2019

Sex Determination Using Discriminant Function Analysis of Carpals from Maya Sites in Belize from Pre-Classic to Spanish Colonial Period

Michelle D. Labbe
University of Central Florida

SEX DETERMINATION USING DISCRIMINANT FUNCTION ANALYSIS OF CARPALS FROM MAYA SITES IN BELIZE FROM PRE-CLASSIC TO SPANISH COLONIAL PERIOD

by

MICHELLE LABBE

A thesis submitted in partial fulfillment of the requirements
for the Honors in the Major Program in Anthropology
in the College of Sciences
and in The Burnett Honors College
at the University of Central Florida
Orlando, Florida

Summer Term, 2019

Thesis Chair: Lana Williams, Ph.D.

ABSTRACT

The sexing of human skeletal remains is important for identification and demographic purposes. It is made more difficult when elements such as the skull and pelvis are not recovered or are in too poor of a condition to assess. Previous studies have used carpal (wrist) bones of contemporary populations to assess the viability of these skeletal elements exhibiting sexual dimorphism, as these bones are small, compact elements that are usually recovered in good condition. This study evaluates the use of carpal bones recovered from an ancient Maya population from Belize to determine the biological sex of individuals. The study sample is part of the Maya Archaeological Skeletal Collection (MASC), which contains individuals from the sites of Lamanai, San Pedro, Altun Ha, and Marco Gonzalez and dates from the Late Maya Pre-Classic (400 BC-AD 250) to the Spanish Colonial period (AD 1521-1821). Multiple measurements were taken on 36 capitate, 34 lunate, 34 scaphoid, 27 trapezium, 24 hamate, 22 triquetral, 22 trapezoid, and 16 pisiform bones from several individuals. Discriminant function analysis was used to determine if sexual dimorphism is measurable in this population using these elements. Previous studies used populations with known identities, assessing individuals from crypts, graveyards, or medical collections from the last few centuries. This study varies from previous studies as it utilizes archaeological remains, making this study one of the first to evaluate non-contemporary remains with unknown sex. Results of this study demonstrate that this population exhibits sexual dimorphism and discriminant function analysis can be used to distinguish between two groups. This demonstrates that carpals could be used to help determine biological sex of archaeological populations as well as a tool to help with identification in forensic cases.

ACKNOWLEDGEMENTS

I would like to thank my thesis chair, Dr. Lana Williams, for opening the door to research for me at the University of Central Florida. I would also like to thank Dr. Sandra Wheeler for agreeing to be on my committee. Both Dr. Williams and Dr. Wheeler guided this process by giving advice, critique, and support to bring this project to completion. Not only did they help me learn how to navigate the research process, but also helped me understand how to take a specific idea and broaden its potential impact to other disciplines.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The ability to determine the biological sex of an individual from skeletal remains is an important step in identification for forensic cases and is important culturally and demographically for bioarcheological instances (Sulzmann et al., 2008; Mastrangelo et al., 2011a; Mastrangelo et al., 2011b; Didi et al., 2016). The possibility for identification increases two-fold if the sex can be determined first. Further, information such as age and stature are best attained from methods that account for sexual dimorphism (Didi et al., 2016). Identification of the sex of skeletal remains depends on the elements available. Sex assessment can be almost 100% accurate if the cranium and pelvis are both available and in good condition (Sulzmann et al., 2008; Mastrangelo et al., 2011a; Mastrangelo et al., 2011b). When one or more of these elements are missing, or are too degraded and damaged to assess, the accuracy of sex assessment decreases.

Dense, small bones such as tarsals and carpals have been shown to preserve better in archaeological situations as opposed to larger or longer bones (Hoover and Berbesque, 2018). Recent studies working with tarsals, metatarsals, and metacarpals have shown that these elements exhibit sexual dimorphism and can be assessed to determine biological sex (Sulzmann et al., 2008; Mastrangelo et al., 2011a; Mastrangelo et al., 2011b). That carpals are often recovered intact and in good condition in both forensic and archaeological contexts, as well as the sexual dimorphism exhibited in other elements of the hands and feet were two factors important to Sulzmann et al. (2008) in deciding to assess sex using only the carpal bones.

