. 2003. Mobility in Upper Paleolithic and Mesolithic Europe: evidence from the lower limb. *Am. J. Phys. Anthropol.* 122:200-215.

Hunt, D.R., and J. Albanese. 2005. History and demographic composition of the Robert J. Terry Anatomical Collection. *Am. J. Phys. Anthropol.* 127:406-417.

Jantz, R.L., and L. Meadows Jantz. 2000. Secular change in craniofacial morphology. *Am. J. Hum. Biol.* 12:327-338.

Jekauc, D., A.K. Reimers, M.O. Wagner, et al. 2012. Prevalence and socio-demographic correlates of the compliance with the physical activity guidelines in children and adolescents in Germany. *BMC Public Health* 12:714.

Lieberman, D.E., J.D. Polk, and B. Demes. 2004. Predicting long bone loading from cross-sectional geometry. *Am. J. Phys. Anthropol.* 123:156-171.

Meadows, L. and R. Jantz. 1995. Allometric secular change in the long bones from the 1800s to the present. *J. Forensic Sci.* 40:762-767.

Meadows Jantz, L. and R.L. Jantz. 1999. Secular change in long bone length and proportion in the United States, 1800-1970. *Am. J. Phys. Anthropol.* 110:57-67.

Meadows, L., and R.L. Jantz. 1995. Allometric secular change in the long bones from the 1800s to the present. *J Forensic Sci* 40:762-767.

Meadows Jantz, L., and R.L. Jantz, 1999. Secular change in long bone length and proportion in the United States, 1800-1970. *Am J Phys Anthropol* 110:57-67.

Moore M.K. 2009. *Body Mass Estimation from the Human Skeleton*. Dissertation, University of Tennessee, Knoxville, Department of Anthropology.

Moore, M.K., and E. Schaefer. 2011. A comprehensive regression tree to estimate body weight from the skeleton. *J. Forensic Sci.* 56:1115-1122.

Nelson, M.C., D. Neumark-Stzainer, P.J. Hannan, et al. 2006. Longitudinal and secular trends in physical activity and sedentary behavior during adolescence. *Pediatrics* 118:1627-1634.

Ogden C.L., M.D. Carrol, B.K. Kit, et al. 2012. Prevalence of obesity in the United States, 2009-2010. Atlanta, GA: National Center for Health Statistics, Center for Disease Control and Prevention, Data Brief No: 82.

Ousley, S.D., and R.L. Jantz. 1997. The forensic data bank: documenting skeletal trends in the United States. In *Forensic Osteology: Advances in the Identification of Human Remains*, K.J. Reichs, ed., Springfield, IL: Charles C. Homas, 442-458.

Ousley, S.D., and R.L. Jantz. 2012. Fordisc 3 and statistical methods for estimating sex and ancestry. In *A Companion to Forensic Anthropology*, D.C.Dirkmaat, ed., New York, NY: Wiley-Blackwell, 311-329.

Pearson, O.M., and D.L. Leiberman. 2004. The aging of Wolff's "law": ontogeny and responses to mechanical loading in cortical bone. *Yrbk. Phys. Anthropol.* 47:63-99.

Roche, A.F., and S.S. Sun. 2005. *Human Growth: Assessment and Interpretation.* New York, NY: Cambridge University Press.

Rockhold, L.A. 1998. *Secular Change in External Femoral Measures from 1840 to 1970: A Biomechanical Interpretation*. Thesis, University of Tennessee, Knoxville, Department of Anthropology.

Ruff, C.B. 1984. Allometry between length and cross-sectional dimension of the femur and tibia in *Homo sapiens sapiens*. *Am. J. Phys. Anthropol.* 65:347-358.

Ruff, C.B. 1987. Sexual dimorphism in human lower limb bone structure: relationship to subsistence strategy and sexual division of labor. *J. Hum. Evol.* 16:391-416.

