"Sex Estimation Using the Calcaneus in a Modern American Skeletal Population"

An Honors Thesis

by

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Abstract

One of the most important aspects of the analysis and identification of human skeletal remains is determination of the biological profile, which consists of the age, sex, ancestry, and stature of an individual. Typically, anthropologists analyze the pubic bone in adult human skeletal remains, which is highly sexually dimorphic due to a female's capacity for childbirth. However, when these fragile bones are broken, damaged, or altogether missing, it is necessary to look to other areas of the skeleton for sex information. DiMichele and Spradley (2012) developed a method of sex estimation using four measurements of the calcaneus. For this project, this method was tested using the left calcanei of modern American skeletal remains from the Texas State University Donated Skeletal Collection (TXSTDSC). This skeletal sample consists of 264 individuals (151 males, 113 females) with an average age-at-death of 65.2 years, 91.3% of whom are classified as white. The sectioning points for individual measurements were able to accurately estimate sex for 76.7–80.9% of this skeletal sample. Univariate and multivariate equations provided classification rates ranging from 77.4% to 89.6%. The results of this study further validate that the calcaneus is sexually dimorphic and can be used to estimate sex in a modern American skeletal sample.

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INTRODUCTION

An accurate estimation of sex is the foundation of the biological profile. It is undeniably useful in archaeological studies and essential in identifying human remains in a forensic context. Additionally, many of the methodologies for estimating age, ancestry, and stature are also dependent upon an accurate estimation of sex. An anthropologist will usually look at the skull and the pelvis (or os coxae) for sex estimation. The morphological features of the pelvis are highly sexually dimorphic due to a female's capacity for childbirth. The skull does typically show some sexual dimorphism, though it can vary between different populations. Nonetheless, it is commonly a source of sex information for anthropologists.

Several scenarios may preclude use of standard methods of sex estimation. Fragmentary, damaged, commingled, or otherwise incomplete human skeletal remains often pose a challenge to anthropologists. Without complete and well-preserved os coxae, other methods of sex estimation must be used. It is quite common to be faced with this issue when dealing with archaeological remains, and though the absence of complete and observable os coxae is less common in forensic cases, the phenomenon is still important for any biological anthropologist to consider.

DNA analysis of skeletal remains can provide accurate determinations of sex, but may not always be a viable option. This method can be costly and time-consuming. Further, destructive analyses may not be permitted when working with archaeological remains, and DNA samples could be contaminated. Therefore, it is necessary to study alternative methods of sex estimation.

Spradley and Jantz (2011) have disproven the once-common belief that the cranium is second best in providing accurate estimations of sex, leading to a shift in anthropological research focusing on metric sex estimation with the postcranial skeleton. This project focuses on a technique used to estimate sex from adult human skeletal remains using the calcaneus (heel bone; DiMichele & Spradley, 2012). This method was tested on modern American skeletal remains from the Texas State University Donated Skeletal Collection (TXSTDSC) to determine the efficacy of this bone to estimate sex with a variety of statistical methods including use of sectioning points, univariate, and multivariate equations.

BACKGROUND

Anthropologists analyze the skull or pelvis in adult human skeletal remains. However, when these fragile bones are broken, damaged, or altogether missing, it is necessary to look to other areas of the skeleton for sex information.

Metric Methods of Postcranial Sex Estimation

Though established biological anthropologist Bill Bass once stated that "the skull is probably the second-best area of the skeleton to use for determining sex," (Bass, 2005, p. 81) Spradley and Jantz (2011) have disproven this idea with an in-depth study focusing on many postcranial skeletal elements' ability to estimate sex. In this study, standard cranial, mandibular, and postcranial measurements (Moore-Jansen, Ousley, & Jantz, 1994) from 704 skulls and 639 postcranial skeletons (reported separately because not all individuals were represented by both a skull and postcranial skeleton) recorded in the Forensic Data Bank were used to estimate sex with univariate and multivariate methods. They found that many metrics including the humerus, radius, clavicle, femur, ulna, and tibia outperformed sex estimation with the skull.

Further, many other works have demonstrated high accuracy rates using univariate or multivariate equations, sectioning points, or other metric methods to estimate sex from vertebrae, long bones, and other elements of the postcranial skeleton for use in the absence of the os coxae (Albanese, 2013; Bethard, & Seet, 2013; Holland, 1991; King, Işcan, & Loth, 1998; Marino, 1995; Marlow, & Pastor, 2011; Safont, Malgosa, & Subira, 2000; Šlaus, & Tomčič, 2005; Steyn, & Işcan, 1999; Tise, Spradley, & Anderson, 2013; Wescott, 2000).