The measurements used to assess sexual dimorphism are based on variation within a population, meaning the application of discriminant function analysis is limited to the specific

population being worked with (Sulzmann et al., 2008; Mastrangelo et al., 2011a; Mastrangelo et al., 2011b). General sexual dimorphism observed by robusticity or gracility depend on regional populations (Mastrangelo et al., 2011a; Mastrangelo et al., 2011b). Factors specific to a population that can affect the carpals and sexual asymmetry can include nutrition, disease, technology, socioeconomic status, division of labor, and population mobility (Mastrangelo et al., 2011a; Mastrangelo et al., 2011b; Hoover and Berbesque, 2018). For this reason, it is important to have population specific formulae.

Previous studies (Sulzmann et al., 2008; Mastrangelo et al., 2011a; Mastrangelo et al., 2011b) of sex determination from carpals used populations with known identities, examining individuals from crypts, graveyards, or medical collections from the last few centuries. This study varies from previous studies as it utilizes archaeological remains, making this study one of the first studies to evaluate non-contemporary remains with unknown identities other than their population of origin. It is also one of the first studies to use archaeological remains for this specific purpose.

My research question was:

Do results from discriminant function analysis suggest that sexual dimorphism in carpals can be identified in the studied population?

The goal of this study is to assess carpal bones within the Maya Archaeological Skeletal Collection (MASC) to determine if there is sexual dimorphism. The collection is comprised of skeletal remains from four sites in Northern Belize: Altun Ha, Lamanai, Marco Gonzalez, and San Pedro. Specimen dates range from Late Maya Pre-Classic (400 BC-250 AD) to the Spanish Colonial period (AD 1521-1821). The measurements assessed on the carpals in this study were

the same measurements used by Sulzmann et al. (2008) and Mastrangelo et al. (2011a; 2011b) for their discriminant function analysis. In the course of measuring each carpal, qualitative data was collected to consider trauma, pathological conditions, and other anomalies that could affect the discriminant function analysis results.

LITERATURE REVIEW

The method of using carpals for sex determination relies on the sample of individuals being specific to a single population. Sulzmann et al. (2008) first developed the discriminant function analysis method of sex determination using carpals and Mastrangelo et al. (2011a; 2011b) adopted this methodology to analyze two different populations. Similar methods have been used by Hoover and Berbesque (2018) and Kivell et al. (2013) but each with different questions being explored and different formulae applied. Other methods, such as the use of Multi Detector Computed Tomography (Didi et al., 2016) and Registration-Based Morphology (Joshi et al., 2016) used the Sulzmann et al. (2008) method, in part, to ascertain the sexual dimorphism of the group.

In addition to the small number of studies that have employed this method, the time period of the populations tested should also be a factor considered in the methodology. The Sulzmann et al. (2008) sample contained individuals from 18th and 19th century London, England. All individuals were from a church crypt. Mastrangelo et al. (2011a) analyzed a sample of 20th century Spaniards from a cemetery, while Mastrangelo et al.(2011b) analyzed a sample of 20th century individuals from Mexico City, Mexico. The Mexico City individuals were in a skeletal collection formed from medical cadavers. Hoover and Berbesque (2018) used similar methods while studying a population of Early Archaic individuals (6,800-5,200 ya) from the St. John's River area of Florida. These bodies were naturally preserved after being buried in a bog.

The population used in this study is curated at the University of Central Florida in the Anthropology Department. This skeletal collection contains individuals from the ancient Belize Maya sites of Lamanai, Altun Ha, San Pedro, and Marco Gonzalez (Figure 1).

