A METRIC ANALYSIS OF THE POSTCRANIAL SKELETON OF HISPANIC INDIVIDUALS TO IMPROVE THE ESTIMATION OF SEX

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A METRIC ANALYSIS OF THE POSTCRANIAL SKELETON OF HISPANIC

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ABSTRACT

A METRIC ANALYSIS OF THE POSTCRANIAL SKELETON OF HISPANIC INDIVIDUALS TO IMPROVE THE ESTIMATION OF SEX

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Forensic anthropologists are impacted by the growing Hispanic population in the United States. When estimating the sex of Hispanic skeletal remains, initial observations cause male individuals to frequently be misclassified as female. Hispanic individuals have been described as smaller and more gracile than the groups to which they are compared, including American Blacks, Whites, and sometimes Native Americans (Spradley et al. 2008).

To help forensic anthropologists more accurately estimate the sex of individuals considered Hispanic, this research took standard postcranial measurements from border crossing fatalities from the United States-Mexico border, at the Pima County Office of the Medical Examiner in Tucson, Arizona. In addition, Hispanic individuals from the Forensic Anthropology Data Bank were used to increase the sample size, which created a total sample of 114 males and 28 females. The standard postcranial measurements were statistically analyzed, and it was determined that the radius and humerus are the best elements for sex estimation in Hispanic individuals. Sex estimation rates from these elements are higher than when using metric methods derived from American Black and White individuals (Spradley et al. 2008). These results highlight that individuals considered Hispanic may exhibit sexual dimorphism differently than American Blacks and Whites, and thus require different methods of sex estimation. The results of this research provide forensic anthropologists with sectioning points and classification functions to use when estimating the sex of Hispanic individuals. Forensic anthropologists are impacted by the growing Hispanic population in the United States. Studies, such as this one, are important to the growing field of forensic anthropology, in accordance with the changing population dynamics of the United States.

CHAPTER I

INTRODUCTION

When unidentified skeletal remains are found, a biological profile is created by a forensic anthropologist to help estimate the sex, ancestry, age, and stature of the individual. Of all of these, sex is one of the most important aspects, as it is a key element in the process of identification. Although many forensic anthropologists tend to first look at the bones of the pelvis and skull when estimating the sex of skeletal remains, many times these elements of the skeleton are not recovered due to taphonomic occurrences, such as weathering or animal scavenging. The pelvis is the best indicator of sex (Phenice 1967; Sutherland and Suchey 1991), but when these bones are not present or too damaged for analysis, many times the initial observations are aimed at the skull or the overall size of the skeleton (France 1998). France (1998) and Spradley (2003) have shown that the elements of the postcranial skeleton are more accurate when estimating sex than the skull. If the sex is assessed or estimated incorrectly, that individual will most likely remain unidentified.

In 2005, the Hispanic population in the United States represented the largest minority group, with a total of 42.7 million individuals, and this number continues to grow every year (www.census.gov). From July 1, 2004 to July 1, 2005, Hispanics accounted for 49 percent of the total growth of the United States' population (www.census.gov). As the Hispanic population grows, it is likely that forensic anthropologists will see more individuals considered Hispanic in their caseloads. With this growing population, it is crucial for forensic anthropologists to be able to identify deceased individuals of Hispanic ancestry. Unfortunately, today, the field of forensic anthropology lacks the data needed to effectively do so.

When using methods based on the morphology of the skull and the overall skeleton size, these observations frequently cause Hispanic male individuals to be misclassified as female (Spradley et al. 2008). Hispanic individuals have been described as small and more gracile than the groups to which they are compared, including American Blacks, American Whites, and sometimes Native Americans (Spradley et al. 2008). When using American White criteria on Hispanic skeletal remains, Spradley's (2008) research found that 100 percent of Hispanic females were correctly classified as female, but 70 percent of Hispanic males were also classified as female, which would most likely cause these males to remain unidentified. Due to this misclassification, it is very important to have a population specific method to aid in the estimation of sex of Hispanic skeletal remains. The purpose of this research is to provide new methodology for sex estimation of skeletal remains for individuals considered Hispanic. The objective is to use new data collected from border crossing fatalities from the United States – Mexico border in conjunction with the existing data from the Forensic Anthropology Data Bank (FDB). This research aims to be the beginning of a process to improve methods and techniques when estimating the sex of Hispanic individuals.

The majority of identification methods currently used by forensic anthropologists were developed on American Black and White individuals (Spradley et al. 2008). The major sources of data for these identification methods primarily come from two anatomical collections consisting of late 19th and early 20th century skeletal remains. The Robert J. Terry Collection at the Smithsonian Institution in Washington D.C. consists of individuals collected from the St. Louis, Missouri area, and the Hamann-Todd Collection at the Cleveland Museum of Natural History in Cleveland, Ohio consists of individuals collected from the Ohio area. Without large amounts of data involving individuals considered Hispanic, and with only a small number of identified Hispanic individuals in the Forensic Anthropology Data Bank (FDB) and in FORDISC 3.0, research has not been conducted in order to improve the methods to include variation within this population group.

The FDB is a collection of measurements and demographic data of identified individuals or individuals in the process of identification (Jantz and Moore-Jansen 1998). Metric and non-metric data have been collected by forensic anthropologists throughout the United States and submitted to the FDB, which is curated by Richard L. Jantz at the University of Tennessee in Knoxville, Tennessee. The FORDISC 3.0 computer program was created by Richard Jantz and Steve Ousley as an interactive computer program used to compare an unknown individual to known population groups, primarily taken from the FDB, for the purpose of estimating sex and ancestry (Ousley and Jantz 2005). In both the FDB and FORDISC 3.0, the majority of individuals are American Blacks and American Whites. With more than 1 in 8 individuals in the United States being of Hispanic ancestry, according to Ramirez and de la Cruz (2002), this is of concern because there are no Hispanic skeletal collections to create new methods for identification purposes that are equivalent to the American Black and American White skeletal collections (Spradley et al. 2008).

Hispanic

When identifying unknown skeletal remains as Hispanic, forensic anthropologists are confronted with the issues associated with the term Hispanic. In the United States, the term Hispanic refers to a diverse group of individuals, which includes individuals originating from Mexico, Central America, and some countries in South America and the Caribbean, such as Cuba and Puerto Rico (Bertoni et al. 2003; Ramirez and de la Cruz 2002). It tends to group individuals who are Spanish-speaking in an attempt to simplify a reference to the "fastest growing minority" group (Melville 1988). The category of Hispanic has been called an "umbrella term" that represents a wide range of people (Ross et al. 2004). There are many differences between the multiple population groups that compose the Hispanic ancestry, such as the histories, cultures, country of origin, residential location, and status within the United States (Melville 1988). On the other hand, there are many similarities among these individuals, as they are all either Spanish-speaking, or come from a Spanish-speaking country, and many have a history of a common culture (Melville 1988). The U.S. Census Bureau refers to Hispanic as an ethnic category, as opposed to a racial category. An ethnicity typically encompasses individuals from either a common geographic, linguistic, or cultural origin, which is what is seen in Hispanics (Itzigsohn and Dore-Cabral 2000; Melville 1988; Stephan and Stephan 2000).

It is important to understand the historical meaning behind the term Hispanic. When the United States was first colonized, Spaniards were the first Europeans to arrive. They travelled throughout the southeastern United States, and St. Augustine, Florida was soon settled by Captain Pedro Menendez and his crew in 1565 (Melville 1988). For three centuries, the Spaniards continued to explore and settle in the areas known today as Texas, New Mexico, California, and Mexico. Mexico gained independence from Spain in 1821 and those settlers remaining in the United States were labeled as "Hispanic" (Melville 1988; Shidner and Davis 2009).

In the early 1900s, the southwest United States was still culturally Mexican, and the individuals who lived there and spoke Spanish were continually called Hispanic and Latino (Melville 1988). In 1968, the term Hispanic was sanctioned for official use in the United States by President Richard Nixon, at the request of New Mexican Senator Joseph A. Montoya and numerous Spanish-speaking congressmen, as the week beginning on September 15 or 16 was declared to be National Hispanic week (Melville 1988). After this declaration and celebration of National Hispanic week, the term began to flourish and was adopted in exchange for the individual origins of each Spanish-speaking population (Melville 1988). Individuals considered Hispanic have also been found to self-identify themselves as Hispanic, when not specifically referring to their original country of origin, which is another contributing factor for the endurance of this term (Itzigsohn and Dore-Cabral 2000).

In 2006, the Hispanic population in the United States was about 11 percent of the total population, making them the fastest growing minority in the United States (Sullivan 2006). The U.S. Census Bureau states that in 2050 the Hispanic population in the United

States is predicted to be 102.6 million individuals, which will be about 24.4 percent of the total predicted population in the United States (Sullivan 2006; www.census.gov). This population prediction only includes those individuals who are recorded in the U.S. Census, therefore causing these numbers to be an underestimation. Figure 1 illustrates where Hispanic individuals are located in the United States in 1980. Figure 2 illustrates how widespread Hispanic individuals are throughout the United States in 2006, as they are demonstrated to be covering all regions of the country (www.census.gov). These two maps emphasize how quickly the Hispanic population is growing in the United States, and how quickly it will continue to expand. Figure 3 portrays the past and current population of Hispanic individuals in the United States, as well as the predicted population of Hispanics in the United States up until 2050 (www.census.gov). New methods are needed in the field of forensic anthropology because of the growing number of Hispanic individuals in the United States.

