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Sexual Dimorphism Of The Posterior Pelvis Of The Robert J. Terry Anatomical Collection And The William M. Bass Donated Skeletal Collection

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SEXUAL DIMORPHISM OF THE POSTERIOR PELVIS OF THE ROBERT J. TERRY ANATOMICAL COLLECTION AND WILLIAM M. BASS DONATED SKELETAL COLLECTION

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ABSTRACT

Studies of sexual dimorphism of the sacrum have generally been conducted as part of broader population research or on living persons and cadavers, making the anthropological literature sparse. The greater sciatic notch and the preauricular sulcus of the ilium have both been found to show sexual dimorphism, although studies of these traits often have ambiguous definitions of characteristics and lack the standardization of measurements. This research was designed to reexamine and test the accuracy of standard scoring systems and measurements of the posterior pelvis used to determine sex and to establish new formulae combining traits and measurements to accurately determine sex using logistic regression analysis. A series of metric measurements and morphological scores were recorded for 104 males and 106 females of both European- and African-American ancestry from the William M. Bass and Terry Collections. In order to reexamine previous research conducted on the posterior pelvis, standard ratios of metric measurements were analyzed to determine ranges and cut-off values for males and females in this sample. The ratio of ala width to the maximum transverse diameter of the sacral base and the ratio of the length and width of the sciatic notch have proven to be the most useful ratios in sex determination, though not as accurate as the formulae created using logistic regression. These data were also analyzed in SPSS using logistic regression to assess the usefulness of metric measurements and morphological scores of the posterior pelvis in sex determination. Using step-wise logistic regression, a combination of traits for both the sacrum and posterior ilium that are the most reliable and accurate for sex determination have been determined. The values for these selected traits can be incorporated into the log odds formulas which will classify an individual as male or female. The ultimate goal of this research was to provide physical anthropologists with

logistic regression equations that can be used to estimate the sex of the posterior ilium and sacrum. Two equations ranging in accuracy from 79-84% were developed to determine sex of the posterior pelvis.

Dedicated to Mom, Dad, and Jason

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CHAPTER 1: INTRODUCTION

Sex determination is important for both forensic and bioarcheological examinations of the human skeleton (Ali & Maclaughlin, 1991). The bones of the pelvis, especially those of the anterior os coxa, are the most reliable and accurate indicators of sex (Bass, 1995; Bruzek, 2002, Byers, 2002; Rogers & Saunders, 1994; Schwartz, 2007; White, 2000). Pubic bones are fragile, however, and often damaged, especially in archeological collections (Walker, 2005). In these instances, other portions of the pelvis that are more resistant to damage can be used to determine the sex of an individual, such as the greater sciatic notch and auricular surface of the ilium (Ali & Maclaughlin, 1991). The sacroiliac joint and surrounding area have been found to exhibit sexual dimorphism mainly due to its role in locomotion, weight bearing, and transfer capabilities (Ali & Maclaughlin, 1991). The proximity of the area to the acetbulo-cristal buttress also increases the likelihood of preservation of this area in comparison to other components of the pelvis (Ali & Maclaughlin, 1991). The posterior pelvis, which includes the sacrum and posterior aspects of the ilium, has been shown to reliably indicate sex though with accuracy rates lower than that of the anterior pelvis (Bruzek, 2002; Rogers & Saunders, 1994; St. Hoyme, 1984; Tague, 2007). The traits of the posterior ilium such as the greater sciatic notch, elevation of the auricular surface, and the preauricular sulcus, have been analyzed thoroughly though the research focused on the sacrum is sparse and often inconclusive (Bruzek, 2002; Buikstra & Ubelaker, 1994; Fawcett, 1938; Flander, 1978; Flander, 1980; Kimura, 1982; Rogers & Saunders, 1994; Steyn et al., 2004; Stradalova, 1975; Walker, 2005).

As part of the bony pelvis, the sacrum is expected to show sexual dimorphism in order to meet the reproductive needs of females while allowing for proper bipedal locomotion in both sexes (Flander, 1978; 1980). Due to its position at the base of the vertebral column and the necessity of weight bearing and up-right posture capabilities, the degree of dimorphism between male and female sacra is not as distinct as that seen in the os coxa (Flander, 1980). Analyses conducted in the first half of the 20^{th} century account for much of the information available on sex differences in the sacrum and are often included as part of broader research focusing on population differences (Flander, 1978). Studies of sexual dimorphism of the sacrum have also generally been conducted on living persons and cadavers and rarely on dry bone, making the anthropological literature on the sacrum sparse.

The anthropological literature focused on the analysis of the posterior ilium is extensive in comparison to that of the sacrum and multiple distinct traits of the ilium used in the analysis of sex determination of the skeleton are often listed in forensic anthropology textbooks while typically only size, shape, and number of segments are listed for the sacrum (Buikstra & Ubelaker, 1994; Byers, 2002; Komar & Buikstra, 2008; Reichs, 1998; Rogers & Saunders, 1994; Walsh-Haney et al., 1999; White & Folkens, 2005). Though morphological traits of the posterior ilium are sexually dimorphic, they lack the standardization of metric analysis that is available for the certain aspects of the sacrum (Benazzi, 2009; Flander, 1980; Kimura, 1982; Steyn et al., 2004; Tague, 2007; Walker, 2005). The greater sciatic notch and the preauricular sulcus of the ilium have both been found to show sexual dimorphism in nonmetric analyses, although studies of these traits often have ambiguous definitions of characteristics and lack the consistency of metric analysis (Byers, 2002; Mitler & Sheridan, 1992; Rogers & Saunders, 1994; Walker, 2005). The main reason cited for the use of morphological traits over metric analysis is the lack of standard, identifiable landmarks in the posterior iliac region (Walker, 2005). The main limitation of morphological techniques of sex determination is the degree of inconsistency in the observation and evaluation of traits that affects both inter- and intra-observer error (Rogers & Saunders, 1994). Visual analysis is influenced by both observer subjectivity and previous experience of the observer (Bruzek, 2002). A second limitation is that many visual techniques use a range of classifications rather than clearly defined categories, which leaves intermediate classifications and examples undefined as male or female (Benazzi et al., 2009). In an effort to increase the accuracy of sciatic notch measurement, Pretorius et al. (2006) provide standard landmarks that are easy to identify and clearly explained. Using these landmarks, metric analysis was conducted in this research comparing the length and width of the sciatic notch to morphological width scores.

As with other skeletal indicators of sex, age, or ancestry, it is likely that a method that combines the analyses of multiple traits of the posterior pelvis would be the most accurate for determining sex, evidenced by the analyses of the preauricular sulcus, sciatic notch, and inferior portion of the os coxa, which have been found to be most reliable when used in combination (Bruzek, 2002; Rogers & Saunders, 1994).

Research Objectives

The primary research objective of this thesis is to determine which traits of the posterior pelvis are the most beneficial using metric and morphological analysis within the William M Bass Donated Skeletal Collection and the Terry Anatomical Collection. Traits of the sacrum and posterior ilium of 210 individuals were examined and both metric measurements and morphological categories were recorded for each individual. The metric measurements of the sacrum and ilia were analyzed using SPSS to establish cut-off values for males and females while the rates of morphological traits within the sexes were determined using crosstabulations. Traits and measurements shown to be statistically significant in sex determination were then analyzed using logistic regression to determine accuracy rates for sex determination within this sample.

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CHAPTER 2: DETERMINING SEX OF THE SACRUM FROM THE TERRY AND BASS COLLECTIONS USING DESCRIPTIVE STATISTICS AND LOGISTIC REGRESSION

Introduction

As part of the pelvis, it is expected that metric and morphological differences between the male and female sacra should be apparent, though anthropological attempts to determine sex differences in the sacrum have been few and the results have typically been inconclusive (Benazzi et al., 2009; Flander, 1978; Kimura, 1982; Rogers & Saunders, 1994; Stradalova, 1975; Tague, 2007). It has also been suggested that functional requirements of the sacrum related to its position at the base of the spinal column and its role in locomotion might obscure sexual dimorphism (Flander, 1980; Tague, 2007). Analyses conducted in the first half of the 20th century account for much of the information available on sex differences in the sacrum and are often included as part of broader research focusing on population differences (Fawcett, 1938; Flander, 1978; Trotter, 1940).

Sexually dimorphic characteristics of the sacrum are included in most forensic anthropology textbooks while the literature and research that these classifications are based on are not included (Bass, 1995; Byers, 2002; Reichs, 1998; Schwartz, 2007). The most common morphological trait of the sacrum used to determine sex is the overall size and shape difference as the female sacrum tends to be short and broad while male's are longer and narrower (Table 1). The ala width and diameter of the base are also often included in lists of useful traits as the difference in sacral width between the sexes is apparent in these specific elements (Table 1) (Bass, 1995; Reichs, 1998; Schwartz, 2007; Tague, 2007). Studies that have been conducted often do not pertain directly to anthropological investigations or have some flaw in their methodology, which leads to lower levels of accuracy and high rates of error (Walker, 2005).

Table 1. Nonmetric methods of sex determination using the sacrum

Characteristic	**Male**	**Female**	**Source**
Shape of sacrum	Long & narrow, more tapering triangle.	Short and Broad	Ascádi & Nemeskéri, 1970; Rogers & Saunders, 1994; Reichs, 1998; Byers, 2002; Komar & Buikstra, 2008
Curvature	Generally more curved, more evenly curved when viewed laterally	Flatter	Ascádi & Nemeskéri, 1970; Bass, 1995; Reichs, 1998; Burns, 2007
Number of segments	5+	No more than 5	Rogers & Saunders, 1994; Walsh-Haney H, et al., 1999; Komar & Buikstra, 2008
Ala size	Appear small relative to S1's articular surface Width of body of the sacrum to the ala may be greater Ala narrower than promontory	Typically quite large, distended & flared laterally; appear large relative to sacral base. Width of the S1 body is equal in width to each ala Ala wider than promontory	Schwartz, 2007; Bass, 1995; Reichs, 1998
Costal process length of S1		Longer in blacks and whites in sample	Tague RG, 2007
Sacroiliac bridging	More frequent Mainly EAB on anterior portion of SIJ	Mainly IAB on posterior portion of SIJ	Dar G & Hershkovitz, 2007
Visibility of SI in posterior view	Visible	Not visible	Rogers & Saunders, 1994; Komar & Buikstra, 2008

Moreover, some anthropological studies that report correlations between morphological traits in male and female sacra were not focused on sex determination of the sacrum but instead on population differences (Flander, 1978; Kimura, 1982; Tague, 2007). Although these studies provide important information, they rely on the knowledge of the decedent's ancestry which may not be known in a forensic anthropology investigation.

Metric methods of determining sex using the sacrum have been attempted by anatomists beginning with Fawcett in 1938 and have focused on the ratio of sacral base width to the width of the body of S1 (Table 2). Fawcett (1938) stated that the narrow width of the female lumbar spine and sacral base results in a lower ratio between this measurement and the width of the sacral body. Stradalova's (1975) research found that the corpora-basal index proved to be useful for determining sex of the sacrum where it was larger in males. Flander (1978) confirmed the findings of earlier analyses in that the ratio of sacral base to the width of S1 is the most indicative index of sex. Tague (2007) also found evidence for the usefulness of the costal process of S1 for sex determination, and further associated the relationship of the length of the costal process to obstetric adaptations. The longer costal processes of S1 in females are likely an adaptation to childbirth as the costal processes contribute to the diameter of the pelvic inlet (Tague, 2007).

Kimura (1982) used the ratios of sacral base breadth, wing breadth, and vertical diameter of the auricular surface to determine sex differences within Japanese, American white, and African American skeletal collections (Table 2). The results contradicted earlier research, finding the ratio of sacral base width to the width of S1 to be the least effective of the three tested (Kimura, 1982). The ratio of the width of the sacral wing to the vertical diameter of the auricular surface was found to be the most reliable method (Kimura, 1982).

Table 2. Metric methods of sex determination using the sacrum

Type	Measurement	Description	Source
Index	Sacral Base Width: Width of S1	Higher ratio (Wider Sacral base) in males. Lower ratio in females	Fawcett, 1938; Flander, 1978; Stradalova, 1975; Tague, 2007; Benazzi et al., 2009
Index	Width of the sacral wing: vertical diameter of the auricular surface	Sacral wing is wider and auricular surface is smaller in females	Kimura, 1982; Flander, 1978
Univariate	Depth of the sacral base Length of the auricular surface Height of the body of S1 Transverse diameter of S1	Larger in males for all traits	Stradalova, 1975
Multivariate	Antero-posterior and transverse diameters of the centrum: Maximum width of S1	Lower ratio in females due to smaller lumbar spine	Flander, 1980

Multivariate techniques have been shown to be more accurate than univariate methods, though single measurement methods are also used depending on the condition of the bone and the number of traits and measurements available for analysis (Table 2). Stradalova (1975) found depth (antero-posterior) of the sacral base, length of the auricular surface, height of the body of S1, and the transverse diameter of S1 to be the most effective measurements for determining sex using univariate analysis though Flander (1978) refuted the reliability of the extent of the auricular surface due to the high correlation of this trait to the width of S1. Flander (1978) also found differences in length and width of the sacrum, number of sacral segments, and the degree of sacral curvature to be unreliable as univariate differences between the sexes while the diameter of S1 in comparison to the width of the ala were found to be the most accurate measurements for determining sex in the sacrum for both blacks and whites. Sacral curvature was found to indicate ancestry rather than sex, with the sacrum of whites being more curved than that of black individuals (Flander, 1978). In a second analysis of the sacrum, Flander (1980) determined that the majority of sexual differences in the sacrum are found on the superior portion of the bone in the relationship between the antero-posterior and transverse diameters of the centrum to the maximum width of the sacral body at S1. The width of the ala alone was found to relate to the size of the individual regardless of sex, though the alae are more horizontally oriented in the female sacrum (Flander, 1980).