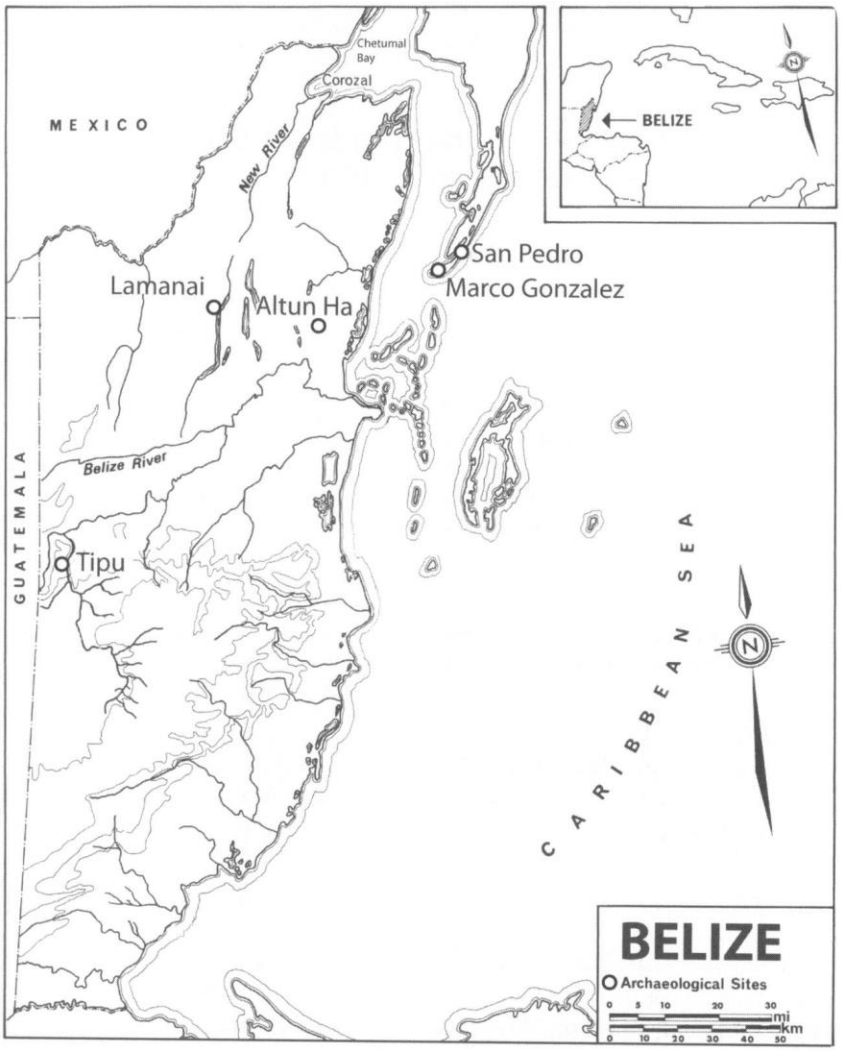


Figure 1. Belize map of Maya sites. This map shows the locations of ancient Maya sites associated with skeletal remains of individuals housed in the collection used in this study.
Source: Williams, J., White, C., Longstaffe, F. (2009) Maya Marine Subsistence: Isotopic Evidence from Marco Gonzalez and San Pedro, Belize. *Latin America Antiquity*, 20(1), p 18. Retrieved from http://www.jstor.org/stable/40650075

The climate of the mainland and islands of Northern Belize, where these sites are located, is not ideal for preservation of archaeological skeletal remains. The climate and geography ranges from humid, to tropical, with punctuated areas of wetlands (Evans, 2013). In addition to the less than ideal climate for preservation, the ancient Maya were known to build on top of already existing

settlements and structures (Evans, 2013). This has often resulted in incomplete, previously damaged, or scattered skeletal remains being recovered, all of which have also undergone taphonomic degradation from the environment. Previous research has indicated carpals, and bones with similar characteristics, are more likely to survive intact and in fair condition as opposed to a skull or long bones (Sulzmann et al., 2008; Mastrangelo et al., 2011a; Mastrangelo et al., 2011b). Therefore, particularly with these types of conditions, using carpals as a method of sex determination with this archaeological population instead of, or in conjunction with, other methods that rely on larger elements that may not be as well preserved, is well justified.

MATERIALS AND METHODS

The sample for this study is comprised of carpals from individuals recovered from three sites in Northern Belize: Lamanai, Marco Gonzalez, and San Pedro. Individuals range in date from the Late Maya Pre-Classic (400 BC-250 AD) to the Spanish Colonial period (AD 1521-1821). San Pedro and Marco Gonzalez are located on the Ambergis Cay, an island off the coast of Belize (Williams et al., 2009). Marco Gonzalez is more southern and closer to the mainland than San Pedro (Figure 1). Excavations at this site indicate it was occupied from the Late Pre-Classic to the Late Post-Classic (100 BC-1350 AD) and had extensive trade with distant communities based on artifacts and architecture recovered (Williams et al., 2009). San Pedro was known to be occupied from the Terminal Post-Classic to the Historic period (AD 1400-1650) and was likely a small fishing town with little socioeconomic status differentiation based on a lack of monumental architecture or grave goods (Williams et al., 2009). Lamanai is a distinct site because of its long continuous occupation starting in the Late Pre-Classic and continuing through the Spanish colonization (400 BC-1821AD) (Loten, 1985). Pottery and architecture have been unearthed as evidence of this long occupation as well as a church that was desecrated in 1640 AD providing additional evidence that the Maya still occupied this area even after the initial Spanish colonization (Loten, 1985; Pendergast, 1981). Lamanai is positioned at the edge of the New River lagoon making trade by waterway easily accessible and a likely variable in the continuous occupation of this site (Pendergast, 1981; Williams et al., 2009).