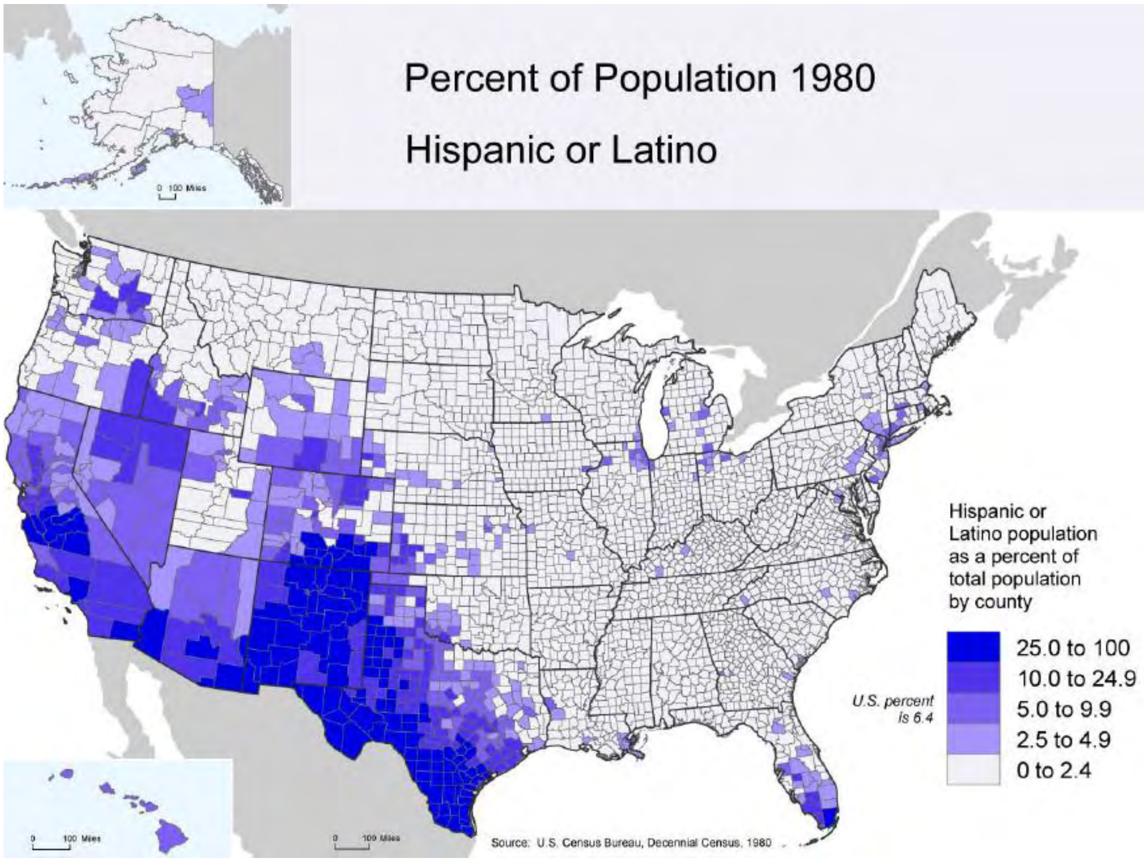

Figure 1: 1980 Hispanic Population Map

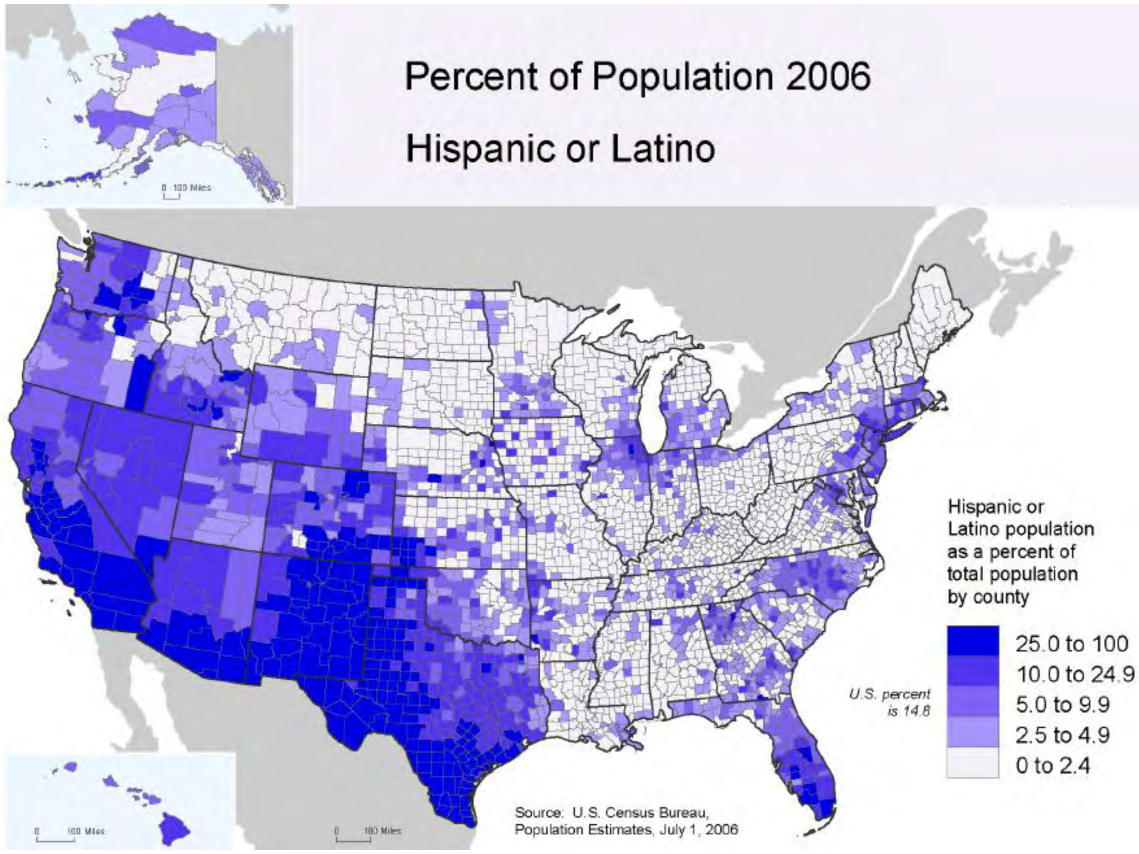

Figure 2: 2006 Hispanic Population Map

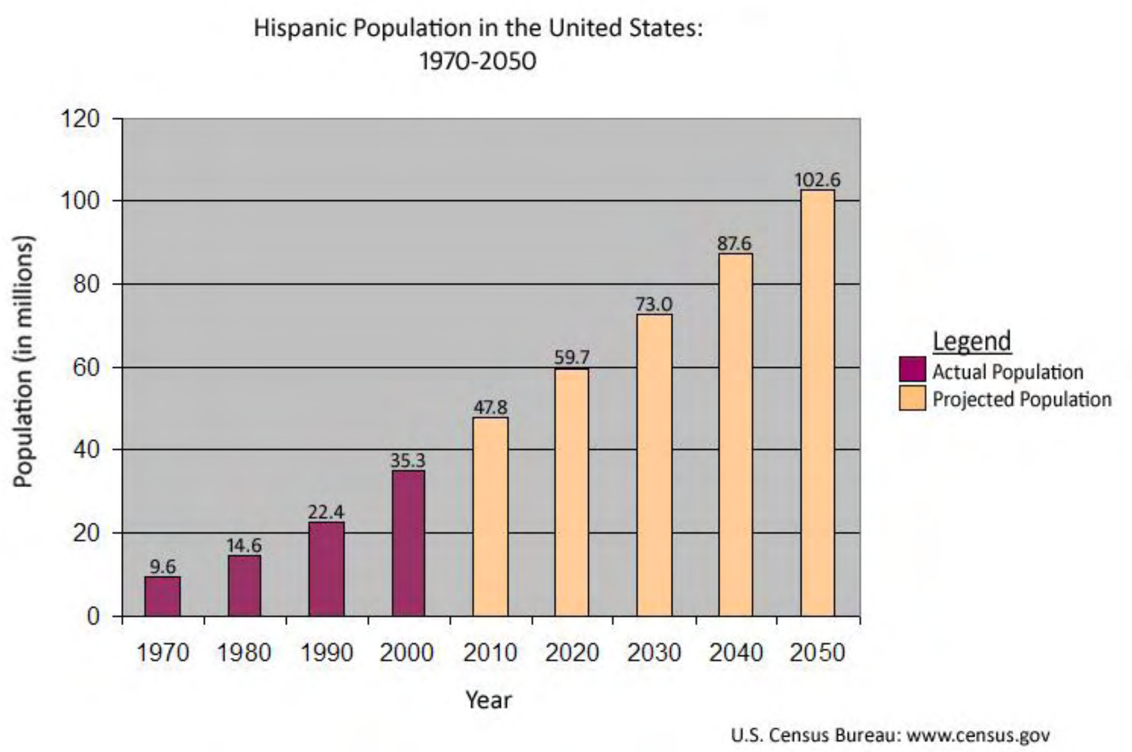

Figure 3: Hispanic Population in the United States from 1970 to the predicted population in 2050

