Determination of sexual dimorphism from the proximal femur in a heterogeneous North American population

A Thesis Presented

by

Kathleen Elizabeth Droesch

to

The Graduate School

in Partial Fulfillment of the

Requirements

for the Degree of

Masters of Arts

in

Anthropology

Stony Brook University

December 2011

Stony Brook University

The Graduate School

Kathleen Elizabeth Droesch

We, the thesis committee for the above candidate for the

Master of Arts degree, hereby recommend

acceptance of this thesis.

Frederick E. Grine – Thesis Advisor
Professor, Department of Anthropology

William L. Jungers
Professor and Chairman, Department of Anatomic Sciences

James B. Rossie
Associate Professor, Department of Anthropology

This thesis is accepted by the Graduate School

Lawrence Martin
Dean of the Graduate School

Abstract of the Thesis

Determination of sexual dimorphism from the proximal femur in a heterogeneous North American population

by

Kathleen Elizabeth Droesch

Master of Arts

in

Anthropology

Stony Brook University

2011

Many studies support the use of population specific standards to establish sexing of skeletal remains. Classic collections, which have been used to establish population standards, may not be reflective of modern societies, which are frequently composed of multiple ethnicities. In this study, vertical head diameter (VHD), superior-inferior neck diameter (SID), hip axis length (HAL) and neck-shaft angle (NSA) were measured from the proximal femur in order to determine if dimorphism can be established in a heterogeneous, contemporary population. Radiographic images from 159 males and 293 females were sampled. Comparisons using a two-tailed t-test indicated significant differences between males and females for all 4 variables. Sexual dimorphism indexes indicate strong dimorphism for VHD, SID and HAL (113.26, 117.58 and 112.47 respectively) but lack of dimorphism for NSA (99.17). Discriminant function analysis indicated VHD to be the most sexually dimorphic feature. Sexing using all 4 variables resulted in 85.4% accuracy. Of the 159 males, 27 were incorrectly classified leading to 83.0% sexing accuracy for males. Of the 293 females, 39 were incorrectly classified leading to 86.7% sexing accuracy for females. The results of this study suggest that

population specific standards are not necessary when sexing based on contemporary skeletal remains.

Table of Contents

List of Figures

List of Tables

Introduction

When confronted with human remains, the primary goal of the forensic anthropologist is the identification of the individual. An immediate identification may be difficult to accomplish if the remains comprise incomplete or fragmentary skeletal elements. The remains could have been dismembered or burnt beyond recognition (Harma 2007; Kranioti 2009), and those in an advanced state of decay may not allow even the ability to access the sex of the individual. Bombings or terrorist attacks may result in only fragmentary bones (Kahana 1997; Mundorff 2009). Mass graves, where bodies are comingled with one another present another extreme challenge for identification.

Sexing skeletal remains allows one to narrow the search in individual identification (Slaus 2003). The pelvis and skull are the two most sexually dimorphic elements in the skeleton (Phenice 1969; Kelley 1979; Rogers 2005; Williams 2006), but these elements may not be available for evaluation. The proximal femur is one of the most robust bones in the skeleton and although it is less accurate than a skull or os coxae for sexing, it is frequently recovered from archaeological and crime scene excavations (DiBennardo 1982; White 2000; Albanese 2008).

Overall, the femur is larger and heavier in males compared to females (Nissen 2005), but size alone has obvious and serious limitations as a sexing criterion (Ruff 1987). Many factors contribute to the ultimate size and shape of the adult femur, including genetic, environmental and nutritional variables (Gray 1980; Varrela 1984; Fewtrell 2009; Romano 2009). Studies of sexual dimorphism have examined several features of the femur, but most of these have been simply assessments of size dimorphism. Thus, vertical head diameter (VHD) (Iscan 1984, 1995; Steyn 1997; Asala 2001, 2002, 2004; Kranioti 2009) and superior-inferior neck diameter (SID) (Ditch 1972; Gomez Alonso 2000; Alunni-Perret 2003; Frutos 2003; Asala 2004; Wheatley 2005) have been studied rather intensely. As would be expected, measurements of VHD (Steyn 1997; Trancho 1997; Asala 2001, 2002, 2004; Slaus 2003) and SID (Seidemann 1998; Gomez Alonso 2000; Alunni-Perret 2003; Frutos 2003; Wheatley 2005) tend to be larger in males than females.

Nissen (2005) studied the geometry of the proximal femur in relation to sex and found males had significantly larger femoral head radii and neck widths compared to female. In addition, Nissen (2005) also measured hip axis length (HAL), defined as the length from the greater trochanter to the top of the femoral head parallel to the neck line, and found it to be significantly larger in males compared to females.

Femoral neck-shaft angle (NSA) is defined as the angle, in the coronal plane, between the axes of the femoral neck and shaft (Trinkaus 1993). This variable has been examined with conflicting results. Some studies have reported smaller angles in females compared to males (Humphry 1889; Parsons 1914; Gomez Alonso 2000; Nissen 2005), while others have found no significant difference between the sexes (Davivongs 1963; Anderson 1998; Toogood 2008). Factors that may contribute to NSA include activity level (Humphry 1889; Houston 1978; Trinkaus 1993; Grine et al. 1995; Anderson 1998), age (Nissen 2005; Toogood 2008), genetic factors (Tanner 1959; Ruff 2003; Fong 2009), height and weight (Nissen 2005), as well as disease states (Houston 1967; Mays 2009). This has led to mixed conclusions and confidence regarding the use of NSA for identifying sexual dimorphism.

Sexing using the proximal femur has been based on both individual features and a combination of variables. When using multivariate analysis, size of the femoral head or distal epicondylar breadth (DEB) has been reported to be the most sexually dimorphic feature (Iscan 1984a, 1984b, 1995; Steyn 1997; Trancho 1997; Mall 2001; Slaus 2003) (Table 1). Slaus (2003) examined 195 femora (104 males, 91 females) from a Croatian population and measured maximum femur length, DEB, maximum head diameter, sagittal and transverse subtrochanteric diameter and transverse diameter at the midshaft of the femur (Table 1). When all variables were considered, 94.4% accuracy of sexing was obtained. However, maximum head diameter alone was the most discriminatory variable with 94.2% accuracy; this was followed very closely by DEB (93.3%).

Mall (2000) measured six femoral variables in a German population of known age and sex (Table 1). These variables included maximal femur length, anterior-posterior (AP) and transverse midshaft diameter, head circumference and vertical and transverse head diameter. Transverse head diameter was found to be the most sexually dimorphic feature. Correct sexual classification was achieved in 89.6% of cases using transverse head diameter, 87.7% using head circumference and 86.8% using VHD. DEB was not included in this study.