Ruff, C.B. 2000. Body size, body shape, and long bone strength in modern humans. *J. Hum. Evol.* 38:269-290.

Ruff, C.B. 2008. Biomechanical analyses of archaeological human remains. In *Biological Anthropology of the Human Skeleton*, M.A. Katzenberg and S.R. Saunders, eds., New York, NY: Wiley, 183-206.

Ruff, C.B., B. Holt, V. Sládek, et al. 2006. Body size, body proportions, and mobility in the Tyrolean "Iceman." *J. Hum. Evol.* 51:91-101.

Ruff, C.B., and C.S. Larsen. 2014. Long bone structural analyses and the reconstruction of past mobility: a historical review. In *Reconstructing Mobility: Environmental, Behavioral, and Morphological Determinants*, K.J. Carlson and D. Marchi, eds. New York, NY: Springer, 13-29.

Ruff, C.B., W.W. Scott, and A. Y-C Liu. 1991. Articular and diaphyseal remodeling from the proximal femur with changes in body mass in adults. *Am. J. Phys. Anthropol.* 86:397-413.

Sandercock, G., C. Voss, D. McConnell. 2010. Ten year secular declines in the cardiorespiratory fitness of affluent English children are largely independent of changes in body mass index. *Arch. Dis. Child.* 95:46-47.

Scheffler, C., and M. Hermanussen. 2014. Is there an influence of modern life style on skeletal build? *Am. J. Hum. Biol.* 26:590-597.

Shaw, C.N., and J.T. Stock. 2011. The influence of body proportions on femoral and tibial midshaft shape in hunter-gatherers. *Am. J. Phys. Anthropol.* 144:22-29.

Sigmundová, D., W. El Ansari, E. Sigmund, et al. 2011. Secular trends: a ten-year comparison of the amount and type of physical activity and inactivity of random samples of adolescents in the Czech Republic. *BMC Public Health* 11:731.

Steckel, R.H. 1995. Stature and the standard of living. *J. Economic Lit*. 33:1903-1940.

Steegmann A.T. 2005. Climate, racial category, and body proportions in the U.S. *Am. J. Hum. Biol.* 17:393-402.

Stock, J.T. 2006. Hunter-gatherer postcranial robusticity relative to patterns of mobility, climatic adaptation, and selection for tissue economy. *Am. J. Phys. Anthropol*. 131:194-204.

Stock, J.T., and S. Pfeiffer. 2001. Linking structural variability in long bone diaphyseas to habitual behaviors: foragers from southern African Later Stone Age and Andaman Islands. *Am. J. Phys. Anthropol.* 115:337-348.

Trotter, M., R.R. Peterson, and R. Wette. 1968. The secular trend in the diameter of the femur of American whites and negroes. *Am. J. Phys. Anthropol.* 28:65-74.

Wescott, D.J. 2001. *Structural Variation in the Humerus and Femur in the American Great Plains and Adjacent Regions: Differences in Subsistence Strategy and Physical Terrain*, Dissertation, University of Tennessee, Knoxville, Department of Anthropology.

Wescott, D.J. 2006. Effect of mobility on femur midshaft external shape and robusticity. *Am. J. Phys. Anthropol.* 130:201-213.