Sex Estimation with Foot Bones

Many researchers have explored the use of foot bones to estimate sex in skeletal remains. Several studies show that other foot bones such as the navicular, talus, and calcaneus are sexually dimorphic.

Salidas, Malgosa, Jordana, and Isidro (2016) tested the navicular bone (one of the tarsals in the mid-foot) for its use to estimate sex in contemporary Spanish individuals. They analyzed the naviculars of 231 individuals from several university skeletal collections in Spain. Eight variables were measured, and it was reported that all measurements showed significant sexual dimorphism. Binary logistic equations were created to estimate sex with these measurements and it was found that maximum width and maximum length of the talar facet; maximum width and maximum length of the cuneiform surface provided the most accurate results. Overall high classification rates were shown for all of the equations used to estimate sex, indicating that the navicular can be used for sex estimation (Salidas, Malgosa, Jordana, & Isidro, 2016).

A 2003 study by Bidmos and Dayal looked at sex estimation using the talus of South African whites. They looked at 9 measurements of 120 individuals and created univariate and stepwise discriminant functions to estimate sex. They found that talus length gave the highest univariate classification rate (81.7%), and height of the head of the talus performed very poorly with a classification rate of 57.5%. The discriminant functions provided accuracy rates between 77.5% and 87.5% (Bidmos & Dayal, 2003).

Barrett, Cavallari, and Sciulli (2001) studied the talus in prehistoric Native American skeletal remains from a variety of archaeological sites in the Ohio Valley region. The "correct" sex was estimated using the os coxae and then compared with talar measurements. Length, width, and height of the talus were measured for 74 males and 68 females. Each of the measurements was found to be significantly sexually dimorphic. Using discriminant function analysis with all three variables, the authors found an overall classification rate of 84.5%. The authors also observed talus "volume" by multiplying the length, width, and height variables. This volume measurement was the least sexually dimorphic, but had similar discriminating abilities. This indicates that while the differences of volume between males and females are small, they are consistent. All three measurements and " volume" were sexually dimorphic and show promise for sex estimation using the talus (Barrett, Cavallari, & Sciulli, 2001).

Lee et. al (2012) tested the talus in Koreans for its use in sex estimation. Data was collected from a total of 140 individuals from skeletal collections at Yonsei University and The Catholic University of Korea. They used nine measurements seen in previous studies and found similar sexual dimorphism in the talus. Univariate, multivariate, and stepwise discriminant function equations were created to estimate sex. They achieved accuracy rates between 67.1% and 87.1%. In addition to their own mathematical methods, they compared their data to equations from another study and found that they were not as accurate, supporting the idea that this is a population specific method (Lee, et al. 2012).

A 2014 study by Mahakkanukrauh et al. looked at the talus of Thai individuals from the Chiang Mai University Skeletal Collection. Ten measurements of the talus were taken for 252 individuals (126 males and 126 females). The authors developed logistic regression equations using the talar measurements and were able to estimate sex with accuracy rates between 84.5% and 88.2%. They also found that trochlear breadth and trochlear length were the most sexually dimorphic of their measurements (Mahakkanukrauh, et al., 2014).

Calcaneus

Steele (1976) was among the first researchers to use the talus and calcaneus for sex estimation. He took 5 measurements for each left talus and calcaneus from 120 individuals from the Terry Anatomical Skeletal Collection at the Smithsonian. This collection consists of white and black Americans who died during or before the 1930s. Discriminant functions from the data resulted in sexing accuracy rates ranging from 79% to 89%. However, Steele questioned whether these discriminant functions would be accurate for more modern Americans, or if temporal changes would affect the use of these bones for sex estimation. It was also found that the discriminant functions are accurate with other ancestral groups, though sectioning points needed to be altered for better results.

Introna et. al (1996) recreated the study done by Steele, focusing just on the calcaneus but adding three more measurements. They studied 80 Southern Italian individuals from skeletal collections at the University of Bari. Their univariate and multivariate discriminant function equations both provided high accuracy rates with up to 85% correct classifications. Additionally, data from the Italian skeletal sample were tested with the equations developed by Steele, but were less accurate for estimating sex. This stresses the need for population specific information and using equations developed from the population of the individual being sexed.