Table 1

Comparison of studies of sexing using multiple variables from the proximal femur

	Slaus 2003	**Mall 2000**	**Trancho 1997**	**Iscan 1984a**	**Iscan 1984a**	**Steyn 1997**	**Iscan 1995**	**Asala 2004**
Ethnicity	Croatian	German	Spanish	NA Whites	NA Blacks	South African	Chinese	South African Blacks
Max femur length	X	X		X	X	X	X	
Epicondylar Breadth	X	X	X	X	X	X	X	
Max. Head diameter	X			X	X	X	X	
A-P subtrochanteric diameter	X		X					X
Transverse subtrochanteric diameter	X		X					X
A-P midshaft diameter	X			X	X	X	X	
Transverse midshaft diameter	X			X	X	X	X	
Midshaft circumference				X	X	X	X	
Vertical head diameter		X	X					X
Transverse head diameter		X	X					
Head circumference		X						
Vertical neck diameter								X
Upper Epicondylar length								X
Medial condylar length								X
Lateral condylar length								X

Bicondylar breadth								X

Trancho (1997) examined five variables on 132 femora of known age and sex from a Spanish population including vertical and horizontal head diameter, AP and transverse subtrochanteric diameters and DEB (Table 1). DEB was reported to be the most discriminatory variable followed by transverse diameter with VHD being third. DEB resulted in 97.5% sexing accuracy, while VHD was 91.2% accurate in this population (Trancho 1997).

Iscan (1984a) examined the remains from 224 North American whites and blacks (56 white males, 55 white females, 52 black males, 61 black females) from the Hamann-Todd collection at the Cleveland Museum of Natural History. Six femoral variables were examined (maximal femoral length, maximal head diameter, AP and transverse shaft diameter, mid-shaft circumference and DEB) (Table 1). Iscan reported all six variables to be larger in males, and stepwise discriminant function analysis indicated that maximum head diameter (MHD) contributed the most to sexual dimorphism in both whites and blacks. In the second step of the analysis, transverse shaft diameter was selected for whites while DEB was selected for blacks. Iscan reported sexing accuracy using head diameter alone at 90.1% and 90.3% in whites and blacks respectively. When five of the six variables were used, 91.8 and 92.8% accuracy was reported for whites and blacks respectively (Iscan 1984a).

Steyn and Iscan (1997) examined the same six variables in a sample of 106 (56 males, 50 females) South African whites (Table 1). Here, DEB was found to be the most discriminating variable followed by head diameter, while transverse diameter was third. The authors reported 90.5% accuracy of sexing using DEB, while head diameter resulted in 85.9% accuracy (Steyn 1997).

Iscan (1995) examined the same six variables in a Chinese population of known age and sex (Table 1). All variables from males were reported to be larger than their female counterparts. The results of discriminant function analysis indicated that DEB was the most sexually dimorphic feature, followed by maximum femur length with AP diameter chosen third. Using these 3 variables, femora were correctly sexed in 92.3% of cases. Iscan (1995) concluded that sexual dimorphism is expressed differently in different populations. Iscan found features of the proximal femur most sexually dimorphic in North American whites and blacks but features of the distal femur most sexually dimorphic in South African whites and Chinese. These conclusions suggest population specific studies are needed to assess sexual dimorphism within specific populations.

Asala (2004) compared variables from the proximal femur with those of the distal femur in order to assess the ability to determine sex from fragmentary remains. The sample consisted of 220 adult blacks (133 males, 87 females) from the Raymond Dart collection in the Department of Anatomical Sciences, University of Witwatersrand, Johannesburg, South Africa. Five variables from the proximal femur (VHD, upper epicondylar length, minimum vertical neck diameter, AP and transverse subtrochanteric diameter) and three variables from the distal femur (bicondylar breadth, medial and lateral condylar length) were examined (Table 1). Asala reported 85.1% accuracy in sexing using the five proximal variables compared to 82.7% using the three distal variables, suggesting that the proximal femur is slightly more sexually dimorphic than the distal femur. VHD was found to be the most dimorphic feature of the proximal femur and resulted in 82.6% accuracy of sexing when assessed alone (Asala 2004) and was as accurate as the three distal femoral variables combined.

The determination of skeletal sex based on single variables has been examined in several studies. Papaloucas (2008) examined the hip joint in 200 Greek specimens (100 males, 100 females) and, as expected, reported the diameter of the femoral head to be significantly larger in males compared to females (Papaloucas 2008). A similar finding was reported in femora from an Anatolian population where VHD was associated with 76.9% accuracy in sexing (Harma 2007).

The femoral neck is preserved more often than the femoral head at archaeological sites (Seidemann 1998). The higher rate of preservation of the femoral neck suggests a possible role for SID in sexing proximal femora. Studies of sexual dimorphism of the femoral neck have reported SID to be significantly larger in males compared to females (Seidemann 1998; Stojanowski 1999; Alunni-Perret 2003; Frutos 2003; Asala 2004; Wheatley 2005).

Seidemann (1998) examined the use of SID for sex assessment in a sample of 203 femora (52 black females, 51 black males, 50 white females, 50 white males) drawn from the Hamann-Todd collection. As expected, SID for males was found to be significantly larger than that for females. Alunni-Perret (2003) examined the use of SID for sex determination in a modern French population. Males were found to be larger than females, and discriminant function analysis resulted in 90.1% accuracy in sexing. Similar findings have been reported for a contemporary Guatemalan sample (Frutos 2003), and a modern sample from New Mexico (Stojanowski 1999).

Humphry (1889) compared femur shaft length and NSA in two samples (30 adults of unknown sex from the Anatomical Museum of the University of Cambridge and 14 adults of known age and sex from the Cambridge Museum). An association between long bone size and NSA was reported in which shorter femur shaft length was associated with a narrower NSA. He also reported NSA to be narrower when the pelvis was wider. Humphry (1889) assumed that since females are of generally smaller stature and have relatively wider hips than males, NSA was narrower in females, but this conclusion is wholly unsubstantiated. However, Parsons (1914) examined 300 femora of known sex from a medieval English population and reported similar findings. Thus, he showed a positive association between femoral neck length and NSA, with males possessing femora with a one degree increase in NSA compared to females (Parsons 1914).

Nissen (2005) examined a Danish sample of 249 healthy adults (94 males, 155 females) age 19 to 79. Using dual-energy X-ray absorptiometry (DEXA), NSA was reported to be significantly greater in males compared to females (131 ± 5 and 129 ± 5 degrees respectively) (Nissen 2005). Gomez Alonso (2000) examined a Spanish population (60 to 80 years of age) with a history of hip fractures. A healthy age-matched control population of 310 females and 235 males was included in the study. In the control population, NSA was found to be 1.7 degrees greater in males, but this difference was not statistically significant (Gomez Alonso 2000).

Toogood (2008) examined 200 adult specimens (50 white males, 50 white females, 50 black males, 50 black females) from the Hamann-Todd collection and reported no significant gender difference in NSA measurements. Davivongs (1963) reported on 130 Australian aborigine femora that were sexed on the basis of associated pelvic morphology, and found no difference in NSA between males and females (127.83 and 127.26 degrees respectively). Anderson (1998) evaluated femora from a number of samples ranging from archaic to modern populations including data derived from measurements performed by himself and data published by other authors. Of the 17 samples where sex was known, NSA was greater in females in 58.8% of cases, but significance was reached in only six of these. Anderson (1998) concluded that sexual differences were both small and inconsistent with regard to NSA.

Populations vary considerably in physical features, and multiple studies have confirmed the need to establish population specific standards for sexing when using skeletal remains. Population specific studies have been undertaken using VHD and SID for sexual differentiation in Chinese (Iscan 1995), Greek (Kranioti 2009), Swedish (Kjellstrom 2004), Danish (Nissen 2005), South African (Steyn 1997),Indian (Purkait 2004), Native American (Van Gerven 1972), Turkish (Harma 2007), Guatemalan (Frutos 2003) and Croat (Slaus 2003) samples.

