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The Efficacy of Carpal Bones in Sex Estimation of American Whites

Ashleigh Watson
University of Tennessee, Knoxville, awatso28@vols.utk.edu

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The University of Tennessee
College of Arts and Sciences
Department of Anthropology

Thesis Advisor: Dr. Amy Mundorff

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INTRODUCTION

The sex of human skeletal remains is a salient aspect of forensic anthropology and bioarchaeology. Estimating sex of skeletal remains can provide researchers with insight into biological and cultural aspects of past populations as well as aid in forensic investigations (Murail et al. 1999). In the bioarchaeological context, knowing the sex allows for a better understanding of the cultures, burial practices, and demography of past populations. In forensics, accurately identifying a skeleton's sex can significantly increase the chances of identifying an unknown victim (Burns 2007).

Typically, the most accurate sex estimations come from the pelvis and cranial elements, but these bones are not always present in skeletal deposits (Murail et al. 1999). If a full skeleton is present, estimating the sex can be done fairly accurately with the pelvis and cranium. Unfortunately, certain disasters, events, and variation in bone preservation result in fragmented skeletons (Murail et al. 1999). Therefore, it is essential to develop adequate methods to sex skeletons from fragments (Kelly 1979). Recently, research studies have found hand and foot bones useful in determining sex specifically with tarsals, metatarsals, and metacarpals (Manolis et al. 2009, Gualdi-Russo 2007, and Murphy 2002).

This study looks at the possible variation between the sexes in the carpal bones by logistic regression analysis in a contemporary American sample of self- or family-reported whites (will now be referred to as "reported whites"). As standard protocol, forensic anthropologists develop population specific standards for sex estimation based on osteological measurements. This is done in case ancestry affects the outcome. This study uses the works of Sulzmann et al. (2008) and Mastrangelo et al. (2011) as models in an attempt to either confirm or refute their findings. While their research found the use of carpal bones in sex estimation to be sufficient, it is not yet certain whether this is true for a contemporary American sample of reported whites.

BACKGROUND

Sexual dimorphism of the human skeleton results from the difference in hormone levels between males and females (Mays 1998). These observable or measurable differences are quite significant to researchers. Knowing the sex of certain skeletal remains allows for a better interpretation of past populations in the biological and cultural sense. For example, Benjamin Auerbach and Christopher Ruff (2010) studied methods for estimating the stature in indigenous North American groups from skeletal remains in the archaeological record. Before the researchers began making the measurements for stature, the sex of each individual was determined using the accepted methods based on the cranial elements and pelvis. Accurately knowing the sex of their specimens was important and therefore, individuals that could not be sexed were excluded from study.

Estimating the sex can also give us a better understanding of past populations' burial practices and demography (Murail et al. 1999). Ross Jamieson (1995) claims that to adequately understand African American burial practices within the plantation slavery context, sex must be considered. The author states that sex would have greatly affected the amount of knowledge individuals would have had on traditional burial practices, e.g., some secret societies where these practices were shared was exclusive to males.

In anthropology, the determination of sex is thought to be population specific, i.e., the methods obtained from one population may not usable in another population (Murail et al. 1999). The extent of sexual dimorphism and the general robusticity/gracility vary from population to population (Rosing et al. 2005). This variation is the result of differences in diet, diseases, labor distribution, available technology, socioeconomic status, and population mobility (Burns 2007). Barrio et al. (2006) claims that due to the variations in body size from population to population, it is necessary to develop regression equations for each population. As previously mentioned, this study will use logistic regression analysis to determine the utility of carpal bones for sex estimation in a modern American sample.

