SEX DISCRIMINATION FROM CARPALS IN AN AMERICAN WHITE SAMPLE

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SEX DISCRIMINATION FROM CARPALS IN AN AMERICAN WHITE SAMPLE

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ABSTRACT

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August 2013

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The purpose of this study was to test the method of estimating sex by carpal measurements designed by Sulzmann et al. (2008) on an American White sample. The sample consisted of 80 (40male and 40 female) adult individuals from the Texas State and Bass collections. Intra-observer error was not significant the sample did have significant normality, asymmetry, and sexual size dimorphism. Univariate sectioning points and multivariate stepwise discriminant function analysis with linear discriminant equations were complete. Univariate sectioning points ranged from having accuracy rates of 47.5% and 88.75%. Multivariate stepwise discriminant analysis had accuracy rates from 82.5% to 92.5%. The univariate sectioning points and linear discriminant equations allow for future researchers to quickly and accurately estimate the sex of American White individuals.

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INTRODUCTION

Purpose and Problem

Identifying the sex of human remains is an important step when compiling a biological profile. Sex estimation is traditionally performed on the pelvis, skull, or on select post-cranial features/measurements. If the skeleton is nearly complete, then an individual can be sexed within nearly 100% percent accuracy (Spradley and Jantz 2011). Estimating sex of an individual utilizing only "the cranium provides an overall cross-validated classification rate of 90-91%, while multiple postcranial elements proved higher cross-validated classification rates between 92% and 94%" (Spradley and Jantz 2011:291). However, in many cases the skeleton is fragmentary, and therefore there is a need to develop accurate, population specific methods for estimating sex based on smaller more compact bones, such as the carpals, using discriminant function analyses.

The aim of this research was to test the accuracy of estimating sex in a modern American White population using carpal measurements in discriminant function analysis. This research has relevance for forensic anthropology, bioarchaeology, and paleodemography since sex estimations of unknown individuals are an important aspect of analysis for each of these areas of research. In forensic anthropology, sex estimation is used in the medicolegal process to narrow down a missing persons list through the creation of a biological profile, while bioarchaeology and paleodemography research studies use sex estimation to make informed interpretations about past life-ways and cultural practices.

Previous Studies Using Carpals to Estimate Sex

Over the last several decades there has been an increasing interest in developing population specific methods of estimating sex through discriminant function analysis. This increased interest in methods using discriminant function analysis is due to its ability to be duplicated and the fact that it “reduces subjective judgment” (Mastrangelo et al. 2011a). One of the new population specific methods utilizes carpal measurements (Sulzmann et al. 2008; Mastrangelo et al. 2011a and b). Previous research has found that the carpals, while presenting some asymmetry, are sexually dimorphic in size and can be used in sex estimation studies (Garn et al. 1976; Plato et al. 1980; Bennett 1981; Sulzmann et al. 2008; Mastrangelo et al. 2011a and b).

Sulzmann et al. (2008) were led to believe that the carpals could be used to accurately estimate the sex of individuals based on previous research that focused on estimating the sex based on metacarpals (Scheuer and Elkington, 1993; Lazenby, 1994; Falsetti, 1995; Smith, 1996; Stojanowski, 1999), metatarsals (Robling and Ubelaker, 1997; Smith, 1997), and tarsals (Steele, 1976; Riepert et al., 1996; Introna et al., 1997; Wilbur, 1998; Bidmos and Asala, 2003, 2004). Based on the high accuracy rates that the previous researchers had with the metacarpals, metatarsals, and tarsals, Sulzmann et al. (2008) focused on estimating sex from carpals from a historic London sample because,

"…all of these are small, compact bones and are often recovered intact in archaeological or forensic material even when the larger bones are fragmented" (Sulzmann et al. 2008: 252).

Sulzmann et al.'s (2008) sample was compiled from Londoners interred in the Christ Church crypt during the 18th and 19th centuries. They found that each carpal, except for the pisiform, had significant sexual dimorphism measurement values. The most significant carpal within their study was the right triquetral with an accuracy rate of 88.6%, while the left triquetral was slightly less accurate at 87.8%.

In 2011, Mastrangelo and co-authors published two articles that found that in both Spanish and Mexican samples, all of the carpals had significant sexual dimorphism values. Mastrangelo et al.'s (2011a) Spanish sample was a 20th century collection that had been interred at the Municipal Cemetery of San José Grande, Spain. Mastrangelo et al. (2011b)'s Mexican sample was a contemporary identified collection from the Laboratory of Physical Anthropology, Faculty of Medicine, UNAM. In the Spanish sample, the most significant carpal was the lunate with an accuracy rate of 97.8%. In the Mexican sample, the most significant carpal was the scaphoid with an accuracy rate of 92.3%.

Mastrangelo et al. (2011b) proposed that the lunate, scaphoid, and triquetral would have the highest accuracy rates due to the biomechanics in the scapho-lunate and luno-triquetral joints, which govern 40% flexion, 33% extension, and 10% ulnar deviation of total wrist motion (Mastrangelo et al. 2011b:13). Flexion is defined as the movement of the carpus along the vertical plane allowing the hand to be a position superior to the ulna and radius (Standring, 2008). Extension is defined as the movement of the carpus along the vertical plane allowing the hand to be in position inferior to the ulna and radius (Standring 2008). Ulna deviation is defined as the movement of the carpus along the horizontal plane of the ulna and radius (Standring 2008). The high accuracy rates of the carpals should correspond to the amount of movement the carpal has in the carpus. Since it is known that the lunate, scaphoid, and triquetral have the greatest movement due to the scapho-lunate and luno-triquetral joints, it is proposed that these three carpals will have some of the highest accuracy rates for estimating sex.

Sex estimation based on carpal measurements using discriminant functions has yielded high accuracy rates in previous studies. The purpose of this study is to test the accuracy of carpal measurements to estimate sex in American Whites. This is vital for forensic analyses since the previous study by Sulzmann et al. (2008) used 18th and 19th century English.

Based on the results of previous studies (Sulzmann et al. 2008; Mastrangelo et al. 2011a and 2011b), there are four main expectations for this study. First, it is expected that the sample used will have significant asymmetry. Sulzmann et al. (2008) found significant asymmetry in the carpals. Because of the historical genetic relationship between American Whites and English, it is likely that American Whites will also exhibit significant asymmetry. Second, if there is significant asymmetry present in the American White sample, it is expected that the left side will have a higher rate of sex estimation accuracy due to the high frequency of the left hand being non-dominant. Third, it is expected that the scaphoid, lunate, and triquetral will have some of the highest accuracy rates based on their biomechanics (Mastrangelo et al. 2011b). Finally, it is expected that the hamate and trapezium will have high accuracy rates, though lower than the proximal row carpals. By developing discriminant function equations for sex estimation in an American White population, it will be possible to use the carpals to estimate the sex of individuals in this population when investigators are unable to use traditional methods due to fragmentary nature of the remains.

CHAPTER 2

MATERIALS and METHODS

Sample

The samples utilized in this study represent a modern American White population derived from the William M. Bass Donated Skeletal Collection (Bass Collection) housed at The University of Tennessee, Knoxville and the Texas State Donated Skeletal Collection housed at Texas State University-San Marcos. The Bass Collection was established in 1981 and fit well with the research parameters since it is primarily comprised of individuals of White ancestry. The Texas State Donated Skeletal Collection was established in 2008 at the Forensic Anthropology Center at Texas State, and is housed in the Grady Early Forensic Anthropology Research Laboratory. Though this collection is smaller, it also fit well with the research requirements as it is mainly comprised of individuals of White ancestry.

The sample is comprised of a total of 80 adult (40 male and 40 female) individuals of self-identified White ancestry (Table 1). Sixty-five individuals were derived from the Bass Collection and 15 from the Texas State Donated Skeletal Collection (Table 1).The ages of individuals sampled in this study were between 18 and 91. All individuals included in the study were considered to be contemporary, having birth years after 1920. Since all of the remains are contemporary, this method of estimating sex will have applications for modern forensic usage.

Table 1. The breakdown of how many individuals came from the Texas State and Bass Collections and their sex.