Standards for North American whites and blacks have been established using specimens from the Hamann-Todd collection (Iscan 1984a; Seidemann 1998), the Terry collection at the Smithsonian Institute (DiBennardo 1982; Iscan 1984b) and the American Museum of Natural History (DiBennardo 1979). These collections were established in the late 1800s to early 1900s. Samples drawn from the Hamann-Todd collection, for example, are from individuals born between 1825 and 1910 (Seidemann 1998).

Angel (1978) compared changes in skeletal growth and stature from the 17^{th} to the 20^{th} century. Osteometrics from populations from the 1600s through the 1800s were compared to the same elements from individuals, the majority of who died between 1962 and 1975. An increase in skeletal size was reported over time (Angel 1976). Angel reported a 3 to 4 cm increase in stature in modern samples compared to 17^{th} century samples, possibly due to improved diet and decreased disease. There was also a notable deepening of the AP diameter of the bony pelvis (Angel 1976).

The femur has shown an upward trend in length over time (Lavelle 1974, Angel 1976, Meadows Jantz 1999, Alunni-Perret 2003, Frutos 2003). Lavelle (1974) examined 590 femora from samples dating from the Bronze Age to modern day periods. The contemporary samples and 19^{th} century London samples were of known sex. Specimens from earlier time periods were sexed using morphological criteria listed by Pearson and Bell (1919). Lavelle reported progressive growth of femoral dimensions (including length of the long bones) from Bronze Age to modern Birmingham specimens (Lavelle 1974).

Meadows Jantz (1999) examined secular changes in stature and long bone length over time. Samples of six long bones were drawn from four collections (Huntington collection, Terry collection, World War II casualties, Forensic Anthropology Data Bank). Meadows Jantz (1999) concluded that the femur of black and white males and females all showed significant increases in size over time.

Alunni-Perret (2003) examined 70 pairs of femora (35 males, 35 females) from a French population and reported SID to be significantly larger than that from a pre-1910 sample from the Hamann-Todd collection. These sorts of skeletal changes reflect well-documented secular trends in a number of populations from around the globe.

Some studies have used standard references based on older collections such as the Hamann-Todd or the Terry collection and found poor applicability to their study group. For example, Frutos (2003) examined SID for a contemporary Guatemalan population and reported a 21.3% accuracy of sexing based on values obtained from the Hamann-Todd collection. They redefined their discriminant functions for sex assessment based on their unique populations and found improved accuracy in sexual assessment. This accuracy increased to 89.5% when new discriminant functions were developed based on contemporary Guatemalan samples.

Thus, it is possible that these classic collections, which have been used to establish population standards, have limited applicability for modern societies. Reference standards need to be updated to reflect changes in body size and stature of populations today. Also, population specific standards can only be applied to a known, homogeneous population. The United States is becoming less homogeneous with time. Currently, the majority of immigrants to the United States come from non-European countries. In 2008, the United States Census Bureau projected that the majority of the population, by 2050, would be made up of non-Europeans (Bernstein 2008). With increased stature of modern populations, and the ever-changing makeup of populations in many places in the United

States, established standards for European-Americans or African-Americans alone may not be accurate for sexing a modern, heterogeneous population.

When a specimen is found at a crime scene there may be no indication of the owner's ethnicity. The bombing of the World Trade Center is a good example. There were many fragmentary bones that were difficult or impossible to identify (Mundorff 2009). It would seem that there might be no "population standard" in this circumstance where such a multinational group of people perished. A standard developed from a randomly chosen sample of specimens from a variety of modern populations may be more representative of the true population of the United States, but only if the sample was contemporaneous (modern day). In fact, Steyn (2009) is unique in her assertion that population specific standards may not be necessary in sexing skeletal remains. Steyn (2009) combined data from measurements of the pelvis of South African blacks, whites and Greeks in order to assess if there was any difference in the ability to sex remains based on a mixed population standard. When using population specific formulae, sex was correctly assigned 94.8%, 94.5% and 94.5% for Greeks, South African whites and South African blacks respectively. When the three samples were combined, average sexing accuracy remained above 94%. Steyn (2009) concluded that no difference in sexing accuracy was found when the combined data were compared to a homogeneous population. Steyn has suggested, contrary to conventional beliefs, that the use of population specific standards may not be necessary.

The identification of human remains using radiographic methods has been well established. Comparison of dental records is a common technique to identify an individual (Kenney 1994). Comparison of ante- and postmortem radiographs can reveal unique features including degenerative changes, signs of prior trauma or idiosyncratic features, which can lead to a positive identification (Atkins 1978, Kahana 1997). Radiographic evaluation of living individuals could provide contemporary reference values for normal males and females. Clinical radiographic studies are performed frequently for indications unrelated to orthopedic pathologies, and can provide a large sample size for analysis. For example, Harma (2007) studied 104 individuals (50 males, 54 females) 18 to 68 years of age from Turkey using computed tomography (CT) scans on the left femur. Maximum length, VHD and midshaft transverse diameter were measured. Maximum length was found to be the most dimorphic with 83.3% accuracy for sexing, while 76.9% accuracy was obtained with VHD (Harma 2007).

Kranioti (2009) attempted to use measurements obtained from digital radiographs of the proximal femur to sex individuals and to compare this method with traditional osteometric techniques. The study consisted of 106 adult femora from modern Greeks of known age and sex. Greek burial habits include the exhumation of remains three to five years after burial; the bones are cleaned, and stored in ossuaries. Nine osteologic measurements were recorded from the skeletal remains (biepicondylar length, maximum head diameter, AP and transverse subtrochanteric diameter, AP and transverse midshaft diameter, midshaft circumference, DEB). Each specimen was then radiographed and 15 variables were measured from the digital radiographic images (Kranioti 2009). Stepwise discriminant function analysis of the traditional osteometric variables identified maximum head diameter as the most sexually dimorphic feature (85.7% sexing accuracy) followed by AP midshaft diameter and transverse midshaft diameter being third. When the three features were considered together, 87.1% sexing accuracy was obtained, whereas 88.6% accuracy was obtained when all nine variables were considered together. Fourteen of the 15 variables obtained from the radiologic studies were significantly larger in males compared to females. Taken together, the three most sexually dimorphic variables resulted in 85.7% sexing accuracy. The results suggested that radiographic techniques are a useful alternative to standard osteometric approaches in individual identification (Kranioti 2009).

A number of studies have compared variables from the proximal femur obtained from DEXA scans (Gomez Alonso 2000; Nissen 2005; Wheatley 2005). DEXA assesses bone mineral density (BMD) in patients at risk for hip fractures (Wheatley 2005). Nissen (2005) evaluated 249 healthy Danish adults age 19 to 79 using DEXA scans of the right hip. SID, NSA and head radius were all found to be significantly greater in males compared to females. Gomez Alonso (2000) performed DEXA scans on 411 patients with a history of a hip fracture and on 545 healthy controls from a population in Spain. NSA and minimum neck diameter were significantly larger in males compared to females in both the hip fracture and control groups.

Wheatley (2005) examined the application of DEXA scans in forensic anthropology. DEXA scans were performed on 41 white patients (17males, 24 females) at the University of Alabama at Birmingham. SID was reported to be significantly larger in males compared to females. A combination of BMD and SID resulted in 92.7% sexing accuracy (Wheatley 2005) .