Benazzi et al.'s (2009) goal was to reduce subjectivity of visual sex determination of the sacrum with standardized measurements taken from digital photographs using AutoCAD. The measurements included the maximum transverse diameter of S1, the maximum superior breadth of the sacrum, the area of the upper face of the body of S1, and the perimeter of the body of S1 (Benazzi et al., 2009). The maximum sacral breadth was found to be ineffective at determining sex, while measurements of S1 were found to be related to sex (Benazzi et al., 2009). Although these measurements were taken from digital photographs of dry bone, the authors noted that this method should not replace standard techniques of sex determination of the pelvis and skull and should be used with fragmentary remains when these other standard techniques are not possible (Benazzi et al., 2009).

The relationship of S1 width to promontory width has been found to be the most reliable indicator of sex determination in the sacrum (Reichs, 1998). As the lumbar vertebrae of males are generally larger and wider than those of females, the sacral base of the female sacrum is expected to be narrower than males as it is the area of articulation of the lumbar vertebrae to the posterior pelvis. In order for a female sacrum to be wider than a male to accommodate the needs of childbirth, the extra width of the sacrum must be made up in the ala which also influences the total width of the body of S1, and likely subsequent sacral bodies, as well (Tague, 2007).

Reexamination of the standard morphological characteristics and metric measurements of the sacrum used to determine sex was conducted to assess the accuracy of these traits and measurements. Characteristics examined in this research include the number of sacral segments and the extent of the sacral auricular surface. Though morphological characteristics are often cited as being faster to use, the degree of experience of the observer likely influences the results of these determinations more than metric measurements (Bruzek, 2002). Metric measurements were recorded and analyzed here to determine whether more objective methods of sex determination have higher accuracy rates and lower levels of error than the more subjective morphological methods.

Materials

The use of documented skeletal collections is necessary for the type of research proposed here. Documented collections are those in which demographic information is known for the individuals within the collection. In order to determine the rates of sexually dimorphic traits within a skeletal population, you must know which individuals are male and which are female, necessitating the use of a skeletal sample in which this data is available for all individuals. In order to achieve a varied sample, known ancestry and chronological age are also important for this research. Age was an especially important consideration as sexually dimorphic traits are not expressed until puberty and the inclusion of juvenile individuals was not appropriate for this type of research. In order include equal numbers of individuals of both European and African

American ancestry, both the William M. Bass and Terry Collections were used in data collection for this thesis.

The William M. Bass Donated Skeletal Collection was started in 1981 and currently contains 679 individuals. The majority of individuals in the collection are of European American or African American ancestry and a small percentage are Hispanic. The age range of the individuals is from fetal up to 101 years at death. The individuals in the sample have donated their bodies to the Anthropology Research Facility at the University of Tennessee or directly to the skeletal collection. The Anthropology Research Facility conducts studies on taphonomy using human cadavers and at the completion of research, the bones are collected, cleaned, and added to the skeletal collection when the individual has indicated that this is their wish and the bones are mostly free of postmortem damage. Other individuals in the collection are unclaimed bodies from local medical examiner's offices. The University of Tennessee will not pay to have bodies shipped to their facilities due to high costs, so most of the individuals that donate their body to the collection are from the area, as are many of the individuals donated by local medical examiner's offices. As a result of this, the demographic composition of the sample is limited and consists mainly of white—typically European American—males. Although white females comprise a significant percentage of the skeletal collection, other ancestral groups are underrepresented. In order to achieve a varied and even sample, it was necessary to use two skeletal collections for this research. The second collection, which has more individuals overall and more individuals of African ancestry specifically, is the Terry Collection at the National Museum of Natural History.

After two failed previous attempts, Dr. Robert J. Terry, the chair of the Anatomy Department of the Washington University Medical School, began collecting the skeletons of cadavers in 1910 (Hunt and Albanese, 2005). The majority of the individuals used at the medical school as teaching specimen were unclaimed bodies from local St. Louis morgues while others came from local hospitals (Hunt and Albanese, 2005). As a result of using primarily unclaimed bodies, many of the skeletons in the collection represent the lower socioeconomic class. Unlike many other contemporaneous skeletal collections of the time, Dr. Terry was concerned with collecting non-pathological skeletons rather than acquiring those with rare or unique variations (Hunt and Albanese, 2005). After Dr. Terry's retirement in 1941, Mildred Trotter took over as collector and curator of the collection. Her main contribution was the balancing of the demographics of the sample by collecting both younger individuals and white females. In 1967, Trotter retired and had the Terry Collection transferred to the Smithsonian Institute in Washington DC. Currently, the Terry Collection consists of 1728 individuals of known age, sex, ancestry, cause of death and antemortem pathology. The age at death of individuals in the collection ranges from 16 to 102 years with the highest percentage of individuals being 45 years of age or older.

The sample in this research consists of 100 individuals from the Bass Collection and 110 individuals from the Terry Collection. The composition of the sample is 51 white males, 50 white females, 53 black males, and 56 black females. All individuals examined are adults over the age of 20. Age was an especially important consideration as sexually dimorphic traits are not expressed until puberty and the inclusion of juvenile individuals was not appropriate for this research. Similar to other research conducted on sex differences of the pelvis, five age categories of 20-29, 30-39, 40-49, 50-59, and 60+ years of age were used to ensure a wide range of ages in the sample (Figure 1) (Walker, 2005). The average age of males was 43.53 and 45.35 for females in this sample.

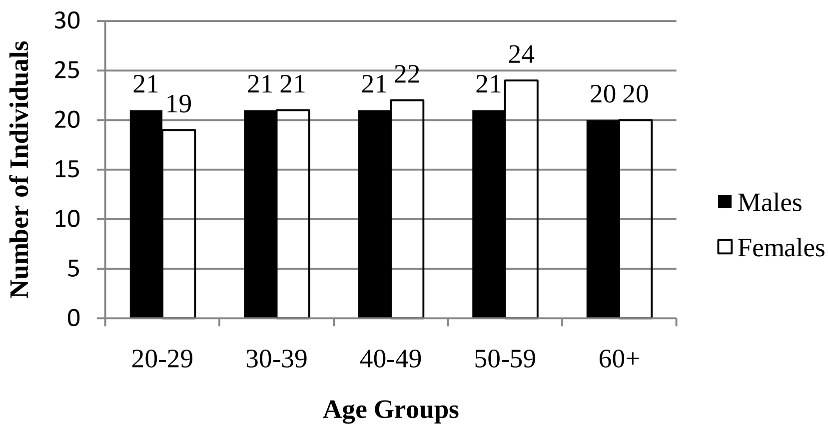

Figure 1. Age distribution of individuals included in sample.

The ability to include both collections in a single sample was determined by coding the two samples as a dichotomous variable (Bass Collection as 0, Terry Collection as 1) in a logistic regression with sacral and iliac traits as the interaction terms. In order to reduce the redundancy of traits and measurements included and eliminate excess data output, the three most accurate and significant traits from both the sacrum and the ilium were included in the regression. The significance levels for iliac and sacral traits with museum category as an interaction term were above p= .05. The chi distribution of the two regressions (with and without ancestry as an interaction term) was also calculated and found to be statistically insignificant at p= .21.

<u>Methods</u>

Metric and nonmetric measurements of the sacrum were recorded for each individual. Sacra were not excluded from the sample if they displayed spondylolysis, lumbralization, sacralization, and clefting or incomplete fusion of the sacral canal. Excluded pathologies included extreme osteoarthritis, sacroiliac fusion, individuals with medical implants such as total hip replacements, or other visible extreme variations in morphology of unknown etiology.

Nonmetric Scores

Sacral variation recorded includes the number of sacral segments, the number of sacral segments the auricular surface extended to, and accessory articulations (Table 3). The extent of the auricular surface of the sacrum was measured qualitatively as the number of body segments the auricular surface extended to on the sacrum and scored as extending to two, two and one half, or three segments. Accessory articulations, if present, were scored according to the type, location, and number of articulations present. The locations of accessory articulations on the sacrum were recorded as lateral to the 1st or 2nd sacral foramina or on the superior angle of ala. The accessory articulations also corresponded to locations on the ilium and were recorded as either on the medial surface of the posterior superior iliac spine or on the iliac tuberosity (Figure 2). For the purpose of simplification, each individual was scored as having (1) or not exhibiting (0) accessory articulations, and this binary code was used in the statistical analysis. The morphological traits were analyzed in SPSS using cross tabulations and using logistic regression to create classification tables to assess the accuracy of each trait if it was determined to be useful in sex determination.

Table 3. Morphological scoring systems

Trait	Scoring System
Number of sacral segments	4 Segments 5 Segments 6 Segments
Extent of the auricular surface	2: S1-S2 2.5: S1-1/2S2 3: S1-S3
Accessory Articulation	Absent (0) Present (1)

Figure 2. Accessory articulations of the ilium. Corresponding sacral articulations not shown.

Metric Measurements and Statistical Analysis

The 15 metric measurements of the sacrum recorded are listed in Table 4 and shown in Figures 3 and 4. Measurements for both the right and left side of the sacrum for each individual were recorded to assess symmetry and eliminate individuals with gross disparities that could indicate pathological conditions though only the left metric measurement and categorical scores were used in data analysis as is standard in the anthropological literature (Rogers & Saunders, 1994). The statistics for each metric measurement were then calculated to determine whether the differences between males and females were statistically significant. Logistic regression was then employed to create classification tables for each measurement to determine its accuracy.

Table 4. Metric measurements

Measurement	Description
Anterior Length	Promontory of the sacral base to the most inferior point of the sacral apex (Buikstra & Ubelaker, 1994)
Anterior Superior Breadth	Measurement perpendicular to the long axis of the sacrum from the most anterior and superior points on the sacral ala (Buikstra & Ubelaker, 1994)
Maximum Transverse Diameter of the Base	The maximum coronal width of the sacral base (Buikstra & Ubelaker, 1994)
Width of Ala	The length of the straight line drawn from the most lateral point of the sacral base to the point on the most lateral point on the ala where a coronal line drawn to bisect the base reaches
Width of S1	The width of the line that bisects the sacral base coronally at the most later point of each ala
Width of S2, S3, S4, & S5	Width of the sacral body at the midpoint of its length
Length of S1, S2, S3, S4, and S5	Taken between the lines of fusion between each sacral body, when still visible

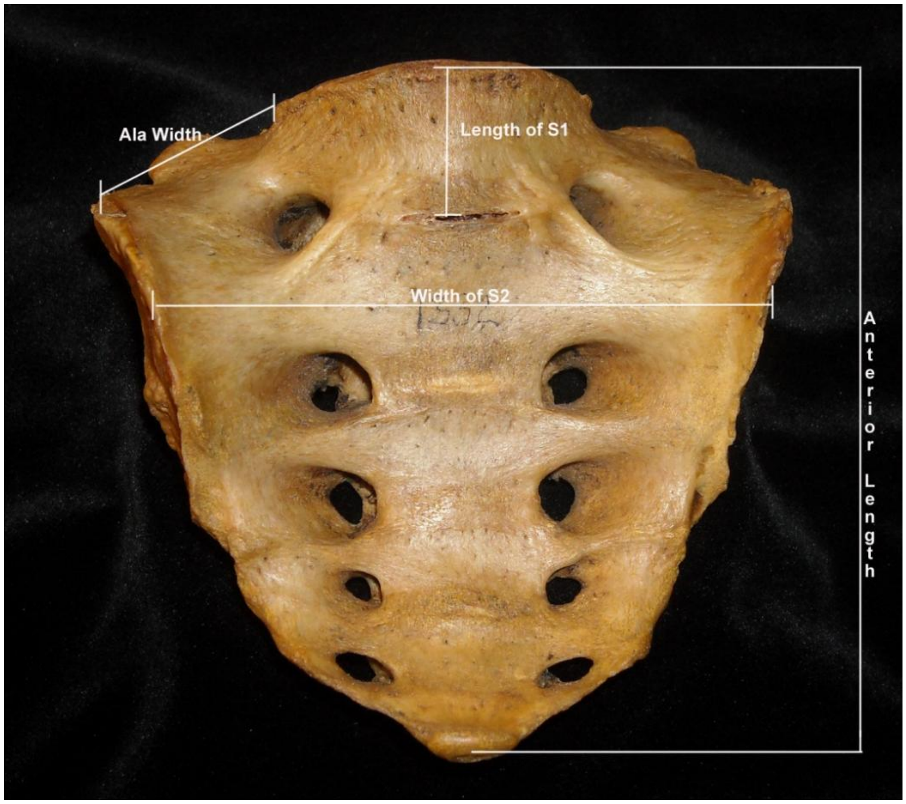

Figure 3.Ventral view of the sacrum showing metric measurements.