CHAPTER II

LITERATURE REVIEW

The pelvis has always been the first skeletal element that forensic anthropologists refer to when estimating the sex of skeletal remains (Bass 1987; Dwight 1905; Phenice 1967; Spradley 2003; Ubelaker 1999). Features on the pelvis, such as the ventral arc and the ischio-pubic ramus, are extremely accurate when assessing sex (Phenice 1969; Sutherland and Suchey 1991). Traditionally, the skull was thought to be the next most useful element for sex estimation, even despite the fact that in 1905, Thomas Dwight recognized that postcranial elements can be more accurate in sex estimation than the skull. Dwight suggests that the femur is visually the most sexually dimorphic postcranial element, besides the pelvis, in the human skeleton. More specifically, Dwight discusses the articular surfaces of the long bones as being extremely sexually dimorphic, and in his article, he focuses on the head of the humerus and femur. Dwight continues by acknowledging that the femoral head is not as sexually dimorphic as the humeral head, but is still useful in aiding in the estimation of sex (Dwight 1905).

Holman and Bennett (1991) compared the measurements of the bones of the arm of American Black and White individuals, and out of 31 possible measurements, 7 were found to be sexually dimorphic. The authors used discriminant function analysis to compare these measurements and see which were best to use when estimating the sex of an individual. The authors mention Jamison's 1972 study that examined the wrist breadth of living Eskimos and determined that it was the most sexually dimorphic trait among a total of 28 standard anthropometric variables. To conduct their study, the authors took 5 measurements on 302 adult skeletons from the Terry Collection at the Smithsonian Institution in Washington D.C., which consisted of almost an equal number of American Black and White male and female individuals. The measurements included the maximum lengths of the humerus, radius, and ulna, and two additional measurements that estimated the wrist breadth of the individual. Their results determined that the American Black individuals measured were less sexually dimorphic than the American White individuals, but this may not be a good representation of modern individuals, as the Terry Collection is an older sample group (Holman and Bennett 1991).

More recently, France (1998) wrote on the metric analysis of sex in skeletal remains. She states that if the forensic anthropologist knows the population group from which the skeletal remains are from, more specifically if the individual is black or white, postcranial measurements can be very reliable when estimating sex. Occasionally, the accuracy rate can be over 90% with some measurements. She first discusses cranial measurements, and then each measureable postcranial bone, and explains what the accuracy rate is for estimating the sex of an individual using that element. For each postcranial element, France gives an equation in which to insert the skeletal measurements. The calculations will then provide a result that indicates whether the individual is most likely a male or female. France's article is extremely important to the history of sex estimation in forensic anthropology. It was the first time an author had addressed all postcranial elements and shown an applicable method for forensic anthropologists to use when estimating sex. This is particularly important when only a few postcranial elements are found in a forensic case, as it still provides a reliable method of sex estimation in these instances (France 1998).

Within the past few years, additional research has been conducted on the estimation of sex from the postcranial skeleton. Unfortunately, none of this research has focused on Hispanic individuals within the United States. In the United States, research has included the estimation of sex from the clavicle (Shirley et al. 2009), scapula (Dabbs and Moore-Jansen 2010), humerus (Ii and Hunt 2004), radius (Sameraro and Passalacqua 2007), calcaneus, talus and metatarsals (Robling and Ubelaker 1997; Stronmeyer and Simmons 2007). These studies were all conducted on American Black and White individuals. International research has also been administered on the estimation of sex from postcranial skeletal remains. The samples for these studies include Koreans (Lee et al. 2008), Cretans (Kranioti et al. 2008), South Africans (Asala 2001; Barrier and Abbé 2008; Steyn and Patriquin 2009), Italians (Gualdi-Russo 2007), and Germans (Mall et al. 2001). This emphasizes the necessity of research involving Hispanic individuals in and out of the United States. Without this research, forensic anthropological methods on Hispanic individuals will remain insufficient and will most likely cause these individuals to remain unidentified.

CHAPTER III

MATERIALS AND METHODS

Materials

With all of the large skeletal collections in the United States consisting primarily of American Black and White individuals, it was necessary to find a sample of skeletal remains that consisted of modern individuals, primarily those that have been found deceased in the last 20 years, who are considered Hispanic. Between 2001 and 2007, over 1000 individuals died in Arizona after attempting to cross the United States - Mexico border (Anderson and Parks 2008). There is still an increase in these deaths every year, primarily just southwest of Tucson, Arizona (Anderson 2008). The dry and hot environment of Arizona causes many of the deceased to decompose quickly, which contributes to the remains becoming skeletonized before they are recovered (Anderson 2008). As these individuals are found, they are brought to Dr. Bruce Anderson, the forensic anthropologist at the Pima County Office of the Medical Examiner (PCOME) in Tucson, Arizona. Although the large number of deaths cause the identification of these individuals to be difficult, the Pima County Office of the Medical Examiner currently has approximately a 70 percent identification rate (Anderson and Parks 2008).

For this project, almost all skeletal remains that were measured were those of unidentified individuals. The measurements were collected as the PCOME worked to make a positive identification on every individual. The sex of each individual was determined by assessing the morphology of the pelvis. If the pelvis was not present, the individual was not used in this study, as the sex could not be assessed with accuracy. One of the main morphological traits assessed on the pelvis to determine the sex of each individual was the ventral arc (Phenice 1969). Studies by Phenice (1969) and Sutherland and Suchey (1991) have shown that the ventral arc on the pelvis has an accuracy of over 95 percent when estimating the sex of the individual (France 1998; Phenice 1969; Sutherland and Suchey 1991).

The PCOME was an ideal location to collect data. The large amount of skeletal remains passing though the medical examiner's office, and the high identification rate in the past, helped to create an appropriate sample. Furthermore, in the past, about 94 percent of the border crossing fatalities have been identified as Mexican nationals (Anderson 2008; Birkby et al. 2008). This will help the sample to stay geographically specific when dealing with individuals considered Hispanic, as the majority are most likely from Mexico. In 2002, 66.9 percent of Hispanics in the United States were of Mexican origin, which emphasizes the significance and importance of using this sample at the United States - Mexico border (Ramirez and de la Cruz 2003). In addition to Mexican nationals, individuals from Central America, especially from Guatemala, are also found to have crossed the border in this area.

Sample and Measurements

Three trips were made to the Pima County Office of the Medical Examiner (PCOME) in 2009. Over this time period, 71 individuals were measured that had postcranial elements, as well as a pelvis to assess the sex. This sample consists of 59 male and 12 female Hispanic individuals. Of this sample, 15 males and 1 female were previously submitted to the FDB by the PCOME and were included in the PCOME sample size. All of the measurements taken will be submitted to the FDB allowing them to be accessible to other researchers (Jantz and Moore-Jansen 1998). As these individuals are identified in the future, these measurements will be included in the FORDISC 3.0 program to help in the identification of other unidentified individuals considered Hispanic (Ousley and Jantz 2005).

To increase the sample size for the project, the FDB was queried for additional (non-PCOME) individuals considered Hispanic. These measurements have been submitted to the FDB by forensic anthropologists throughout the United States. They are identified forensic cases with known ancestry, sex, and age. The information in the FDB is public information and is used for research in many different aspects in forensic anthropology. Although all Hispanics in the FDB are not necessarily Mexican, all individuals considered Hispanic were used in order to make the sample size as large as possible. The sample size taken from the FDB includes 55 male and 16 female Hispanic individuals. This does not include the 15 males and 1 female from the PCOME that were in the FDB, as they are included in the PCOME sample size.

Measurement definitions used in sex estimation analyses are from two sources. To begin, postcranial measurements found in the *Manual for Post-cranial Measurements*, compiled by Javier Urcid in 1992 (Zobeck 1983), were taken from the skeletal remains of the border crossing fatalities at the PCOME in Tucson, Arizona. The data collection sheet used at the PCOME is located in Appendix A. A list of the measurements, and the sources in which they were derived, is listed in Appendix B (Bass 1987; Moore-Jansen and Jantz 1989; Urcid 1992; Zobeck 1983). The measurements found in Urcid (1992) include all of the standard postcranial measurements that are also found in Moore-Jansen, Ousley and Jantz (1994). Although the Urcid (1992) measurements were taken on all PCOME skeletal remains, only the standard postcranial elements were used in order to increase the sample size by including the FDB standard measurements. All measurements were taken with a wooden bone board, GPM sliding calipers, GPM spreading calipers, and a small plastic tape measure. If any surface of the bone was damaged due to trauma or postmortem damage, or for any reason an accurate measurement could not be taken, due to cartilage being present for example, the associated measurement was not taken.