The purpose of the present study is to examine a mixed contemporary population of individuals of known sex to determine if dimorphism of the femur can be established in a heterogeneous population. Additionally, this study will address whether digital radiologic techniques can be applied to establish sexual identity.

Materials and methods

Study population

Radiographic studies from patients 18 to 80 years of age undergoing hip evaluations in the radiology department at John T. Mather Hospital from January 2007 until June 2009 were included in the initial study. Patients with pathologic abnormalities including osteoporosis, osteoarthritis, hip fracture, hip replacement, neoplastic growths or infection were excluded.

Mather Hospital utilizes the PAC (picture archival and communication) system. This system provides computerized radiologic images, which are digitally stored using Dynamic Imaging software. All studies were performed on a General Electric Medical System Legacy radiologic device with the patient in a supine position, 40 inches from the x-ray source with a setting of 80KV and 40 MAS. In order to obtain an AP view, the toes were inverted 15 degrees in order to overcome the anteversion of the femoral neck (Ballinger 1982). In an AP view, the greater trochanter projected laterally and the lesser trochanter projected medially (Figure 1). Orientation of the films was evaluated and those found not to be true AP views were excluded from the study (Figures 2 and 3).

Fig. 1 Digital image of an AP view of the proximal right femur. The greater trochanter is projecting laterally and the lesser trochanter is projecting medially.

Figs. 2 and 3 Digital images of right and left proximal femurs. In the image on the left, the greater trochanter is projecting laterally but the lesser trochanter is not projecting medially. In the image on the right, the lesser trochanter is projecting medially but the greater trochanter is not projecting laterally, indicating that these are not AP views.

Measurements

The following dimensions were measured digitally using calipers provided through the PAC system:

Vertical head diameter: (Figure 4, A-B) (maximal vertical diameter of the femoral head)

Superior-inferior neck diameter: (Figure 4, C-D)(the narrowest diameter of the femoral neck)

Hip axis length: (Figure 4, E-F) (the length from the greater trochanter to the top of the femoral head parallel to the neck line) The axis for the femoral neck was determined by first establishing two lines perpendicular to the femoral neck (Figure 4; C-D and K-L), and using the midpoint of these two lines to establish a third line that bisects the first two lines (Figure 4; E-F)

Neck-shaft angle: (Figure 4) (the angle, in the coronal plane, between the axes of the femoral neck and shaft) The femoral shaft axis was determined by first establishing two lines perpendicular to the femoral shaft (Figure 4; G-H and I-J) and using the midpoint of these two lines to establish a third line that bisects the first two lines (Figure 4; M-N).

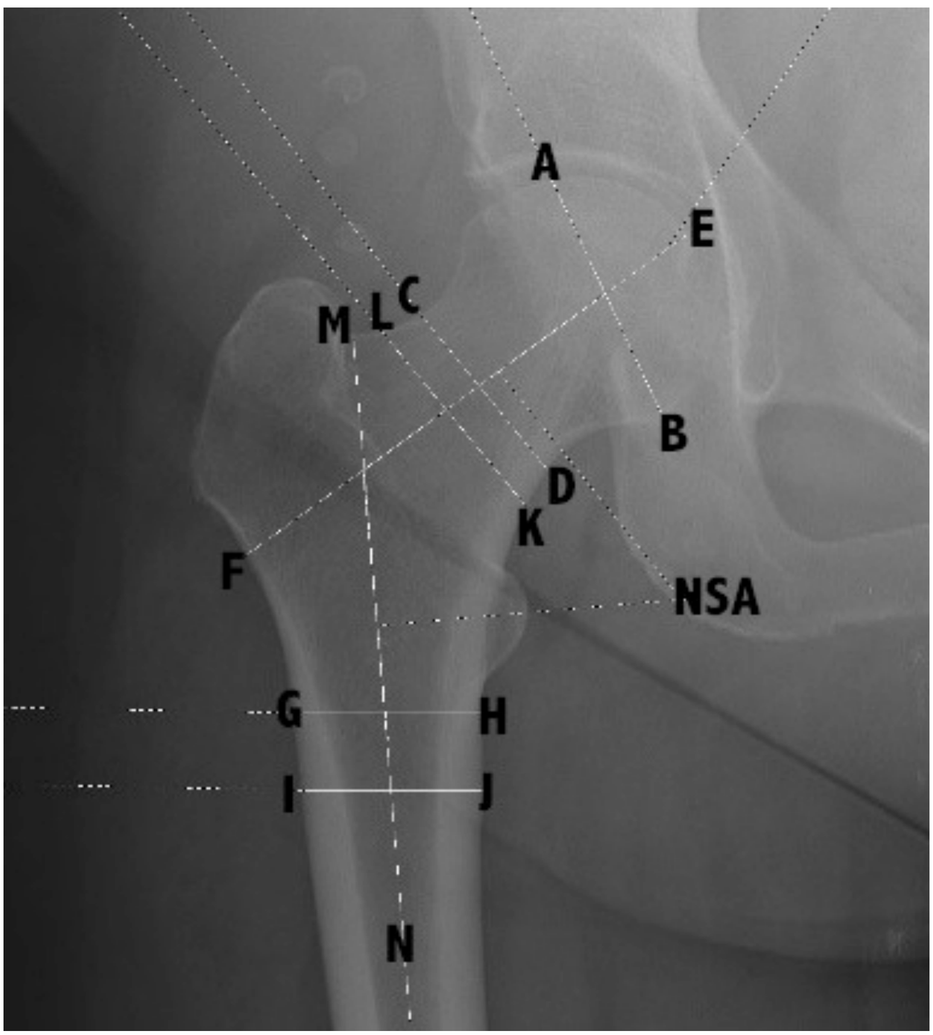

Fig. 4 Digital AP view of right proximal femur. The four variables measured were VHD (A-B), SID (C-D), HAL (E-F) and NSA

A ratio of sexual dimorphism was calculated for each variable following Slaus (2002). The index was computed as Mm/Mf x 100 where Mm is the mean value for males and Mf was the mean value for females.

Statistical Analysis

Univariate statistics

Statistical calculations were performed using the Statistical Product and Service Solution (SPSS) for Windows 2007. Measurements of central tendency including mean, median and standard deviation were calculated for each variable. Levene's Test of Equality of Variances was applied to assess if the variances of the two groups were equal. Data were collected from either the right or left side for each case. In order to determine if laterality affected measurements of the femur, comparisons were made between right and left sides for the four variables. A two-tailed t-test for independent samples was used to assess whether significant differences existed between males and females. Statistical significance was set at $p<.05$.

Discriminant analysis

Linear discriminant analysis was performed on the complete set of variables. Wilks' Lambda was calculated for the model as a whole to assess if a significant difference between males and females existed based on the four variables. Discriminant analysis investigates differences between two or more mutually exclusive groups and indicates the best discrimination for the pre-defined groups based on a set of characteristics (Klecka 1984). Given a set of variables, discriminant analysis will differentiate between the groups and provide the probability of obtaining a correct classification using those variables. Discriminant analysis assumes a multivariate, normal distribution, a reasonably large sample size, and that the dependent variables must be a true dichotomy (Klecka 1980). Classification matrices were generated to summarize the accuracy of the discriminant analysis. In order to obtain an improved estimate of misclassification, the data were subjected to a cross-validation procedure. One at a time, individual cases were omitted from the analysis, and the discriminant formula was recalculated. The omitted case was classified based on all of the cases except itself (leave out one method).