Collection	Male	Female	Total
Texas State Collection	10	5	15
Bass Collection	30	35	65
Total	40	40	80

Thirty-four measurements designed by Sulzmann et al. (2008) were split among the five carpals. They "were designed to capture the general size of the bone (length, breadth, and width) as well as the size of facets…" (Sulzmann et al. 2008: 253). A list of the measurements taken in this study can be found in Table 2, with the definition of each measurement available in the Appendix. Figures 1 through 5 depict the measurement of each carpal. All definitions of measurements were taken from Sulzmann et al. (2008).

Data Collection Procedure

The data collection process began with the identification and separation of the necessary carpals from the other carpals, metacarpals, tarsals, metatarsals, and phalanges of each individual. Following this step, sorting and siding of carpals included in this study was performed. After all five of the carpals for both the right and left side of each individual was sorted and sided, a short description of their condition and the date they were measured was recorded in a Microsoft 2010 Excel spreadsheet next to their identification number. Individuals were not used if they were missing carpals, or if the carpals had postmortem wear damage, severe degenerative joint disease, or severe bony growth. Individuals were not included in the sample if they had these conditions due to the inability to take accurate measurements on the carpals that were affected.

Once the description and date were recorded, measurements were taken with a digital Kobalt 293883 sliding caliper and recorded in a separate Microsoft 2010 Excel spreadsheet. The order in which the carpals were measured and recorded was as follows: right lunate, left lunate, right scaphoid, left scaphoid, right triquetral, left triquetral, right hamate, left hamate, right trapezium, and left trapezium. After all the measurements were completed for each individual the data file was saved. At the end of each day of data collection, the file was backed-up and a hard copy was printed to ensure data loss would not occur.

Table 2. A list of the 34 measurements used for the study which were taken for each carpal with their denomination.

Carpal Bone	Variable	Denomination
Lunate	ML	Maximum Length
	MW	Maximum Width
	MWDH	Maximum Width of Dorsal Horn
	MWTF	Maximum Width of Triquetral Facet
	HTF	Height of the Triquetral Facet
Scaphoid	ML	Maximum Length
	MW	Maximum Width
	MLRF	Maximum Length of Radius Facet
	MLST	Maximum Length of Scaphoid Tubercle
	MLCF	Maximum Length of the Capitate Facet
	MWCF	Maximum Width of the Capitate Facet
Triquetral	ML	Maximum Length
	MH	Maximum Height
	MW	Maximum Width
	MLLF	Maximum Length of Lunate Facet
	MWLF	Maximum Width of Lunate Facet
	MLPF	Maximum Length of Pisiform Facet
	MWPF	Maximum Width of Pisiform Facet
	MHHF	Maximum Height of Hamate Facet
	MWHF	Maximum Width of Hamate Facet
Hamate	MH	Maximum Height
	MW	Maximum Width

Table 2. Continued		
Hamate	HB	Height of Body
	MWH	Maximum Width of the Hamulus
	MWDF	Maximum Width of the Distal Facets
	HM(V)F	Height of the Fifth Metacarpal Facet
	HM(IV)F	Height of the Fourth Metacarpal Facet
Trapezium	ML	Maximum Length
	MH	Maximum Height
	MLM(I)F	Maximum Length of the First Metacarpal Facet
	MWM(I)F	Maximum Width of the First Metacarpal Facet
	MLTF	Maximum Length of the Trapezoid Facet
	MLTSF	Maximum Length of Trapezoid and Scaphoid Facets
	WSF	Width of the Scaphoid Facet

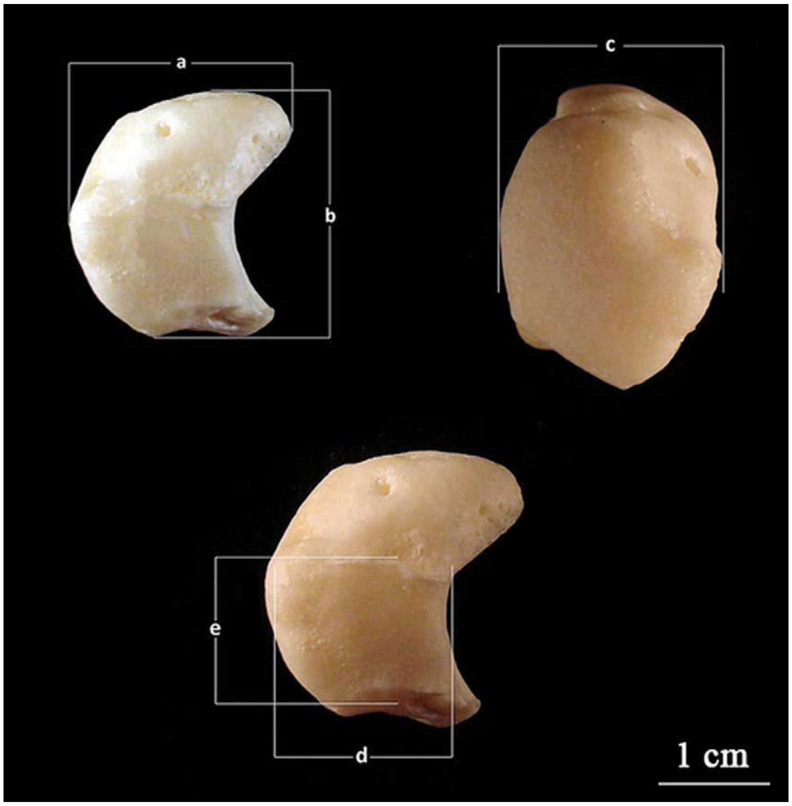

Figure 1. Lunate Measurements a to e (right side shown): a, maximum length; b, maximum width; c, maximum width of the dorsal horn; d, maximum width of the triquetral facet; e, height of triquetral facet (From Mastrangelo et al. 2011b:3).

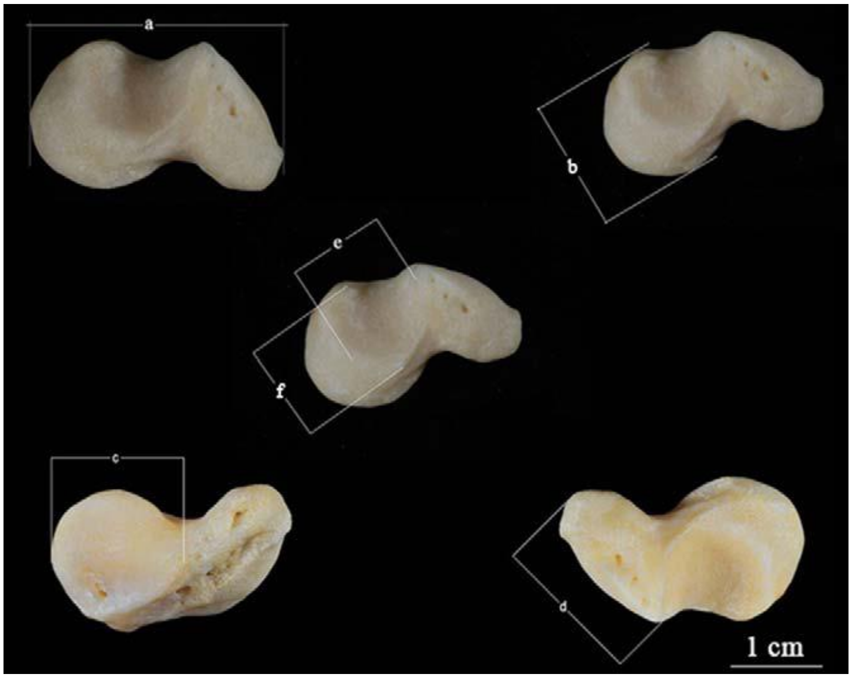

Figure 2. Scaphoid measurements a to f (right side shown): a, maximum length; b, maximum width; c, maximum length of radius facet; d, maximum length of scaphoid tubercle; e, maximum length of capitate facet; f, maximum width of capitates facet (From Mastrangelo et al. 2011b: 4).