Figure 4. Superior view of the sacrum showing metric measurements.

The statistical analyses were conducted using logistic regression in SPSS 17.0. Backward Step-Wise logistic regression was used to determine the variables that were the most accurate in sex determination and statistically significant. Step-wise regression begins with all of the variables being included in the analysis. SPSS then tests them one by one for statistical significance (<.05) and deletes those that are not significant. Backward step-wise regression progresses until the accuracy is maximized or when the improvements fall below some critical value. This method also eliminates redundant traits such as those that are highly correlated to others and less statistically significant.

Logistic regression is an extension of multiple regression used when the dependent variable is a categorical dichotomy— in this case, males versus females—and the independent variables are categorical, continuous, or discreet numerical values (Hosmer & Lemeshow, 1989). Logistic regression allows for the allocation of an unknown individual to a set of *a priori* defined groups—male or female here—and generates posterior probabilities of group membership (Hosmer & Lemeshow, 1989). The predictive accuracy of the logistic regression is determined by examination of the classification table which shows correct and incorrect classifications of males and females (Hosmer & Lemeshow, 1989). Logistic regression is used to determine the relationship between the independent variables and the logit function of the odds of occurrence and predicts the likelihood of an occurrence, measured in probability. The logit function is the natural logarithm of the odds of occurrence. The resulting formula is in the form of

$$\text{Log-odds} = A + B_1(X_1) + B_2(X_2) + B_3(X_3)\ldots$$

where A is the constant, B values are the coefficients and X values are the metric or morphological measurements.

Logistic regression is similar to discriminant analysis in that both analyze the relationship between several independent variables and one dependent variable—male/female in this analysis (Sweet & Grace-Martin, 2003). The difference between the two is that discriminant analysis classifies an observation into one of several populations while logistic regression relates qualitative variables to other variables through a logistic cdf functional form (Sweet & Grace-Martin, 2003). Linear regression requires a quantitative dependent variable while logistic regression requires a binary qualitative dependent variable (Sweet & Grace-Martin, 2003). While discriminant function analysis is used more commonly in paleoanthropology to classify unknown biological specimen into predetermined categories, it is sensitive to uneven group sizes while logistic regression is less influenced by violations of the assumptions of equal sample sizes (Hosmer & Lemeshow, 1989). The flexibility of logistic regression is one of its advantages as it does not assume a linear of relationship between the independent and dependent variables and does not require a normally distribution of the variables (Hosmer & Lemeshow, 1989). Logistic regression does require, however, independent observations and a linear relationship of the independent variables to the logit of the dependent (Hosmer & Lemeshow, 1989).

As a method of verifying the results of the SPSS analysis on a sample of this size, boot-strapping was used progressively to determine which variables were the most accurate and significant. In this resampling technique, repeated random samples are taken of the data—a random 75% of the individuals in this research—to compute the average accuracy rates. The typical method of resampling is to select random cases in the population with replacement from the original data set and each resample includes the same number of individuals. As boot-strapping uses replacement, the drawn samples will include repeated cases.

Results

Sacral Segments

The majority of individuals in this sample—91%— had five sacral segments. One individual had a 4 segment sacrum with a fused fifth lumbar vertebrae. The number of sacral segments for this individual was determined by counting the number of cervical, thoracic and lumbar vertebrae and only four lumbar vertebrae were included. Though it is possible that one lumbar vertebra was missing, the morphology of the most superior sacral body was more similar in morphology to a lumbar vertebra than a sacral body segment. Males and females expressed a six segment sacrum in equal numbers and accounted for almost equal percentages within the male and female populations (Table 5). As an equal number of males and females were scored with a six segment sacrum and the Pearson Chi-Square p-value was .598, the accuracy level of this variable in determining sex was not included as the difference between the sexes is not statistically significant.

Table 5. Frequency of Segment Number by Sex

			Sex		Total
			Male	Female	
Segment Number	4	Count	1	0	1
		% within Sex	1.0%	.0%	.5%
	5	Count	94	97	191
		% within Sex	90.4%	91.5%	91.0%
	6	Count	9	9	18
		% within Sex	8.7%	8.5%	8.6%
Total		Count	104	106	210
		% within Sex	100.0%	100.0%	100.0%

Extent of the Sacral Auricular Surface

The extent of the auricular surface of the sacrum was measured qualitatively as the number of body segments the surface extended on the sacrum. In males, the most typical category expressed was 2.5 segments, which generally included S1- ½ of S3 (Table 6). In females, an almost equal number of individuals had two and 2.5 sacral segment auricular surfaces and included 76.4% of the females combined (Table 6). While there is a trend for males to have a longer sacral auricular surface than those of females, this trait cannot be used in sex determination.

Table 6. Frequency of Extent of the Auricular Surface by Sex

			Sex		
			Male	Female	Total
Extent of the Auricular Surface	2.0	Count	23	40	63
		% within Sex	22.5%	38.8%	30.7%
	2.5	Count	49	41	90
		% within Sex	48.0%	39.8%	43.9%
	3.0	Count	30	22	52
		% within Sex	29.4%	21.4%	25.4%
Total		Count	102	103	205
		% within Sex	100.0%	100.0%	100.0%

Using analysis of variance (ANOVA), the significance was found to be .02 indicating that there is a statistically significant difference of the means of the extent of the auricular surface between males and females though the overlap of measurements is high. Despite this determination, logistic regression was used to assess the accuracy of this trait in sex determination and the accuracy level for males was found to be much higher than that for females—77.5% and 38.8% respectively. The accuracy level for females was likely low as the result of an almost equal number of female individuals scored as having two and 2.5 segment auricular surfaces while almost half of the males in the sample had 2.5 segment auricular surfaces. This tendency to cluster in one category increases the accuracy level in males.

Accessory Articulations

If present, the number and type of accessory articulations for each individual were scored and recorded. In data analysis, the scoring system was simplified to the presence or absence of accessory articulations for each individual (Table 7). The percentage of males with accessory articulations (27.9%) was higher than that of females (20.8%), as expected, though this variable was not run to determine the level of prediction accuracy as the Pearson chi-square p-value was .228, indicating that the difference between males and females was not statistically significant.

Table 7. Frequency of Accessory Articulations by Sex

			Sex		
			Male	Female	Total
Accessory Articulations	Absent	Count	75	84	159
		% within Sex	72.1%	79.2%	75.7%
	Present	Count	29	22	51
		% within Sex	27.9%	20.8%	24.3%
Total		Count	104	106	210
		% within Sex	100.0%	100.0%	100.0%

Maximum Transverse Diameter of the Base

The mean maximum transverse diameter of the base in males is larger than that of females though the difference is not statistically significant (ANOVA = .726). The means of males and females are close and overlap at the level of 1 standard deviation and this measurement alone is of little value in determination of sex (Table 8). The accuracy of this trait was assessed using logistic regression and found to be 69% for males and females combined in this population. The accuracy rate was slightly higher in males than in females because larger females are more likely to be classified as male than small males are to be classified as female in this population.

The cut-off value for males and females was determined using the logistic regression output. The logistic regression equation is

$$\text{Log-odds} = A + B_1(X_1) + B_2(X_2) + B_3(X_3)\ldots$$

where A is the constant, B values are the coefficients and X values are the metric or morphological measurements. When the odds that the individual is a male are absolute, the log-odd value is zero giving the formula

$$0 = A + B(X) \text{ (for a single variable).}$$

To determine the value of X, the negative of the constant is divided by the coefficient. This X value is the cut-off between male and female. This value for the maximum transverse diameter of the base is 50.86.

Table 8. Maximum Transverse Diameter of the Base Descriptive Statistics

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Male	99	52.97	5.352	.538	51.90	54.04	38	73
Female	104	48.38	4.113	.403	47.58	49.17	40	62
Total	203	50.62	5.275	.370	49.89	51.35	38	73

Ala Width Ratios

Ala width alone was of no value in sex determination due to the overlap of values for males and females though the mean for females was larger than that of males (ANOVA F=20.098). Listed below in descending order of accuracy are the ratios analyzed in this data.

1. Ala width: Maximum transverse diameter of the base (accuracy= 71.0%)
2. Maximum transverse diameter of the base: Width of S1 (accuracy= 69.7%)
3. Anterior length: Anterior superior breadth (accuracy= 59.5%)

All three ratios showed higher mean values in males than females (Table 9). Cut-off values are likely not possible for the ratio of anterior length to anterior superior breadth as the means for males and females are well within one standard deviation of each other (Table 9). The means for both males and females for ala width to the maximum transverse diameter of the base and maximum transverse diameter of the base to the width of S1 fall just at one standard deviation away from each other (Table 9). Therefore, cut-off values for these ratios are possible though not advisable.

Table 9. Ala Width Ratios Descriptive Statistics

					95% Confidence Interval for Mean	
		N	Mean	Std. Deviation	Lower Bound	Upper Bound
AL:ASB	Male	98	1.066040	.1180295	1.042377	1.089704
	Female	102	.994163	.1511986	.964465	1.023861
	Total	200	1.029383	.1403241	1.009816	1.048950
Ala:MTDB	Male	98	.595754	.1040868	.574886	.616623
	Female	102	.703993	.1079240	.682795	.725191
	Total	200	.650956	.1188905	.634378	.667534
MTDB:S1	Male	98	.472892	.0434070	.464189	.481594
	Female	100	.429544	.0383587	.421933	.437155
	Total	198	.450999	.0462521	.444517	.457481

The combination of all three ratios using logistic regression showed the highest accuracy rate of 73.4% for males and females together though the level of accuracy was slightly higher in females. As the ratio of anterior length to anterior superior breadth was expected to relate mainly to differences in stature rather than shape and morphology differences between males and females, it was eliminated from the analysis to increase accuracy. However, the accuracy level for both males and females combined dropped to 70.6% when this variable was eliminated, meaning basic size differences between male and female sacra account for a degree of dimorphism. Step-wise logistic regression was then conducted in order to determine the most accurate and significant ratios for sex determination. This method eliminated the ratio of maximum transverse diameter of the base to width of S1 due to the high level or correlation between this trait and the ratio of ala width to the maximum transverse diameter of the base and attained an accuracy rate of 73.0%. The accuracy rate for the anterior length to the anterior superior breadth was only slightly better than random assignment for males at 59.5% accurate. The accuracy rates for females were higher than those for males when the ratios were used alone or in combination, meaning that males were slightly more likely to be classified as females than females were to be classified as males.

Logistic Regression

All sacral variables were included in the logistic regression analysis and through the process of step-wise regression, those that were the least significant were eliminated (Table 10).

Table 10. Variables in the Equation At Step 1 and Step 8

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	Segment#	.760	.752	1.022	1	.312	2.138
	Ant.Length	-.019	.021	.775	1	.379	.981
	Ant.Sup.Breadth	.197	.047	17.228	1	.000	1.217
	MaxTransDiamofbase	-.209	.059	12.647	1	.000	.811
	ASE#	-.762	.584	1.701	1	.192	.467
	AlaWidth	.030	.076	.160	1	.689	1.031
	WidthS1	-.064	.059	1.188	1	.276	.938
	LengthS1	-.224	.079	8.072	1	.004	.799
	AA	-.317	.477	.441	1	.507	.729
	Constant	3.953	5.052	.612	1	.434	52.106
Step 8[a]	Ant.Sup.Breadth	.154	.031	25.126	1	.000	1.166
	MaxTransDiamofbase	-.243	.051	22.578	1	.000	.785
	LengthS1	-.223	.074	9.003	1	.003	.800
	Constant	3.652	2.921	1.564	1	.211	38.551

The most statistically significant measurements for determining sex in the sacrum were the anterior superior breadth, the maximum transverse diameter of the base of the sacrum, and the length of sacral body 1 when used in combination. As these variables all had significance levels below .05 and were not correlated, all three were included in the final equation. The equation for sex determination of the sacrum using logistic regression is

Log-odds= $A + B_1$(Anterior superior breadth) + B_2(maximum transverse diameter of the base) + B_3(Length of S1)

Discussion

Morphological Traits of the Sacrum

After analysis of the morphological traits of the sacrum it was determined that the vast majority of individuals in this sample—91%— had five sacral segments. Males and females expressed a six segment sacrum in equal numbers and accounted for almost equal percentages within the male and female populations though the forensic anthropology literature typically lists a six segment sacrum as a male characteristic (Komar & Buikstra, 1994; Rogers & Saunders, 1994; St. Hoyme, 1984; Walsh-Haney et al., 1999). Sampling or observer error could account for the disparity between the numbers of individuals scored as a six segment sacrum in this research though data to compare these findings to are not readily available. Overall, a six segment sacrum does not influence determination of sex.