All existing measurements found in the FDB were used (Ousley and Jantz 1998). Currently, 87 individuals, 70 males and 17 females, of Hispanic ancestry exist in the FDB, although 15 males and 1 female are from the PCOME. These individuals are either identified or in the process of identification (Ousley and Jantz 1998). The skeletal remains in the FDB were measured using standard postcranial measurements, which consists of a set of clearly defined measurements used by all forensic anthropologists (Buikstra and Ubelaker 1994; Urcid 1992). The total sample size from the PCOME is 59 males and 12 females, and the total sample size from the FDB is 55 males and 16 females. Therefore, with both the PCOME and the FDB measurements, the total sample size for this study is 142 Hispanic individuals, with 28 females and 114 males. While most of these individuals are most likely from Mexico, only 31 out of the 142 total have a known country of origin. The total sample sizes are shown in Table 1.

Table 1: Total Sample Size by Source

	Female N	**Male N**	**Total**
PCOME	12	59	71
FDB	16	55	71
TOTAL	28	114	142

Methods

All of the standard postcranial measurements, from the PCOME and the FDB, were imported into an Excel spreadsheet listing the case number and sex for each individual. The data were then imported into Statistical Analysis Software (SAS 9.1.3) for use as a training sample to generate univariate and multivariate estimates of sex. First, summary statistics were generated, including the mean, standard deviation, minimum values, and maximum values for each measurement by sex. The summary statistics using the PROC MEANS function were then used to generate sectioning points for univariate sex estimation. Sectioning points were obtained by taking the average of the male and female means for each measurement, and then dividing by two. With the resulting sectioning point, those individuals who have a measurement above the sectioning point are considered males, those below the sectioning point are considered females, and those equaling the sectioning point are considered indeterminate. Next, a stepwise discriminant function analysis using the PROC STEPDISC application was used to determine the best subsets of variables for sex estimation for each postcranial bone. Following stepwise variable selection, a linear discriminant function analysis (DFA) was employed using the stepwise selected variables to generate cross-validated classification rates for the male and female Hispanic individuals. An analysis of variance (ANOVA) option was used to test for significant differences between sexes. After gaining cross-validated classification rates, the elements of the postcranial skeleton were ranked by classification rate from the highest to the lowest. Classification functions were then generated for use by forensic anthropologists to aid in the estimation of sex of Hispanic individuals with each postcranial bone.

CHAPTER IV

RESULTS

Univariate Sex Estimation

The summary statistics were used to generate sectioning points and are available in Table 2. Sectioning points were calculated for each individual standard postcranial measurement with a resulting classification rate for each. The sectioning points are presented in Table 2 for each postcranial measurement in order of their resulting classification rate, which is the average between the male and female classification rate.

Table 2: Postcranial Measurement Sectioning Points and Resulting Classification Rates for Hispanic Individuals

Postcranial Measurement	Female N	Male N	Sectioning Point (mm)	Total Classification Rate
Clavicle Maximum Length	15	48	147	87.29
Humeral Head Diameter	18	74	43	85.66
Humerus Epicondylar Breadth	21	73	57	85.32
Femur Head Diameter	15	81	43	83.83
Humerus Maximum Length	17	77	300	83.08
Scapula Height	18	60	146	81.67
Femur Epicondylar Breadth	15	76	78	81.45
Tibia Circumference at Nutrient Foramen	16	70	88	80.89
Scapula Breadth	17	67	99	80.73
Radius Transverse Diameter at Midshaft	13	64	14	79.81
Ischium Length	7	21	80	78.57
Tibia Proximal Epipheseal Breadth	14	69	73	78.42
Ulna Maximum Length	17	57	248	77.71
Ulna Least Circumference of Shaft	12	46	33	76.63
Tibia Maximum Length	14	83	354	75.47
Fibula Maximum Length	14	64	349	74.78
Radius Anterior-Posterior Diameter at Midshaft	13	64	11	73.68
Innominate Height	14	69	204	73.34
Sacrum Anterior Height	10	46	104	72.61
Calcaneus Breadth	6	34	40	71.57
Radius Maximum Length	12	58	232	70.55
Humerus Minimum Diameter at Midshaft	20	81	16	70.19
Femur Maximum Length	16	87	430	69.76
Femur Transervse Diameter at Midshaft	16	91	25	65.69
Ulna Dorso-Volar Diameter	15	59	14	64.69
Sacrum S1 Breadth	11	45	47	63.94
Calcaneus Length	7	35	77	62.86
Femur Subtrochanteric Anterior-Posterior Diameter	19	95	27	61.58
Femur Subtrochanteric Transverse Diameter	19	95	29	61.58
Clavicle Anterior-Posterior Diameter at Midshaft	12	59	12	60.45

Table 2: Continued

Postcranial Measurement	Female N	Male N	Sectioning Point (mm)	Total Classification Rate
Fibula Maximum Diameter at Midshaft	15	68	14	58.68
Illiac Breadth	15	70	149	57.86
Ulna Transverse Diameter	15	59	13	55.48
Sacrum Breadth	13	56	103	53.71
Clavicle Transverse Diameter at Midshaft	12	59	10	50.28
Pubis Height	6	21	76	39.29

As seen in Table 2, clavicle maximum length (CLAXLN), humerus head diameter (HUMHDD), and humerus epicondylar breadth (HUMEBR) are the most accurate single measurements when estimating the sex of Hispanic skeletal remains. Clavicle maximum length, with a sectioning point of 147 mm, resulted in an overall classification rate of 87.29 %. Humerus head diameter, with a sectioning point of 43 mm, resulted in an overall classification rate of 85.66 %, and humerus epicondylar breadth, with a sectioning point of 57 mm, resulted in an overall classification rate of 85.32 %. A summary of the univariate results can be found in Appendix C.

Multivariate Sex Estimation

The ANOVA indicates that there is a significant difference between male and female Hispanic individuals for each postcranial measurement. The stepwise procedure results, indicating which measurements are the best at estimating sex for each individual postcranial element, are presented in Table 3. The cross-validated classification rates from the DFA using the stepwise selected measurements, as well as the sample size and D^2 for each element, are presented in Table 4 in order of the highest cross-validated classification rate to the lowest.

Table 3: Stepwise Selected Measurements for Hispanic Male and Female Individuals

Element	**Stepwise Selected Measurements**
Clavicle	Clavicle Maximum Length
Scapula	Scapula Height, Scapula Breadth
Humerus	Humerus Maximum Length, Humerus Head Diameter, Humerus Maximum Diameter at Midshaft
Radius	Radius Maximum Length, Radius Anterior-Posterior Diameter of Midshaft
Ulna	Ulna Dorso-Volar Diameter, Ulna Physiological Length, Ulna Minimum Circumference of Shaft
Sacrum	Sacrum S1 Breadth
Innominate	Pubis Height, Ishium Length
Femur	Femur Epicondylar Breadth, Femur Maximum Diameter of Head
Tibia	Tibia Proximal Epiphyseal Breadth
Fibula	Fibula Maximum Length
Calcaneus	Calcaneus Breadth

Table 4: Cross-validated Classification Rates for Hispanic Male and Female Individuals

Element	Female N	Male N	D^2	Cross-Validation Rate for Females	Cross-validation Rate for Males	Total Cross-Validation Rate
Radius	11	54	6.04437	81.82	97.04	89.43
Humerus	16	73	6.72607	87.50	90.41	88.96
Clavicle	15	48	4.45559	93.33	81.25	87.29
Ulna	12	41	7.20284	83.33	90.24	86.79
Scapula	17	60	5.11302	88.24	85.00	86.62
Innominate	6	21	7.04250	83.33	85.71	84.52
Femur	14	74	4.27863	78.57	89.19	83.88
Tibia	12	68	1.57915	75.00	91.18	83.09
Sacrum	11	45	4.97160	81.82	73.33	77.58
Fibula	14	64	2.19302	71.43	78.13	74.78
Calcaneus	6	34	3.34066	66.67	76.47	71.57

Table 3 indicates that the radius, humerus, and clavicle are the best postcranial elements for sex estimation based on their overall cross-validation classification rates. The radius provides the best overall cross-validated classification rate using the stepwise selected variables radius maximum length (RADXLN) and radius anterior-posterior diameter at midshaft (RADAPD), as seen in Table 3. When using these two measurements, the radius had a female cross-validation rate of 81.82 %, a male cross-validation rate of 97.04 %, and a total cross-validation classification rate of 89.43 % after averaging the male and female rates. The humerus, when using the stepwise selected variables of humerus maximum length (HUMXLN), humerus head diameter (HUMHDD), and humerus maximum diameter at midshaft (HUMMXD), had a female cross-validation rate of 87.50 % and a male cross-validation rate of 90.41 %, creating a total cross-validation rate of 88.96 %. Finally, the clavicle, with the stepwise selected measurement of clavicle maximum length (CLAXLN), had a female cross-validation rate of 93.33 % and a male cross-validation rate of 81.25 %, with a total cross-validation rate of 87.29 %. The remaining elements are listed in order according to their total cross-validation classification rates in Table 4.