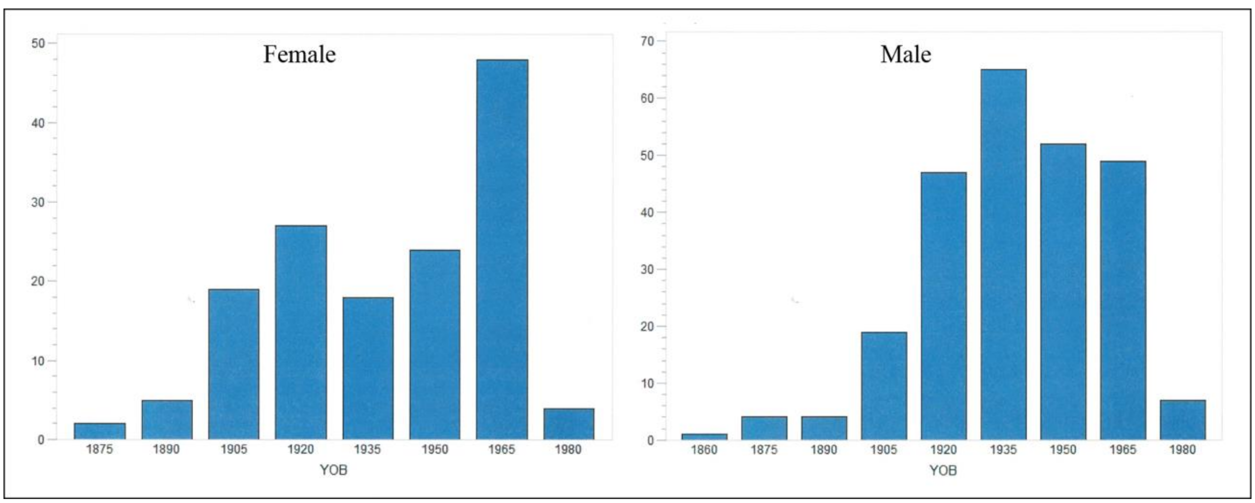
Wescott, D.J. 2014. The relationship between femur shape and terrestrial mobility patterns. In *Reconstructing Mobility: Environmental, Behavioral, and Morphological Determinants*, K.J. Carlson and D. Marchi, eds. New York, NY: Springer, 111-132.

Wescott, D.J., and R.L. Jantz. 2005. Assessing craniofacial secular change in American whites and blacks using geometric morphometry. In *Modern Morphometrics in Physical Anthropology*, D. Slice, ed., New York, NY: Klwer Academic Press, 231-246.

Figure captions

Figure 1. Sample frequency (y axis) distribution for females and males in 15 year increments (Female n = 147, Male n = 248).

Figure 2. Secular trend in FMS, APM, and MLM for females and males.



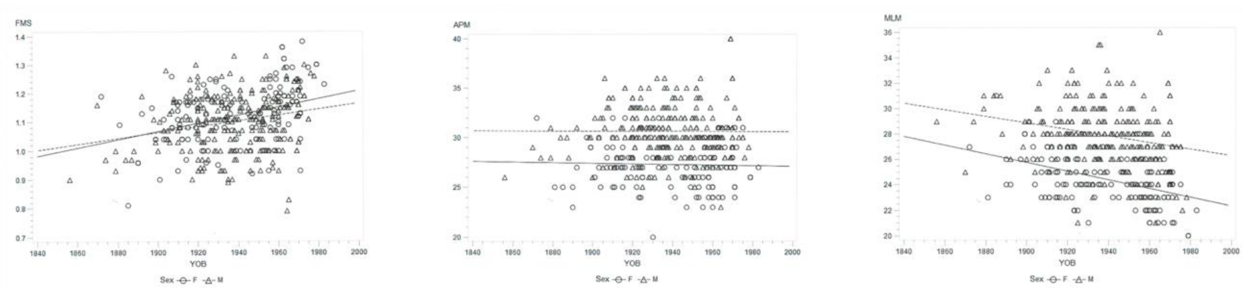


Table 1. Measurements.

MEASUREMENTS[1]	ABBREVIATIONS
Femur maximum length	FML
Femur head diameter	FHD
Anteroposterior diameter at subtrochanteric	APS
Mediolateral diameter at subtrochanteric	MLS
Anteroposterior diameter at midshaft	APM
Mediolateral diameter at midshaft	MLM

[1]See Rockhold (1998) and Wescott (2001) for description of measurements

Table 2: Equations and Abbreviations for Derived Properties.