Accessory joints can be found within, above, or behind the sacroiliac joint (SIJ) and are movable, diarthrodial joints with joint spaces, capsules, and articular surfaces (Walker, 1992). Sites of accessory joints between the sacrum and ilium can be located at the level of the first or second posterior sacral foramen between the sacral crest and the medial surface of the posterior superior iliac spine or on the iliac tuberosity and the sacral tuberosity at the level of the first sacral dorsal foramen (Walker, 1992). Accessory articulations were expressed in 23.8% of individuals included in this research; typically two or more as corresponding sacral and iliac articulations were scored separately. Males were slightly more likely than females to express accessory articulations though the presence or absence of an accessory articulation was not found to be a useful method for sex determination. Walker (1992) found accessory joints in 8-40% of some samples, with some individuals having two or three accessory joints. Trotter (1940) reviewed 958 sacroiliac joints and found a higher rate of accessory joints in males than in females, and higher rates in European Americans than in African Americans. As rates of accessory articulations are likely population specific and of unknown etiology, though likely due to age and stress related processes, it is unlikely that further research will increase the accuracy levels of their use in sex determination (Walker, 1992)

Metric Traits of the Sacrum and Statistical Analysis

The accuracy rates for sex determination using traits of the sacrum were determined using logistic regression and ranged from 58.0%-76.2% (Table 11). All traits included in the accuracy analyses, other than the extent of the auricular surface, were metric measurements as the morphological characteristics of the sacrum were not significantly different between the sexes. Accuracy rates of the sacrum were lower than other traits and measurements of the pelvis previously recorded which can achieve levels of 95%-98% in combination (Rogers & Saunders, 1994). Other studies have found higher rates of accuracy using the sacrum, but in these instances overall sacral shape was used in combination with a trait of the pubic bone which likely accounted for the high accuracy rates (Rogers & Saunders, 1994). Methods that have determined the accuracy of only sacral indices have typically achieved accuracy levels around 80% (Kimura, 1982).

Table 11. Classification accuracy for traits of the sacrum

Rank	Measurement	Males	Females	Total
1	Logistic Regression Equation	74.4%	77.9%	76.2%
2	AL:ASB, Ala: MTDB & MTDB:S1	71.7%	75.0%	73.4%
3	Ala: MTDB	69.4%	72.5%	71.0%
4	MTDB:S1	67.3%	72.0%	69.7%
5	Maximum Transverse Diameter of the Base	70.7%	67.3%	69.0%
6	Extent of the Auricular Surface	77.5%	38.8%	58.0%

The extent of the auricular surface in males tended to extend further than that of females though not to a degree that it would be of value in sex determination alone in this examination of the sacrum. While almost half of the males in this sample had an auricular surface that extended two and half segments, there were a number of females that exhibited this trait, as well. Due to the high percentage of males that scored in a single category, the accuracy level for males for this variable was much higher than that for females which showed a more skewed distribution (Table 11). It has been reported that the auricular surface of the sacrum may extend from the superior edge of the ala inferiorly to the region of S3 in males, while the auricular surface will typically only extend to S1 or S2 in females (St. Hoyme, 1984; Schwartz, 2007; Steele & Bramblett, 1988). Previous literature listed a larger auricular surface as a male characteristic and this research supports that finding, though it is unlikely that this trait can be used in sex determination (St. Hoyme, 1984; Stradalova, 1975). Other studies have also found that though the means between the sexes are separate, variance in the size of the auricular surface of males and females is high (Flander, 1978; Stradalova, 1975). Due to the high level of variation within the sexes, this trait is not useful in sex determination alone. Rather than record the extent as a category of the number of sacral segments, future research should record the metric length of the auricular surface of the sacrum to determine whether there is a significant difference in length between males and females.

Analysis of the metric measurements determined that the maximum transverse diameter of the base is wider in males than females though the difference between males and females was not statistically significant. The maximum transverse diameter of the base was expected to be lower, on average, in females than in males as the widths of the lumbar vertebrae are typically smaller in females than in males (Flander, 1980; Stradalova, 1975). Apparent variation between males and females in size of the maximum transverse diameter of the base, though not significant enough for sex determination, has also been found by Benazzi, et al. (2009). The statistical insignificance could be accounted for by the restriction in size decrease of the sacral base as even small males are likely to still have wider lumbar vertebrae than women of similar stature (Tague, 2007). The classification accuracy level for males was slightly higher than that for females, possibly due to restrictions in size decrease of the sacral base (Table 11) (Tague, 2007).

A combination of three ratios proved to be the second most accurate method of sex determination at 73.4%, and was only exceeded by the accuracy of the logistic regression equation (Table 11). The three ratios used were ala width: the maximum transverse diameter of the base, the maximum transverse diameter of the base: width of S1, and the anterior superior breadth: anterior length. The ratio shown to be the most accurate when used in isolation was the ala width to the maximum transverse diameter of the base, though the width of the base to the width of the body of S1 has been the focus of previous indices created (Benazzi et al., 2009; Fawcett, 1938; Flander, 1978; Stradalova, 1975; Tague, 2007). The current research generally supports the findings of the usefulness of the ratio of the width of the base to the width of the body of S1as the mean for males was higher than that for females and the values are separated by one standard deviation (Benazzi et al., 2009; Fawcett, 1938; Flander, 1978; Stradalova, 1975; Tague, 2007). The accuracy rate for this ratio was found to be 69.7% for both sexes, which is lower than that for the ala width to the maximum transverse diameter of the base which proved to be 71% accurate, however (Table 11). A number of studies have found that the ratio of the width of the body of S1 to the width of the base is not useful in sex determination though it has proven useful here.

The anterior superior breadth of the sacrum is a customary measurement in Buikstra and Ubelaker's (1994) *Standards* though this measurement may have a high rate of imprecision as it not measured on known, tangible landmarks but is taken from the most anterior and superior point on the angle of the ala. As a result of this, the use of the ratio of the anterior superior breadth to the anterior length is cautioned.

Logistic Regression

The formula created using logistic regression incorporated three measurements of the sacrum and was the most accurate method in this research for sex determination at 79.0% for both sexes (Table 11). The formula created for this research is:

Log-odds= A + B_1(anterior superior breadth) + B_2(maximum transverse diameter of the base) + B_3(Length of S1)

where A is the constant and B values are the coefficients. The formula finds the log-odds value which is then used to determine the probability by taking the exponent of the log-odds, giving the odds. Sex determination is based on probabilities, however, and the odds value must then be used to determine the probability. The probability will always fall between 0 and 1 and is a measure of how likely an event is to occur or not occur. The event in this analysis is actually sex, set up as a binary with males scored as 0 (not occurring) and females scored as 1 (occurring), making probabilities above .5 more likely to be female and those below .5 more likely be male.

The strength of the probability of correct sex determination increases as probability values approach zero and one.

The inclusion of the length of the first sacral body in the logistic regression equation is questioned as the rate of sacral body fusion varies and the line of fusion might be obliterated in some older individuals. Though the length of S2 could also have been included in this formula, it was not because it is likely fused in adults in their late 20s and older, as the sacral bodies fuse in an inferior-superior direction.

As an example of the use of the logistic regression formula, sample #13 was randomly selected. The values for this individual are:

Anterior superior breadth: 107
Maximum transverse diameter of the base: 60
Length of S1: 33

The constant and coefficients used in this equation are based on the logistic regression output.

The logistic regression formula is:

Log-odds= 3.652 + .154(107) + -.243(60) + -.223(33)

Log-odds= -1.809

Odds= .163 (Found by taking the exponent of the log-odds value)

In order to determine whether an individual is male or female, a probability is required so the odds value must be changed to probability using the formula

Probability= odds/odds + 1.

The probability for this individual is .14, which means likely male as the cut value for determining sex is .5. After it was determined that this individual was likely male, the demographic information was examined and Sample #13 is in fact male.

Ancestry and Sex Determination

The influence of ancestry on sex determination in this sample was determined by including each sacral and iliac trait and measurement with ancestry as an interaction term in a logistic regression. The significance levels for all trait and ancestry interactions were above .05 except for ala width and the ratio of ala width to the maximum transverse diameter of the base. Two sacral traits included in the logistic regression equation (anterior superior breadth and maximum transverse diameter of the base) were not found to be significantly influenced by ancestry though length of S1 was significant at p= .025. Differences in stature between ancestral groups could account for the significance of ancestry in using the length of S1 for sex determination. The chi squared distribution was also calculated to determine the influence of ancestry on sex determination and was found to be significant (p= <.000). Flander (1978) stated that in order to use metric traits of the sacrum for sex determination, it is important to know the ancestry of the individual, making this method impractical in a standard biological profile analysis.

Conclusions

In the process of determining a biological profile, it is essential to include as many methods as possible for the available skeletal elements. This study, based on the William M. Bass and Terry Collections, has demonstrated the value of the sacrum in sex determination. With a success rate of over 79%, the logistic regression formula has the potential to assist the physical anthropologist in sex determination of an individual. Though the sacral ratios only proved to be 73.4% accurate when used in combination, further refinement of the measurements and technique could lead to higher levels of accuracy in the future. Though aspects of the sacrum have proven to be significantly different between males and females in this research, there are complications concerning the sacrum and its use in the determination of sex. El Najjar & McWilliams (1978) cautioned that use of the sacrum in sex determination is “risky” though accuracy rates approached 80% here. The anatomy of the sacrum makes standardized measurements difficult and the degree of sexual dimorphism is constrained by the necessities of bipedality. The combination of these factors decreases the use of the sacrum in sex determination though in instances where the sacrum is one of the few bones available for analysis, the sacrum can prove valuable. Further research into the variation observed in this study will increase the accuracy of the proposed methods and augment the potential of the sacrum in the process of building a biological profile.

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CHAPTER 3: DETERMINING SEX OF THE POSTERIOR ILIUM FROM THE TERRY AND BASS COLLECTIONS USING DESCRIPTIVE STATISTICS AND LOGISTIC REGRESSION

Introduction

Sex determination is important for both forensic and bioarcheological examinations of the human skeleton. The bones of the pelvis, especially those of the anterior os coxa, are the most reliable and accurate indicators of sex (Bass, 1995; Bruzek, 2002; Byers, 2002; Rogers & Saunders, 1994; Schwartz, 2007; Walsh-Haney, 1999; White, 2000). Pubic bones are fragile and often damaged, however, especially in archeological collections (Kelley, 1979; Walker, 2005). In these instances, other portions of the pelvis can be used to correctly determine the sex of an individual such as the greater sciatic notch, elevation of the auricular surface, and the preauricular sulcus (Ascádi & Nemeskéri, 1970; Bruzek, 2002; Buikstra & Ubelaker, 1994; Rogers & Saunders, 1994; Steyn et al., 2004; Walker, 2005; Walsh-Haney, 1999).

Forensic anthropology textbooks often include the greater sciatic notch as an indicator of sex by classifying wide width notches as a female trait while narrow, deep notches are indicative of males (Byers, 2002; Komar & Buikstra, 2008; Reichs, 1998; Schwartz, 2007; Stewart, 1979. The main limitation of this classification system is the amount of subjectivity allowed in the description. Other than Reich’s (1998) measurement standards of the greater sciatic notch, the definitions of “wide” and “narrow” are rarely explained further than the “thumb rule.” Walker (2005) suggests a categorization method for the sciatic notch based on previous categorizations of width created by Ascádi & Nemeskéri (1970), with a score of one indicating a very wide sciatic notch and a score of five being a very narrow sciatic notch. According to Walker’s (2005) method, individuals scored as one are typically female while those scored as three, four, or five are often males. The original method of Ascádi & Nemeskéri (1970) used a scale of -2 to +2, indicating very narrow to very wide, respectively, with 0 as the intermediate score. The method proposed by Walker (2005) sought to reduce the subjectivity and error of the previous method by developing diagrams that were easier to use when comparing to actual ilia.

The presence or absence of the preauricular sulcus has been used as a morphological trait for the purpose of sexing the ilium as the sulcus is present and more pronounced in females than in males; however some research has indicated that the preauricular sulcus is an independent variable influenced by individual variation (Schwartz, 2007). Those scholars who list the preauricular sulcus as a characteristic of sex determination describe the groove as large, deep, or circular impressions in females and absent or very thin lines in males (Bruzek, 2002; Buikstra & Ubelaker, 1994; Komar & Buikstra, 2008; Rogers & Saunders, 1994; St. Hoyme, 1984; Walsh-Haney, 1999). More basic distinctions include "rare" in males and "well developed" in females (Byers, 2002).

The elevation of the auricular surface of the ilium is also often included as a method of sex determination with females expressing a raised surface while males typically have a nonelevated or depressed surface (Buikstra & Ubelaker, 1994; Rogers & Saunders, 1994; St. Hoyme, 1984). The elevation of the auricular surface lacks clear definitions of what is considered to be raised or nonelevated and this trait is difficult to assess without experience, which could account for the lower accuracy rates in sex determination in comparison to other traits of the posterior pelvis (Rogers & Saunders, 1994; Stewart, 1979). Intra-observer error for this trait has also shown to be relatively high in a reexamination of the traits of the pelvis in sex determination (Rogers & Saunders, 1994). The elevation of the auricular surface was recorded and analyzed for the individuals in this sample along with a metric measurement of the vertical diameter of the auricular surface. The metric measurement did not assess the height of the surface but the anterior-posterior length in an attempt to determine whether a different aspect of the surface would be more accurate in sex determination and have lower intra- and inter-observer error.

Reexamination of the standard morphological characteristics of the posterior pelvis used to determine sex that include the greater sciatic notch, preauricular sulcus, and the elevation of the auricular surface was conducted in order to assess the accuracy of these traits.