Through ample amounts of research, it has been widely accepted that the human pelvis provides tremendously accurate sex estimations (Washburn (1948), Wilson et al. (2008), and Waldron 1987)). But according to Murail et al. (1999), it is common for the pelvis, especially the pubis, to disintegrate before the rest of the skeleton. Waldron (1987) states that pubic preservation rarely exceeds thirty percent. When the pelvis is not usable, most researchers turn to the cranial elements for sex diagnosis, but these elements are also extremely fragile and are therefore usually found broken (Murail et al. 1999). This fragmentation of skeletal remains requires methods of sexing skeletons using elements other than the pelvis and cranium. Recent studies have explored sex diagnosis using the hand and foot bones. These bones are compact and frequently found intact in the recovery of skeletal remains (Sulzmann et al. 2008). The talus and calcaneus (Gualdi-Russo (2007), Murphy (2002)) and metatarsals (Robling and Ubleaker (1997), Mountrakis et al. (2010)) have been found useful in sex determination in various populations. Barrio et al. (2006), Falsetti (1995), Manolis et al. (2008), and Smith (1996) researched the use of metacarpals in sex estimation. But the carpals have received less attention and only two different researchers have studied their utility for sex estimation.

Originally, visual methods of determining sex were used, but then researchers desired quantitative methods to make the data more "scientific" (Calcagno 1980). Therefore, discriminant function analysis became a commonly used method by researchers when developing methods of estimating sex (Manolis et al. (2009), Gualdi-Russo (2007), and King et al. (1998)). While this is the method used by both Sulzmann et al. (2008) and Mastrangelo et al. (2011), this study will actually use logistic regression. Poulsen and French (2008) state that logistic regression essentially addresses the same research questions as discriminant functions but is actually preferred by many due to its flexibility and requirements. It is also able to analyze data that is not normally distributed, which was necessary for this study (Poulsen and French 2008). Using logistic regression will also aid in confirming and strengthening the results of Sulzmann et al. (2008) and Mastrangelo et al. (2011) because Shah et al. (2015) found that this method had a higher average percent accuracy than discriminant function analysis (5).

The research of Sulzmann et al. (2008) was one of the first published works on the use of carpal bones in the estimation of sex using discriminant function analysis. The sample used for this study is located at the Natural History Museum in London, UK. A detailed description is given of how four to nine measurements were taken of each bone. The number of measurements varied due to the specific morphology of each bone. The chosen measurements aimed to give an idea of the general size of the bone. In this study, asymmetry was found between the left and right carpals. However, this study did not test inter- and intra-observer error. The osteometric data and discriminant function analysis showed that sexual dimorphism did exist in the carpals, and therefore would be useful in sex estimations. The pisiform was found to be the least sexually dimorphic. Through univariate discriminant function analysis, it was determined that the width of the hamate was the most sexually dimorphic. Both univariate and stepwise discriminant functions for carpals were between 64.6 and 88.6 percent effective in assigning the bone to one of the sex groups. Sulzmann et al. (2008) call for the application of discriminant functions to other populations as the results are population specific.

Mastrangelo et al. (2011) also studied the use of carpal bones in sex assessment by discriminant function analysis in a contemporary Mexican sample and 20th century Spanish sample. Following Sulzmann et al. (2008), between four and nine measurements were taken for each carpal bone. Both studies accounted for inter- and intra-observer error as well as possible asymmetry between carpals. The inter- and intra-observer error was found to be insignificant. Inconsistent with the findings of Sulzmann et al. (2008), no asymmetry among the carpals was found in either of Manstrangelo et al.'s (2011) samples. For both the 20th century Spanish and modern Mexican sample, osteometric measurements were found to be accurate methods of estimating the sex of skeletal remains. The results showed that male carpals are generally larger than female carpals. In the contemporary Mexican Sample, the stepwise discriminant function analysis showed the scaphoid to give the highest accuracy (92.3%) in estimating sex. For the 20th century Spanish sample, he found the lunate to be the most sexually dimorphic. Mastrangelo et al. (2011) also suggest that the study of sex estimation in carpal bones should be performed in more populations in order to create new discriminant functions for other populations.

HYPOTHESIS

This study tests the null hypothesis of no variation in all carpal bones between males and females in reported whites from the William M. Bass Collection.

Materials and Methods

Sample

The skeletal remains for this study were selected from the William M. Bass Collection that was established in 1981 and is located at the Forensic Anthropology Center in Knoxville, Tennessee. This modern American collection consists of individuals with birth years ranging from 1892 to 2011 and representing 36 states, although the majority of specimens are from Tennessee and the Southeastern United States. The collection contains the following information on most of the identified skeletons: age, sex, ancestry, cause of death, and body mass information.