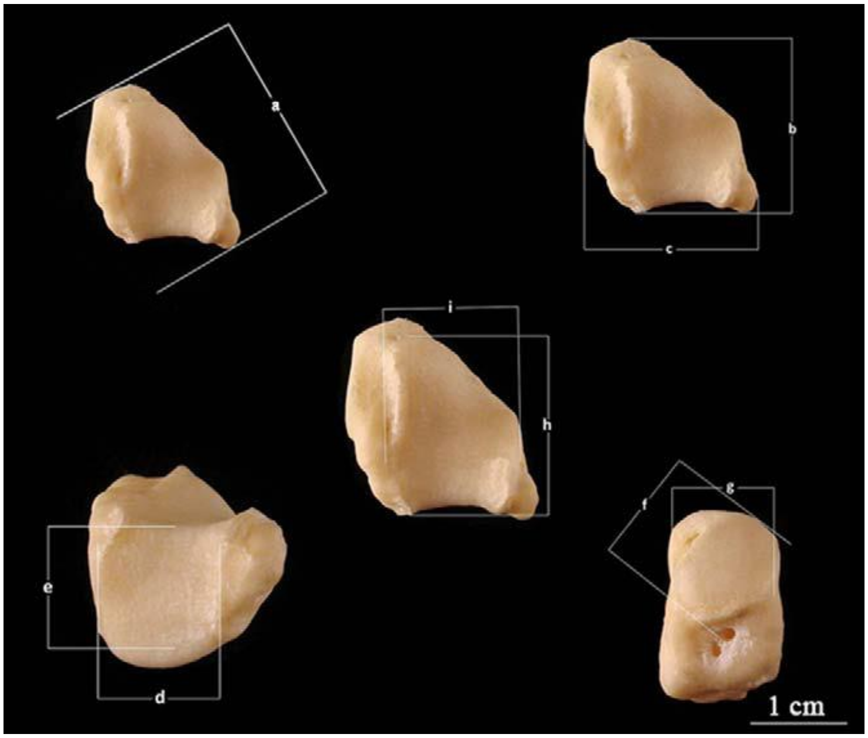

Figure 3. Triquetral measurements a to g (right side shown): a, maximum length; b, maximum height; c, maximum width; d, maximum length of lunate facet; e, maximum width of lunate facet; f, maximum length of pisiform facet; g, maximum width of pisiform facet; h, maximum height of hamate facet; I, maximum width of hamate facet (From Mastrangelo et al. 2011b: 4).

Figure 4. Hamate measurements a to g (right side shown): a, maximum height; b, maximum width; c, height of the body; d, maximum width of the hamulus; e, maximum width of the distal facets; f, height of metacarpal V facet; g, height of metacarpal IV facet (From Mastrangelo et al. 2011b: 5).

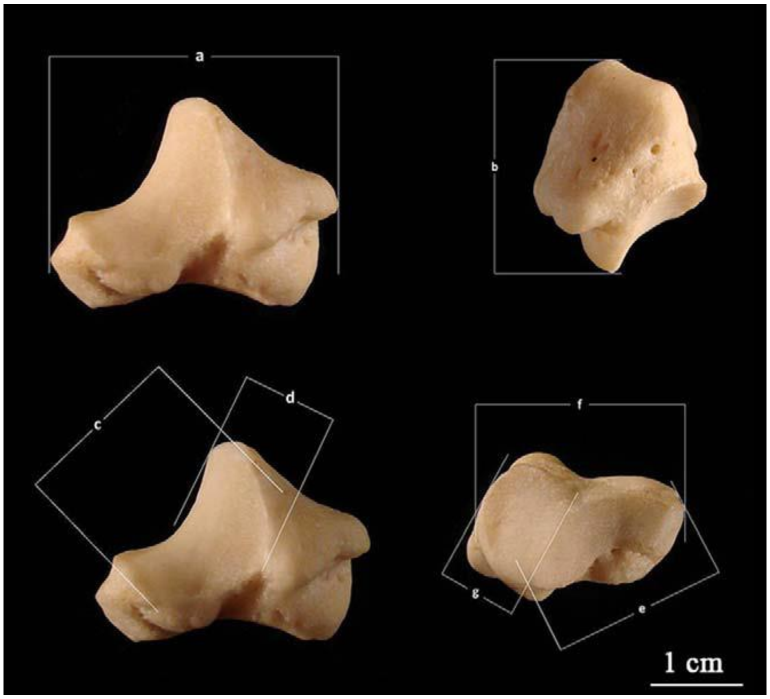

Figure 5. Trapezium measurements a to g (right side shown): a, maximum length; b, height; c, maximum length of metacarpal I facet; d, maximum width of metacarpal I facet; e, maximum length of trapezoid facet; f, maximum length of trapezoid and scaphoid facets; g, width of scaphoid facet (From Mastrangelo et al. 2011b: 7).

Statistical Analysis

To test for intra-observer error, 10% of the sample was re-measured after the total sample data was complete and compared through a correlation test. Any measurement that had a significant error rate was excluded from further analysis.

Once all of the individual carpal measurements had been recorded, descriptive statistics (mean, standard deviation, and maximum and minimum values), independent t-tests, a paired t-tests, univariate discriminant functions, and multivariate stepwise discriminant functions were conducted and analyzed using Statistical Package for the Social Sciences (SPSS). Normality was tested using Kolmogorov-Smirov tests.

The paired t-tests were analyzed to estimate the existence and direction of any side asymmetry. The paired t-tests were completed to look at which measurements in the sample had significant asymmetry.

Independent t-tests were performed to determine if the sexual dimorphism of the measurements had significant values. Any measurements without significant sexual dimorphism values were excluded from further analysis.

The univariate discriminant functions were analyzed to determine which measurements had the highest accuracy for estimating sex independent of other measurements. At this time sectioning points were also calculated for each measurement by adding the male mean to the female mean and then dividing by two. The sectioning point is to help future researchers estimate the sex of individuals based on a single measurement. Values equal or greater to listed number are male and values less than the listed number are female.

The multivariate stepwise discriminant functions were analyzed to determine which combinations of measurements gave the highest accuracy rates. Two multivariate stepwise discriminant function analyses were completed. The first analysis was to determine the accuracy rates for each carpal independent of the other carpals. This was done to find which combination of measurements within each carpal would have the highest accuracy rate. The second analysis was to determine which measurements combined to have the highest accuracy rates if all of the carpals were able to be measured.

All statistical results were accepted as significant at a 0.05 level and were considered useful for future use with an accuracy rate of 80% or higher (Sulzmann et al. 2008 and Mastrangelo et al. 2011a and b).

CHAPTER 3

RESULTS

Intra-Observer Error Test

The sample was analyzed for intra-observer error using a Pearson correlation coefficient to assess any deviations of the 10% of the sample that were measured from the original measurements. This resulted in the lowest correlation were 0.98%. The Pearson correlation results showed that the rate of intra-observer error between the remeasured and original individuals was not significant, at 2% or less for all remeasured individuals (Table 3). Due to low intra-observer error, no data was excluded at this point in the analysis.

Table 3. Pearson correlation between the remeasured 10% and the original measurements of the individuals.

Individual	Pearson Correlation
D09-2009	0.991216065
D02-2010	0.992082741
D04-2010	0.992393681
D10-2010	0.991655044
D11-2010	0.988916652
D12-2010	0.995593336
D04-2011	0.989471408
D06-2011	0.991696453

Normality of Measurements

Using Kolmogorov-Smirnov tests, the normality of each carpal was confirmed (Table 4). One-sample Kolmogorov-Smirnov tests were completed for each measurement of the carpals to analyze if all of the measurements had a normal distribution. With all of the measurements resulting in significances between 0.114 and 0.999 each measurement had a normal distribution and can be interpreted as being from the same population.

Table 4. One-Sample Kolmogorov-Smirnov tests' significance supporting the normality of the sample.

Measurement	Right Significance	Left Significance
Lunate		
ML	0.331	0.437
MW	0.838	0.558
MWDH	0.239	0.412
MWTF	0.999	0.977
HTF	0.877	0.982
Scaphoid		
ML	0.858	0.513
MW	0.114	0.996
MLRF	0.558	0.689
MLST	0.747	0.389
MLCF	0.967	0.880
MWCF	0.807	0.938
Triquetral		
ML	0.824	0.948
MH	0.980	0.903
MW	0.199	0.277
MLLF	0.984	0.958
MWLF	0.820	0.594
MLPF	0.996	0.773
MWPF	0.527	0.949
MHHF	0.525	0.464
MWHF	0.601	0.934
Hamate		
MH	0.929	0.773
MW	0.799	0.931

Table 4. Continued		
HB	0.569	0.628
MWH	0.982	0.991
MWDF	0.939	0.531
HM(V)F	0.767	0.821
HM(IV)F	0.845	0.999
Trapezium		
ML	0.573	0.642
MH	0.861	0.690
MLM(I)F	0.992	0.836
MWM(I)F	0.935	0.532
MLTF	0.994	0.470
MLTSF	0.631	0.942
WSF	0.435	0.691

Assessment of Asymmetry

The sample was then tested for asymmetry between the left and right carpals using paired t-tests. The paired t-tests were done to compare the left measurements to their corresponding right measurements. This resulted in significant asymmetry in the lunate, hamate, and trapezium measurements. Of those three carpals, only the lunate's height of the triquetral facet, the hamate's maximum height, and the trapezium's width of the scaphoid facet did not have a significant amount of asymmetry. The scaphoid and the triquetral did not display significant, except the maximum width of the scaphoid and the triquetral's maximum height of the hamate facet. Overall there were 18 of the 34 measurements had significant asymmetry present Of the 18 measurements that had significant asymmetry, directional asymmetry was to the right in fifteen and to the left in three (Table 5).