Intraobserver error

Intraobserver variation was determined by randomly selecting ten cases in which the measurements were repeated on three separate occasions, each 4 weeks apart. Systematic random sampling as described in *Social Statistics for a Diverse Society* (Frankfort- Nachmias 2006, pg 350) was performed to select the 10 cases. Estimation of the measurement error was performed according to White (2000). The means of the three measurements for each variable were calculated. The differences between the original three measurements and the means were calculated, added together and divided by three to obtain an average difference. This was converted to a percentage to indicate the average measurement error.

Results

A total of 3635 films were examined of which 452 (12.4 %) met the criteria for inclusion in the study. Of the 452 cases, 293 (64.8 %) were female and 159 (35.2%) were male. Males were, on average, four years younger than females (46.62 and 50.89 years respectively). Levene's Test for Equality of Variance was significant so the null hypothesis that the variances were equal was rejected.
The t-score was -2.472 (Table 2; $p<0.05$).

Table 2

Age of males and females in study population

Gender	Number	Mean Age (years)
Males	159	46.62 $\pm$18.82
Females	293	50.89 $\pm$14.91

Two tailed t-test
t-value -2.472 ($p<.05$)

Both right and left sided films were included in the study. Comparisons were made between right and left sides for the variables VHD, SID, HAL and NSA. There were 241 (53.3%) cases from the right side and 211 (46.7%) from the left side. There was no significant difference between the two sides for VHD, SID, or HAL (Table 3). NSA was found to be two degrees smaller on the right compared to the left side (Table 3; $p<.001$). When NSA from right or left sided measurements was compared between males and females, no significant difference was detected. (Table 4) Since no significant difference between sides could be detected, results of measurements for right and left sides were combined.

Table 3

Comparison of right and left sided values for VHD, SID, HAL and NSA

	VHD (mm)	**SID** (mm)	**HAL** (mm)	**NSA** (degrees)
Right (n= 241)	53.7 ±5.0	37.4 ± 4.5	118.2 ± 11.3	130.70 ±5.17
Left (n=211)	53.7 ±4.8	36.7± 4.2	116.2 ± 11.5	132.65± 5.68
t-value	0.098	1.682	1.903	-3.833**

Two tailed t-test; values presented as means ± standard deviation

** $p < .001$

Table 4

Comparison of NSA and gender for right and left sided cases

	Male	**Female**	**t- value**
Mean NSA (degrees) right side	130.12 ±5.23	131.03 ± 5.12	-1.320
Number (right side)	89	152	
Mean NSA (degrees) left side	131.9 ± 6.34	133.02 ± 5.31	-1.335
Number (left side)	70	141	

Two tailed t-test; values presented as means ± standard deviation

Table 5 contains measures of central tendency for the study population. For VHD, the mean was 53.7 ± 4.9 mm and median was 53.0mm. For SID, the mean was 37.0 ± 4.4 mm while the median was 36.5 mm. Mean HAL was 117.3 ± 11.5 mm with a median of 115.8. Mean NSA was 131.61 ± 5.5 degrees with a median of 132.0 degrees (Table 5).

Table 5

Measures of central tendency for the study population

	VHD (mm)	**SID** (mm)	**HAL** (mm)	**NSA** (degrees)
Mean	53.7	37.0	117.3	131.61
Median	53.0	36.5	115.8	132.0
Standard deviation	4.9	4.4	11.5	5.5

Results for measurements of VHD, SID, HAL and AI for males and females are shown in Table 6. Levene's test for equality of variance was significant, indicating the null hypothesis can be rejected and equal variances could not be assumed for VHD, SID and HAL but was not rejected for NSA. Comparison using a two-tailed t-test indicated significant differences between males and females for all four variables. VHD, SID, and HAL were found to be significantly larger in males compared to females (Table 6). VHD was 58.1 ± 4.3 mm in males compared to 51.3 ± 3.3 mm in females ($p<.001$). SID was 40.8 ± 3.8 mm in males compared to 35.0 ±3.2 mm in females ($p<.001$). HAL was 126.3 ± 9.6 mm and 112.3 ± 9.1 mm for males and females respectively ($p<.001$). Females were found to have a larger NSA compared to males. NSA in females was 131.99 degrees compared to 130.91 degrees in males ($p< 0.05$) (Table 6).

Intraobserver error was less than 1.5% for all variables. The mean error was 1.38 ± 1.21 % for VHD, 1.02 ± 0.42 % for SID, 0.83 ± 0.70 for HAL and 0.95 ± 0.50 for NSA (Table 6).

Table 6

Comparison of VHD, SID, HAL and NSA between males and females

Gender	**VHD** (mm)	**SID** (mm)	**HAL (**mm)	**NSA** (degrees)
Males	58.1 ± 4.3	40.8 ±3.8	126.3 ± 9.6	130.91 ± 5.80
Maximum	69.9	51.7	152.4	145
Minimum	46.0	32.0	100.8	114
Females	51.3 ± 3.3	35.0 ± 3.2	112.3 ± 9.1	131.99 ± 5.30
Maximum	59.3	43.5	150.9	146
Minimum	43.5	27.2	94.1	110
t-value	18.885**	17.485**	14.842**	-1.945*
Intraobserver error (%)	1.38±1.21	1.02±0.42	0.83±0.70	0.95±0.50
Sexual dimorphism index	113.26	117.58	112.47	99.17

Two Tailed T-test; values presented as means ± standard deviation

** p<.001

*p<.05

The larger size of VHD, SID and HAL resulted in sexual dimorphism indices of >100 for the three variables. The sexual dimorphism index was 113.26 for VHD, 117.58 for SID and 112.47 for HAL indicating strong sexual dimorphism. The difference of one degree in NSA resulted in a sexual dimorphism index of 99.17 indicating the lack of sexual dimorphism for this variable (Table 6).

Discriminant analysis resulted in an eigenvalue of .906 (Table 7), which reflects the high relative discriminatory power of the discriminant function. Wilks' Lambda was .525 (p<.001) (Table 7) indicating a significant difference between males and females based on the four variables.

Table 7

Summary of Canonical Discriminant Function

Function	Eigenvalue	Canonical Correlation	Wilks' Lambda	X^2	df	Significance
1	.906	.690	.525	289.037	4	P<.001

The standardized discriminant function coefficient illustrates the relative contribution of each variable to the function. The standardized coefficient of VHD was highest at .508, indicating VHD contributes the most to the discriminant function followed by HAL (.323) and SID (.318) (Table 8). NSA contributed the least to the discriminant function (-.091). The group centroids are 1.289 and -.700 for males and females respectively, indicating the mean discriminating scores for the dependent variables are well apart from one another (Table 8).

Table 8

Standardized Canonical Discriminant Function Coefficients

	Standardized Discriminant Function Coefficient	Structure Coefficient	Centroid
VHD	.508	.935	
SID	.318	.866	Male = 1.289
HAL	.323	.747	
NSA	-.091	-.099	Females = -.700

The structure coefficient indicates the correlation between a given independent (predictor) variable and the discriminant score associated with the discriminant function. The structure coefficient indicates how strongly each discriminating variables relates to the total correlation (not unique) and the direction of the relationship. VHD contributes the most to the discriminant score with a value of .935, followed by SID (.866) second and HAL (.747) third. NSA (-.099) did not contribute to the discriminatory score in this function (Table 8).