The sample consists of identified specimens between the age of 25 and 60 that were reported to be white. In order for the results to be significant, 60 individuals (30 females and 30 males) with no pathological or traumatic lesions in the carpal bones with will be analyzed. All severely damaged bones were eliminated from study.

Measurements

Measurements were obtained following the descriptions given by both Mastrangelo et al. (2011) and Sulzmann et al. (2008). As previously mentioned this study aims to confirm the previous authors' findings while also building on their findings to help produce a replicable method. Initially, Mastrangelo et al. (2011) took a total of 52 different measurements, but not all of them were significant. Therefore, for this study, only the measurements that he found to have an 80% or more accuracy in discriminating between male and female (Mastrangelo et al., Mexico). This gave measurements from each carpal except for the pisiform which totally eliminated from this study. Table 1 shows a list of the measurement taken for this study.

Bone	Measurement	Abbreviation
Lunate	maximum width	LMW
	maximum width of the triquetral facet	LMWTF
	height of the triquetral facet	LHTF
Scaphoid	maximum length	SML
	maximum length of radial facet	SMLRF
	maximum length of the capitate facet	SMLCF
	maximum width of capitate facet	SMWCF
Triquetral	maximum length of lunate facet	TMLLF
	maximum width of lunate facet	TMWLF
	maximum width of hamate facet	TMWHF
Capitate	maximum height	CMH
	maximum length of the distal base	CMLDB
Hamate	maximum height	HMH
	maximum width of the hamulus	HMWH
	maximum width of the distal facets	HMWDF
	height of Metacarpal V facet	HHMVF
Trapezium	maximum length	TML
	maximum length of metal carpal I facet	TMLMCIF
	maximum width of metal carpal I facet	TMWMCIF
Trapezoid	maximum height	TMH
	maximum length of the trapezium facet	TMLTF

Table 1. List of Measurements

Sulzmann et al. (2008) found asymmetry in the carpals, but Mastrangelo et al. (2011) did not in either of their studies. Therefore, to account for possibly side asymmetry, all measurements were taken for the left carpal to decrease variation. Then, the rights were also measured for a random sub-sample of ten donations in order to test for a statistically significant difference. Another random sub-sample of ten donations was also remeasured by the researcher in order to test intra-observer agreement.

All measurements were obtained using digital sliding calipers and were recorded to the nearest 0.01 mm.

Statistical Testing

The main sample of all left carpal measurements was divided into two groups based on the sex of the individual. Within these groups, maximum and minimum values, mean, and standard deviation were determined for each measurement. A paired t-test was then performed to determine if there is a significant difference in the measurements mean values for males and females. A p-value less than 0.05 is considered to be significant for this study. These results will be analyzed to determine if the data follows a normal distribution using the Shapiro-Wilk test of normality. The previous authors used the Kolmogorov-Smirnov test, but Razali et al. (2011) found that the Shapiro-Wilk test was the most powerful test for determining normality (32).

To test for possible intra-observer error, the intraclass correlation coefficient between the two measurements was determined. Also, a paired t-test will be conducted to determine if there is a significant difference between the right and left carpals in our sub-sample of ten. A p-value less than or equal to 0.05 will indicate a significant difference between the two sides.

Lastly, logistic regression analysis will be performed for all the left carpal measurements. Before actually doing the logistic regression, possible correlations between the sex and the predictor variables (in this case the measurements) using bivariate correlation analysis. Then the binary logistic regression analysis was conducted for all the measurements of each bone and then all the measurements together. For these purposes, the value 1 was assigned to male and 0 to female.

All statistical analysis will be performed using SPSS Version 23.

RESULTS

Intra-observer agreement

The intraclass correlation analysis showed a high correlation coefficient for each of the measurements. Each was above 0.900 showing that the second measurement was strongly correlated to the initial measurement for each measurement each time. Therefore, it is safe to say that there was no intra-observer error in this study and the measurements are easily replicable.