Materials

The use of documented skeletal collections was necessary for the type of research conducted here. There are a number of documented skeletal collections throughout the United States and the William M. Bass and Terry Collections were used in data collection for this thesis.

The William M. Bass Donated Skeletal Collection was started in 1981 and currently contains 679 individuals. The majority of individuals in the collection are of European American or African American ancestry and a small percentage are Hispanic. The age range of the individuals is from fetal up to 101 years at death. The individuals in the sample have donated their bodies to the Anthropology Research Facility at the University of Tennessee or directly to the skeletal collection. The Anthropology Research Facility conducts studies on taphonomy using human cadavers and at the completion of research, the bones are collected, cleaned, and added to the skeletal collection when the individual has indicated that this is their wish and the bones are mostly free of postmortem damage. Other individuals in the collection are unclaimed bodies from local medical examiner's offices. The University of Tennessee will not pay to have bodies shipped to their facilities due to high costs, so most of the individuals that donate their body to the collection are from the area, as are many of the individuals donated by local medical examiner's offices. As a result of this, the demographic composition of the sample is limited and consists mainly of white—typically European American—males. Although white females comprise a significant percentage of the skeletal collection, other ancestral groups are underrepresented. In order to achieve a varied and even sample, it is necessary to use two skeletal collections for this research. The second collection, which has more individuals overall and more individuals of African ancestry specifically, was the Terry Collection at the National Museum of Natural History.

Dr. Robert J. Terry began collecting the skeletons of cadavers as the chair of the Anatomy Department of the Washington University Medical School in 1910 after two failed previous attempts (Hunt and Albanese, 2005). The majority of the individuals used at the medical school as teaching specimen were unclaimed bodies from local St. Louis morgues while others came from local hospitals (Hunt and Albanese, 2005). As a result of using primarily unclaimed bodies, many of the skeletons in the collection represent the lower socioeconomic class. Unlike many other contemporaneous skeletal collections of the time, Dr. Terry was concerned with collecting non-pathological skeletons rather than acquiring those with rare or unique variations (Hunt and Albanese, 2005). After Dr. Terry's retirement in 1941, Mildred Trotter took over as collector and curator of the collection. Her main contribution was the balancing of the demographics of the sample by collecting both younger individuals and white females. In 1967, Trotter retired and had the Terry Collection transferred to the Smithsonian Institute in Washington DC. Currently, the Terry Collection consists of 1728 individuals of known age, sex, ancestry, cause of death and antemortem pathology. The age at death of individuals in the collection ranges from 16 to 102 years with the highest percentage of individuals being 45 years of age or older.

The sample in this research consists of 200 individuals from the Bass Collection and 110 individuals from the Terry Collection. The composition of the sample is 51 white males, 50 white females, 53 black males, and 56 black females. All individuals examined are adults over the age of 20. Age was an especially important consideration as sexually dimorphic traits are not expressed until puberty and the inclusion of juvenile individuals was not appropriate for this type of research. Similar to other research conducted on sex differences of the pelvis, five age categories of 20-29, 30-39, 40-49, 50-59, and 60+ years of age were used to ensure a wide range of ages in the sample (Figure 5) (Walker, 2005). The average age of males was 43.53 and 45.35 for females in this sample.

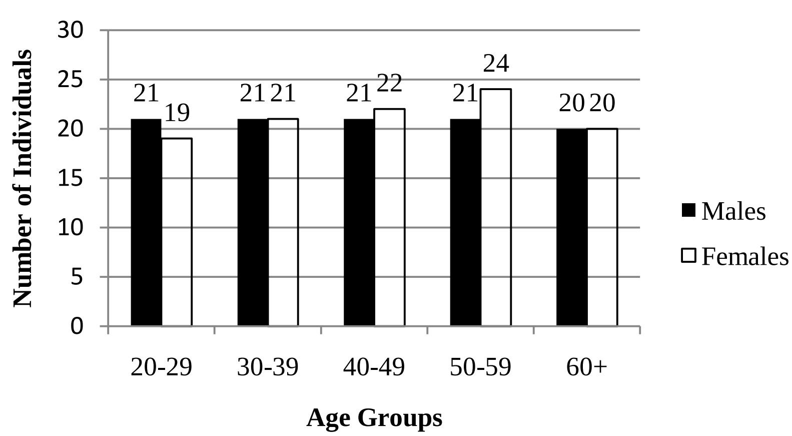

Figure 5. Age distribution of individuals included in sample.

The ability to include both collections in a single sample was determined by coding the two samples as a dichotomous variable (Bass Collection as 0, Terry Collection as 1) in a logistic regression with sacral and iliac traits as the interaction terms. In order to reduce the redundancy of traits and measurements included and eliminate excess data output, the three most accurate and significant traits from both the sacrum and the ilium were included in the regression. The significance levels for iliac and sacral traits with museum category as an interaction term were above $p= .05$. The chi distribution of the two regressions (with and without ancestry as an interaction term) was also calculated and found to be statistically insignificant at $p= .21$.

Methods

Metric and nonmetric measurements of the posterior ilium were recorded for each individual. Individuals were excluded from this sample if they displayed pathologies such as extreme osteoarthritis, medical implants such as total hip replacements, or other visible extreme variations in morphology of unknown etiology

Morphological Measurements

Morphological scores of the ilium were recorded using Buikstra and Ubelaker's *Standards* (1994) and include the elevation of the auricular surface, the presence of a preauricular sulcus, and the width score of the greater sciatic notch (Table 12). Elevation of the auricular surface was scored as nonelevated (0) or elevated (1). The distinction was made by examining the surface in profile to determine whether it was elevated or depressed in comparison to the rim of the surface. The presence (1) or absence (0) of the preauricular sulcus was scored next. If a sulcus was present, it was scored using the 1-4 scale of Buisktra & Ubelaker (1994) which classifies considering the width, depth, and length of the sulcus (Table 12, Figure 6). The sciatic notch width was scored using the 1-5 scale (Figure 7) of Buisktra & Ubelaker (1994) with 1 being the widest and 5 as the most narrow. The morphological traits were analyzed in SPSS version 17.0 using cross tabulations and logistic regression to create classification tables to assess the accuracy of each trait if it was determined to be useful in sex determination.

Table 12. Morphological traits and scoring system

Trait	Scoring System
Elevation of auricular surface	0: Nonelevated 1: Raised 2: Midline raised: Score defined in this research only
Presence of a Preauricular Sulcus (Figure 6)	0: Absence of a sulcus 1: Sulcus is wide and deep 2: Sulcus is wide but shallow 3: Sulcus is narrow but deep 4: Sulcus is narrow and shallow. Typically only lies along the posterior half of the auricular surface
Width of the Sciatic Notch (Figure 7)	1: Widest 2: Wide 3: Intermediate 4: Narrow 5: Narrowest

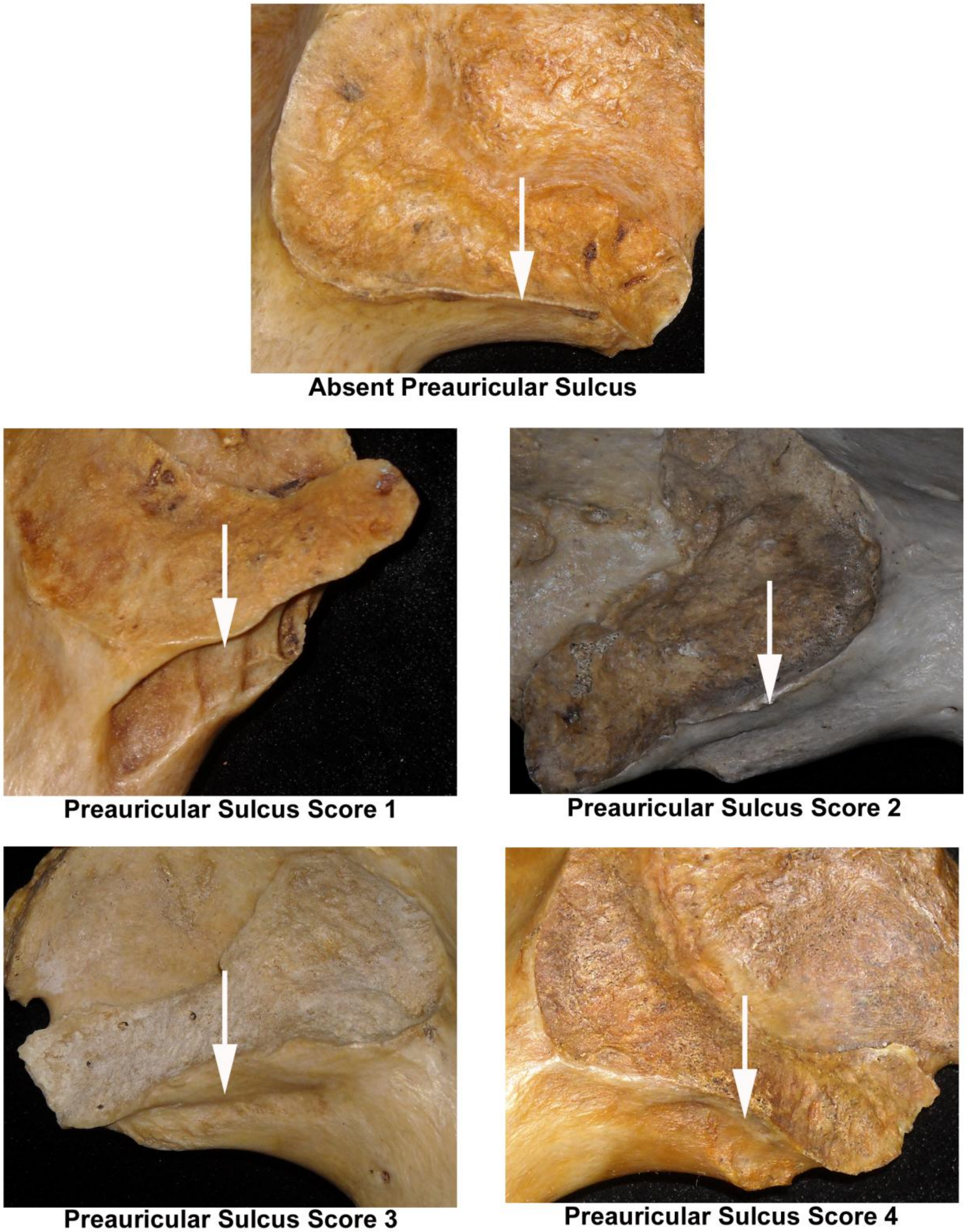

Figure 6. Examples of an absent preauricular sulcus and four morphological classifications of present sulci.

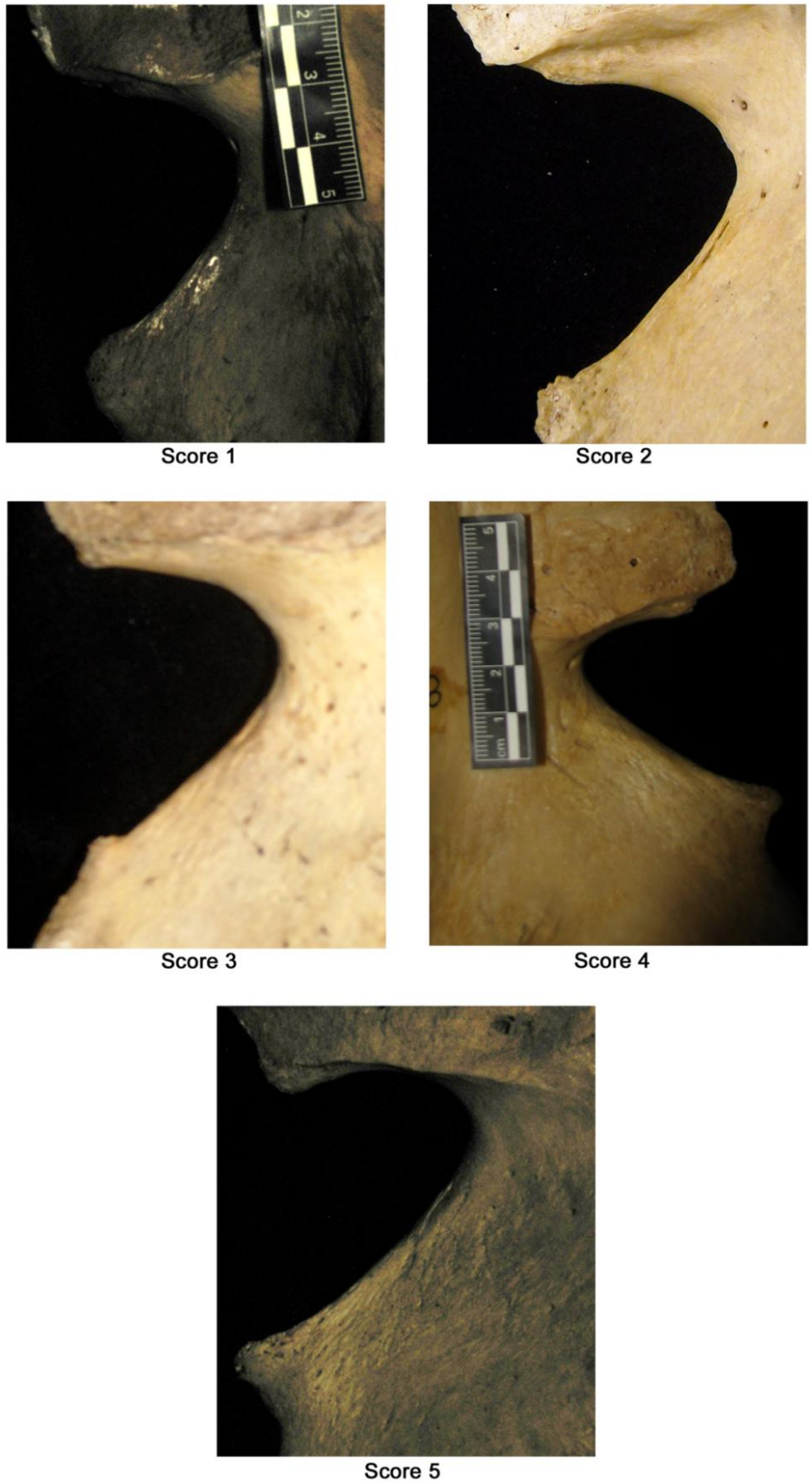

Figure 7. Examples of Sciatic Notch Morphological Scores

Metric Measurements and Statistical Analysis

The metric measurements of the sciatic notch and auricular surface that were recorded are listed in Table 13. The vertical diameter of the auricular surface was measured from the midpoint of the antero-superior border to the most posterior point on the surface (Figure 8). The metric analysis used in this research to determine the length and width of the sciatic notch was based on the landmarks presented by Steyn et al. (2004) which categorized the sciatic notch widths of South African males and females. In order to keep the measurements consistent, a piece of cardboard was used to hold the line between Landmarks 1 and 3 while the midpoint of the line was marked on the cardboard with the points of the calipers (Figure 9).