Table 9

Classification Results

Predicted group membership

		Sex	Male	Female	Total
Original	Counts	Male	132	27	159
		Female	39	254	293
	Percentage	Male	83.0	17.0	100
		Female	13.3	86.7	100
Cross-validation	Counts	Male	132	27	159
		Female	40	253	293
	Percentage	Male	83.0	17.0	100
		Female	13.7	86.3	100

The accuracy of the discriminant function is presented in Table 9. Sixty-six out of 452 were incorrectly classified, resulting in a sexing accuracy of 85.4%. Twenty-seven out of 159 males were incorrectly classified, resulting in 83.0% accuracy of sexing males using this function. Thirty-nine out of 293 females were incorrectly classified for 86.7% accuracy of sex prediction in females.

Cross validation of the estimates (leave out one method) supports the original analysis. It resulted in one additional female incorrectly classified while no change in sexing accuracy for males occurred. The four variables resulted in 83.0% accuracy in sexing males and 86.3% accuracy in sexing females.

Discussion

Many studies support the use of population specific standards to establish sexing of skeletal remains (Alunni-Perret 2003; Asala 2004; Frutos 2003; Iscan 1984a, 1984b, 1995; Kranioti 2009; Mall 2000; Papaloucas 2008; Purkait 2004; Seidemann 1998; Slaus 2003; Steyn 1997, 2009; Stojanowski 1999; Trancho 1997; Wheatley 2005). Sexing accuracy based on these studies has ranged from 76.9 % to 97.5% (Table 10). Although studies of sexing based on the femur have generally focused on one ethnic group, several studies, (Seidemann 1998, Stojanowski 1999, Iscan 1984a) examined populations of North American whites and blacks and reported comparable sexing accuracy (85% to 93%).

Steyn (1997) examined the accuracy of sexing using the femur and reported 90.5% accuracy in a population of South African whites. A number of years later, Steyn (2009) questioned the validity of the long held belief that sexing should be based on population specific standards. Steyn (2009) examined a group that included South African whites and blacks as well as Greeks. Rather than the femur, Steyn (2009) examined seven osteometric features from the pelvis and found acetabular diameter to be the most sexually dimorphic feature with an accuracy of 82.5% (Table 10). When the seven variables were considered together, 94% sexing accuracy was obtained. Steyn concluded that when using the pelvis for sexing, a population specific formula might not be necessary.

Table 10

Comparison of sexing accuracy

Author	Population	Feature	Sexing discrimination (%)
Steyn 1997	South African whites	Distal epicondylar breadth	90.5
Iscan 1995	Chinese	Distal epicondylar breadth	94.9
Trancho 1997	Spanish	Distal epicondylar breadth	97.5
Slaus 2003	Croatian	Maximum head diameter	94.2
Mall 2000	German	Transverse head diameter	89.6
Asala 2004	South African blacks	Vertical head diameter	82.6
Papaloucas 2008	Greek	Vertical head diameter	76.9
Kranioti 2009	Greek	Maximum head diameter	85.7
Purkait 2004	Indian	Maximum head diameter	93.5
Wheatley 2005	North American whites	Superior- inferior neck diameter	92.7
Alunni-Perret 2003	French	Superior- inferior neck diameter	90.1
Frutos 2003	Guatemalan	Superior- inferior neck diameter	89.5
Seidemann 1998	North American whites and blacks	Superior- inferior neck diameter	93.0
Stojanowski 1999	North American whites and blacks	Superior- inferior neck diameter	85.0
Iscan 1984a	North American whites and blacks	Maximum head diameter	90.2
Steyn 2009	Greeks, South African whites, blacks	Acetabular diameter	82.5

The aim of Steyn's study was to obtain measurements from " widely differing populations" (Steyn 2009 p. 113.e1) in order to create "global formulae" (Steyn 2009 p. 113.e1). Greeks are certainly geographically different from South Africans but from a size perspective, these populations may not be as different as Steyn suggests. Studies using European and South African samples have reported similar VHD measurements (Asala 2004; Mall 2000; Papaloucas 2008; Trancho 1997). VHD for Greek and South African white males are almost identical (48.5mm and 48.47mm respectively) (Table 11) and are very similar between Greek females and South African white females (41.6mm and 42.36mm respectively) (Table 11). Mall (2000) reported VHD in a German sample to be 49.0mm and 44.0 mm for males and females respectively. Trancho (1997) reported VHD from a Spanish sample to be 47.2 mm and 41.1mm for males and females respectively. South African blacks are somewhat smaller compared to South African whites and Europeans (Greeks, Germans and Spanish) with VHD of 45.4mm and 40.7mm for males and females respectively (Table 11). From a size perspective, therefore, Steyn's samples may not have been different enough to conclude that population specific standards are not necessary.

Table 11

Comparison of mean VHD

Population	**Males** (mm)	**Females** (mm)
Greek **Papaloucas (2008)**	48.5 ± 2.3 n= 100	41.6 ±1.9 n= 100
South African whites **Asala (2001)**	48.5 ± 2.6 n= 160	42.4 ± 2.4 n= 100
South African blacks **Asala (2004)**	45.4 ± 2.6 n= 132	40.7 ±2.3 n= 86
German **Mall (2000)**	49.0 ± 3.0 n= 100	44.0 ± 3.0 n= 70
Spanish **Trancho (1997)**	47.2 ± 2.5 n= 52	41.1 ± 1.9 n= 62

Results expressed as means ± standard deviation

Frutos (2003) compared femoral neck size in a Guatemalan population to that of North American whites and blacks from the Hamann-Todd collection and reported SIN in Guatemalan males to be smaller than that of North American white and black males (29.0 mm, 33.53 mm and 31.93 mm respectively) (Table 12), and to be closer in size to North American white and black females (29.0 mm, 27.86 mm and 27.31 mm respectively). Guatemalan females were reported to be smaller than North American white and black females (24.7 mm, 27.86 mm and 27.31 mm respectively) (Table 12). When discriminant functions for SIN from the Hamann-Todd collection were applied to this Guatemalan population, a sexing accuracy between 21.3% and 36% was obtained. When a new discriminant function was developed based on a Guatemalan sample, 89.5% accuracy was reported (Frutos 2003).

Table 12

Comparison of mean SIN in Guatemalan, North American whites and blacks

	Guatemalan (Frutos 2003)	**North American Whites** (Seidemann 1998)	**North American Blacks** (Seidemann 1998)
Males (mm)	29.0 ±2.0 n= 75	33.53 ±2.2 n= 50	31.93 ±1.7 n= 51
Females (mm)	24.7 ±1.2 n= 39	27.86 ±1.7 n= 50	27.31 ±1.7 n= 52

A comparison of average stature of Guatemalans and Americans reveals the former to be substantially shorter. Guatemalan males and females are 20 cm shorter than their American counterparts (Table 13). Guatemalans are also over 12 cm shorter than South African males and females (Table 13). This Hispanic population is clearly much smaller than populations of African or European descent.