Measurement	Intraclass Correlation
LMW	0.999
LMWTF	0.991
LHTF	0.957
SML	1
SMLRF	0.995
SMLCF	0.947
SMWCF	0.985
TMLLF	0.971
TMWLF	0.974
TMWHF	0.973
CMH	1
CMLDB	0.975
HMH	0.984
HMWH	1
HMWDF	0.998
HHMVF	0.974
TML	1
TMLMCIF	0.98
TMWMCIF	0.94
TMH	0.99
TMLTF	0.93

Table 2. Intraclass Correlation Coefficient Results

Descriptive Statistics and Logistic Regression

The Shapiro-Wilk test showed that the data for all measurements was normally distributed except for the following: LHTF, SML, SMLRF, TML, and TMWMIF (Table 3).

	Shapiro-Wilk		
	Statistic	df	Sig.
Lunate Maximum Width	0.963	60	0.069
Lunate Maximum Width of the Triquetral Facet	0.988	60	0.823
Lunate Height of the Triquetral Facet	0.838	60	0
Scaphoid Maximum Length	0.797	60	0
Scaphoid Maximum Length of Radial Facet	0.895	60	0
Scaphoid Maximum Length of Capitate Facet	0.974	60	0.221
Scaphoid Maximum Width of Capitate Facet	0.983	60	0.583
Triquetral Maximum Length of Lunate Facet	0.989	60	0.883
Triquetral Maximum Width of Lunate Facet	0.98	60	0.428
Maximum Width of Hamate Facet	0.981	60	0.469
Capitate Maximum Height	0.973	60	0.203
Capitate Maximum Length of the Distal Base	0.987	60	0.793
Hamate Maximum Height	0.982	60	0.517
Hamate Maximum Width of Hamulus	0.979	60	0.4
Hamate Maximum Width of Distal Facets	0.981	60	0.467
Hamate Height of Metacarpal V Facet	0.962	60	0.061
Trapezium Maximum Length	0.952	60	0.019
Trapezium Maximum Length of Metacarpal I Facet	0.985	60	0.66
Trapezium Maximum Width of Metacarpal I Facet	0.949	60	0.014
Trapezoid Maximum Height	0.974	60	0.223
Trapezoid Maximum Length of the Trapezium Facet	0.974	60	0.229

Table 3. Results from Shapiro-Wilk test of normality.

As previously mentioned, the sub-sample of ten donations was analyzed for side asymmetry using a paired t-test. The results showed that there was no side asymmetry for most of the measurements, but three measurements did have a p-value less than 0.05 showing there was a statistical difference in size between the right and left carpal. These measurements were the trapezium maximum length, hamate maximum width of distal facets, and the triquetral maximum width of hamate facet.

The descriptive statistics for the left male measurements and left female measurements are given in Tables 4 and 5 respectively. The initial paired t-test between the male and female left measurements showed a statistically significant difference between the two with all p-values being less than 0.05 (Table 6). This confirms the presence of sexual dimorphism among the carpal bones in this white American sample suggesting that metric analysis of carpal bones should be effective for sex estimation. Therefore, it was logical to move forward with the logistic regression analysis.

	N	Minimum	Maximum	Mean	Std. Deviation
Lunate Maximum Width	30	16.13	20.72	18.2013	1.01289
Lunate Maximum Width of the Triquetral Facet	30	8.87	12.45	10.4267	0.79574
Lunate Height of the Triquetral Facet	30	1.12	11.26	9.3707	1.86154
Scaphoid Maximum Length of Radial Facet	30	16.12	27.27	18.8563	2.18286
Scaphoid Maximum Length	30	8.39	33.14	27.264	4.02325
Scaphoid Maximum Width of Capitate Facet	30	11.17	16.11	12.9953	1.26823
Scaphoid Maximum Length of Capitate Facet	30	13.59	18.6	15.8223	1.49686
Triquetral Maximum Length of Lunate Facet	30	8.17	11.14	9.8017	0.61844
Triquetral Maximum Width of Lunate Facet	30	7.33	11.94	9.3123	0.91946
Maximum Width of Hamate Facet	30	9.58	13.12	11.521	0.91053
Capitate Maximum Height	30	23.52	30.87	28.2593	1.6707
Hamate Maximum Height	30	16.51	2041	90.5413	368.38972
Capitate Maximum Length of the Distal Base	30	16.03	21.25	18.32	1.29728
Hamate Maximum Width of Hamulus	30	6.99	13.84	10.553	1.7492
Hamate Height of Metacarpal V Facet	30	10.04	13.6	11.4187	0.78351
Trapezium Maximum Length	30	22.28	26.32	24.526	1.10222
Trapezoid Maximum Height	30	18.58	21.45	19.9837	0.8212
Trapezoid Maximum Length of the Trapezium Facet	30	12.96	17.53	14.7157	1.02458
Trapezium Maximum Width of Metacarpal I Facet	30	10.2	13.9	12.0643	0.96019
Trapezium Maximum Length of Metacarpal I Facet	30	13.34	16.96	15.077	0.83593
Hamate Maximum Width of Distal Facets	30	12.71	17.94	15.553	1.01803
Valid N (listwise)	30				