Since a majority of the measurements had statistically significant results, all further tests were run separately between the right and the left carpal measurements. By continuing to analyze both the right and left sides separately "this allowed the functions to have higher discriminating powers and accuracies, and also maximizes the potential for individual elements when remains are fragmentary," (Sulzmann et al. 2008:257).

Table 5. Results of the paired t-tests to determine significant asymmetry between left and right carpal measurements, the t-stat is significant at 1.664125 and is indicated by a 1.

Variable	T Stat	Sign.
Lunate		
ML	-4.39401	1
MW	-2.52801	1
MWDH	-1.91375	1
MWTF	2.808558	1
HTF	-1.5047	0
Scaphoid		
ML	-1.61601	0
MW	-1.86476	1
MLRF	-0.2516	0
MLST	-0.44121	0
MLCF	-1.18707	0
MWCF	0.151544	0
Triquetral		
ML	0.822912	0
MH	-0.95175	0
MW	-1.31759	0
MLLF	1.406156	0
MWLF	0.571222	0
MLPF	-1.4893	0
Triquetral		
MWPF	-1.05236	0
MHHF	1.72338	1
MWHF	0.497551	0
Hamate		
MH	0.101173	0
MW	-2.69701	1
HB	3.677245	1
MWHF	-2.1278	1
MWDF	-6.00566	1
HM(V)F	-3.58552	1
HM(IV)F	-2.19605	1
Trapezium		
ML	-4.11645	1
MH	-2.09317	1
MLM(I)F	-3.18605	1
MWM(I)F	-5.2002	1
MLTF	-3.82207	1
MLTSF	-3.63387	1
MSF	-1.0559	0

Assessment of Sexual Size Dimorphism

Descriptive statistics for each measurement are provided in Appendix B. To determine if the measurements had significant sexual size dimorphism, independent t-tests were analyzed between the male and female samples. The independent t-tests for both the right and left the carpal measurements had significant results for each measurement taken between the female and male individuals (Appendix B). Due to this, no measurements were excluded from the discriminant function analysis.

Univariate Sectioning Points

Univariate sectioning points were completed to determine which measurements by themselves could be used to estimate sex. The accuracy rates of the right carpals were between 47.5% and 86.25%. The accuracy rates of the left carpals were between 61.25% and 88.75%. Each carpal for both sides had at least two measurements with accuracy rates of between 80% and 89%. In total, 16 measurements on the right and 13 measurements on the left had accuracy rates of between 80% and 89%, with ten of these measurements roughly equal between the right and left sides.

The measurement with the highest accuracy rate in estimating sex was the left scaphoid's maximum length of the radius facet at 88.75%. The right side of this measurement had a slightly lower accuracy rate at 86.25%. Two other measurements had accuracy rates at 86.25%, the right lunate's maximum width and the left trapezium's maximum length of the first metacarpal facet. The right trapezium's MLM(I)F and maximum length, the right hamate's maximum height, and both the right and left hamate's height of the body all had accuracy rates of 85%. The left lunate's maximum width, the left scaphoid's maximum length, right triquetral's maximum height of the hamate facet left triquetral's maximum length, and the hamate's height of the fifth metacarpal facet all have accuracy rates of 83.75%. The right scaphoid's maximum length, the right trapezium's maximum height and maximum width of the first metacarpal facet, the left hamate's maximum height, and the left trapezium's maximum length and maximum height all have accuracy of 82.5%. The right scaphoid's maximum width, the right triquetral's maximum height, the right hamate's height of the fourth metacarpal facet, and the left triquetral's maximum height of the hamate facet all have accuracy rates of 81.25%. The right lunate's maximum length, the right hamate's maximum width and height of the fifth metacarpal facet, the left lunate's maximum width of the dorsal horn, and the left triquetral's maximum length of the pisiform facet all have accuracy rates of 80%.

Refer to Appendix C for a full list of the measurements, their accuracy rates and the sectioning points of the right and left sides. The accuracy rates reflect the accuracy rate for using the sectioning points of each measurement independent of the other measurements. For using the sectioning points when measurements are compared to them if the value is greater than the given sectioning point the individual represented by the measurement is male, and if the value is less than the individual is female.

Multivariate Stepwise Discriminant Function

Before analyzing the measurements in a multivariate stepwise discriminant function they were first tested for homogeneity of within covariance matrices using Chi-squired tests. Due to the significant values found for the right scaphoid, left lunate and left hamate a multivariate stepwise discriminant analysis was not complete for each of these carpals. After the multivariate stepwise discriminant analyses were complete for each carpal and the combined samples, linear discriminant equations were created for quick application based on the measurements chosen from the analyses.

Multivariate stepwise discriminant functions were analyzed for each right carpal separately to determine the accuracy rates per carpal. The carpals of the right side had accuracy rates that varied from 87.5% to 92.5% for females, 80% to 82.5% for males, and 82.5% to 88.75% for the pooled sample (Table 6). The trapezium's accuracy rates were 92.5% for females, 85% for males, and 88.75% for the pooled sample. The hamate's accuracy rates were 92.5% for females, 82.5% for males, and 87.5% for the pooled sample. The triquetral's accuracy rates were 87.5% for females, 80% for males, and 83.75% for the pooled sample. The lunate had the lowest accuracy rates at 85% for females, 80% for males, and 82.5% for the pooled sample.

A multivariate stepwise discriminant function analysis using all of the right carpals was completed to determine the best carpals and measurements to use if all were able to use. This yielded four measurements as having the highest accuracy rate when used together: the trapezium's maximum length, hamate's height of the fourth metacarpal facet, scaphoid's maximum length of radius facet, and hamate's maximum width. The accuracy rates were 95% for females, 92.5% for males, and 93.75% for the pooled sex sample.

Table 6. Multivariate stepwise discriminant function results per carpal for the female, male, and pooled sex samples of the right carpals.

Carpal	Right			
	Measurement	F. Accuracy	M. Accuracy	Total Accuracy
Lunate	MW MWDH MWTF	85%	80%	82.5%
Triquetral	MLLF MHHF	87.5%	80%	83.75%
Hamate	MW MH HM(V)F	92.5%	82.5%	87.5%
Trapezium	ML MLM(I)F	92.5%	85%	88.75%

Table 6. Continued.

Combined	Scaphoid MLRF Hamate MW Hamate HM(IV)F Trapezium ML	95%	92.5%	93.75%

Table 7. Multivariate linear discriminant equations for the right carpals.

Carpal	Right
Lunate	1.12405(ML) + 1.49449(MWDH) + -0.93357(MWTF) – (-29.97624)
Triquetral	0.99244(MLLF) + 1.72147(MHHF) – (-33.19569)
Hamate	0.83315(MW) + 0.54798(MH) + 1.61266(HM(V)F) – (-47.51685)
Trapezium	1.35503(ML) + 0.743888(MLM(I)F) – (-43.08327)
Combined	0.98953(TP.ML) + 0.96873(H.HM(IV)F) + 0.73217(S.MLRF) + 0.60293(H.MW) – (-60.09119)

Multivariate stepwise discriminant functions were analyzed for each left carpal separately to determine the accuracy rates per carpal. The carpals of the left side had accuracy rates that varied from 87.5% to 92.5% for females, 80% to 85% for males, and 86.25% to 88.75% for the pooled sample (Table 8). The scaphoid had the highest accuracy rates at 92.5% for females, 85% for males, and 88.75% for the pooled sample. The trapezium's accuracy rates were 92.5% for females, 80% for males, and 86.25% for the pooled sample. The triquetral's accuracy rates were 87.5% for females, 85% for males, and 86.25% for the pooled sample. Refer to Table 8 for a breakdown of the measurements used for each carpal and their accuracy rates.