PROPERTY	ABBREVIATION	FORMULA
Subtrochanteric shape	FSS	APS/MLS
Subtrochanteric robusticity	FSR	100*(√APS*MLS)/FHD
Subtrochanteric polar SMA[1,2]	FSJ	100*(-124812 + 2925*APS + 3360*MLS)/(BM*FML)
Subtrochanteric area[2]	FSA	100*(π *(APS/2)*(MLS/2)/BM)
Midshaft shape	FMS	APM/MLM
Midshaft robusticity	FMR	100*(√APM*MLM)/FHD
Midshaft polar SMA[1,2]	FMJ	100*(-102286 +2721*APM + 2697*MLM)/(BM*FML)
Midshaft area[2]	FMA	100*(π *(APM/2)*(MLM/2)/BM)

[1]SMA = second moment of area
[2]BM = body mass calculated from FHD following Ruff et al. (1991)

Table 3. Linear Relationship between Variables and Year of Birth Adjusted for Age.

		FEMALE		MALE	
LOCATION	VARIABLE	T Value	Pr>T	T Value	Pr>T
Subtrochanteric	APS	-0.97	0.3347	0.74	0.4592
	MLS	1.27	0.2077	0.05	0.9635
	FSS	**-2.11**	**0.0363**	0.67	0.5050
	FSR	1.76	0.0808	0.47	0.6371
	FSJ	0.77	0.4409	0.08	0.9376
	FSA	0.46	0.6459	0.55	0.5836
Midshaft	APM	0.95	0.3426	**1.99**	**0.0481**
	MLM	**-2.64**	**0.0093**	-1.41	0.1590
	FMS	**3.10**	**0.0024**	**3.18**	**0.0017**
	FMR	0.57	0.5724	0.39	0.6972
	FMJ	-0.29	0.7711	-0.05	0.9632
	FMA	-0.37	0.7100	0.45	0.6567

Pr>T is the probability value for T (≤ 0.05 is significant and in bold type)

Table 4. Partial Correlations of Diaphyseal Measurements and Biomechanical Variables with Femur Length and Head Diameter.

		FEMALE				MALE			
		FML		FHD		FML		FHD	
LOCATION	VARIABLE	R^2	Pr>T	R^2	Pr>T	R^2	Pr>T	R^2	Pr>T
Subtrochanteric	APS	-0.002	0.6822	**0.135**	**<0.0001**	**0.018**	**0.0346**	**0.072**	**<0.0001**
	MLS	-0.004	0.4229	**0.180**	**<0.0001**	0.008	0.1539	**0.095**	**<0.0001**
	FSS	0.000	0.8249	0.001	0.6461	0.001	0.5615	0.001	0.5727
	FSR	-0.004	0.4391	-0.022	0.0706	**0.020**	**0.0262**	**-0.090**	**<0.0001**
	FSJ	**-0.075**	**0.0008**	**0.167**	**<0.0001**	-0.014	0.0656	-0.003	0.4066
	FSA	0.005	0.3804	**0.094**	**0.0002**	**0.020**	**0.0246**	**-0.047**	**0.0006**
Midshaft	APM	**0.091**	**0.0002**	0.025	0.0556	**0.038**	**0.0021**	**0.115**	**<0.0001**
	MLM	**-0.032**	**0.0308**	**0.226**	**<0.0001**	0.000	0.6268	**0.137**	**<0.0001**
	FMS	**0.157**	**<0.0001**	**0.091**	**0.0002**	**0.018**	**0.0333**	0.004	0.3272
	FMR	0.007	0.3098	**-0.068**	**0.0014**	**0.017**	**0.0381**	**-0.065**	**<0.0001**
	FMJ	-0.014	0.1503	**0.101**	**<0.0001**	**-0.020**	**0.0263**	**0.000**	**0.7396**
	FMA	0.001	0.6753	**0.055**	**0.0044**	**0.018**	**0.0337**	**-0.025**	**0.0124**

[1] R^2 is the squared, type II partial correlation

[2] Pr>T is the probability value for T (≤ 0.05 is significant)