Table 4 also lists the female and male sample size for each element as well as the Mahalanobis distance (D^2) for each element, which is a reflection of the sexual dimorphism of that element within this Hispanic sample group (Johnson1998). A larger D^2 value implies that the specific element is more sexually dimorphic (Johnson 1998). As seen in Table 4, the ulna has the largest D^2 value, 7.20, suggesting that it is the most sexually dimorphic postcranial element. Immediately following the ulna is the innominate, with a D^2 value of 7.04, and then the humerus, with a D^2 value of 6.73. The

D^2 measurement is less subjective when using small sample sizes, which is ideal for this research (Johnson 1998).

Classification functions were then created for each postcranial element to allow forensic anthropologists to better estimate the sex of Hispanic individuals. These classification functions are formulae that allow forensic anthropologists to insert the appropriate postcranial measurement(s) for each element and the result will provide an estimation of the sex of the individual. Calculated for a sectioning point of zero, after inserting the appropriate measurements in millimeters, if the resulting number is positive, the element is considered male, if the number is negative, the element is considered female, and if the number is exactly zero, the element is considered indeterminate. Table 5 lists the classification function to use for each element.

Table 5: Classification Functions for all Postcranial Elements for Hispanic Individuals Based on Selected Stepwise Measurements

Element	**Classification Functions**
Clavicle	(0.2792 * Clavicle Maximum Length) + (-40.9437)
Scapula	(0.13079 * Scapula Height) + (0.25747 * Scapula Breadth) + (-44.65048)
Humerus	(0.04077 * Humerus Maximum Length) + (0.5688 * Humerus Head Diameter) + (0.59429 * Humerus Maximum Diameter at Midshaft) + (-48.91311)
Radius	(0.1331 * Radius Maximum Length) + (1.06951 * Radius Anterior-Posterior Diameter at Midshaft) + (-42.7206)
Ulna	(0.50558 * Ulna Dorso-Volar Diameter) + (0.11455 * Ulna Physiological Length) + (0.3922 * Ulna Circumference) + (-44.92571)
Sacrum	(0.2921 * Sacrum S1 Breadth) + (-13.85477)
Innominate	(-0.25109 * Pubis Height) + (0.55312 * Ischium Length) + (-25.54586)
Femur	(0.16297 * Femur Epicondylar Breadth) + (0.6166 * Femur Head Diameter) + (-39.3832)
Tibia	(0.44003 * Tibia Proximal Epiphyseal Breadth) + (-32.15113)
Fibula	(0.06648 * Fibula Maximum Length) + (-23.21457)
Calcaneus	(0.83516 * Calcaneus Breadth) + (-33.4066)

CHAPTER V

DISCUSSION

The primary goal of this research is to use new and existing postcranial metric data to determine which postcranial elements and single measurements are best to use when attempting to estimate the sex of an unidentified Hispanic skeleton. The research was conducted in order to develop sex estimation methods using the postcrania for Hispanic individuals, much like what has been created for American Blacks and Whites, when using the postcrania to estimate sex. The results provide sectioning points for each individual measurement from Hispanic skeletal remains, which can especially be useful when dealing with fragmentary remains, as well as classification functions for forensic anthropologists to use when estimating the sex utilizing whole elements of the postcranial skeleton.

When comparing the results of this research to Spradley and Jantz's (2003) research on American Black and White skeletal remains, based on measurements available in the FDB, a difference in sexual dimorphism is evident. Table 6 demonstrates and emphasizes these differences.

Table 6: Comparison of D^2 and Total Cross-validated Classification Rates of Hispanic, American Black and American White Individuals

Hispanic			**American Black***			**American White***		
Element	**D^2**	**Cross-Validation Rate**	**Element**	**D^2**	**Cross-Validation Rate**	**Element**	**D^2**	**Cross-Validation Rate**
Radius	6.04437	89.43	Humerus	9.55282	95.52	Humerus	9.44993	93.23
Humerus	6.72607	88.96	Clavicle	9.54684	94.74	Ulna	8.11181	92.25
Clavicle	4.45559	87.29	Scapula	9.28383	92.85	Femur	7.62803	93.12
Ulna	7.20284	86.79	Innominate	9.07737	94.54	Radius	6.93686	91.02
Scapula	5.11302	86.62	Ulna	6.82174	90.38	Clavicle	7.52092	92.90
Innominate	7.04250	84.52	Femur	6.62225	89.23	Scapula	7.33181	92.47
Sacrum	4.97160	77.58	Radius	5.23913	91.23	Tibia	7.11827	91.76
Femur	4.27863	83.88	Tibia	4.97469	84.82	Innominate	6.39133	87.88
Tibia	1.57915	83.09	Calcaneus	4.28551	89.58	Fibula	3.00595	80.77
Fibula	2.19302	74.78	Fibula	2.72001	77.36	Calcaneus	3.01388	80.33
Calcaneus	3.34066	71.57	Sacrum	0.73186	66.66	Sacrum	2.73815	74.18

* American Black and American White data from Spradley and Jantz (2003)

Table 6 shows data calculated by Spradley and Jantz (2003) on American Blacks and Whites, compared to the Hispanic data and results from the present research. For each population, the postcranial elements are ranked according to their accuracy in estimating sex, with their cross-validated classification rate next to each element. The classification rate shows, on average, what percentage of the time the bone is classified as the correct sex. The most accurate bones in Hispanic individuals were found to be the radius and humerus, in American Blacks it was found to be the humerus and clavicle, and in American Whites it was found to be the humerus and ulna. Although the elements with the highest cross-validation rates are similar, they should each be compared to the appropriate ancestral group's measurements when estimating the sex of that individual.

The D^2 value for each element is also listed in Table 6 for each population group. With this table, a comparison can be made between the most sexually dimorphic elements for Hispanic, American Black, and American White individuals. As previously stated, the most sexually dimorphic postcranial elements for Hispanic individuals were found to be the ulna, with a D^2 value of 7.20, and the innominate, with a D^2 value of 7.04. The most sexually dimorphic elements for American Black are the humerus, with a D^2 value of 9.55, and the clavicle, with a D^2 value of 9.55 (Spradley and Jantz 2003). Finally, the most sexually dimorphic elements for American Whites are the humerus, with a D^2 value of 9.45, and the ulna, with a D^2 value of 8.11 (Spradley and Jantz 2003).

When comparing the overall trend in D^2 values in Table 6, it is evident that the overall D^2 values are much smaller in the Hispanic individuals, compared to the American Black and White individuals. Several reasons may account for this difference. To begin, Hispanic individuals may be less sexually dimorphic as a group than either

American Black and American White individuals. While there is a large amount of variation in the country of origin of Hispanic individuals, physically there may be less variation between the male and female individuals. Additionally, although this value tends to not be as affected by a small sample size, a difference may be found as more Hispanic individuals are used in the research.

The diversity between these three ancestry groups can also be seen in the univariate results. The top three univariate estimators for sex in Hispanic individuals, as seen in Table 2, were found to be clavicle maximum length (CLAXLN), with a cross-validation rate of 87.29 %, humerus head diameter (HUMHDD), with a cross-validation rate of 85.66 %, and humerus epicondylar breadth (HUMEBR), with a cross-validation rate of 85.32 %. For American Black individuals, Spradley and Jantz (2003) found that the top three estimators for sex was the scapula height (SCAPHT), with a cross-validation rate of 90.78 %, humerus head diameter (HUMHDD), with a cross-validation rate of 89.92 %, and humerus epicondylar breadth (HUMEBR), with a cross-validation rate of 89.31 %. Lastly, in American White individuals, Spradley and Jantz (2003) found that the top three estimators for sex was the humerus epicondylar breadth (HUMEBR), with a cross-validation rate of 91.14 %, tibia proximal epicondylar breadth (TIBPEB), with a cross-validation rate of 90.89 %, and femur epicondylar breadth (FEMEBR), with a cross-validation rate of 88.99 % (Spradley and Jantz 2003). The differences in these measurements and the ranking of each emphasize, again, the importance of population specific methods to estimate the sex of skeletal remains.

Variation can be seen between these three population groups when comparing the overall cross-validation classification rates for each element, the Mahalanobis distance for each element, and the top univariate measurements for estimating the sex of postcranial skeletal remains. Overall, these results demonstrate how different the postcranial skeleton is in each population. These results emphasize the importance of population specific methods when estimating the sex of skeletal remains and support the fact that the ancestry of the skeletal remains should be assessed before the estimation of sex, if possible.

Some limitations within this research were found. The small sample size is of concern, especially with the small number of females used in this research, but without any other collection of modern Hispanic skeletal remains, it was necessary to use what was available. Furthermore, it is important, within the Hispanic ancestral group, to attempt to remain geographically specific, as individuals considered Hispanic originate from very diverse geographic areas. Those Hispanic individuals found in the FDB are not all from the same geographic location (Jantz and Ousley 1998). While most of these individuals are most likely from Mexico or Central America, only 31 out of the 142 individuals in the total sample have a known country of origin.