Table 4. Descriptive Statistics for left male carpal measurements.

	N	Minimum	Maximum	Mean	Std. Deviation
Lunate Maximum Width	30	14.94	17.7	16.1157	0.77755
Lunate Maximum Width of the Triquetral Facet	30	6.79	11.01	9.2217	0.9819
Lunate Height of the Triquetral Facet	30	7	11.31	8.598	1.03162
Scaphoid Maximum Length	30	21.3	27.07	24.7447	1.36418
Scaphoid Maximum Length of Radial Facet	30	13.72	17.9	15.7203	1.02385
Scaphoid Maximum Length of Capitate Facet	30	1.3	17.51	13.2553	2.63652
Scaphoid Maximum Width of Capitate Facet	30	8.06	12.74	10.79	1.01959
Triquetral Maximum Length of Lunate Facet	30	7.71	11.78	9.0503	0.8177
Triquetral Maximum Width of Lunate Facet	30	6.89	10.48	8.3163	0.79833
Maximum Width of Hamate Facet	30	8.75	13.22	10.523	0.9275
Capitate Maximum Height	30	21.95	28.55	25.0467	1.44335
Capitate Maximum Length of the Distal Base	30	13.9	18.95	16.254	1.10614
Hamate Maximum Height	30	18.95	22.84	20.6807	1.01091
Hamate Maximum Width of Hamulus	30	6.87	12	9.2413	1.15339
Hamate Maximum Width of Distal Facets	30	12.02	16.34	13.6093	0.96767
Hamate Height of Metacarpal V Facet	30	8.66	10.62	9.5097	0.60445
Trapezium Maximum Length	30	20.71	24.01	22.1137	0.84795
Trapezium Maximum Length of Metacarpal I Facet	30	11.61	14.84	13.215	0.85468
Trapezium Maximum Width of Metacarpal I Facet	30	9.6	12.94	10.8587	0.7835
Trapezoid Maximum Height	30	14.99	20.99	17.975	1.17232
Trapezoid Maximum Length of the Trapezium Facet	30	10.62	15.2	13.3413	1.18444
Valid N (listwise)	30				

Table 5. Descriptive Statistics for left female carpal measurements.