DiMichele and Spradley (2012) analyzed the calcanei in 320 modern American individuals from the Bass Donated Skeletal Collection housed at the University of Tennessee Knoxville. They looked at four measurements: MXL, LAL, LAW, and PCF (defined below in Table 2.3). Sectioning points were developed by taking the weighted average between males and females for each measurement. Additionally, a discriminant function multivariate equation was created to estimate sex. Approximately 16% of the skeletal sample used in this study was non-white, with the remaining 84% of individuals classified as white. Tests for correlations between measurements and ancestry did show some significant trends, but it was determined that the calcaneus is not a good estimator of ancestry. The authors also argue that if the calcaneus is being used for sex estimation, it's likely one of the most complete bones available for analysis. Thus, an estimation of ancestry may not be prioritized (DiMichele & Spradley, 2012)

The sectioning points resulted in classification rates ranging from 80.08 % to 88.10%, and the discriminant function equation was found to correctly assess sex for 88.64% of females and 84.75% of males. It is pointed out that though Spradley and Jantz (2011) found that there were no differences in estimating sex with the calcaneus for American whites and blacks, there may be differences among other populations.

Many other studies have also found similar results demonstrating that the calcaneus is useful for sex estimation (Murphy, 2002; Peckmann, Orr, Meek, & Manolis, 2015; Bidmos & Asala, 2004).

MATERIALS AND METHODS

Skeletal Sample

The Texas State Donated Skeletal Collection (TXSTDSC) is a documented skeletal collection consisting of individuals who lived and died in the 21st century. Donated bodies are first used in studies of human decomposition, and the skeletal remains are later curated into the skeletal collection. Most of the donations are individuals from the state of Texas, but bodies are accepted from all over the United States and around the world.

A total of 264 adult individuals (113 females, 151 males) from the TXSTDSC were used for this study. These individuals range in age from 18 to 102 with a mean age of 65 years.

Table 2.1 – Skeletal sample age and sex information

Age	18-34	35-49	50-64	65+	Total
Males	10	8	55	78	151
Females	4	9	35	65	113
Total	14	17	90	143	264

Of the 264 individuals studied, 241 were classified as white, 9 as black, 11 as Hispanic, and 3 as "other" (Table 2.2). Because of the small amount of non-white individuals represented in the sample, all individuals were pooled and ancestry was not used as a factor in this study. Additionally, as DiMichele and Spradley (2012) found that the calcaneus is not a good estimator of ancestry. If the calcaneus is being used for sex estimation, it is likely because it is one of the most complete bones, and an estimation of ancestry may not be prioritized. No further tests for associations between race and sex were performed.

Table 2.2 – Skeletal sample race information

Race	Black	Hispanic	White	Other
Count	9	11	241	3
Percent	3.41%	4.17%	91.29%	1.14%

Methods and Measurements

Left calcanei were measured for the purpose of consistency, and the right calcaneus was used for individuals whose left calcaneus was missing. Any calcanei which were too damaged or appeared to have any pathological conditions were excluded from this study. Further, if the left calcaneus was excluded due to pathology or damage, the right side was not used as a replacement since the issue was typically reflected on both left and right calcanei in the same individual.

Measurements for length and width were taken using Mitutoyo Absolute digital sliding calipers and measured to the nearest .01mm. Circumference measurements were taken using a retractable fabric tape measure and rounded to the nearest 0.1cm. The project investigator was kept blind regarding age and sex until after measurements were taken.

Measurements taken include maximum length (MXL; Buikstra & Ubelaker, 1994), load arm length (LAL; Steele, 1976), load arm width (LAW; Buikstra & Ubelaker, 1994; Steele, 1976), and posterior circumference (PCF; DiMichele & Spradley, 2012), as shown in Figure 2.1 and Table 2.3.