Measurements for both the right and left ilium for each individual were recorded to assess symmetry and eliminate individuals with gross disparities that could indicate pathological conditions, though only the left metric measurement and categorical scores were used in data analysis as is standard in the anthropological literature (Rogers & Saunders, 1994).

Table 13. Metric measurements of the posterior ilium

Measurement	Description
Vertical Diameter of the Auricular Surface	Midpoint of the antero-superior border of the surface to the most posterior point on the surface. This measurement should be perpendicular to the anterior border of the auricular surface. Shown in Figure 8
Width of the Sciatic Notch	Ischial spine (1) to the most posterior margin of the notch before it angles up the auricular surface (3). Landmarks shown in Figure 9
Length of the Sciatic Notch	Midpoint of a line drawn between points 1and 2 to the point of deepest curvature of the notch (2). Landmarks shown in Figure 9

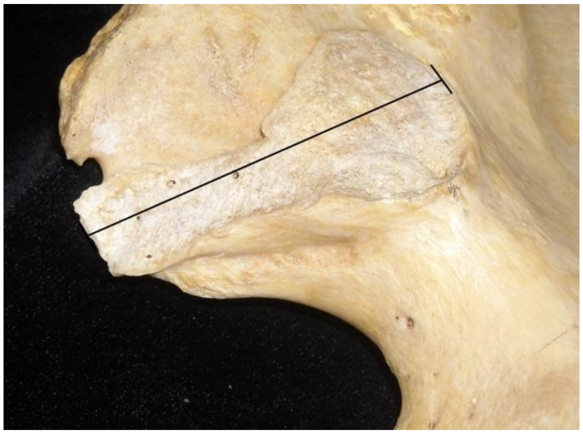

Figure 8. Vertical diameter of the auricular surface

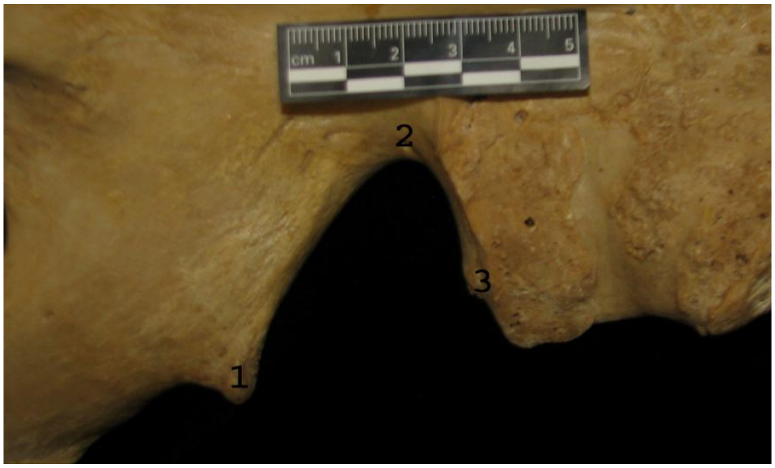

Figure 9. Landmarks of the sciatic notch used for the length and width.

The statistical analysis in the research was conducted using logistic regression in SPSS version 17.0. The descriptive statistics for each metric measurement were calculated to examine the mean and variances for each sex. Analysis of variance (ANOVA) determined whether each measurement was useful in sex determination by examining the difference between the means of the sexes. Logistic regression was then employed to create classification tables for each measurement to determine accuracy.

Backward Step-Wise logistic regression was then used to determine the variables that were the most accurate in sex determination and statistically significant. Step-wise regression begins with all of the variables being included. SPSS then tests them one by one for statistical significance (<.05) and deletes those that are not significant. Backward step-wise regression progresses until the measurement is maximized or when the improvements fall below some critical value. This method also eliminates redundant traits such as those that are highly correlated to others and less statistically significant.

Logistic regression is an extension of multiple regression and is used when the dependent variable is a nominal binary—in this case, males versus females—and the independent variables are categorical or continuous or discreet numerical values (Hosmer & Lemeshow, 1989). Logistic regression allows for the allocation of an unknown individual to a set of a priori defined groups—male or female-- and generates posterior probabilities of group membership (Hosmer & Lemeshow, 1989). The predictive accuracy of the regression is determined by examination of the classification table which shows correct and incorrect assignments of the dependent (Hosmer & Lemeshow, 1989). Logistic regression is used to find the relationship between the independent variables and the logit function of the odds of occurrence and predicts the likelihood of an occurrence, measured in probability. The logit function is the natural logarithm of the odds of occurrence. The resulting formula is in the form of

$$\text{Log-odds} = A + B_1(X_1) + B_2(X_2) + B_3(X_3)\ldots$$

where A is the coefficient, B values are the constants and X values are the metric or morphological measurements.

Logistic regression is similar to discriminant analysis in that both analyze the relationship between several independent variable (measurements and traits) and one dependent variable—male/female in this analysis (Sweet & Grace-Martin, 2003). The difference between the two is that discriminant analysis classifies an observation into one of several populations while logistic regression relates qualitative variables to other variables through a logistic cdf functional form (Sweet & Grace-Martin, 2003). Linear regression requires a quantitative dependent variable while logistic regression requires a binary qualitative dependent variable (Sweet & Grace-Martin, 2003). While discriminant function analysis is used more commonly in paleoanthropology to classify unknown biological specimen into predetermined categories, it is sensitive to uneven group sizes while linear regression is considerably less influenced by violations of the assumptions of equal group sizes (Hosmer & Lemeshow, 1989).

As a method of verifying the results of the SPSS analysis on a sample of this size, boot-strapping was used progressively to determine which variables were the most accurate and significant. In this resampling technique, repeated random samples are taken of the data—a random 75% of the individuals in this research—to compute the average accuracy rates. The typical method of resampling is to select random cases in the population with replacement from the original data set and each resample includes the same number of individuals. As boot-strapping uses replacement, the drawn samples will include repeated cases.

Results

Preauricular Sulcus Morphological Score

Nearly 64% of the females in this sample exhibited a preauricular sulcus while only 6% of males did (Table 14). Along with the frequency of individuals exhibiting a sulcus, there was also a difference between males and females in the categories of scores for those individuals exhibiting a sulcus (Table 15). The six out of 104 male individuals with a preauricular sulcus were scored as 4, which is a shallow, narrow groove that only extends along the posterior half of the auricular surface. Forty-eight percent of the females with a preauricular sulcus were scored in category 2, which is a wide but shallow sulcus (Table 15). The difference between males and females in classification of individuals with a sulcus indicates that though some males may express this trait, it is only to a limited degree in comparison to the extent of the female sulci. This trait was useful overall in classification with an accuracy rate 78.9% for males and females, though the rate for females alone was lower at 63.8%. The Pearson chi-square p-value was <.000 meaning the differences between males and females are not likely due to chance.

Table 14. Frequency of the Presence of a Preauricular Sulcus by Sex

			Sex		
			Male	Female	Total
Preauricular Sulcus	Absent	Count	98	38	136
		% within Sex	94.2%	36.2%	65.1%
	Present	Count	6	67	73
		% within Sex	5.8%	63.8%	34.9%
Total		Count	104	105	209
		% within Sex	100.0%	100.0%	100.0%

Table 15. Preauricular Sulcus Score Frequencies

		Preauricular Sulcus Score					
		Absent	Present				
			1	2	3	4	Total
Sex	Male	98	0	0	0	6	104
	Female	38	10	32	4	21	105
Total		136	10	32	4	27	209

Auricular Surface Relief

The standard scoring method for the auricular surface is binary based on a nonelevated (0) or elevated (1) surface (Buikstra & Ubelaker, 1994). A third category (2) was also included here for individuals that expressed an auricular surface that was raised along the midline of the surface in an antero-posterior direction. The ridge did not run along the entire surface in these individuals. The majority of females had a raised auricular surface while males had a nonelevated auricular surface (Table 16). The additional category of those individuals with an auricular surface raised along the midline was found in a higher percentage of males (6.7%) than females (1.9%), though the frequency within both sexes was low. Males were also more likely to be classified correctly according to the elevation of the auricular surface alone. The Pearson chi-square value for this variable was p= < .000 meaning the differences between males and females were not likely due to chance.

Table 16. Auricular Surface Elevation by Sex

			Sex		
			Male	Female	Total
Auricular Surface Relief	Non-elevated	Count	80	25	105
		% within Sex	76.9%	23.8%	50.2%
	Raised	Count	17	78	95
		% within Sex	16.3%	74.3%	45.5%
	Raised midline	Count	7	2	9
		% within Sex	6.7%	1.9%	4.3%
Total		Count	104	105	209
		% within Sex	100.0%	100.0%	100.0%

Greater Sciatic Notch Morphological Scores

The frequency of morphological scores for the greater sciatic notch for males and females are listed in Table 17. Males, in general, expressed narrower notches than females, and zero males in this sample were scored in the widest category (1). Additionally, no females in this sample were scored in the narrowest category (5). The analysis of the scores showed an inverse relationship between males and females, as well, though the scores of males showed more variance than those of females. This singular trait proved to be very accurate for both males and females in sex determination and the Pearson chi-square value was p= <.000, meaning the differences between males and females were not likely due to chance.

Table 17. Frequency of Sciatic Notch Score by Sex

			Sex		Total
			Male	Female	
Sciatic Notch Score	1	Count	0	60	60
		% within Sex	.0%	57.7%	28.8%
	2	Count	9	30	39
		% within Sex	8.7%	28.8%	18.8%
	3	Count	24	10	34
		% within Sex	23.1%	9.6%	16.3%
	4	Count	32	4	36
		% within Sex	30.8%	3.8%	17.3%
	5	Count	39	0	39
		% within Sex	37.5%	.0%	18.8%

Greater Sciatic Notch Metric Measurements

The ratio of the length and width of the sciatic notch for males and females was examined to determine trends and cut-off values for males and females. Though there is a degree of overlap in the ranges of values, it was evident that cut-off values for males and females could be created (Table 18). The cut-off value for males and females was determined using the logistic regression output. The logistic regression equation is

$$\text{Log-odds}= A + B_1(X_1) + B_2(X_2) + B_3(X_3)\ldots$$

where A is the constant, B values are the coefficients and X values are the metric or morphological measurements. When the odds that the individual is a male are absolute, the log-odd value is zero giving the formula

0= A + B(X) (for a single variable).

To determine the value of X, the negative of the constant is divided by the coefficient. This X value is the cut-off between male and female. This value for the sciatic notch ratio is .66. This value falls in the center of the indeterminate values of the cut-off values determined using the means and ranges of scores for each sex at one standard deviation (Table 19). In this method, the range of scores for each sex was determined by adding and subtracting one standard deviation from the mean. The ranges were then compared and the areas of overlap were considered to be indeterminate while the values that did not overlap were indicative of sex. The metric analysis of the sciatic notch proved to be less accurate than the morphological scoring method.

Table 18. Sciatic Notch Ratio Descriptive Statistics

	N	Mean	Std. Deviation	95% Confidence Interval for Mean		Minimum	Maximum
				Lower Bound	Upper Bound		
Male	99	.72	.09	.708	.74	.57	1.03
Female	104	.60	.09	.58	.61	.42	.97
Total	203	.66	.11	.64	.67	.42	1.03

Table 19. Greater Sciatic Notch Cut-off Values

Classification	Range Values
Male	.81-.70
Indeterminate	.69-.63
Female	.62-.51

Vertical Diameter of the Auricular Surface

The mean vertical diameter of the auricular surface of males was found to be 59 mm with a standard deviation (SD) of 5 and 54.27 with a SD of 4 in females (Table 20). Though the means of males and females are close and overlap at the level of 1 SD, and this measurement alone is of little value in determination of sex, cut-off values were created though there is a range of scores that would be considered indeterminate. The expected range of scores for both sexes at one SD is shown in Table 21. The same method of determining the cut-off scores using logistic regression as that employed in the sciatic notch ratio analysis was used for the vertical diameter and found to be 56.89. This score falls in the range of indeterminate scores created using the means and standard deviations for sex.