		Paired Differences					t	df	Sig. (2-tailed
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	mLM+B4:B18W - fLMW	2.08567	1.18656	0.21664	1.6426	2.52874	9.628	29	0
Pair 2	mLMWTF - fLMWTF	1.205	1.2627	0.23054	0.7335	1.6765	5.227	29	0
Pair 3	mLHTF - fLHTF	1.106	1.32458	0.24183	0.61139	1.60061	4.573	29	0
Pair 4	mSML - fSML	2.51933	3.96553	0.724	1.03858	4.00009	3.48	29	0.002
Pair 5	mSMLRF - fSMLRF	3.136	2.44197	0.44584	2.22415	4.04785	7.034	29	0
Pair 6	mSMLCF - fSMLCF	2.567	3.21163	0.58636	1.36776	3.76624	4.378	29	0
Pair 7	mSMWCF - fSMWCF	2.20533	1.75239	0.31994	1.55098	2.85968	6.893	29	0
Pair 8	mTMLLF - fTMLLF	0.75133	0.85248	0.15564	0.43301	1.06965	4.827	29	0
Pair 9	mTMWLF - fTMWLF	0.996	1.21823	0.22242	0.5411	1.4509	4.478	29	0
Pair 10	mTMWHF - fTMWHF	0.998	1.20369	0.21976	0.54853	1.44747	4.541	29	0
Pair 11	mCMH - fCMH	3.21267	2.12966	0.38882	2.41744	4.00789	8.263	29	0
Pair 12	mCMLDB - fCMLDB	2.066	1.76884	0.32294	1.4055	2.7265	6.397	29	0
Pair 13	mHMH - fHMH	2.50767	2.43329	0.44426	1.59906	3.41627	5.645	29	0
Pair 14	mHMWH - fHMWH	1.31167	2.06878	0.37771	0.53917	2.08416	3.473	29	0.002
Pair 15	mHMWDF - fHMWDF	1.94367	1.28419	0.23446	1.46414	2.42319	8.29	29	0
Pair 16	mHMVF - fHMVF	1.909	0.93582	0.17086	1.55956	2.25844	11.173	29	0
Pair 17	mTML - fTML	-10.695	1.2979	0.23696	-11.17964	-10.21036	-45.134	29	0
Pair 18	mTMLMCIF -	1.862	1.25773	0.22963	1.39236	2.33164	8.109	29	0
Pair 19	mTMWMCIF -	1.20567	1.26255	0.23051	0.73422	1.67711	5.23	29	0
Pair 20	mTMH - fTMH	2.00867	1.33789	0.24426	1.50909	2.50824	8.223	29	0
Pair 21	mTMLF - fTMLF	1.37433	1.25191	0.22857	0.90686	1.8418	6.013	29	0

Table 6. Paired t-test between left male and female carpal measurements. The m or f in front of the measurement abbreviation indicated male or female respectively.

As stated earlier, a bivariate correlations analysis was done first to look for correlations between the predictor variables (the measurements) and the outcome (sex). There was a strong correlation for all measurements with HHMVF having the highest Pearson Correlation value (Table 7). Since all were strong correlated to sex, none of the measurements were eliminated before moving on to the binary logistic regressions.

		Sex
Sex	Pearson Correlation	1
	Sig. (2-tailed)	
	N	60
Lunate Maximum Width	Pearson Correlation	0.761
	Sig. (2-tailed)	0
	N	60
Lunate Maximum Width of the Triquetral Facet	Pearson Correlation	0.566
	Sig. (2-tailed)	0
	N	60
Lunate Height of the Triquetral Facet	Pearson Correlation	0.253
	Sig. (2-tailed)	0.051
	N	60
Scaphoid Maximum Length	Pearson Correlation	0.392
	Sig. (2-tailed)	0.002
	N	60
Scaphoid Maximum Length of Radial Facet	Pearson Correlation	0.683
	Sig. (2-tailed)	0
	N	60
Scaphoid Maximum Length of Capitate Facet	Pearson Correlation	0.611
	Sig. (2-tailed)	0
	N	60
Scaphoid Maximum Width of Capitate Facet	Pearson Correlation	0.698
	Sig. (2-tailed)	0
	N	60
Triquetral Maximum Length of Lunate Facet	Pearson Correlation	0.466
	Sig. (2-tailed)	0
	N	60
Triquetral Maximum Width of Lunate Facet	Pearson Correlation	0.507
	Sig. (2-tailed)	0
	N	60
Maximum Width of Hamate Facet	Pearson Correlation	0.483
	Sig. (2-tailed)	0
	N	60
Capitate Maximum Height	Pearson Correlation	0.723
	Sig. (2-tailed)	0
	N	60

Capitate Maximum Length of the Distal Base	Pearson Correlation	0.657
	Sig. (2-tailed)	0
	N	60
Hamate Maximum Height	Pearson Correlation	0.581
	Sig. (2-tailed)	0
	N	60
Hamate Maximum Width of Hamulus	Pearson Correlation	0.411
	Sig. (2-tailed)	0.001
	N	60
Hamate Maximum Width of Distal Facets	Pearson Correlation	0.705
	Sig. (2-tailed)	0
	N	60
Hamate Height of Metacarpal V Facet	Pearson Correlation	0.811
	Sig. (2-tailed)	0
	N	60
Trapezium Maximum Length	Pearson Correlation	0.78
	Sig. (2-tailed)	0
	N	60
Trapezium Maximum Length of Metacarpal I Facet	Pearson Correlation	0.746
	Sig. (2-tailed)	0
	N	60
Trapezium Maximum Width of Metacarpal I Facet	Pearson Correlation	0.573
	Sig. (2-tailed)	0
	N	60
Trapezoid Maximum Height	Pearson Correlation	0.71
	Sig. (2-tailed)	0
	N	60
Trapezoid Maximum Length of the Trapezium Facet	Pearson Correlation	0.534
	Sig. (2-tailed)	0
	N	60