Figure 2.1 – Calcaneus measurements

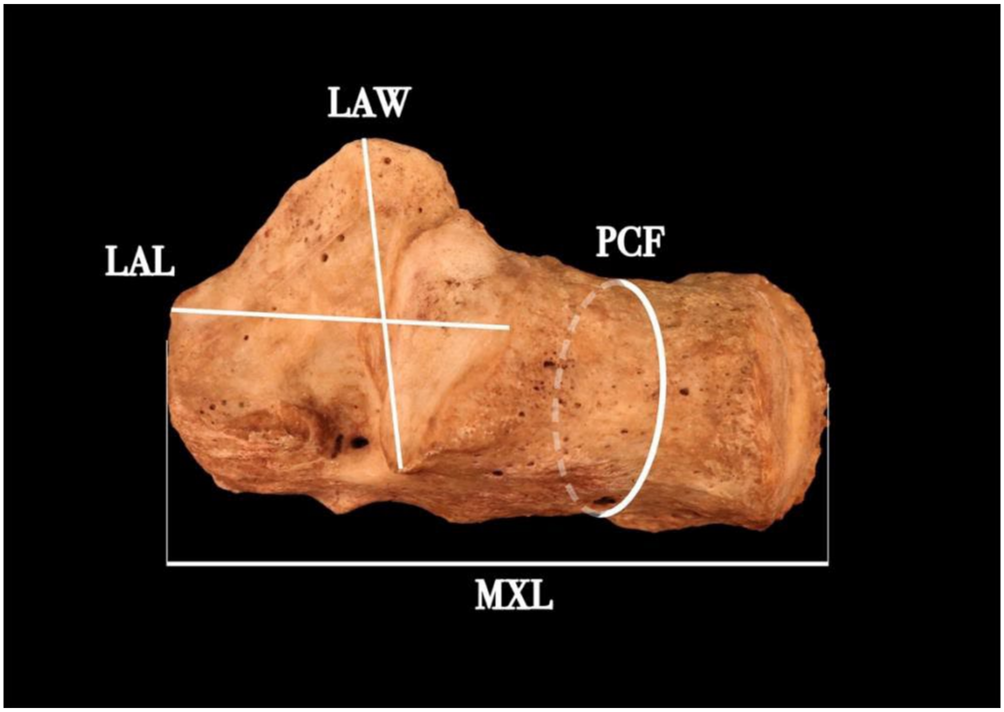

Table 2.3 – Measurement definitions

Measurements	Adapted From	Definition
Maximum Length (MXL)	Buikstra & Ubelaker, 1994	Distance between the most projecting point on the tuberosity and the most anterior point on the superior margin of the articular facet for the cuboid measured in the sagittal plane and projected onto the underlying surface.
Load Arm Length (LAL)	Steele, 1976	Defined as the projected line from the most posterior point of the dorsal articular facet, to the most anterior/superior point of the cuboidal facet
Load Arm Width (LAW)	Buikstra & Ubelaker, 1994; Steele, 1976	Distance between the most laterally projecting point on the dorsal articular facet and the most medial point on the sustentaculum tali
Posterior Circumference (PCF)	DiMichele & Spradley, 2012	Defined as the minimum circumference of the area between the posterior point of the dorsal articular facet and most posterior point of the calcaneus.

Posterior circumference (PCF) was the only measurement which had not been used multiple times in prior studies. Therefore, DiMichele and Spradley (2012) provide additional explanation for this metric:

> "To properly take this measurement, lay measuring tape flat against the surface of the bone. Pass the measuring tape around anteriorly to the inner and outer tuberosity of the calcaneus. Avoid projecting heel spurs located on the inferior surface of the calcaneus by laying the measuring tape beneath them. In certain cases, calcaneal tuberosities have been seen to be located at a more anterior position, in which case it may be appropriate to measure on the posterior side of the tuberosity, avoiding the feature, in order to properly obtain the minimum circumference." (DiMichele & Spradley, 2012, p. 2)

Additionally, cadaver stature (CS), defined as the maximum length of a cadaver from the base of the heel to the top of the head, was used in some analyses.

Statistical Analyses

Inter- and Intraobserver Error

A sample of 23 individuals were measured in two separate trials by the author several days apart, and once by an experienced observer to test for inter- and intraobserver error.

Sex Estimation

Data collected from the TXSTDSC were used to estimate sex with the sectioning points determined by DiMichele and Spradley (2012). Additionally, sectioning points were derived from this skeletal sample by taking the weighted average between males and females for each measurement. If a measurement is below the sectioning point, the individual is estimated to be a female; if the measurement is over the sectioning point, the individual is estimated to be a male. Pearson's correlation coefficients were calculated in Statistical Analysis Software (SAS) v. 9.04 (SAS Institute Inc., Cary, NC, USA) to observe the correlations between each measurement, sex, and cadaver stature.

All four measurements were used to create univariate functions for estimating sex and a multivariate equation was created using all four variables. The sex variable was coded as males=1; females=0 to calculate the mathematical equations, and 0.5 was used as a sectioning point for estimating sex. If the result of the equations is more than 0.5, they are estimated to be a male; if the result is less than 0.5, they are estimated to be a female.

RESULTS

Inter- and Intraobserver Error

Tests for inter- and intraobserver error show that these measurements are replicable (Table 3.1). Interobserver error (2.11%) was overall higher than intraobserver error (0.86%) indicating that different individuals may take measurements slightly differently. However, intraobserver error was very low, making it very easy to replicate results with the same observer. In both scenarios, load arm length (LAL) had the highest error rates, indicating that this measurement is less reliable than the others. In different individuals, the most anterior/superior point of the cuboidal facet (a surface of the bone which contains a measurement landmark) can vary in its location, which may have led to the differences in measurements. A better-defined metric may clarify the issue to provide for lower error rates in the future.