The carpals used in this study were first separated out from other skeletal remains in the Maya Archaeological Skeletal Collection. For this studies purpose, only carpals from adults were used. The selected samples, though catalogued with unique identifiers, did not guarantee all

elements of that identifier belonged to the same wrist or the same individual. Archaeological contexts often included multiple individuals buried in one area collected under the same identifier. Only samples from Lamanai and San Pedro with one additional specimen from Marco Gonzalez were preserved well enough for use in the study. All carpals were represented though sample size varied (Table 1). Measurements were assessed on all of these bones but not every measurement could be attained on every bone due to the variable states of preservation.

Table 1. The specific number of carpals from each site.

	San Pedro	Lamanai	Marco Gonzalez	Total Combined
Lunate	10	24	--	34
Scaphoid	9	25	--	34
Triquetral	7	15	--	22
Capitate	9	27	--	36
Hamate	10	14	--	24
Pisiform	4	12	--	16
Trapezium	8	18	1	27
Trapezoid	10	11	1	22

The specific carpal is listed in the left column while the Maya site is listed on the top row.

The discriminant function analysis developed by Sulzmann et al. (2008) and Mastrangelo et al. (2011a; 2011b) was used to assess sexual dimorphism. Quantitative data was collected using a set of Tengyes IP54 digital calipers. The measurements collected were the same as those collected by Mastrangelo et al. (2011a; 2011b). Figures 2, 3 and 4 show a range of the type of measurements taken. Appendix C contains figures with the measurements assessed on all eight carpals. Notes regarding the condition of the bones were recorded when warranted. These included the chipping and breaking of the bone, if there was any remaining matrix that could not be removed without causing damage, and any other anomalies that affected measurements.