Table 7. Bivariate Correlation Analysis Results.

First, logistic regression analysis was done for each individual carpal bone where all of the measurements for that bone were analyzed together. The model created for each one gave a male-female classification accuracy between 81.7 to 100 percent. The trapezoid measurement had the lowest accuracy, and the hamate gave the highest accuracy. Table 8 shows all of the accuracy percentages, and Table 9 shows the β (beta) values and constants to be used in the regression equation for the carpal. The regression equations for each carpal, except the pisiform, were determined in order to allow for sex estimation even if not all carpals were present.

Carpal	Percent Accuracy
Lunate	88.3
Scaphoid	96.7
Triquetral	83.3
Capitate	90
Hamate	100
Trapezium	90
Trapezoid	81.7
All	100

Table. 8. Percent Accuracy

	B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
							Lower	Upper
LMW	2.664	0.755	12.441	1	0	14.358	3.267	63.104
LMWTF	1.246	0.677	3.39	1	0.066	3.478	0.923	13.108
LHTF	-0.546	0.431	1.603	1	0.206	0.579	0.249	1.349
Constant	-52.797	13.78	14.681	1	0	0		
SML	1.176	0.707	2.765	1	0.096	3.242	0.81	12.969
SMLRF	1.387	0.874	2.519	1	0.112	4.005	0.722	22.217
SMLCF	0.458	0.426	1.158	1	0.282	1.581	0.687	3.64
SMWCF	3.323	1.957	2.884	1	0.089	27.748	0.599	1284.627
Constant	-100.145	41.766	5.749	1	0.016	0		
TMLLF	0.289	0.55	0.277	1	0.599	1.336	0.454	3.926
TMWLF	1.103	0.48	5.283	1	0.022	3.014	1.176	7.722
TMWHF	0.934	0.431	4.684	1	0.03	2.544	1.092	5.927
Constant	-22.685	5.908	14.741	1	0	0		
CMH	0.831	0.309	7.215	1	0.007	2.295	1.252	4.208
CMLDB	0.995	0.501	3.945	1	0.047	2.706	1.013	7.225
Constant	-39.117	9.822	15.861	1	0	0		
HMH	-11.151	973.229	0	1	0.991	0	0	.
HMWH	49.314	2070.691	0.001	1	0.981	2.61202E+21	0	.
HMWDF	79.139	3301.743	0.001	1	0.981	2.34316E+34	0	.
HHMVF	179.799	7028.944	0.001	1	0.98	1.218E+78	0	.
Constant	-3271.787	126841.207	0.001	1	0.979	0		
TML	2.236	0.863	6.721	1	0.01	9.36	1.726	50.763
TMLMCIF	2.485	1.217	4.169	1	0.041	12.001	1.105	130.375
TMWMCII	1.006	0.688	2.134	1	0.144	2.734	0.709	10.54
Constant	-98.662	33.571	8.637	1	0.003	0		
TMH	1.7	0.513	10.991	1	0.001	5.475	2.004	14.958
TMLTF	0.324	0.494	0.431	1	0.512	1.383	0.525	3.641
Constant	-36.922	8.96	16.982	1	0	0		

Table 9. Variables in equation for each carpal.

If all the carpals were present, the sex estimation is even more reliable. Using all the measurements together, there was a male-female classification accuracy of 100 percent correct. Table 10 provides the β (beta) values and constants to be used in the regression equation when all measurements are taken.