Table 13

Average height of males and females worldwide

Country	Males (cm)	Females (cm)
Guatemala	157.5	142.2
Indonesia	158.0	147.0
China	164.8	154.5
South Africa	169.0	159.0
Spain	170.0	161.0
Greece	175.9	162.9
Germany	178.0	165.0
United States	177.9- whites 177.0- blacks	164.8- whites 163.2- blacks
Iceland	181.7	167.6

Source: www.disabledworld.com/artman/publizedheight-chart.shtml

The population of the United States includes Hispanics, Native Americans, Hawaiians and Asians in addition to North American blacks and whites. Only 72.4% of the United States population is of northern European descent; 16.3% are Hispanic according to the 2010 census (US Census 2010) (Table 14). Frutos' (2003) study, as well as recent stature data, suggests individuals of Hispanic origin are, on average, smaller than those of African or European descent. Thus, a sample drawn from a heterogeneous population in the United States, which includes more than 16% Hispanics, would certainly be expected to be more varied than Steyn's (2009) sample of Greeks and South Africans. Using a diverse population for sexing, the present study found 85.4% sexing accuracy based on features of the proximal femur. The results of this study are within the range reported by prior studies using population specific standards and support the findings of Steyn (2009), suggesting that population specific standards may not be needed to sex based on skeletal remains. Indeed, they may be misleading.

Table 14

Ethnic Distribution of Suffolk County and New York State in 2010

Ethnicity	Suffolk County (%)	New York State (%)	United States (%)
White	80.8	65.7	72.4
Black	7.4	15.9	12.6
Native American	0.4	0.6	0.9
Asian	3.4	7.3	4.8
Hawaiian	0.2	0.0	0.0
Hispanic	16.5	17.6	16.3

- Source: http://quickfacts.census.gov/qfd/states/36/36103.html

The sampling for the present study was drawn from a hospital in Suffolk County, New York. When examining data from a hospital based population, it is assumed the patients represent the population of the surrounding community. According to the 2010 US Census, the population of Suffolk County included 80.8% whites, 7.4% blacks and 16.5% Hispanics (US Census 2010) (Table 14). This represents a higher percentage of whites living in Suffolk County compared to New York State (80.8 and 65.7% respectively) and the country as a whole (80.8 and 72.4% respectively) (Table 14). Fewer blacks reside in Suffolk County compared to New York State (7.4% and 15.9% respectively) and the United States (7.4% and 12.6% respectively) (Table 14). Unlike the data for whites and blacks, the percentage of the population made up of Hispanics in Suffolk County is similar to that for the country as a whole (16.5 and 16.3% respectively) and only slightly less than that of New York State (16.5 and 17.6% respectively) (Table 14). Thus, census data suggests that Suffolk County is not as diverse as New York State or the United States with regard to the percentage of white or black individuals, but that it is representative of the percentage of Hispanics in the United States population.

The comparatively lower percentages of whites and blacks in Suffolk County is likely to have minimal impact on the results of this study. This is because the stature of blacks and whites in the United States is similar, while both groups are, on average, 20 cm taller than Guatemalans (Table 13). Human stature is positively correlated with limb bone length (White 2000; Byers 2008), and estimates of stature based on femur length have a 68% probability to be within 3.417 cm of actual stature (White 2000). Femur length can be assumed to be similar between American whites and blacks, and greater than in populations from Central America. Since Hispanics are, on average, smaller than American whites and blacks, it is more important to have a study population with a percentage of Hispanics comparable to the country as a whole.

In addition to the differences in heterogeneity of populations in Suffolk County compared to New York, hospital patients may not accurately reflect the makeup of the surrounding community. Patients of lower socio-economic levels may not have health insurance, which may limit their visits to a private hospital. At the same time, undocumented aliens may be hesitant to present themselves for medical care. One limitation of this study is the lack of information on patient ethnicity. Thus, the population included in this study may be less diverse than the census data report for Suffolk County.

An additional limitation of this study was the examination of only the proximal femur. Trancho (1997), Iscan (1984a), and Steyn (1997) have reported that the distal femur, namely distal epicondylar breadth, is the most sexually dimorphic feature of the femur. The distal femur was not examined in this series, limiting comparisons with these prior studies.

In the future, measurements that include the proximal and distal ends of the femur need to be recorded to clarify which is more sexually dimorphic in this heterogeneous population. Data should be sampled from a university hospital with a broad- based population to include all socio-economic levels, including data on patient ethnicity.

Ultimately, a database should be compiled for future use in sexing skeletal remains. The development of discriminant functions for the study population could be used by forensic investigators to sex skeletal remains.

References

Albanese J, Eklics G, Tuck A. 2008. A metric method for sex determination using the proximal femur and fragmentary hip bone. J Forensic Sci 53(6): 1283-1288.

Alunni-Perret V, Staccini P, Quatrehomme G. 2003. Reexamination of a measurement for sexual determiation using the superio-inferior femoral neck diameter in a modern European population. J Forensic Sci 48(3): 517-520.

Anderson JY, Trinkaus E. 1998. Patterns of sexual, bilateral and interpopulational variation in human femoral neck-shaft angles. J Anatomy 192: 279-285.

Angel JL. 1976. Colonial to modern skeletal changes in the USA. Am J Phys Anthropol 45: 723-736.

Asala SA. 2001. Sex determination from the head of the femur of South African blacks and whites. Forensic Sci Int 117: 15-22.

Asala SA. 2002. The efficiency of the demarking point of the femoral head as a sex determining parameter. Forensic Sci Int 127: 114-118.

Asala SA, Bidmos MA, Dayal MR. 2004. Discrimnant function sexing of fragmentary femur of South African blacks. Forensic Sci Int 145: 25-29.

Atkins L, Potsaid MS. 1978. Roentgenographic identification of human remains. Jama. 240:2307-08.

Ballinger PW. 1982 Merrill's atlas of radiographic positions and radiologic proceedures. CV Mosby Company, St Louis.

Bernstein R, Edwards T. 2008. An older and more diverse nation by midcentury. U.S. Census Bureau News. U.S. Department of Commerce, Washington D.C.

Byers SN. 2008. Introduction to Forensic Anthropology. Boston, Ma. Pearson Education, Inc.

Davivongs V. 1963. The pelvic girdle of the Australian Aborigine. Am J Phys Anthropol 21: 443-445.

DiBennardo R, Taylor JV. 1979. Sex assessment of the femur: A test of a new method. Am J Phys Anthropol 50: 635-38.

DiBennardo R., Taylor JV. 1982. Classification and misclassification in sexing the black femur by discriminant function analysis. Am J Phys Anthropol 58: 145-151.

Disabled world. 2008. Height chart of men and women in different countries. www.disabled-world.com/artman/publish/height-chart.shtml

Ditch LE, Rose JC. 1972. A multivariate dental sexing technique. Am J Phys Anthropol 37: 61-64.

Fong L, Tan K, Tran C, Cool J, Scherer MA , Elovaris R, Coyle P, Foster BK, Rofe AM, Xian CJ . 2009. Interaction of dietary zinc and intracellular binding protein metallothionein in post natal bone growth. Bone 44: 1151-1162.

Frutos LR. 2003. Brief communication: Sex determination accuracy of the minimum supero-inferior femoral neck diameter in a contemporary rural Guatemalan population. Am J Phys Anthropol 122: 123-126.