A multivariate stepwise discriminant function analysis using all of the left carpals was completed to determine the best carpals and measurements to use if all were available to use. This yielded five carpal measurements as having the highest accuracy rate when used together: the hamate's height of the fourth metacarpal facet, the trapezium's maximum length of the first metacarpal facet, triquetral's maximum length of the pisiform facet, the scaphoid's maximum width of the capitate facet, and the triquetral's maximum width of the hamate facet. The accuracy rates were 97.5% for females, 87.5% for males, and 92.5% for the pooled sex sample.

Table 8. Multivariate stepwise discriminant function results per carpal for the female, male, and pooled sex samples of the left carpals.

Carpal	Left			
	Measurement	F. Accuracy	M. Accuracy	Total Accuracy
Scaphoid	MW MLRF	92.5%	85%	88.75%
Triquetral	MLLF MLPF MHHF	87.5%	85%	86.25%
Trapezium	ML MLM(I)F	92.5%	80%	86.25%
Combined	Scaphoid MWCF Triquetral MLPF Triquetral MWHF Hamate HM(IV)F Trapezium MLM(I)F	97.5%	87.5%	92.5%

Table 9. Multivariate linear discriminant equations for the left carpals.

Carpal	Left
Scaphoid	0.7283(MW) + 1.17499(MLRF) – (-32.26943)
Triquetral	1.36773(MLLF) + 0.94691(MLPF) + 1.09634(MHHF) – (-37.94812)
Trapezium	1.07771(ML) + 1.1239(MLM(I)F) – (-41.40435)
Combined	0.723(H.HM(IV)F) + 1.31788(TP.MLM(I)F) + 0.84251(T.MLPF) + 0.70145(S.MWCF) + -0.50715(T.MWHF) – (-37.81306)

CHAPTER 4

DISCUSSION

The purpose of this research was to test the method of estimating sex on an American White sample using carpal measurements designed by Sulzmann et al. (2008) for and tested on a British sample and duplicated by Mastrangelo et al. (2011a and 2011b) on Spanish and Mexican samples, respectively. The current research yielded results supporting the idea that the carpals can be used to estimate sex alongside more traditional methods currently in practice. Results show that the accuracy rates of the carpals are comparable to accuracy rates for estimating sex based on postcranial elements (Spradley and Jantz 2011). The carpals can be used to estimate sex due to being sexually dimorphic in size.

The results from this study can help researchers estimate the sex of individuals from American White populations when 1) the carpal bones are present, and 2) fragmentation or other damage renders more traditional methods of sex estimation impossible. One of the chief benefits of using this approach for estimating sex on fragmentary remains is that Sulzmann et al. (2009) purposefully designed the measurements for areas of the carpals that would be the most resistant to fragmentation or postmortem wear (Sulzmann et al. 2009:253). Whether using the sectioning points or one of the linear discriminant equations, researchers have several options for identifying remains.

By using the univariate sectioning points for each measurement, researchers will be able to quickly estimate the sex of isolated carpals independently with a single measurement. Using one of the multivariate discriminant function analysis results researchers can more thoroughly estimate the sex of individuals using several measurements.

Proximal Row Expectations

Mastrangelo et al. (2011b) predicted that the proximal row of the carpals (scaphoid, lunate, and triquetral) would have higher accuracy rates then the distal row (trapezium and hamate) due to the biomechanics of the carpus. Among American Whites this prediction and expectation held true for the scaphoid but only partially true for the lunate and triquetral. The scaphoid had the highest accuracy rates for both the right and left univariate sectioning points and the highest total accuracy rate for the left carpals' multivariate discriminant analysis. Compared to the lower than expected accuracy rates of the lunate and triquetral which were comparable to the accuracy rates of the hamate and trapezium.

Among the carpals the scaphoid has the largest range of motion functioning in both the sagittal plane (flexion-extension) and the coronal plane (radio-ulnar deviation) “as a bridge between the proximal and distal carpal rows” (Freedman and Garcia-Elias 1997:458). Current biomechanical research on the scaphoid suggests that the scaphoid has the large range of motion due to its placement which allows the scaphoid to function in a spectrum of motions with varying extremes. One extreme being that the scaphoid's motion is as a "row" with the lunate, triquetral, and pisiform, while the other extreme being that the scaphoid's motions is as a "column" with the trapezium for movement of the first metacarpal (Craigen and Stanley 1995; Freeman and Garcia-Elias 1997). Further research is needed on the interdependence of the carpus.

Based on Mastrangelo et al. (2011b)'s prediction of the scapho-lunate joint from the Mexican sample, it was expected that the lunate would have one of the highest accuracy rates. Instead the lunate had the lowest multivariate stepwise discriminant functions per carpal accuracy rates for the right and left sides, and none of the lunate measurements were used in either of the right or left combined multivariate stepwise discriminant function analyses. These lower than expected accuracy rates are possibly due to the fact that there are two different morphological types of lunates (Dyankova 2007:1). Type one lunates have one facet on their distal surfaces only for the capitate, while Type two lunates have two facets on their distal surfaces for the capitate and hamate (Dyankova 2007:1). The hamato-lunate joint is only present in individuals with the Type 2 lunate. Therefore while each type of lunate has the necessary landmarks to perform the measurements, the locations of the landmarks vary slightly depending on the type of lunate in each individual. Currently only a few studies have been done looking at the ratio of Type one to Type two lunates, but none using an American White sample. Further study on the effects of lunate types on estimating sex needs to be assessed in future research.

As part of the proximal row of carpals the triquetral was also expected to have one of the highest accuracy rates (Mastrangelo et al. 2011b). While the triquetral's accuracy rates were high, they were equal or lower than the accuracy rates of the distal row carpals. Currently there is no research focusing on the biomechanics of the triquetral and further research should be done.

Distal Row Expectations

Based on the previous results (Sulzmann et al. 2008; Mastrangelo et al. 2011a and 2011b) it was expected that the hamate and the trapezium being from the distal row would have results with lower accuracy rates for estimating sex than the proximal row carpals. Unexpectedly, both the hamate and trapezium had higher than expected results in the multivariate stepwise discriminant function analysis per carpal when compared to the accuracy rates of the proximal row carpals.

The hamate was expected to have results that would correlate in accuracy rate with the lunate if there was the presence of the hamato-lunate joint on the lunate type two (Dyankova 2007). The hamate had higher accuracy rates in both the right and left sides than the lunate in multivariate stepwise discriminant function analysis per carpal. It is possible that the higher accuracy rates of the hamate could be due to the presence of the type two lunates in the sample. Another possible reason for the high accuracy rates of the hamate when viewed alongside the previous studies is that similar to the Mastrangelo et al. (2011a and 2011b) studies the sample used was a contemporary sample, compared to Sulzmann et al.'s (2008) historical sample. The current results of the hamate are closer to Mastrangelo et al.'s (2011a and 2011b) results of 90.7% and 91.1% at 87.5% for the right and left then Sulzmann et al.'s (2008) result of 79.7%. Therefore it is possible that due to changes in human behavior and work between the historical period and the contemporary period there has been an increase in the biomechanical use of the hamate. Further studies are needed on the biomechanical relationships between the hamate and lunate need to be done alongside further comparison between historical and contemporary samples.

The trapezium was included in this study due to the fact that in the previous studies (Sulzmann et al. 2008; Mastrangelo et al. 2011a and 2011b) the trapezium's measurement of maximum length of the first metacarpal facet was the only significant measurement present in all three previous univariate sectioning point tables. Except for in the combined multivariate stepwise discriminant function analysis of the right carpals, this measurement was either included or had accuracy rates of 80% or higher. Based on current biomechanical research it is possible that the trapezium has high accuracy rates in relationship to this measurement because of the carpals' relation to the scaphoid and the first metacarpal forming a functional column (Craigen and Stanley 1995; Freeman and Garcia-Elias 1997).

In the analysis of the multivariate stepwise discriminant functions of the trapezium the same two measurements were used for both the right and left tests: the maximum length and maximum length of the first metacarpal facet. For the left carpal the maximum length of the first metacarpal facet was also included in the combined multivariate stepwise discriminant function analysis. For the right carpal the maximum width was also included in the combined multivariate stepwise discriminant function analysis. The repeated use of these measurements in multiple analyses points to an increased importance of these measurements for this sample.