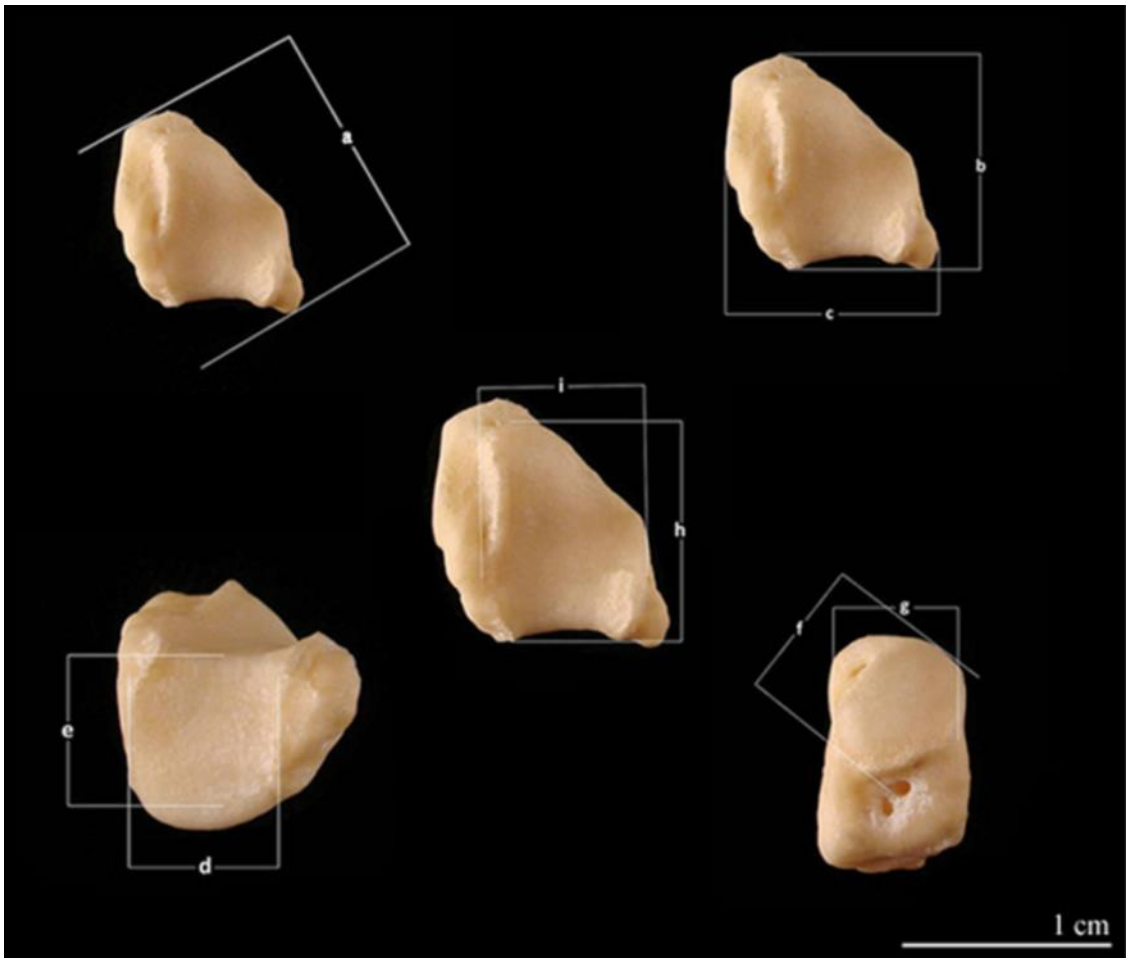


Figure 2. Triquetral measurements. The measurements assessed were: a, maximum length; b, maximum height; c, maximum width; d, maximum length of lunate facet; e, maximum width of lunate facet; f, maximum length of pisiform facet; g, maximum width of pisiform facet; h, maximum height of hamate facet; and i, maximum width of hamate facet.

Source: Mastrangelo, P., De Luca, S., Sanchez-Mejorada, G. (2011b). Sex Assessment from Carpal Bones: Discriminant Function Analysis in a Contemporary Mexican Sample. *Forensic Science International*, 209(196), 196.e1-196.e15. Doi:10.1016/j.forsciint.2011.04.019