One major implication of this research is that all statistical data provided in this research, including the sectioning points, classification functions, Mahalanobis distances and cross-validated classification rates, will certify that these methods of sex estimation adhere to the *Daubert* ruling by providing classification rates (Bohan 2010; Christensen and Crowder 2009; *Daubert* 2003). Organizations, such as the Scientific Working Group for Forensic Anthropology (SWGANTH), have been organized to encourage discussion within the field of forensic anthropology and to develop proper guidelines for the “best practice” of the methods used and dissemination of these practices in forensic anthropology (Christensen and Crowder 2009). The suggestions for "best practice" include the use of validation and error rate estimation, as well as quantifiable methods like what has been provided with this research.

Recommendations for Future Research

This research produced results that are essential in the estimation of sex of Hispanic skeletal remains. To overcome the limitations of this study, data will continue to be collected on Hispanic skeletal remains at the Pima County Office of the Medical Examiner in Tucson, Arizona. With these additional data, the sample size, of both male and female individuals, will continue to grow. As these individuals are identified, future research can aim to focus on a specific geographic area, most specifically on Hispanic individuals from Mexico. In addition, as these unknown individuals are identified, their metric data and biogeographical information will be submitted to the FDB in order to assist and improve identification rates of Hispanic individuals in the United States in the future. Furthermore, a test sample should be used with all positively identified individuals, as opposed to a training sample used in this research to increase the sample size.

CHAPTER VI

CONCLUSION

Although it has been assumed that the skull can provide an accurate estimation of sex, France (1998) showed that the postcranial skeleton is more accurate when estimating the sex of skeletal remains. With regard to Hispanic individuals, who make up the largest minority group in the United States (www.census.gov), there are no population specific methods for the estimation of sex. When estimating the sex of the postcranial skeleton, Spradley's (2008) research shows that the gracility of Hispanic individuals causes them to be misclassified when using American White criteria. The present research stresses that metric variation is found between the postcranial skeleton of Hispanic, American Black, and American White individuals. This variation should be taken into consideration when a forensic anthropologist is creating a biological profile for skeletal remains, and the ancestry of the individual should be assessed before the sex is estimated or assessed.

The results of this research provide forensic anthropologists methods to use when metrically estimating the sex of individuals considered Hispanic. Univariate and multivariate statistical analyses were performed to create these methods. The univariate analysis created sectioning points to aid in the analysis of single postcranial measurements, which are ideal for fragmentary or damaged skeletal remains. This research found that the clavicle maximum length (CLAXLN) is the most accurate single measurement when estimating the sex of Hispanic skeletal remains, with a sectioning point of 147 mm and a total cross-validated classification rate of 87.29 %. The multivariate analysis provided stepwise selected measurements to show which individual measurements of each bone were the most accurate when estimating the sex and assisted in creating classification functions to use when estimating the sex of entire postcranial elements. For multivariate sex estimation, it was found that the radius is the most accurate postcranial element to use when estimating the sex of Hispanic skeletal remains, with a total cross-validated classification rate of 89.43 %. Because the sex of skeletal remains is population specific, and the degree of sexual dimorphism can vary between populations, it is important to use as many of these methods provided as possible to increase the accuracy of a correct estimation of sex (Bruzek and Murail 2006).

Furthermore, this research demonstrates how complex and difficult sex estimation is for Hispanic individuals. The results of this research begin to provide population specific methods for the estimation of sex for Hispanic individuals that have not been available to forensic anthropologists in the past. Without these population specific methods, many Hispanic individuals may remain unidentified.

APPENDIX A

Pima County Office of the Medical Examiner
Skeletal Measurements

Case No. ________________ Recorder ________________ Date ______________

Postcranial Measurements

		Left	Right
1. Clavicle max length*	(CML-CLAXLN)	______	______
2. Clavicle A-P diam midshaft*	(CSD-CLAAPD)	______	______
3. Clav S-I diam midshaft*	(CVD-CLAVRD)	______	______
4. Scapula max height*	(SML-SCAPHT)	______	______
5. Scapula max breadth*	(SMB-SCAPBP)	______	______
6. Scapula spine length	(SLS)	______	______
7. Scapula supraspinous length	(SSL)	______	______
8. Scapula infraspinous length	(ISL)	______	______
9. Scap glenoid cavity breadth	(GCB)	______	______
10. Scap glenoid cavity height	(GCH)	______	______
11. Scap glenoid to inf angle	(GIL)	______	______
12. Manubrium length	(MML)	______	
13. Mesosternum length	(MSL)	______	
14. Stenebra 1 width	(S1W)	______	
15. Stenebra 3 width	(S3W)	______	
16. Humerus max length*	(HML-HUMXLN)	______	______
17. Hum prox epiph breadth	(BUE)	______	______
18. Hum max diam midshaft*	(MDS-HUMMXD)	______	______
19. Hum min diam midshaft*	(MDM-HUMMWD)	______	______
20. Hum max vert diam head*	(MDH-HUMHDD)	______	______
21. Hum epicondylar breadth*	(EBR-HUMEBR)	______	______
22. Hum least circum of shaft	(LCS)	______	______
23. Radius max length*	(RML-RADXLN)	______	______
24. Radius max diam head	(RDH)	______	______
25. Radius A-P diam of shaft*	(RSD-RADAPD)	______	______
26. Radius M-L diam of shaft*	(RTD-RADTVD)	______	______
27. Radius neck shaft circum	(MCS)	______	______
28. Ulna max length*	(UML-ULNXLN)	______	______
29. Ulna physiological length*	(UPL-ULNPHL)	______	______
30. Ulna max br olecranon	(BOP)	______	______
31. Ulna min br olecranon	(MBO)	______	______
32. Ulna max wd olecranon	(WOP)	______	______
33. Ulna olec-radial notch	(ORL)	______	______
34. Ulna olec-coronoid length	(OCL)	______	______

		Left	Right
35. Ulna A-P diam shaft*	(UAB-ULNDVD)	______	______
36. Ulna M-L diam midshaft*	(UMD-ULNTVD)	______	______
37. Ulna least circum shaft*	(UMD-ULNCIR)	______	______
38. Sacrum anterior length*	(SAL-SACAHT)	______	
39. Sacrum A-S breadth*	(SAB-SACABR)	______	
40. Sacrum max breadth S1*	(SMB-SACS1B)	______	
41. Innominate height*	(INH-INNOHT)	______	______
42. Iliac breadth*	(ILB-ILIABR)	______	______
45. Femur max length*	(FML-FEMXLN)	______	______
46. Femur bicondylar length*	(FOL-FEMBLN)	______	______
47. Femur trochanteric length	(FTL)	______	______
48. Fem subtroch A-P diam	(APD-FEMSAP)	______	______
49. Fem subtroch M-L diam	(MLD-FEMSTV)	______	______
50. Fem A-P diam midshaft*	(APS-FEMMAP)	______	______
51. Fem M-L diam midshaft*	(MLS-FEMMTV)	______	______
52. Fem max vert diam head*	(VDH-FEMHDD)	______	______
53. Fem max horiz diam head	(HHD)	______	______
54. Fem A-P diam lat condyle	(APL)	______	______
55. Fem A-P diam med condyle	(APM)	______	______
56. Fem epicondylar breadth*	(FEB-FEMEBR)	______	______
57. Fem bicondylar breadth	(BCB)	______	______
58. Fem min vert diam neck	(VDN)	______	______
59. Femur circum midshaft*	(FCS-FEMCIR)	______	______
60. Tibia condylo-malle length*	(TML-TIBXLN)	______	______
61. Tibia max br prox epiph*	(BPE-TIBPEB)	______	______
62. Tibia max br dist epiph*	(BDE-TIBDEB)	______	______
63. Tibia A-P diam nut for*	(APN-TIBNFX)	______	______
64. Tibia M-L diam nut for*	(MLM-TIBNFT)	______	______
65. Tibia position of nut for	(CFL)	______	______
66. Tibia cirum at nut for*	(PCN-TIBCIR)	______	______
67. Fibula maximum length*	(BML-FIBXLN)	______	______
68. Fibula max diam midshaft*	(FMD-FIBMDM)	______	______
69. Calcaneus maximum length*	(CLL-CALCXL)	______	______
70. Calcaneus middle breadth*	(CMB-CALCBR)	______	______

Numbers refer to associated Zobeck definition.
* Standard measurements

APPENDIX B

Postcranial Measurements

(Taken from the *Manual for Post-cranial Measurements* by Javier Urcid (1992))

1. **Clavicle Maximum Length**: (CML-CLAXLN) Maximum distance between the lateral and medial extremities. Place the sternal end of the clavicle against the vertical end board and press the movable upright against the acromial end. The bone is moved until the maximum length is obtained. (Bass 1987)

2. **Clavicle Anterior-Posterior Diameter at Midshaft**: (CSD-CLAAPD) The distance from the anterior to the posterior surface of the midshaft. Determine the midpoint of the diaphysis on the osteometric board. (Moore-Jansen and Jantz 1989)