Giroux CL, Wescott DJ. 2008. Stature estimation based on dimensions of the bony pelvis and proximal femur. J Forenssic Sci 53: 65-68.

Gomez Alonso C, Diaz CM, Hawkins C F, Perez C R, Diez P A. 2000. Femoral bone mineral density, neck-shaft angle and mean femoral neck width as predictors of hip fracture in men and women. Osteoporosis Int 11: 714-720.

Gray JP, Wolfe LD. 1980. Height and sexual dimorphism of stature among human societies. Am J Phys Anthropol 53: 441-456.

Grine F, Jungers WL, Tobias PV , Pearson OM. 1995. Fossil Homo femur from Berg Aukas, Northern Namibia. Am J Phys Anthropol 97: 151-185.

Harma A, Karakas HM. 2007. Determination of sex from the femur in Anatolian Caucasians: A digital radiological study. J Forensic and Legal Medicine 14: 190-194.

Houston CH, Zaleski WA. 1967. The shape of vertebral bodies and femoral necks in relation to activity. Radiol 89: 59-66.

Houston CS. 1978. The radiologist's opportunity to teach bone dynamics. J Assoc Canadian Radiologists 29: 232-238.

Humphry F. 1889. The angle of the neck with the shaft of the femur at different periods of life and under different circumstances. J. Anat Physiol 23: 273-282.

Iscan MY, Miller-Shaivitz P. 1984a. Determination of sex from the femur in blacks and whites. Coll Anthropol 8(2): 169-175.

Iscan MY, Miller-Shaivitz P. 1984b. Discriminant function sexing of the tibia. J Forensic Sci 29(4): 1087-1093.

Iscan MY, Ding S. 1995. Sexual dimorphism in the Chinese femur. Forensic Sci Int 74: 79-87.

Kahana T, Ravioli JA, Urroz CL, Hiss J. 1997. Radiographic identification of fragmentary human remains from a mass disaster. Am J Forensic Medicine Pathol 18(1): 40-44.

Kelley MA. 1979. Parturition and pelvic changes. Am J Phys Anthropol 51: 541-546.

Kenney J, Standish SM, Souviron RR, Vale GL, McGivney J, Jones G. 1994. Body Identification Guidelines. J Am Dental Assoc 125(9): 1244.

Kjellstrom A. 2004. Evaluations of sex assessment using weighted traits on incomplete skeletal remains. Int J Osteoarchaeol 14: 360-373.

Klecka WR. 1980. Discriminant Analysis. Sage Publications Inc. Beverly Hills, Ca.

Kranioti EF, Vorniiotakis N, Galiatsou C, Iscan MY, Michalodimitrakis M. 2009. Sex identification and software development using digital femoral head radiographs. Forensic Sci Int 189: 113.e1-113.e7.

Lavelle CLB. 1974. An analysis of the human femur. Am J Anat 141: 415-426.

Mall G, Hubig M, Buttner A, Kuznik J, Penning R, Graw M. 2000. Sex determination and estimation of stature from the longbones of the arm. Forensic Sci Int 117: 23-30.

Mays S, Brickley M, Ives R. 2009. Growth and vitamin D deficiency in a population from 19th century Birmingham, England. Int J Osteoarchaeol 19: 406-415.

Meadows Jantz L, Jantz RL. 1999. Secular changes in long bone length and proportion in the United Sates, 1800-1970. Am J Phys Anthropol. 110:57-67.

Mundorff AZ, Bartelink EJ, Mar-Cash E. 2009. DNA preservation in skeletal elements from the World Trade Center disaster: Recommendations for mass fatality management. J Forensic Sci 54(4): 739-745.

Nissen N, Hauge EM, Abrahamsen B. Jensen JEB, Mosekilde L, Brixen K. 2005. Geometry of the proximal femur in relation to age and sex: a cross sectional study in healthy Danes. Acta Radiologica 46: 514-518.

Papaloucas C, Fiska A, Demetriou T. 2008. Sexual dimorphism of the hip joint in Greeks. Forensic Sci Int 179: 83.e1-83.e3.

Parsons F. 1914. The characters of the English thigh bone. J Anat Physiol: 238-267.

Phenice TW. 1969. A newly developed visual method of sexing the os pubis. Am J Phys Anthropol 30: 297-302.

Purkait R, Chandra H. 2004. A study of sexual variation in Indian femur. Forensic Sci Int 146: 25-33.

Rogers TL. 2005. Determining the sex of human remains through cranial morphology. J Forensic Sci 50(3): 493-500.

Ruff C. 1987. Sexual dimorphism in human lower limb bone structure : relationship to subsistance strategy and sexual division of labor. J Hum Evol 16: 391-419.

Ruff C. 2003. Growth in bone strength, body size, and muscle size in a juvenile longitudinal sample. Bone 33: 317-329.

Seidemann RM, Stojanowski CM, Doran GH. 1998. The use of the supero-inferior femoral neck diameter as a sex assessor. Am J Phys Anthropol 107: 305-313.

Slaus M, Strinovic D, Skavic J, Petrovecki V. 2003. Discriminant function sexing of fragmentary and complete femora: standards for contemporary Croatia. J Forensic Sci 48(3): 509-512.

Steyn M, Iscan MY. 1997. Sex determination from the femur and tibia in South African whites. Forensic Sci Int 90: 111-119.

Steyn M, Patriquin ML. 2009. Osteometric sex determination from the pelvis- Does population specificity matter? Forensic Sci Int 191: 113.e1-113.e5.

Stojanowski CM, Seidemann RM 1999. A reevaluation of the sex prediction accuracy of the minimum superio-inferior femoral neck diameter for modern individuals. J Forensic Sci 44(6): 1215-1218.

Tanner JM, Prader A, Haich H, Ferguson-Smth MA. 1959. Genes on the Y chromosome influencing rate of maturation in man. Lancet 2: 141-144.

Toogood PA, Skalak A, Cooperman DR. 2008. Proximal femoral anatomy in the normal human population. Clin Orthoped and Relat. Res 467: 876-885.

Trancho GJ, Robledo B, Lopez-Bueis I, Sanchez JA. 1997. Sex determination of the femur using discriminant functions. Analysis of a Spanish population of known sex and age. J Forensic Sci 42(2): 181-185.

Trinkaus E. 1993. Femoral neck-shaft angles of the Qafzeh-Skhul early modern humans and activity levels among immature Near Eastern Middle Paleolithic hominids. J Hum Evol 25: 393-416.

Van Gerven D. 1972. The contribution of size and shape variation to patterns of sexual dimorphism of the human femur. Am J Phys Anthropol 37: 49-60.

Varrela J. 1984. Effects of X and Y chromosomes on body size and shape. Proceedings of the Finnish Dental Society.

Wheatley BP. 2005. An evaluation of sex and body weight determination from the proximal femur using DEXA technology and its potential for forensic anthropology. Forensic Sci Int 147: 141-145.

White TD. 2000. Human Osteology. San Diego, California, Academic Press.

Williams BA, Rodgers TL. 2006. Evaluating the accuracy and precision of cranial morphological traits for sex determination. J Forensic Sci 51(4): 729-735.

US Census Bureau. 2010. State and county quick facts.
http://quickfacts.census.gov/qfd/states/36/36103.html