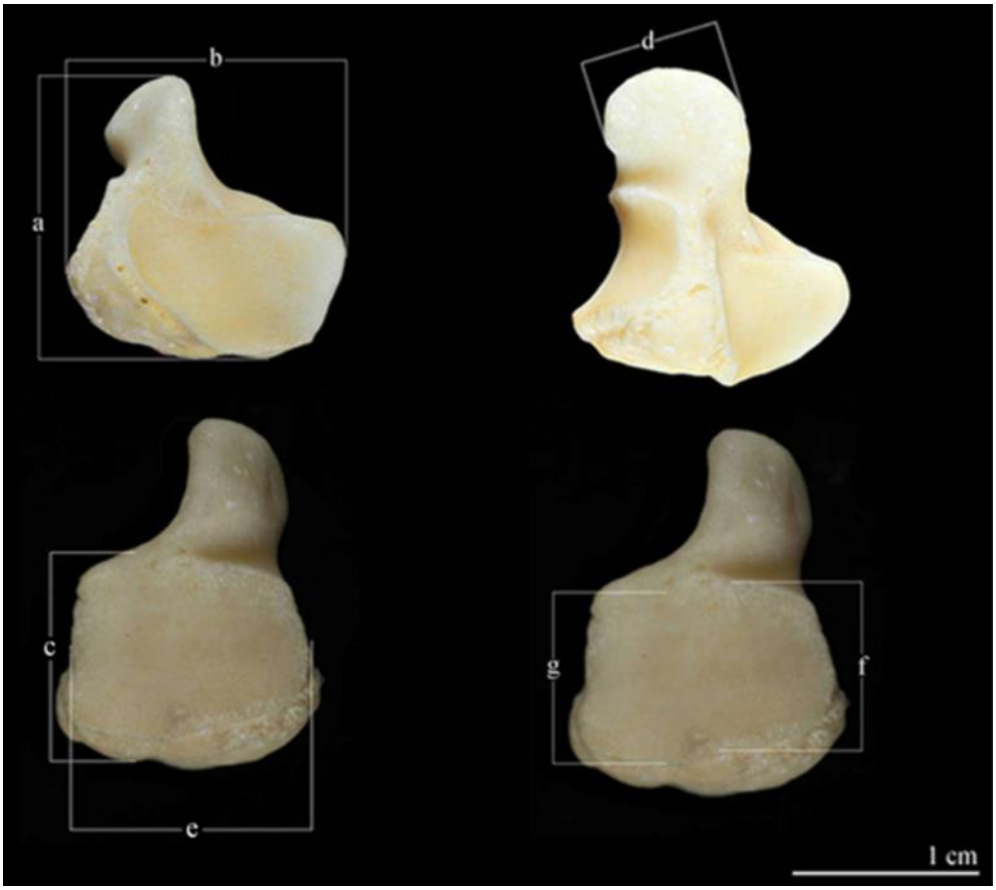


Figure 3. Hamate measurements. Measurements assessed on the hamate were: a, maximum height; b, maximum width; c, height of the body; d, maximum width of the hamulus; e, maximum width of the distal facets; f, height of metacarpal 5 facet; and g, height of metacarpal 4 facet.
Source: Mastrangelo, P., De Luca, S., Sanchez-Mejorada, G. (2011b). Sex Assessment from Carpal Bones: Discriminant Function Analysis in a Contemporary Mexican Sample. *Forensic Science International*, 209(196), 196.e1-196.e15. Doi:10.1016/j.forsciint.2011.04.019

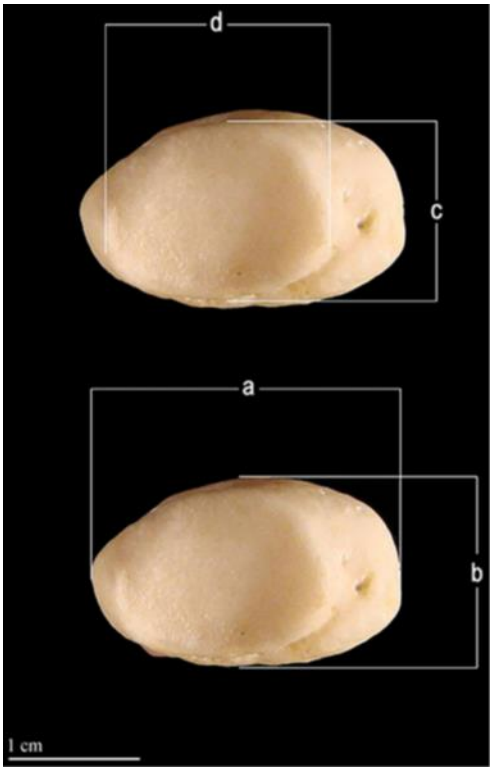


Figure 4. Pisiform measurements. The measurements assessed on the pisiform were: a, maximum length; b, maximum width; c, height of triquetral facet; and d, width of triquetral facet.
Source: Mastrangelo, P., De Luca, S., Sanchez-Mejorada, G. (2011b). Sex Assessment from Carpal Bones: Discriminant Function Analysis in a Contemporary Mexican Sample. *Forensic Science International*, 209(196), 196.e1-196.e15. Doi:10.1016/j.forsciint.2011.04.019

Examples of specimens that were measured in this study and the variation of chipping and breakage can be seen in Figures 5, 6, and 7. In the course of measuring each carpal, additional qualitative data was also collected to evaluate trauma, pathological conditions, and other anomalies that could be related to biomechanics of the wrist (e.g., task-related repetitive motions) and might therefore affect the outcome of the discriminant function analysis.

Figure 5. A triquetral used in this study with chipping of a facet circled in red.

Figure 6. A hamate used in this study with damage circled in red.

Figure 7. A trapezium used in this study with chipping of a facet circled in red.

A paired t-test was used to assess intra-observer error to check that the measurements used were reliably duplicated. To do this test, a random sample of 11 sets of measurements were remeasured at a later date. These paired measurements were then run through a paired t-test in SPSS 24 to check for the significance of the difference between measurements. P was set to greater than 0.05.

The data for each bone was input into SPSS 24. A discriminant function analysis was run to determine if there was sexual dimorphism in the population. The program assessed the data and a discriminant function for each specimen was produced. Other result statistics yielded were a constant and unstandardized coefficients which are placed into the formula:

$$Y=a + (b_1x_1) + (b_2x_2) \ldots (b_nx_n)$$

In this formula, '*a*' is the constant, '*b*' is the specific measurement, '*x*' is the coefficient for that measurement, and '*Y*' is the discriminant score. The discriminant score, when averaged for each group, gives a group centroid. The demarking point is the average of these two centroids. The

further away from the demarking point the individual discriminant function score is, the higher the probability that a specific bone belongs to that grouping.