3. **Clavicle Superior-Inferior Diameter at Midshaft**: (CVD-CLAVRD) The distance from the cranial to the caudal surface at midshaft. (Moore-Jansen and Jantz 1989)

4. **Scapula Maximum Height**: (SML-SCAPHT) The maximum straight-line distance from the superior to the inferior border. (Bass 1987)

5. **Scapula Maximum Breadth**: (SMB-SCAPBR) From the middle of the dorsal surface of the glenoid fossa to the spinal axis on the vertebral border. (Bass 1987)

6. **Scapula Spine Length**: (SLS) From the end of the spinous axis on the vertebral border to the most lateral point on the acromion process. (Bass 1987)

7. **Scapula Supraspinous Length**: (SSL) From the end of the spinous axis on the vertebral border to the top of the superior-anterior angle. (Bass 1987)

8. **Scapula Infraspinous Length**: (ISL) From the end of the spinous axis on the vertebral border to the tip of the inferior angle. (Bass 1987)

9. **Scapula Glenoid Cavity Breadth**: (GCB) Taken at a point just below the constriction of the ventral border. Measured across the breadth of the glenoid cavity from the ventral to the dorsal margin. (Zobeck 1983)

10. **Scapula Glenoid Cavity Height**: (GCH) Taken from the superior to the inferior margin of the glenoid cavity being sure that the measurement is taken perpendicular to the glenoid cavity breadth measurement. (Zobeck 1983)

11. **Scapula Glenoid to Inferior Angle**: (GIL) Taken from the middle of the glenoid cavity to the inferior angle. (Zobeck 1983)

12. **Manubrium Length**: (MML) The distance from the jugular notch to the sagittal midpoint of the manubriosternal joint. (Bass 1987)

13. **Mesosternum Length**: (MSL) The distance from the sternal angle to the sagittal midpoint of the xiphisternal joint. (Bass 1987)

14. **Sternabra 1 Width**: (S1W) The distance between the left and the right first sternebra (depressions between the articulation notches for the second and third costal cartilage). (Bass 1987)

15. **Sterneba 3 Width**: (S3W) The distance between the left and right third sternebra (depressions between the articulation notches for the fourth and fifth costal cartilage). (Bass 1987)

16. **Humerus Maximum Length**: (HML-HUMXLN) Place the head against the fixed vertical of the board and adjust the movable upright to the distal end. Move the bone slightly until the maximum length is obtained. (Bass 1987)

17. **Humerus Breadth of Proximal Epiphysis**: (BUE) Widest distance across the upper epiphysis, being sure to include the greater tubercle. (Zobeck 1983)

18. **Humerus Maximum Diameter of Midshaft**: (MDS-HUMMXD) Taken at exactly mid-length. Maximum diameter in an anterior-medial direction. (Bass 1987)

19. **Humerus Minimum Diameter of Midshaft**: (MDM- HUMMWD) Diameter taken at right angle to the maximum diameter of midshaft. (Bass 1987)

20. **Humerus Maximum Diameter of Head**: (MDH-HUMHDD) Taken from a point on the edge of the articular surface of the bone across the opposite side. The bone is rotated until the maximum distance is obtained. (Bass 1987)

21. **Humerus Epicondylar Breadth**: (EBR-HUMEBR) Maximum distance across the epicondyles on the distal end. (Zobeck 1983)

22. **Humerus Least Circumference of the Shaft**: (LCS) Taken at about the second third of the shaft, distal to the deltoid tuberosity. (Bass 1987)

23. **Radius Maximum Length**: (RML-RADXLN) Maximum length from head to tip of the styloid process. The head is placed against the fixed vertical section of the osteometric board and the movable portion is adjusted to the distal end. Bone is raised slightly and moved until maximum length is obtained. (Bass 1987)

24. **Radius Maximum Diameter of the Head**: (RDH) Taken from a point on the edge of the articular surface of the bone across to the opposite side. The bone is rotated until the maximum distance is obtained. (Zobeck 1983)

25. **Radius Anterior-Posterior Diameter of Midshaft**: (RSD-RADAPD) The distance from the anterior to the posterior surface of the midshaft. (Moore-Jansen and Jantz 1989)

26. **Radius Medial-Lateral Diameter of Midshaft**: (RTD-RADTVD) The distance between the lateral and the medial surfaces of the midshaft. (Moore-Jansen and Jantz 1989)

27. **Radius Neck Shaft Circumference**: (MCS) Taken at a point just superior to the radial tuberosity. (Zobeck 1983)

28. **Ulna Maximum Length**: (UML-ULNXLN) Maximum length from the top of the olecranon process to the tip of the styloid process. (Bass 1987)

29. **Ulna Physiological Length**: (UPL-ULNPHL) The two measuring points being the deepest point in the longitudinal ridge running across the floor of the semilunar notch and the deepest point of the distal surface of the head, not taking the groove between it and the syloid process. (Bass 1987)

30. **Ulna Maximum Breadth of the Olecranon Process**: (BOP) Measured from the medial and lateral margins of the articular surface of the olecranon process at its greatest breadth. (Zobeck 1983)

31. **Ulna Minimum Breadth of Olecranon Process**: (MBO) Measured from the medial and lateral margins of the articular surface of the olecranon process where the constriction on the medial margin becomes apparent. (Zobeck 1983)

32. **Ulna Maximum Width of the Olecranon Process**: (WOP) Measured in an anterior-posterior direction from the anterior most portion of the olecranon process to the posterior most portion. (Zobeck 1983)

33. **Ulna Olecranon Process to Radial Notch Length**: (ORL) From the most anteriorly projecting point on the olecranon process to the inferior most margin of the radial notch. (Zobeck 1983)

34. **Ulna Olecranon Process to Coronoid Process Length**: (UAD) From the most anteriorly projecting point on the olecranon process to the radial most margin of the coronoid process. (Zobeck 1983)

35. **Ulna Anterior-Posterior Diameter of the Shaft**: (UAD-ULNDVD) The maximum diameter of the diaphysis where the crest exhibits the greatest development. (Moore-Jansen and Jantz 1989)

36. **Ulna Medial-Lateral Diameter of the Shaft**: (UMD-ULNTVD) The diameter measured perpendicular to the anterior-posterior diameter at the level of the greatest crest development. (Moore-Jansen and Jantz 1989)

37. **Ulna Least Circumference of Shaft**: (ULC-ULNCIR) Located a little above the distal epiphysis, where the shaft, through the reduction of the muscular ridges and crests, becomes nearly cylindrical. (Bass 1987)

38. **Sacrum Anterior Length**: (SAL-SACAHT) The distance from a point on the promontory positioned in the midsagittal plane to a point on the anterior border of the tip of the sacrum measured in the midsagittal plane. (Moore-Jansen and Jantz 1989)

39. **Sacrum Anterior-Superior Breadth**:(SAB-SACABR) The maximum transverse breadth of the sacrum at the level of the anterior projection of the auricular surfaces. (Moore-Jansen and Jantz 1989)

40. **Sacrum Maximum Breadth of S1**: (SMX-SACS1B) The direct distance between the two most laterally projecting points on the sacral base measured perpendicular to the midsagittal plane. (Moore-Jansen and Jantz 1989)

41. **Innominate Height**: (INH- INNOHT) The distance from the most superior point on the iliac crest to the most inferior point on the ischial tuberosity. Place the ischium against the vertical end board and press the moveable upright against the iliac crest. Move the ilium to obtain the maximum distance. (Moore-Jansen and Jantz 1989)

42. **Iliac Breadth**: (ILB-ILIABR) The distance from the anterior-superior iliac spine to the posterior-superior iliac spine. This measurement is not necessarily identical to the maximum breadth of the ilium as taken with an osteometric board. (Moore-Jansen and Jantz 1989)

43. **Pubis Length**: (PUL-PUBCHT) The distance from the point in the acetabulum where the three elements of the innominate meet to the upper end of the pubic symphysis. The measuring point in the acetabulum can be divided by 1) an irregularity in the acetabulum and inside the pelvis, 2) a change in thickness, which may be seen by holding the bone up to light, or 3) by the presence of a notch in the border of the articular surface in the acetabulum. In measuring the pubis, care should be taken to hold the caliper parallel to the long axis of the bone. (Moore-Jansen and Jantz 1989)

44. **Ischium Length**: (ICL-ISCHLN) The distance from the point in the acetabulum where the three elements forming the innominate meet to the deepest point on the ischial tuberosity. Ishium length should be measured approximately perpendicular to pubis length. (Moore-Jansen and Jantz 1989)

45. **Femur Maximum Length**: (FML-FEMXLN) Place the distal condyles against the fixed vertical of the board and the movable upright to the head. Raise the bone slightly and move until maximum length is obtained. (Bass 1987)

46. **Femur Bicondylar Length**: (FOL-FEMBLN) Place both condyles in contact with the vertical foot board, reading of the plane parallel to foot board and tangent to the head. (Zobeck 1983)

47. **Femur Trochanteric Length**: (FTL) Greatest distance between top of greater trochanter and external condyle. (Zobeck 1983)