Structure and Function

Most osteology textbooks and anatomy text refer to the carpals as being part of the structure of either the proximal or distal rows (White et al. 2012), with little to no mention of the carpals functioning as columns. In comparison, the literature in hand surgery journals also discuss the intra-relations of the proximal and distal rows with certain carpals forming columns between the two rows, where they discuss the functional aspects of carpals as columns are in relation to the scaphoid with the trapezium and the lunate with the capitate (Craigen and Stanley 1995; Freeman and Garcia-Elias 1997). The idea of the carpals functioning as columns is of interest in relation to the multivariate stepwise discriminant function results per carpals for both the right and left scaphoids and trapeziums. This interest is because only these two carpals used the exact same measurements to estimate sex for both the right and left sides. These two carpals together form a functional column with the radius and first metacarpal (Craigen and Stanley 1995; Freeman and Garcia-Elias 1997). The scaphoid's measurements were the maximum length of the radius facet and maximum width, while the trapezium's measurements were the maximum length and maximum length of the first metacarpal facet. The similarities between these two carpals' structure and function working in both separate rows and together as a column could be a possible reason why both carpals results in high multivariate stepwise discriminant function per carpal accuracy rates and why both carpals had measurements included in the combined multivariate stepwise discriminant function analyses.

Since there is currently only a small published body of literature referencing carpals functioning as columns, it cannot be said that there is causation between the function of these carpals forming columns and the similarities of the right and left side, but there is an interesting correlation present that needs to be further studied. Further research should be done to expand the limited knowledge in the literature of how the carpals function together as both rows and columns. With future research studies should expand to include the capitate to see if this correlation would also be seen in the column formed by the lunate and capitate.

It is possible that the reason why the scaphoid and trapezium had such high accuracy rates was due to their relationship with each other, functioning as a column. This is also a possible reason why both carpals had the repeated use of several measurements during testing.

Asymmetry

Traditionally, when measuring paired bones in individuals, if both bones are present and in good condition, it is standard to measure the left side rather than the right side (Buikstra and Ubelaker 1994). When using only the left side it is therefore assumed that the unmeasured right side will have similar measurements and in the end have similar accuracy rates. However, by running both sides separately in this project as a result of the significant asymmetry found, there were differing accuracy rates between the left and right sides. As expected the left side had higher accuracy rates in the majority of the multivariate stepwise discriminant function analyses. Unexpectedly in the univariate discriminant function analyses the right side had higher accuracy rates in a majority of the 34 measurements. Sixteen measurements had higher accuracy rates for the right side, 14 measurements had higher accuracy rates for the left side, and four measurements had the same accuracy rates regardless of side. Of interest correlating with this a majority of the asymmetry was also found on the right side. A possible explanation for both of these is that since a majority of the asymmetry was found in the male sample, this increased the differences in the means between the female and male sample, which also increased the accuracy rates for the right side.

A possibility for the higher accuracy rates on the left side in a majority of the multivariate tests could be due to a natural non-dominance of the left hand worldwide (Uomini 2009). Only approximately 15% of the world's population is left handed (Uomini 2009). Since the left hand is the non-dominant hand it would be less likely to have been culturally influenced size and structure.

There are additional possible reasons for the asymmetry found in this sample when compared to the previous three studies (Sulzmann et al. 2008; Mastrangelo et al. 2011a and 2011b). First is that the current sample is comprised of contemporary individuals similar to Mastrangelo et al.'s (2011a) Spanish sample and Mastrangelo et al.'s (2011b) Mexican sample, versus Sulzmann et al.'s (2008) historic London sample. However since there was significant asymmetry present similar to that found in Sulzmann et al.'s (2008) sample, a second possibility must also be considered.

The second possible reason for the significant asymmetry in the current sample might be related to population specificity. Both the contemporary American Whites and the historic British (Sulzmann et al. 2008) comprised of individuals who self-identified as having European ancestry. Compared to the work by Mastrangelo and co-authors (2011ab) samples which were of Spanish and Mexican ancestry. It is possible that both the current study's and Sulzmann et al.'s (2008) sample both had higher than average rates of individuals with significant asymmetry comprising the samples, then what would be normal for the population. Further study with multiple ancestry groups with larger samples sizes should be done to see if asymmetry can be found in other ancestry groups.

Limitations and Assumptions

It was assumed that the individuals comprising the sample were representative of the wider contemporary American White population. The number of individuals included in the sample was limited to the individuals who had all of the carpals present and in measurable condition. Individuals were not included in the sample if they were missing any of the right or left carpals. If any of the carpals had postmortem damage or pathologies that would prevent accurate measurements the individual was not included in the sample. Within the Texas State Donated Skeletal Collection individuals were most often cut from the sample because there were missing carpals, compared to individuals from the Bass Collection who were most often excluded from the sample because of postmortem damage or pathology. This difference between the collections was probably due to the difference in inventory methods and the environment in which the individuals decomposed. Most of the individuals who were excluded from the sample from the Texas State Donated Skeletal Collection were from the initial years of the founding of the collection. During this time the type of inventory sheet used did not record the carpals present. Also during this time chicken wire was not placed over the cages to prevent animal scavenging activity if an arm was too close to a side of the cage. Since the Bass Collection was already inventoried to show which individuals had missing carpals those individuals were not included on the list given as viable research subjects. As such individuals at the Bass Collection were only excluded from the sample due to postmortem wear damage or pathology.

The main limitations of the generalization that can be drawn from this study are due to the fact that not all of the carpals were used in the study. This affects the generalization about the distal row since only two of the four carpals were measured, compared to three of the four carpals measured from the proximal row. Also affected are the generalizations drawn from the multivariate stepwise discriminant analyses per carpal, since the right scaphoid and left lunate and hamate could not be analyzed at this point. Future research should include the capitate and trapezoid in order to have a fuller understanding of the biomechanics of the carpus.

CHAPTER 5

CONCLUSION

This study confirms that using carpal measurements to estimate the sex of individuals is a valid method of estimating sex, with accuracy rates on par with more traditional methods using postcranial elements. While the results of this study were not what were fully expected for the accuracy rates of each carpal, they did show that the carpals can be used to estimate the sex of individuals of American White ancestry. Estimating the sex of individuals using the carpals was possible because the measurements designed by Sulzmann et al. (2008) were significantly sexually dimorphic in size.

The analysis of the carpal measurements showed that as individual carpals, the left scaphoid and right trapezium had the highest pooled accuracy rates, at 88.75% on the left. It was unexpected was that the right lunate had the lowest accuracy rates at 82.5%. The predictions and expectations for this study were based on the biomechanics of the structure of the carpus (Mastrangelo et al. 2011b). However based on the finding of this research it would be better to broaden future studies to include a functional analysis of the carpus.

Since the current research was done using a contemporary sample of American

White individuals the methods and results of this research discussed above can have practical application for estimating the sex of modern individuals of European ancestry. The method discussed can be quickly used with minimal osteometric equipment (sliding caliper) that forensic anthropologists and bioarchaeologists have on hand in the laboratory or field for preliminary analysis.

Ultimately, if a researcher is able to measure the scaphoid of either side, they will be able to estimate sex with an accuracy rate comparable to traditional methods using the pelvis.

The reason to expand the analysis of the carpus to a structural-functional approach is that recent research in biomechanics of the carpals suggests the range of motion and interaction between carpals is greater than traditionally thought (White 2012). Current focuses are on re-analyzing the scaphoid, lunate, and trapezium, but should be expanded in the future to include the other five carpals.

Future studies should utilize a larger sample sizes. Ideally an equal ratio of male to females with measureable carpals should be used. Additionally, the methods should be expanded to include the measurements of the capitate and trapezoid. These carpals should be included based on the observations that the carpals act not only as rows but also as columns at times. Lastly, future studies should be done using more than one ancestral group as the sample. By including more than one ancestral group in the sample research can be done to see how dependent the carpal measurements are to ancestry in this discriminant function.

The results of this research demonstrate that in an American White sample the carpals can be used to estimate sex of unknown individuals. Osteologists who have access to the scaphoid, hamate, or trapezium can use them to estimate sex with high accuracy rates, either alone as single elements or as part of a suite of sex estimation methods. This research can be used for quick field assessments and when the remains are too fragmentary for traditional methods with the skull, pelvis, or long bone.