Table 20. Vertical Diameter of the Auricular Surface Descriptive Statistics

	N	Mean	Std. Deviation	95% Confidence Interval for Mean		Minimum	Maximum
				Lower Bound	Upper Bound		
Male	102	59.19	5.306	58.14	60.23	45	70
Female	103	54.27	4.817	53.33	55.21	39	68
Total	205	56.72	5.622	55.94	57.49	39	70

Table 21. Cut-off Values for the Vertical Diameter of the Auricular Surface

Classification	Range of Values
Male	64.00-59.01 mm
Indeterminate	59.00-54.00 mm
Female	53.99-49 mm

Logistic Regression

All iliac variables were included in the logistic regression analysis and through the process of step-wise regression, those that were the least significant were eliminated (Table 22). Sciatic notch width was included in the final step of the analysis but was eliminated from the final equation as the significance was above .05 and that measurement is correlated to the sciatic notch score. The most statistically significant measurements for determining sex were the sciatic notch score, vertical diameter, and the presence or absence of a preauricular sulcus (Table 23). The formula for sex determination of the posterior ilium using logistic regression is

Log-odds= $A + B_1$(Sciatic Notch Score) + B_2(Vertical Diameter) + B_3(Preauricular Sulcus). This formula has proven to be the most accurate method of sex determination in this research with an accuracy rate for males and females of 95.1%.

Table 22. Variables in the Equation At Step 1 and Step 4

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	SNScore			15.397	4	.004	
	SNScore(1)	43.688	7179.506	.000	1	.995	9.409E18
	SNScore(2)	24.893	5538.433	.000	1	.996	6.469E10
	SNScore(3)	21.976	5538.433	.000	1	.997	3.502E9
	SNScore(4)	20.565	5538.433	.000	1	.997	8.538E8
	SNLength	-.016	.145	.013	1	.910	.984
	SNWidth	-.120	.095	1.587	1	.208	.887
	PAS(1)	-3.591	1.023	12.308	1	.000	.028
	AS			3.259	2	.196	
	AS(1)	-1.032	1.950	.280	1	.596	.356
	AS(2)	.458	1.963	.054	1	.816	1.580
	Vert.Diam	-.141	.090	2.443	1	.118	.868
	Constant	-5.539	5538.435	.000	1	.999	.004
Step 4[a]	SNScore			19.632	4	.001	
	SNScore(1)	44.548	7115.456	.000	1	.995	2.223E19
	SNScore(2)	24.620	5587.824	.000	1	.996	4.922E10
	SNScore(3)	22.013	5587.824	.000	1	.997	3.631E9
	SNScore(4)	20.097	5587.824	.000	1	.997	5.347E8
	SNWidth	-.141	.074	3.579	1	.059	.869
	PAS(1)	-4.128	.994	17.251	1	.000	.016
	Vert.Diam	-.167	.076	4.772	1	.029	.846
	Constant	-3.501	5587.825	.000	1	1.000	.030

Table 23. Variables in the Final Logistic Regression Equation

	B	S.E.	Wald	df	Sig.	Exp(B)
SNScore			19.072	4	.001	
SNScore(1)	42.012	7151.048	.000	1	.995	1.760E18
SNScore(2)	22.913	5608.381	.000	1	.997	8.931E9
SNScore(3)	20.599	5608.381	.000	1	.997	8.833E8
SNScore(4)	18.989	5608.381	.000	1	.997	1.766E8
Vert.Diam	-.239	.074	10.366	1	.001	.788
PAS(1)	-3.870	.894	18.750	1	.000	.021
Constant	-4.999	5608.383	.000	1	.999	.007

Discussion

Though morphological characteristics are cited as being faster to use than metric measurements, the degree of experience of the observer likely influences the results of these determinations more than metric measurements (Bruzek, 2002). To determine whether more objective methods of sex determination have higher accuracy rates and lower levels of error than the more subjective morphological methods, metric measurements of the traits of the posterior pelvis were also recorded and analyzed.

Reexamination of Standard Literature

The accuracy rates for sex determination using the posterior ilium ranged from 68.8%-95.1% (Table 24). Only two of the traits and combinations of measurements (the logistic regression equation and sciatic notch morphological score) had average accuracy rates of over 85% though the presence or absence of a preauricular sulcus proved to be 94% accurate for males in this sample (Table 24). Analysis of the morphological traits of the posterior ilium revealed that some were clearly more valuable than others in sex determination due to the accuracy levels and ease of use (Table 24). As single independent variables, morphological characteristics were more accurate than the metric measurements. In all of the morphological traits of the ilium, males were more likely to be classified correctly according to each trait individually than females (Table 24). In the binary categories of present or absent preauricular sulcus and raised or nonelevated auricular surface, females expressed the typically masculine traits more frequently than males expressed the feminine characteristics (Table 24).

Table 24. Classification accuracy for traits of the posterior pelvis

Rank	Measurement	Male	Female	Total
1	Logistic Regression Equation	97.1%	93.1%	95.1%
2	Sciatic Notch Morphological Score	91.3%	86.5%	88.9%
3	Auricular Surface Relief	83.7%	74.3%	78.9%
4	Preauricular Sulcus	94.2%	63.8%	78.9%
5	Sciatic Notch Metric	74.0%	75.5%	74.8%
6	Vertical Diameter of the Auricular Surface	68.6%	68.9%	68.8%

The levels of accuracy between males and females were especially disparate for the presence or absence of an auricular sulcus where the accuracy for males was 94.2% and only 63.8% for females (Table 24). The disparity between the accuracy levels for males and females in the classification table are likely because 94% of males lacked a preauricular sulcus indicating that this trait is linked to males while only roughly 64% of females exhibited an auricular sulcus which is the typically female trait (Table 24) (Bass, 1995; Buikstra & Ubelaker, 1994; Byers, 2002; Rogers & Saunders, 1994). Though it is likely that an individual with a preauricular sulcus is female, a lack of a sulcus does not necessarily indicate that the individual is male. Males that displayed a preauricular sulcus were all classified with a score of four, which is a wide but shallow sulcus that only extends along the posterior half of the sulcus (Table 15). In these males, the sulcus may have been due to specific activities they performed in life and more similar to the para-glenoid groove than an actual preauricular sulcus (Bruzek, 2002). This fact further increases the accuracy of sex determination of the sulcus as the six males of 104 that did exhibit a sulcus, only shallow, narrow, and short sulci were recorded. Though an individual that exhibits a sulcus could be male according to this research, individuals with a sulcus scored as 1, 2, or 3 were never male.

Almost 77% of males in this sample exhibited nonelevated auricular surfaces while 74% of females had a raised surface (Table 16). With the inclusion of the individuals expressing a surface raised only along the midline, the number of males with a raised surface increases by 6.7% while the number of females only increases by 2%. In the anthropological literature, a raised auricular surface is classified as a trait of the female ilium, and was found significantly more frequently in females in this sample though males were found to express this trait, as well (Bass, 1995; Byers, 2002; Rogers & Saunders, 1994; St. Hoyme, 1984). The accuracy rate of both males and females was 78.9% which is the same as that for the presence or absence of a preauricular sulcus (Table 24). There was much less variation between the percentages of males and females for this trait, however, indicating that this trait would likely prove more accurate on an unknown sample overall. The presence of a raised auricular surface is more likely to indicate female though the absence of the trait does not necessarily indicate a male individual, which is also similar to the findings for the preauricular sulcus. As the elevation of the auricular surface is difficult to assess without osteological experience, it is recommended that this be used in combination with a suite of other sexually dimorphic traits of the pelvis rather than as a singular indicator of sex.

Greater Sciatic Notch Morphological and Metric Analysis

The analysis of the greater sciatic notch scores in this research followed the standard anthropological literature in that males generally had narrow sciatic notches while females typically had wide, shallow notches (Bass, 1995; Bruzek, 2002; Buikstra & Ubelaker, 1994; Byers, 2002; Rogers & Saunders, 1994; Steyn et al., 2004; Walker, 2005). Anthropological references for the greater sciatic notch in sex determination often limit their classifications to wide, narrow, and intermediate and exclude definitions for what should be considered wide or narrow. This research sought to determine width morphologically using the five category scale of Walker (2005) and metrically using the measurements of the notch provided by Steyn et al. (2004). Differing from the work of Walker (2005), scores for males in this research ranged from two to five while those of females ranged from one to four. The results of Walker's (2005) research included 12 males out of a 165 total scored as one and 71 of 165 scored as two. Due to the degree of overlap of males and females in category two, Walker (2005) claimed that this was the intermediate or indeterminate rather than category three. The definition of category two as intermediate differs from both the findings of this research and the classification system of Buikstra & Ubelaker (1994) in which the indeterminate category was found to be three. An explanation for the disparity between the research of Walker (2005) and this and other research is inter-observer error. In Walker's (2005) method, inexperienced undergraduates along with experienced osteologists were asked to score the sample according to five diagrams of sciatic notches, one example for each score. Even those relatively experienced with human osteology could misuse the scale as the score of one—the widest and most feminine—appears to also be the largest in the scale, especially compared to the score of five, which is the narrowest and most masculine. As the sciatic notch of larger males tends to be more similar in size to the score of one in the standard rather than the smaller score of five, those inexperienced with using this standard may have misclassified males as females more often than they would misclassify females as males due to the size differences.

Walker (2005) also proposed that there is a relationship between age and sexual dimorphism as there was a trend for individuals of higher ages (approaching 50) to have narrower notches than younger individuals. This trend was not noted in the current data to the point of statistical significance, however. Population differences might account for the disparity between the scores of Walker (2005) and those of this research as a relationship between sciatic notch width and age has only been found in European samples and could be population specific.

In order to decrease the amount of subjectivity involved in morphological trait analysis, the metric measurements of the sciatic notch were recorded and analyzed to determine whether accuracy rates would improve if error rates were decreased. The ratio of the length and width of the notch was used to eliminate the variable of overall stature differences between males and females in order to examine differences in shape and depth. The ratios of the sciatic notch, however, proved to be less accurate for determining sex than the morphological scores. The accuracy rate for both males and females combined was approximately 75% which makes it a valuable tool when used in combination with other characteristics, though not accurate enough to be used alone (Table 24). The method for determining cut-off values for the sciatic notch ratio is listed in the results section, along with the value ranges for male, female, and indeterminate (Table 19). To use this method of sex determination, the length and width of the sciatic notch would first be measured and then the ratio would be computed by dividing the length by the width. Individuals that fall in the range of .69 or higher would likely be males and those that are

.59 or lower would likely be female. Individuals that fall between .68-.60 would be classified as indeterminate (Table 19).

Future research on the symmetry of the length of the anterior and posterior halves of the sciatic notch should be conducted, though it was not considered here. Of note is Bruzek's (2002) method of separating the notch into sections and comparing the symmetry of the sections. In this method, the width of the sciatic notch is bisected and the lengths of the anterior and posterior halves are compared. Males showed more asymmetry in the two portions while females tended to be more symmetrical (Bruzek, 2002). Asymmetry of the notch has also been noted by Steyn, et al. (2004) where the sciatic notch of males was more asymmetrical than that of females though further tests should be conducted as the sample in that research was only comprised of South Africans.

Logistic Regression Equations for the Posterior Ilium

The formula created using logistic regression incorporated three measurements of the posterior pelvis and was the most accurate method in this research for sex determination at 95.1% for both sexes (Table 24). The formula created for this research is:

Log-odds= A + B_1(Sciatic Notch Score) + B_2(Vertical Diameter) + B_3(Preauricular Sulcus Score)

where A is the constant and B values are the coefficients. The formula finds the log-odds value which is then used to determine the odds by taking the exponent of the log-odds. Sex determination is based on probabilities, however, and the odds value must then be used to determine the probability. This probability will always fall between zero and one and is a measure of how likely an event is to occur or not occur. The event in this analysis is actually sex set up as a binary with males scored as 0 (not occurring) and females scored as 1 (occurring) making probabilities above .5 more likely to be female and those below .5 to more likely be males. The strength of the probability of correct sex determinations increases as values approach zero and one.

As an example of the use of this formula, sample #54 was randomly selected. The values for this individual are:

Sciatic Notch Score: 4
Vertical Diameter: 65
Preauricular Sulcus Score: 0

The constant and coefficients used in this equation are based on the logistic regression output. For the sciatic notch score which lists a coefficient for four of the scores, the number included in the equation depends on the sciatic notch score for each individual. For the example below, the coefficient that corresponds to the score of four was used and the X value entered was one. As the logistic regression equation output for categorical values was determined with the highest score as the reference, there is no coeffiecient for individuals with scores of five for the sciatic notch and the equation for those individuals would have a zero for that variable. The actual sciatic notch score of the individual is not entered as the X value because the categorical values in the equations are based on the binary code of present or absent for each score. For the preauricular sulcus, there are only two categories, therefore there is only one coefficient used and the X value is based on the presence or absence of the sulcus for the individual.