The majority of the individuals in the sample were not identified as male or female. The grouping was therefore done by a sum of the measurements for each carpal. Any specimens that had missing measurements were removed from further analysis to prevent potential outliers. The individuals that were known were grouped accordingly, the rest were split by this sum of measurements with the smaller sums being grouped as female and the larger sums as male. This was in accordance with the findings of Mastrangelo et al. (2011a; 2011b) that, on average, female carpals were smaller than males. The discriminant function analysis returned an accuracy percentage based on this initial grouping. The greater the accuracy percentage, the better discerning that specific carpal was for detecting sexual dimorphism in this population.

RESULTS

The purpose of this study was to determine if sexual dimorphism is present in this population and if discriminant function analysis, using the same carpal measurements used by Sulzmann et al. (2008) and Mastrangelo et al. (2011a; 2011b), can produce a formula to separate this dimorphism. The first step in this analysis was to make sure the method of measurements could be reasonably duplicated. To evaluate this, a paired t-test was performed and the results are shown in Tables 2-9 below.

Table 2. Lunate paired t-test results.

Measurement	Pairing	N	Mean	Standard Deviation	Standard Error Mean	t	Sig. (P)
LunL	Original	5	16.9660	1.13074	0.50568	-1.621	0.180
	Second		17.7320	1.80487	0.80716		
LunW	Original	5	17.8440	0.80451	0.35979	-1.179	0.304
	Second		18.0780	0.81122	0.36279		
LunWDoH	Original	5	11.8820	0.81910	0.36631	-1.750	0.155
	Second		12.2000	0.67268	0.30083		
LunWTF	Original	5	11.3120	4.40453	1.96976	0.862	0.437
	Second		9.6820	0.99886	0.44670		
LunHTF	Original	5	9.2940	0.53210	0.23796	-0.792	0.472
	Second		9.5300	0.19339	0.08649		

The P-value (P>0.05) indicates that none of the lunate measures are significant.

Table 3. Scaphoid paired t-test results.

Measurement	Pairing	N	Mean	Standard Deviation	Standard Error Mean	t	Sig. (P)
ScaL	Original	9	26.7533	1.45393	0.48464	-0.346	0.739
	Second		26.7867	1.41605	0.47202		
ScaW	Original	9	16.3478	0.71996	0.23999	0.309	0.765
	Second		16.2711	0.99713	0.33238		
ScaLRF	Original	9	17.9938	1.28080	0.45283	-1.238	0.256
	Second		18.2538	1.20534	0.42615		
ScaLScaT	Original	9	15.7300	1.74458	0.58153	1.634	0.141
	Second		15.5889	1.58186	0.52729		
ScaLCF	Original	9	14.5389	0.89754	0.29918	-1.514	0.169
	Second		15.1911	0.89275	0.29758		
ScaWCF	Original	9	11.1433	0.90785	0.30262	-2.284	0.052
	Second		11.9467	1.08940	0.36313		

The P-value (P>0.05) indicates that none of the scaphoid measures are significant.

Table 4. Triquetral paired t-test results.

Measurement	Pairing	N	Mean	Standard Deviation	Standard Error Mean	t	Sig. (P)
TriL	Original	3	19.8033	0.88940	0.51350	-0.579	0.621
	Second		19.9300	0.52602	0.30370		
TriH	Original	3	15.9867	0.45794	0.26422	-0.347	0.762
	Second		16.0500	0.23643	0.13650		
TriW	Original	3	14.0933	0.51387	0.29610	-0.132	0.907
	Second		14.1133	0.25146	0.14518		
TriLLunF	Original	2	9.2550	0.13435	0.09500	-2.200	0.272
	Second		9.4750	0.27577	0.19500		
TriWLunF	Original	2	7.9950	0.92631	0.65500	-6.600	0.096
	Second		9.4560	0.57276	0.40500		
TriLPisF	Original	3	11.2167	0.55869	0.32256	-0.252	0.824
	Second		11.3567	0.41102	0.23730		
TriWPisF	Original	3	7.9200	0.87504	0.50521	-.950	0.442
	Second		8.0167	0.91697	0.52941		
TriHHamF	Original	3	13.8900	0.77175	0.44557	1.383	0.301
	Second		13.6767	1.00729	0.58156		
TriWHamF	Original	3	11.8233	1.17347	0.67750	-0.871	0.476
	Second		12.4733	0.71557	0.41313		

The P-value (P>0.05) indicates that none of the triquetral measures are significant.