APPENDIX A:

Definitions of Measurements (Sulzmann et al. 2009)

Lunate:
Maximum Length: Place the two ‘horns’ flat against one of the caliper arms and then close the other caliper arm on the most extended point on the rounded medial side.

Maximum Width: Place the caliper arms on the projecting palmar and dorsal points of the horns. Move the caliper arms, pivoting on the most palmar and dorsal points of the carpal, until the maximum height is gained.

Maximum Width of the Dorsal Horn: Hold the lunate on a dorsal view and place the caliper arms on the most projecting proximal and distal points either side of the dorsal horn, keeping the most lateral and medial points in a vertical plane with the caliper arms.

Maximum Width of Triquetral Facet: Place one caliper arm against the most projecting point of the triquetral facet on the medial rounded edge and then place the other horizontally across from that point laterally where the hamate facet meets the triquetral facet.

Height of Triquetral Facet: Orientate the calipers so that the maximum height of the facet is gained; from the base (palmar direction) to the top of the facet (dorsal direction).

Scaphoid:
Maximum Length: Place the tip of the tubercle against one caliper arm and the medial lunate facet against the other and then rotate the calipers until the maximum length is gained.

Maximum Width: Place the caliper arms against the most projecting points either side of the scaphoid body and rotate the caliper arms until the maximum width is gained.

Maximum Length of Radius Facet: Measured from the medial base of the body where the lunate articulates to the top of the radius facet laterally near the tubercle. Rotation is not usually required for this measurement.

Maximum Length of Scaphoid Tubercle: Place one caliper arm against the tip of the tubercle and the other against the ascending point of the tubercle, where it meets the capitate facet. The observer must turn the scaphoid on to its side and measure from the crest of the tubercle near the capitate facet to the most projecting end of the tubercle.

Maximum Length of Capitate Facet:: Orientate the calipers so that they give the maximum length of the facet. Measured from the highest part of the rim of the facet at the medial base of the body to the highest part of the lateral rim near the tubercle. If the edge of the rim is not clear then the observer should angle the scaphoid in increase the clarity of the landmarks.

Maximum Width of Capitate Facet: Place the caliper arms so that they are on either side of the facet at the maximum points, perpendicular to the length of the scaphoid. The measurement is taken usually in the middle of the facet; however, individual variation can complicate the taking of this measurement. In most scaphoids, the widest point of the facet is in the middle, however in some cases, the widest point is at the base of the facet near the lunate facet. Regardless of the variation in the capitate facet shape, the widest measurement is always taken.

Triquetral:

Maximum Length: Orientate the calipers so that the maximum length of the carpal is gained; place one caliper arm against the most projecting proximal point near the lunate facet and the other arm near the top of the pisiform facet distally. Rotation of the calipers may be required to gain the maximum length.

Maximum Height: Place the lunate facet flat against one arm of the calipers and the most projecting point thereafter against the other arm. No rotation of the caliper arms is required for this measurement.

Maximum Width: Place the palmar pisiform facet flat against one caliper arm and the most projecting dorsal point thereafter against the other arm. Rotation of the caliper arms may be required to obtain the maximum width.

Maximum Length of Lunate Facet: Orientate the calipers so that the maximum length of the facet is obtained by placing caliper arms on the palmar to dorsal rims of the facet. Often, particularly in females, the facet border was not well defined, so the observer should angle the carpal to observe the rim of the facet to measure.

Maximum Width of Lunate Facet: Orientate the calipers so that the maximum width of the facet is obtained by placing the caliper arms on the medial rim (which connects to the hamate facet) and the lateral rim of the facet. Like measurement (d) the observer may have to angle the carpal to observe the rim of the facet if the border cannot be seen.

Maximum Length of Pisiform Facet: Place the caliper arms on the most projecting points of the facet, normally in a diagonal plane.

Maximum Width of Pisiform Facet: Place the caliper arms on the most projecting points of the facet in the horizontal plane.

Maximum Height of Hamate Facet: Orientate the calipers so that one arm is on the border between the lunate and hamate facets and the other is at the distal peak of the hamate facet to obtain maximum height.

Maximum Width of Hamate Facet: Place one caliper arm against the most projecting dorsal point of the facet and place the other arm against the point horizontal from the first arm, on the palmar side, where the facet ends.

Hamate:
Maximum Height: Place the dorsal base of the hamate flat against one arm of the calipers then place the other arm on the highest palmar point of the hamulus. The dorsal base of the hamate can often be undulating, however, by adjusting the placement of the calipers the observer can measure the maximum height at all times.

Maximum Width: Place the most projecting point of the palmar hamulus and the dorsal base of the hamate against one arm of the calipers and the place the other arm against the most projecting proximal point.

Height of the Body: With the capitate facet facing towards you place one arm on the dorsal base of the hamate and the other arm on the highest point of the body excluding the hamulus. This measurement was designed to be taken if the hamulus was missing and measurement (a) and (b) could no longer be taken.

Maximum Width of the Hamulus: Place the caliper arms on either side of the widest points of the hamulus. Rotate the calipers to gain the maximum width.

Maximum Width of the Distal Facets: orientate the calipers from the medial rim of metacarpal V facet to the lateral rim of metacarpal IV facet so that the maximum width of the two facets is obtained.

Height of the Fifth Metacarpal Facet: Place one arm of the calipers at the top of the metacarpal V facet nearest the palmar hamulus and the other arm at the bottom of the facet near the dorsal side.

Height of Fourth Metacarpal Facet: Place one arm of the calipers at the top of the metacarpal IV facet, at the top of the body (palmar side) and the other arm at the bottom of the facet (dorsal side).

Trapezium:
Maximum Length: Place one caliper arm against the most projecting distal point of the metacarpal II facet and the other against the projecting proximal point of the palmar ridge to obtain maximum length.

Maximum Height: Hold the trapezium so that the metacarpal I facet is superior, then place one caliper arm on the superior point at the top of the metacarpal I facet and the other on the most inferior point where the trapezoid and the scaphoid facets meet.

Maximum Length of the First Metacarpal Facet: Orientate calipers so the maximum length is obtained; place one arm on the edge of the facet near the distal metacarpal II facet and the other arm on the opposite side of the most projecting point. Rotation of the trapezoid may be necessary.

Maximum Width of First Metacarpal Facet: Place the caliper arms against the widest point s of the facet, which is normally at the proximal end of the trapezium.

Maximum Length of Trapezoid Facet: Place one caliper arm against the most projecting edge of the trapezoid facet near the distal metacarpal II facet and the other at the furthest proximal palmar edge, on the border between the trapezoid and scaphoid facet.

Maximum Length of Trapezoid and Scaphoid Facets: Place the caliper arms on the most projecting points of the trapezoid facet near the distal metacarpal II facet and proximal edge of the scaphoid facets. Rotation of the trapezium may be required.

Width of Scaphoid Facet: Place one caliper arm on the border between the trapezoid facet and the scaphoid facet and the other arm on the most projecting proximal point of the facet opposite.

APPENDIX B:

Descriptive statistics and independent t-test for ech measurement.