48. **Femur Subtrochanteric Anterior-Posterior Diameter**: (APD-FEMSAP) Taken on the shaft just below the lesser trochanter, with the gluteal tuberosity avoided. (Bass 1987)

49. **Femur Subtrochanteric Medial-Lateral Diameter**: (MLD-FEMSTV) Taken at the same level as femur subtrochanteric anterior-posterior diameter and perpendicular to it. (Bass 1987)

50. **Femur Anterior-Posterior Diameter of Midshaft**: (APS-FEMMAP) Locate midshaft point on osteometric board. Measure maximum anterior-posterior diameter. (Bass 1987)

51. **Femur Medial-Lateral Diameter of the Midshaft**: (MLS-FEMMTV) Taken right angle to femur anterior-posterior diameter of midshaft. (Bass 1987)

52. **Femur Maximum Vertical Diameter of Head**: (VHD-FEMHDD) The greatest vertical diameter in the vertical plane passing through the axis of the neck. (Zobeck 1983)

53. **Femur Maximum Horizontal Diameter of the Head**: (HDD) The maximum diameter at right angle to femur maximum vertical diameter of head. (Zobeck 1983)

54. **Femur Anterior-Posterior Diameter of Lateral Condyle**: (APL) The projected distance between the most posterior point on the lateral condyle and lip of the patellar surface taken perpendicular to the axis of the shaft. (Zobeck 1983)

55. **Femur Anterior-Posterior Diameter of Medial Condyle**: (APM) The projected distance between the most posterior point on the medial condyle and the lip of the patellar surface taken perpendicular to the axis of the shaft. (Zobeck 1983)

56. **Femur Epicondylar Breadth**: (FEB-FEMEBR) Measured over the most outstanding points of the epicondyles, parallel to the infracondylar plane. (Zobeck 1983)

57. **Femur Bicondylar Breadth**: (BCB) Greatest breadth across the condyles (transverse condylar breadth) taken at a point in the middle of each condyle (posteriorly). (Zobeck 1983)

58. **Femur Minimum Vertical Diameter of Neck**: (VDN) The minimum vertical diameter of the neck. (Zobeck 1983)

59. **Femur Circumference of Midshaft**: (FCS-FEMCIR) The circumference measured at the midshaft at the same level as the anterior-posterior and medial-lateral diameter. If the *linea aspera* exhibits a strong projection, which is not evenly expressed across a larger point of the diaphysis, then this measurement is recorded approximately 10 mm above the midshaft. (Moore-Jansen and Jantz 1989)

60. **Tibia Condylo-Malleolar Length**: (TML-TIBXLN) End of malleolus against vertical wall of the osteometric board, bone resting on its doral surface when its long axis parallel with the long axis of the board, block applied to the most prominent part of the medial half of the medial condyle. (Zobeck 1983)

61. **Tibia Maximum Breadth of the Proximal Epiphysis**: (BPE-TIBPEB) Maximum distance between the medial and lateral condyles. (Zobeck 1983)

62. **Tibia Maximum Breadth of the Distal Epiphysis**: (BDE-TIBDEB) Maximum distance between the fibular articular surface and the medial surface of the medial malleolus. (Zobeck 1983)

63. **Tibia Anterior-Posterior Diameter at the Nutrient Foramen**: (APN-TIBNFX) Maximum anterior-posterior diameter of shaft at the nutrient foramen. (Bass 1987)

64. **Tibia Medial-Lateral Diameter at the Nutrient Foramen**: (MLM-TIBNFT) Maximum transverse diameter at right angle to tibia anterior-posterior diameter at nutrient foramen. (Bass 1987)

65. **Tibia Position of the Nutrient Foramen**: (CFL) Measured from the top of the lateral intercondylid eminence to the most distal point of the foramen. (Zobeck 1983)

66. **Tibia Circumference at Nutrient Foramen**: (TCF-TIBCIR) The circumference of the shaft measured at the level of the nutrient foramen. (Bass 1987)

67. **Fibula Maximum Length**: (BML-FIBXLN) Maximum distance between the proximal end and distal extremities. (Bass 1987)

68. **Fibula Maximum Diameter at Midshaft**: (FMD-FIBMDM) The maximum diameter is most commonly located between the anterior and lateral crests. Find the midpoint on the osteometric board. Place the diaphysis of the bone between the two branches of the caliper while turning the bone to obtain the maximum diameter. (Moore-Jansen and Jantz 1989)

69. **Calcaneus Maximum Length**: (CLL-CLAXLN) The distance between the most posteriorly projecting point on the tuberosity and the most anterior point on the superior margin of the articular facet for the cuboid measured in the sagittal plane and projected onto the underlying surface. (Moore-Jansen and Jantz 1989)

70. **Calcaneus Middle Breadth**: (CMB-CALCBR) The distance between the most laterally projecting point on the dorsal articular facet and the most medial point on the sustentaculum wall. The two measuring points lie at neither the same height nor in a plane perpendicular to the sagittal plane. Accordingly, the measurement is projected in both dimensions. Span the calcaneus from behind with the square branches of the calipers so that the stem of the instrument is positioned in a flat and transverse plane across the bone. (Moore-Jansen and Jantz 1989)

APPENDIX C

Final Univariate Results

	Female				Male					
Variable	N	Mean	Standard Deviation	% Correct	N	Mean	Standard Deviation	% Correct	Sectioning Point	Overall Classification
CLAXLN	15	138.67	6.17	93.33	48	154.63	7.93	81.25	147	87.29
HUMHDD	18	39.94	2.36	88.89	74	45.92	2.59	82.43	43	85.66
HUMEBR	21	52.33	4.44	85.71	73	61.05	3.88	84.93	57	85.32
FEMHDD	15	40.27	2.63	80.00	81	45.98	2.57	87.65	43	83.83
HUMXLN	17	282.12	20.25	88.24	77	317.03	17.69	77.92	300	83.08
SCAPHT	18	137.39	8.02	83.33	60	155.12	9.32	80.00	146	81.67
FEMEBR	15	73.40	5.94	80.00	76	83.08	4.73	82.89	78	81.45
TIBCIR	16	81.44	5.82	87.50	70	94.04	7.72	74.29	88	80.89
SCAPBR	17	93.12	4.90	82.35	67	104.57	5.64	79.10	99	80.73
RADTVD	13	12.62	0.87	84.62	64	15.00	1.89	75.00	14	79.81
ISCHLN	7	74.29	5.94	71.43	21	86.62	5.59	85.71	80	78.57
TIBPEB	14	68.64	4.11	78.57	69	76.93	4.14	78.26	73	78.42
ULNXLN	17	234.18	15.80	76.47	57	261.75	14.98	78.95	248	77.71
ULNCIR	12	30.58	2.94	75.00	46	36.22	2.92	78.26	33	76.63
TIBXLN	14	337.57	26.45	71.43	83	369.72	24.75	79.52	354	75.47
FIBXLN	14	332.71	25.00	71.43	64	365.70	21.67	78.13	349	74.78
RADAPD	13	10.08	0.95	69.23	64	12.45	1.47	78.13	11	73.68
INNOHT	14	196.79	11.94	78.57	69	210.41	10.36	68.12	204	73.34
SACAHT	10	98.70	10.42	80.00	46	109.43	11.37	65.22	104	72.61
CALCBR	6	38.00	2.60	66.67	34	42.00	2.13	76.47	40	71.57
RADXLN	12	219.00	18.51	58.33	58	244.98	13.53	82.76	232	70.55
HUMMWD	20	14.60	1.70	70.00	81	17.31	1.87	70.37	16	70.19
FEMXLN	16	412.81	24.56	62.50	87	446.34	24.93	77.01	430	69.76
FEMMTV	16	23.19	2.61	68.75	91	26.68	2.21	62.64	25	65.69
ULNDVD	15	12.33	2.26	66.67	59	15.47	2.11	62.71	14	64.69
SACS1B	11	44.72	4.15	54.55	45	50.13	4.34	73.33	47	63.94
CALCXL	7	74.43	7.50	57.14	35	79.40	6.54	68.57	77	62.86
FEMSAP	19	26.11	2.60	63.16	95	28.33	2.51	60.00	27	61.58
FEMSTV	19	27.42	2.80	57.89	95	30.60	2.80	65.26	29	61.58
CLAAPD	12	11.08	3.18	66.67	59	12.39	1.58	54.24	12	60.45
FIBMDM	15	13.27	1.83	60.00	68	14.94	1.96	57.35	14	58.68

Final Univariate Results - Continued

ILIABR	15	147.00	12.59	60.00	70	151.23	8.78	55.71	149	57.86
ULNTVD	15	12.00	1.60	53.33	59	14.56	2.14	57.63	13	55.48
SACABR	13	101.92	11.67	53.85	56	104.58	8.22	53.57	103	53.71
CLAVRD	12	9.25	2.83	66.67	59	10.17	1.38	33.90	10	50.28
PUBCHT	6	77.50	7.09	50.00	21	75.05	8.36	28.57	76	39.29

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