The formula would follow as:

$$\text{Log-odds} = -4.999 + 18.989(1) + -.239(65) + -3.870(0)$$

Log-odds= -1.545

Odds= .21 (Found by taking the exponent of the log-odds value)

In order to determine whether an individual is male or female, a probability is required so the odds value must be changed to probability using the formula

Probability= odds/odds + 1.

The probability for this individual is .17 which means very likely male as the cut-off value for determining sex is .5. After it was determined that this individual was likely male, the demographic information was examined and Sample #54 is in fact male.

Ancestry and Sex Determination

The influence of ancestry on sex determination in this sample was determined by including each iliac trait and measurement with ancestry as an interaction term in a logistic regression. The significance levels for all traits and ancestry interactions were above p= .05. In addition, the chi distribution was calculated and found to statistically insignificant at p= .88. The accuracy rate for all iliac traits increased from only 96.5% to 97% when ancestry was included as an interaction term, as well.

Conclusions

In the determination of a biological profile, it is critical to include as many methods as possible for the available skeletal elements. This study, based on the William M. Bass and Terry Collections, has established the value of the posterior ilium in sex determination. Standard measures of the posterior ilium proved to be valuable in determining sex when used individually, such as the greater sciatic notch morphological score (88.9%) and presence or absence of an preauricular sulcus (78.9%). With a success rate of over 95%, the logistic regression formula has the potential to greatly assist the physical anthropologist in sex determination of an individual. Though the sciatic notch ratios only proved to be 74.8% accurate, further refinement of the measurements and technique could lead to higher levels of accuracy in the future. Future research on the asymmetry observed in the greater sciatic notch in this study will augment the accuracy and usefulness of this method in the process of sex determination.

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Chapter 4: CONCLUSION

Introduction

The goal of this research was to reexamine accuracy rates of standard morphological and metric traits of the posterior pelvis used to determine sex and to create formulas of multiple traits with logistic regression. The bones of the anterior pelvis are typically more accurate than those of the posterior pelvis in sex determination though their fragility may leave them unavailable for analysis due to postmortem trauma, taphonomic processes, or mishandling (Ali & Maclaughlin, 1991; Bass, 1995; Bruzek, 2002; Byers, 2002; Rogers & Saunders, 1994; Schwartz, 2007; Walker, 2005; White, 2000). In these instances, the more robust and durable bones of the posterior pelvis, especially the sacroiliac iliac region, can be used for accurate sex determination.

Discussion

Ultimately, methods that combine traits of both the ilium and sacrum were not created as the statistical analysis determined that high levels of correlation between measurements of the two bones created redundancy in equations without increasing accuracy. Overall, traits and measurements of the ilium were more accurate than those of the sacrum, though both proved to be useful in sex determination.

As part of the bony pelvis, there should be differences in the structure of the sacrum between males and females as females require a wider and larger pelvic inlet and outlet to accommodate the needs of childbirth (Flander, 1978, 1980). However, much of the differences between the male and female pelvis are found in the bones of the os coxa rather than the sacrum, due to the necessity of the sacrum's weight bearing capabilities (Ali & Maclaughlin, 1991). Significant differences, however, were noted between the male and female sacra in this research.

Differences between the male and female sacrum were found mainly in the superior portion of the bone and generally not below the level of S2 with the exception of the extent of the auricular surface. The most significant differences between males and females were found in the measurements of the superior surface of the sacrum, including the maximum transverse diameter of the base, the anterior superior breadth, and the width of the body of S1. The length measurements did not show statistically significant differences, though they were expected due to stature differences between males and females. The fact that the traits that are the most different between males and females were on the superior surface of the sacrum in the transverse plane indicates that the distinction between male and female sacra is one of overall width.

All recorded nonmetric traits of the posterior ilium exhibited statistically significant sexual dimorphism. Additionally, the means of the metric measurements were significantly different between males and females. Though there is a tendency for wider width in the female posterior ilium, especially in the sciatic notch, the differences between males and females have varied expression. The general tendency is for females to express certain traits such as an auricular sulcus or raised auricular surface while males lack these traits.

Separation of Iliac and Sacral Traits

Traits of the sacrum and ilium were not used in combination in a logistic regression equation because the traits of both showed high levels of correlation and, in general, the traits of the ilium were more accurate than those of the sacrum. As the posterior ilium and sacrum comprise the sacroiliac joint and region, they share size and shape characteristics which lead to high levels of correlation in statistical analysis. For example, the extent of the auricular surface of the sacrum and the vertical diameter of the iliac auricular surface were both recorded and the inclusion of both measurements in a single equation would not be beneficial as they are measuring the superior-inferior diameter of the sacroiliac joint in different ways. Traits of the posterior pelvis that do not directly articulate could still be highly correlated as the source for one could be the same for the both. The sciatic notch width and the width of the ala are not directly related, but both influence the overall width of the pelvis and can be expected to be highly correlated as those individuals with higher widths in one measurement would likely be high in the other, as well. Along with correlation of traits, spurious relationships could exist between variables. A spurious relationship is one in which two variables seem related but the relationship could actually be due to an unknown third variable that is not accounted for.

The iliac traits showed higher levels of accuracy than those of the sacrum; therefore using both sacral and iliac measurements in a single equation would likely decrease the accuracy levels. The iliac traits proved to be more useful as the whole os coxa is more sexually dimorphic than the sacrum. The differences between usefulness in sex determination of the bones of the pelvis are due to the position of the sacrum at the base of the spinal column and its role in locomotion and weight bearing and transfer compared to that of the os coxa. Though the pelvis is necessarily wider in females to accommodate childbirth, the shape and size differences are mainly in the os coxa as the sacrum is constrained by its function in locomotion and upright posture (Tague, 2007).

Accuracy Rates of all Measurements of the Posterior Pelvis

Of the five most accurate measurements or combination of measurements analyzed, four were traits of the posterior ilium while only one was based on measurements of the sacrum (Table 25). For both the ilium and sacrum, the most accurate methods were the logistic regression equation (Methods 1 & 5, Table 25). Methods one and five (Table 25) incorporate three separate and non-correlated measurements and morphological scores while the other methods consider only one measurement or an index of two measurements. The second, third, and fourth most accurate methods were all individual morphological classifications of the ilium (Table 25). Unlike the iliac equation (Method 1, Table 25), the sacral logistic regression equation (Method 5, Table 25) contains only metric measurements while that of the ilium is comprised of two morphological scores and a metric measurement. Previous research has also focused on metric measurements and indices of the sacrum as its unique anatomy and morphology does not provide for clear categories needed for a morphological categorization scale (Benazzi et al., 2009; Fawcett, 1938; Flander, 1978; Kimura, 1982; Stradalova, 1975; Tague, 2007). Also, differences between male and female sacra are mostly in size and shape rather than the presence of distinctive traits between males and females. Traits of the ilium such as the greater sciatic notch and the auricular surface differ not only in size but also in morphology and the expression of specific traits such as the preauricular sulcus and the elevation of the auricular surface. This fact makes the analysis of single traits of the ilium and the other bones of the os coxa useful in sex determination, even when considered in isolation (Methods 2, 3, and 4, Table 25). A combination of traits is typically the most accurate method, however, as variation exists within the sexes (Methods 1 & 5, Table 25).

Table 25. Classification accuracy for traits of the posterior pelvis

Rank	Measurement	Male	Female	Total
1	Ilium Logistic Regression Equation	97.1%	93.1%	95.1%
2	Sciatic Notch Morphological Score	91.3%	86.5%	88.9%
3	Auricular Surface Relief	83.7%	74.3%	78.9%
4	Preauricular Sulcus	94.2%	63.8%	78.9%
5	Sacrum Logistic Regression Equation	74.4%	77.9%	76.2%
6	Sciatic Notch Metric	74.0%	75.5%	74.8%
7	AL:ASB, Ala: MTDB & MTDB:S1	71.7%	75.0%	73.4%
8	Ala: MTDB	69.4%	72.5%	71.0%
9	MTDB:S1	67.3%	72.0%	69.7%
10	Maximum Transverse Diameter of the Base	70.7%	67.3%	69.0%
11	Vertical Diameter of the Auricular Surface	68.6%	68.9%	68.8%
12	Extent of the Auricular Surface	77.5%	38.8%	58.0%

Reliability

The precision (replicability) of the recorded measurements was determined to assess the repeatability of these methods without regard to accuracy. To assess the precision of the measurements taken, ten individuals from the sample at each collection were randomly selected on the last day of data collection and measured a second time. The correlation of the set of measurements for each individual was then determined (Table 26). Despite the supposed subjectivity of using morphological traits of the posterior pelvis in sex determination, this research has found high levels of correlation between the first and second scoring of the nonmetric triats recorded. Morphological traits that did not show differences between the original scoring and the second round of scoring include the sacral segment number, the extent of the sacral auricular surface, the presence or absence of a preauricular sulcus, and the score of those individuals exhibiting a preauricular sulcus. Previous research has attempted to quantitatively define sex differences of the posterior pelvis, especially the sciatic notch, though these methods have not attained widespread use (Kelley 1979, MacLaughlin & Bruce, 1986; Walker, 2005). The lack of quantitative methods for sex determination of the posterior pelvis has been explained by a lack of easily located anatomical landmarks in the area (Walker, 2005). Using standard measurements from Buikstra & Ubelaker's *Standards* (1994) and the greater sciatic notch landmarks of Steyn et al. (2004), this research has attained high levels of precision of measurements. Excluding the ala width, which attained a correlation value of .945, all metric measurements included in the analysis had correlation coefficient values above .95 (Table 26). The measurements used in the sacral logistic regression equation (Method 5, Table 25) which include anterior superior breadth, maximum transverse diameter of the base, and length of S1, had high levels of correlation between the two measurements taken at .975, .988, and .994, respectively (Table 26). The morphological and metric measurements of the iliac logistic regression (Method 1, Table 25) which include the sciatic notch score, vertical diameter, and presence or absence of a preauricular sulcus, similarly showed high levels of precision with .97, .988, and 1.0 correlation between the first and second measurements (Table 26).

Table 26. Correlation coefficients of reliability test

Measurement	Pearson Correlation
Sciatic Notch Length	.992
Sciatic Notch Width	.992
Sciatic Notch Ratio	.982
Vertical Diameter	.988
Anterior Length	.998
Anterior Superior Breadth	.975
Maximum Transverse Diameter of the Base	.988
Ala Width	.945
Width S1	.983
Length S1	.994
Width S1	.988
Sciatic Notch Score	.97 (Spearman Correlation)

Limitations & Implications

One limitation of this research is also found in most anthropological studies. As this sample is comprised of only African- and European American individuals, it may not possible to assume that the findings of this research will apply to other populations. Associations between ancestry and sex were tested for within this sample and proved to be statistically insignificant, however. Though it is possible that other populations might show variations in accuracy levels, this research indicates that an individual's ancestry does not significantly influence sex determination.

The type of measurements used in sex determination can also influence the accuracy levels. The rapidity of the use of the morphological analysis and the ability to visually classify traits when skeletal elements are damaged and complete measurements cannot be made necessitate their use in osteological analyses (Bruzek, 2002; Rogers & Saunders, 1994). The anatomy of the posterior pelvis also makes metric measurements difficult as standard landmarks are difficult to describe and accurately reproduce (Rogers & Saunders, 1994). The degree of subjectivity involved when using morphological traits is higher than that of metric measurements and can lead to higher levels of both inter- and intra-observer error (Rogers & Saunders, 1994). This research has proven that morphological traits such as the greater sciatic notch, auricular surface relief, and preauricular sulcus are very accurate and precise (Tables 25 & 26). Metric measurements taken from carefully located and measured anatomical landmarks also proved to be both accurate and precise (Tables 25 & 26). As with most measurements, metric and morphological, more experience will likely lead to lower levels of intra-observer error.

Conclusions

For sex determination in the process of building a biological profile, it is critical to include as many methods as possible in the analysis for the skeletal elements that are available. Though the bones of the anterior pelvis are more accurate in sex determination, their fragility leads to instances where they are not available for analysis. In these instances, the more robust and durable bones of the posterior pelvis may still be undamaged and functional for sex determination. This study, based on the William M. Bass and Terry Collections, has established the value of the posterior pelvis in skeletal sex determination. With success rates of over 79% and 95%, the logistic regression formulae of the sacrum and ilium have the potential to be valuable and accurate in the determination of sex of an individual (Table 25). Previous research has indicated that using the sacrum in sex determination is risky, though aspects of the sacrum have proven to be significantly different between males and females in this research (El Najjar & McWilliams, 1978). The anatomy of the sacrum and constraint of the necessities of bipedality decreases the usefulness of the sacrum in sex determination though in instances where the sacrum is one of the few bones available for analysis, it can prove valuable. Standard measures of sex of the posterior ilium proved to be valuable in determining sex when used individually such as the greater sciatic notch morphological score (88.9% accuracy) and presence or absence of an auricular surface (78.9% accuracy) (Table 25). Further research into the variation observed in this study will serve to increase the accuracy of the proposed methods and augment their potential for sex determination in the process of building a biological profile.

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