Variable	Right								Left							
	Female		Male		Total				Female		Male		Total			
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	T	Sig. (2-tailed)	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	T	Sig. (2-tailed)
Lunate																
ML	16.58	1.08	19.03	1.81	17.81	1.93	-7.365	0.000	16.42	1.16	18.98	1.55	17.55	1.77	-7.384	0.000
MW	16.58	1.10	18.71	1.39	17.64	1.64	-7.620	0.000	16.44	1.10	18.52	1.32	17.48	1.60	-7.626	0.000
MWDH	11.93	0.82	13.66	1.19	12.79	1.34	-7.576	0.000	11.85	0.68	13.53	1.13	12.69	1.25	-8.031	0.000
MWTF	9.29	0.92	9.93	1.14	9.61	1.08	-2.766	0.007	9.39	0.96	10.28	0.94	9.84	1.05	-4.207	0.000
HTF	8.63	0.91	9.38	0.98	9.00	1.01	-3.542	0.001	8.57	0.91	9.19	0.84	8.88	0.92	-3.174	0.002
Scaphoid																
ML	24.83	1.86	28.80	2.42	26.81	2.93	-8.234	0.000	24.72	1.77	28.62	2.37	26.67	2.85	-8.324	0.000
MW	15.02	1.03	17.42	1.45	16.22	1.74	-8.511	0.000	15.02	1.08	17.06	1.34	16.04	1.59	-7.431	0.000
MLRF	16.16	1.01	18.92	1.49	17.54	1.88	-9.699	0.000	16.19	1.15	18.84	1.47	17.51	1.87	-8.938	0.000
MLST	14.73	1.67	17.58	2.11	16.16	2.37	-6.706	0.000	14.73	1.66	17.47	2.13	16.10	2.34	-6.400	0.000
MLCF	14.15	1.12	15.84	1.42	14.99	1.53	-5.908	0.000	13.99	1.25	15.77	1.52	14.88	1.65	-5.723	0.000
MWCF	10.67	0.99	12.53	1.27	11.60	1.47	-7.280	0.000	10.86	1.19	12.39	1.13	11.63	1.38	-5.861	0.000
Triquetral																
ML	17.75	1.33	19.64	1.40	18.69	1.66	-6.177	0.000	17.76	1.18	19.69	1.47	18.73	1.64	-6.486	0.000
MH	14.89	1.20	16.57	1.13	15.73	1.44	-6.432	0.000	14.75	1.15	16.54	1.27	15.65	1.50	-6.585	0.000
MW	14.42	1.25	15.97	1.59	15.19	1.62	-4.866	0.000	14.39	0.79	15.63	1.30	15.01	1.24	-5.109	0.000
MLLF	8.63	0.71	9.51	0.78	9.07	0.86	-5.253	0.000	8.70	0.71	9.68	0.67	9.19	0.84	-6.319	0.000
MWLF	7.16	0.76	8.03	0.84	7.60	0.91	-4.906	0.000	7.06	0.79	8.24	1.08	7.65	1.11	-5.518	0.000
MLPF	9.76	1.03	11.29	1.06	10.53	1.29	-6.531	0.000	9.60	0.78	11.19	1.16	10.39	1.27	-7.171	0.000
MWPF	7.80	1.10	8.89	0.87	8.35	1.13	-4.937	0.000	7.63	0.92	8.84	1.17	8.24	1.21	-5.129	0.000

MHHF	13.08	0.95	15.04	1.07	14.06	1.41	-8.636	0.000	13.24	0.92	15.06	1.14	14.15	1.37	-7.824	0.000
MWHF	10.48	1.00	11.59	1.13	11.22	1.12	-3.150	0.002	10.84	1.00	11.68	0.93	11.26	1.05	-3.868	0.000
Hamate																
MH	21.28	1.36	24.18	1.53	22.73	2.05	-8.961	0.000	21.46	1.16	24.02	1.69	22.74	1.93	-7.887	0.000
MW	19.89	1.20	22.91	1.76	21.40	2.13	-8.952	0.000	19.84	1.24	22.57	1.78	21.20	2.05	-7.949	0.000
HB	13.13	0.80	14.83	0.97	13.98	1.23	-8.560	0.000	13.33	0.90	15.10	0.88	14.22	1.25	-8.867	0.000
MWH	9.73	1.42	11.65	1.59	10.69	1.78	-5.716	0.000	9.69	1.19	11.41	1.58	10.55	1.64	-5.466	0.000
MWDF	14.38	1.13	16.37	1.41	15.38	1.62	-6.986	0.000	14.11	1.06	15.74	1.23	14.92	1.40	-6.301	0.000
HM(V)F	9.93	0.77	11.44	0.81	10.69	1.09	-8.579	0.000	9.65	0.74	11.24	0.80	10.44	1.11	-9.165	0.000
HM(IV)F	10.28	0.91	11.87	1.10	11.07	1.28	-7.039	0.000	10.15	0.96	11.69	0.94	10.92	1.22	-7.188	0.000
Trapezium																
ML	22.39	1.27	25.35	1.38	23.87	1.99	-9.967	0.000	22.14	1.22	25.08	1.49	23.61	2.00	-9.610	0.000
MH	15.62	1.09	17.63	1.27	16.62	1.55	-7.588	0.000	15.40	1.02	17.46	1.24	16.43	1.53	-8.092	0.000
MLM(I)F	13.42	1.05	15.45	1.25	14.44	1.53	-7.862	0.000	13.15	0.91	15.22	1.13	14.19	1.45	-9.014	0.000
MWM(I)F	10.96	0.79	12.20	0.90	11.58	1.05	-6.574	0.000	10.62	0.67	11.78	0.87	11.20	0.97	-6.571	0.000
MLTF	12.19	1.50	13.72	1.56	12.95	1.70	-4.472	0.000	11.66	1.53	12.99	2.21	12.32	2.00	-3.120	0.003
MLTSF	16.32	1.36	18.77	1.67	17.55	1.95	-7.195	0.000	16.03	1.55	18.17	1.62	17.10	1.91	-6.012	0.000
WSF	8.19	1.03	9.62	1.07	8.90	1.27	-6.123	0.000	8.39	0.95	9.27	1.12	8.83	1.12	-3.740	0.000

APPENDIX C:

Univariate sectioning points and accuacy rates for each measurement.

	Right				Left			
Measurement	Sectioning Point	Female	Male	Total	Sectioning Point	Female	Male	Total
Lunate								
ML	17.80	90%	70%	80%	17.55	80%	77.5%	78.75%
MW	17.64	87.5%	85%	86.25%	17.48	82.5%	85%	83.75%
MWDH	12.79	80%	75%	77.5%	12.69	85%	75%	80%
MWTF	9.61	35%	60%	47.5%	9.83	67.5%	70%	68.75%
HTF	9.00	37.5%	65%	51.25%	8.88	65%	65%	65%
Scaphoid								
ML	26.81	87.5%	77.5%	82.5%	26.67	87.5%	80%	83.75%
MW	16.22	85%	77.5%	81.25%	16.04	80%	75%	77.5%
MLRF	17.54	90%	82.5%	86.25%	17.51	92.5%	85%	88.75%
MLST	16.15	82.5%	70%	76.25%	16.10	85%	70%	77.5%
MLCF	14.99	75%	75%	75%	14.88	80%	67.5%	73.75%
MWCF	11.60	80%	75%	77.5%	11.62	75%	75%	75%
Triquetral								
ML	18.69	75%	75%	75%	18.72	77.5%	90%	83.75%
MH	15.73	80%	82.5%	81.25%	15.64	80%	75%	77.5%
MW	15.19	75%	65%	70%	15.01	80%	67.5%	73.75%
MLLF	9.07	75%	70%	72.5%	9.19	77.5%	75%	76.25%
MWLF	7.59	72.5%	70%	71.25%	7.65	80%	70%	75%
MLPF	10.52	77.5%	75%	76.25%	10.39	82.5%	77.5%	80%
MWPF	8.34	67.5%	80%	73.75%	8.23	77.5%	70%	73.75%
MHHF	14.06	85%	82.5%	83.75%	14.15	80%	82.5%	81.25%
MWHF	11.21	70%	60%	65%	11.26	62.5%	65%	63.75%
Hamate								
MH	22.73	87.5%	82.5%	85%	22.74	85%	80%	82.5%

MW	21.40	85%	75%	80%	21.20	75%	75%	75%
HB	13.98	92.5%	77.5%	85%	14.21	82.5%	87.5%	85%
MWH	10.69	80%	77.5%	78.75%	10.55	72.5%	67.5%	70%
MWDF	15.37	77.5%	75%	76.25%	14.92	77.5%	80%	78.75%
HM(V)F	10.68	85%	75%	80%	10.44	87.5%	80%	83.75%
HM(IV)F	11.07	80%	82.5%	81.25%	10.92	80%	75%	77.5%
Trapezium								
ML	23.87	87.5%	82.5%	85%	23.61	87.5%	77.5%	82.5%
MH	16.62	87.5%	77.5%	82.5%	16.46	87.5%	77.5%	82.5%
MLM(I)F	14.43	85%	85%	85%	14.18	87.5%	85%	86.25%
MWM(I)F	11.58	85%	80%	82.5%	11.20	77.5%	65%	71.25%
MLTF	12.95	67.5%	67.5%	67.5%	12.32	65%	57.5%	61.25%
MLTSF	17.54	80%	70%	75%	17.10	77.5%	72.5%	75%
WSF	8.90	67.5%	75%	71.25%	8.83	62.5%	65%	63.75%

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