	B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
							Lower	Upper
LMWTF	4.974	41894.439	0	1	1	144.626	0	.
LHTF	-0.828	48981.842	0	1	1	0.437	0	.
SML	0.569	13187.639	0	1	1	1.766	0	.
SMLRF	0.222	21505.59	0	1	1	1.249	0	.
SMLCF	-1.153	37457.652	0	1	1	0.316	0	.
SMWCF	4.878	40450.55	0	1	1	131.386	0	.
TMLLF	-8.572	42026.595	0	1	1	0	0	.
TMWLF	1.648	46612.864	0	1	1	5.197	0	.
TMWHF	2.405	53034.866	0	1	1	11.074	0	.
CMH	-2.327	30932.19	0	1	1	0.098	0	.
CMLDB	-6.241	32466.779	0	1	1	0.002	0	.
HMH	1.749	16761.971	0	1	1	5.75	0	.
HMWH	-3.805	10836.573	0	1	1	0.022	0	.
HMWDF	4.915	41276.321	0	1	1	136.259	0	.
HHMVF	15.413	44941.9	0	1	1	4941377.6	0	.
TML	7.048	96452.504	0	1	1	1150.664	0	.
TMLMCIF	2.027	16521.127	0	1	1	7.593	0	.
TMWMCII	-0.707	38403.455	0	1	1	0.493	0	.
TMH	5.28	36432.91	0	1	1	196.32	0	.
TMLTF	-1.691	76853.015	0	1	1	0.184	0	.
Constant	-467.195	384779.61	0	1	0.999	0		

Table 10. Variables in equation for all carpals.

Below is the standard regression equation to be used:

$$\log\left(\frac{s}{1-s}\right) = \left(\sum_{i=0}^{n} \beta_i M_i\right) + C$$

To use this equation for sex estimation, you would enter in the β (beta) values for β, the measured values for M, and the constant for C. After plugging in the values, you solve for s which will give a value between 0 and 1. If the value is near 1, the individual from which the measurement were obtained is estimated to be male. Conversely, if the value is near zero, the individual is estimated to be female.

DISCUSSION

As previously highlighted, the estimation of sex is incredibly important, therefore having various and accurate methods of doing so is necessary. The results from this study confirm the conclusion drawn from both Mastrnagelo et al. (2011) and Sulzmann et al. (2008) which found the carpals to be useful for sex estimation. It has also built on their study by using logistic regression analysis instead of discriminant functions and creating regression equations that require less measurements.

Our initial t-test found that there was a significant difference in size between the male and female carpals. This established that there was sexual dimorphism in the carpals for the white American sample. This rejects out null hypothesis of no variation in all carpal bones between males and females in reported whites from the William M. Bass Collection.

The test of laterality showed there to be a significant difference in the following right and left carpal measurements: the trapezium maximum length, hamate maximum width of distal facets, and the triquetral maximum width of hamate facet. This assessment included an equal number of male and female specimens indicating this to be constant across the sexes. While Sulzmann et al. (2008) did find evidence of side asymmetry, Mastrangelo et al. (2008) did not in either of their studies. The inconsistency across all studies, including this one, suggests that a more in depth study of carpal laterality is necessary, especially across populations. In terms of the white American sample, the possible side in the trapezium, hamate and triquetral suggests that the results can only confidently apply to the left carpal for these bones. Therefore, new regression analysis should be done for these three bones to create separate equations for the right hand.

The logistic regression analysis again rejected our null hypothesis. The male carpal bone measurements were consistently larger than the female carpals. The results showed that using all the measurement from at least one carpal bone can estimate sex with at least an 81.7 percent accuracy. The hamate, scaphoid, trapezium, and capitate were the most sexually dimorphic giving estimation accuracies of 100, 96.7, 90, and 90 percent respectively. When using all of the measurements together, our model predicted sex with a 100 percent accuracy.

This information will likely be beneficial to future researchers who need to identify the sex of skeletal remains whether in forensics or bioarchaeology. It could be useful in studies where only the hand bones are recovered or if further confirmation of sex is needed due to the deterioration of other bones. As previously mentioned, sexual dimorphism is presumed to be population specific; therefore, when using osteometric data to estimate sex, it is necessary to population specific regression equations. With the rejection of the null hypothesis, this study adds to the collection of data from varying populations and calls for the replication of this study in other contemporary American race groups.

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