Table 3.1 – Error rates

	MXL	LAL	LAW	PCF	Average
Intraobserver	0.36	1.51	1.06	0.52	0.86
Interobserver	2.23	3.65	1.32	1.24	2.11

Sex Estimation

The means and standard deviation for each measurement for males and females are shown in Table 3.2.

Table 3.2 - Simple statistics

	Males			Females		
Var	N	Mean	SD	N	Mean	SD
MXL	148	87.55	4.83	109	80.21	4.31
LAL	148	54.87	3.17	108	49.68	2.90
LAW	146	44.85	2.66	111	40.42	2.33
PCF	150	113.8	7.3	112	102.0	6.3

Sectioning points developed for the current study were found to be close to those of the study done by DiMichele and Spradley (2012), who also looked at modern American individuals. Both the sectioning points from this study and those created by DiMichele and Spradley (2012) provided high accuracy rates for sex estimation (Table 3.3).

Table 3.3 – Sectioning points and accuracy rates

	MXL	LAL	LAW	PCF
Sectioning points from present study	83.9	52.3	42.6	10.8
Pooled accuracy rates	78.2	79.3	80.5	80.2
Sectioning points from DiMichele & Spradley (2012)	83.8	51.6	42.0	11.0
Pooled accuracy rates	78.2	80.9	79.8	76.7

The Pearson correlation coefficients showed statistically significant correlations between sex and each measurement. Additionally, cadaver stature also showed high correlations with each of the measurements, indicating that calcaneal measurements may be more closely associated with stature than with sex.

Table 3.4 – Pearson correlation coefficients

	Sex	MXL	LAL	LAW	PCF	CS
Sex	1.00	0.62	0.64	0.66	0.65	0.72
MXL		1.00	0.84	0.74	0.68	0.77
LAL			1.00	0.74	0.72	0.70
LAW				1.00	0.74	0.71
PCF					1.00	0.67
CS						1.00

Each of the univariate equations provided high classifications for sex estimation, ranging from 77.43% to 80.86%. All four equations classified males correctly more often than females, meaning females were misclassified more often. This could be due to the sample size and the ratio of males to females (approximately 4:3). With sectioning points set at 0.5, it is assumed that there is an equal likelihood of an individual being a male or a female. However, this is not the case with the skeletal sample used in this study.

The multivariate equation was also able to classify sex with high accuracy, and with similar results for males and females.

Table 3.5 – Univariate and multivariate equations and accuracy rates

	l	2	3	4	5
MXL	0.0523				-0.0067
LAL		-0.0798			-0.0263
LAW			-0.0976		-0.0356
PCF				-0.0356	-0.0144
Constant	-3.8405	4.6278	4.6230	4.2980	5.4653
Sectioning point	0.5	0.5	0.5	0.5	0.5
Males classified correctly (%)	81.76	85.14	83.56	86.67	90.28
Females classified correctly (%)	71.56	75.00	76.58	72.32	88.68
Total classified correctly (%)	77.43	80.86	80.54	80.53	89.60

DISCUSSION

Despite low error rates, some clarification on the LAW and LAL measurements may help inexperienced observers. Because it can be difficult to hold a single calcaneus in exact anatomical position when in isolation, the exact points from which to measure are not always clear.

The present project had very similar results to the study done by DiMichele and Spradley (2012), with high accuracy rates and similar sectioning points. However, as shown in other studies (Lee et. al, 2012; Bethard & Seet, 2013), metric methods of sex estimation tend to be population specific. While these sectioning points are accurate for majority-white American skeletal populations, they may not be accurate for individuals of other ancestral groups or from different geographic regions. In the contexts of American forensic anthropology, future studies should look toward developing standards for other demographics commonly found in the United States.

The univariate equations also provided high overall accuracy rates. Since those and the sectioning points only require one simple measurement, these are the preferred methods compared to using a multivariate equation. While the calcaneus may often be present in archaeological settings (Waldron, 1987), it may also be damaged or broken, making it more difficult to get all four measurements needed for a multivariate equation.

CONCLUSION

This study validates the findings of DiMichele and Spradley (2012), and demonstrates that the calcaneus is sexually dimorphic and produces high classifications for sex estimation in a modern American skeletal population.

Like many authors have done in the past, future studies could focus on more measurements of the calcaneus to determine which metric(s) are the most useful in estimating sex regardless of ancestry or for different ancestral groups/populations. Additionally, it may be useful to look into what causes the misclassifications of sex. Differences in calcaneal metrics could be caused by a variety of factors including body weight, lifestyle, whether an individual overpronates or oversupinates, or has had a foot injury. Further, more advanced techniques may be necessary to determine what can affect sex estimation with the calcaneus.

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