Table 5. Capitate paired t-test results.

Measurement	Pairing	N	Mean	Standard Deviation	Standard Error Mean	t	Sig. (P)
CapH	Original	8	26.1000	1.83848	0.65000	2.003	0.085
	Second		25.7975	1.77756	0.62846		
CapMiWHd	Original	8	11.3813	0.81151	0.28691	-1.209	0.266
	Second		11.7363	0.26832	0.09487		
CapMaWHd	Original	8	14.4725	1.01830	0.36002	-2.161	0.068
	Second		14.9063	1.35473	0.47897		
CapLDiB	Original	8	19.3650	1.07339	0.37950	1.029	0.338
	Second		19.0813	1.07598	0.38042		
CapWDiB	Original	8	14.0338	2.29466	0.81128	2.151	0.062
	Second		12.0925	1.07311	0.37940		
CapLT	Original	8	14.4100	1.24496	0.44016	-1.651	0.143
	Second		15.4988	1.95108	0.68981		

The P-value (P>0.05) indicates that none of the capitate measures are significant.

Table 6. Hamate paired t-test results.

Measurement	Pairing	N	Mean	Standard Deviation	Standard Error Mean	t	Sig. (P)
HamH	Original	5	22.2200	2.32070	1.03785	-0.833	0.452
	Second		22.4480	2.04159	0.91302		
HamW	Original	5	20.5920	1.81333	0.81095	-2.195	0.093
	Second		21.1260	2.24129	1.00234		
HamHBd	Original	5	12.9180	1.57533	0.70451	0.636	0.560
	Second		12.8800	1.50323	0.67226		
HamMaWHa	Original	5	8.3860	1.36315	0.60962	-4.248	0.012
	Second		9.4760	1.30220	0.58236		
HamWDiF	Original	5	15.0500	0.93907	0.41996	-0.431	0.688
	Second		15.0540	0.93996	0.42036		
HamHMe5F	Original	5	10.5180	1.43407	0.64134	0.401	0.709
	Second		10.4600	1.32155	0.59102		
HamHMe4F	Original	5	10.0820	1.24676	0.55757	0.580	0.593
	Second		9.8900	0.61774	0.27626		

The P-value (P>0.05) indicates that all but one of the hamate measures are not significant. The exception being the maximum width of the hamulus (HamMaWHa) measurement with a P-value of 0.012.

Table 7. Pisiform paired t-test results.

Measurement	Pairing	N	Mean	Standard Deviation	Standard Error Mean	t	Sig. (P)
PisL	Original	2	13.8800	0.77782	0.55000	-0.484	0.713
	Second		13.9550	0.55861	0.39500		
PisW	Original	2	9.1150	0.85560	0.60500	-5.857	0.108
	Second		9.3200	0.90510	0.64000		
PisHTriF	Original	2	8.4300	0.16971	0.12000	-0.769	0.583
	Second		8.5300	0.01414	0.01000		
PisWTriF	Original	2	10.3050	1.01116	0.71500	-0.795	0.572
	Second		10.4600	0.73539	0.52000		

The P-value (P>0.05) indicates that none of the pisiform measures are significant.

Table 8. Trapezium paired t-test results.

Measurement	Pairing	N	Mean	Standard Deviation	Standard Error Mean	t	Sig. (P)
TrmL	Original	5	24.3200	0.74206	0.33186	0.041	0.970
	Second		24.3180	0.83808	0.37480		
TrmH	Original	5	16.8000	0.69394	0.31034	-0.931	0.404
	Second		17.0220	0.71335	0.31902		
TrmLMe1F	Original	5	14.8920	0.76290	0.34118	-0.450	0.676
	Second		14.9560	0.87352	0.39065		
TrmWMe1F	Original	5	11.5340	0.68922	0.30823	-0.230	0.829
	Second		11.6400	1.32259	0.59148		
TrmLTrdF	Original	5	15.3080	0.95277	0.42609	-1.639	0.177
	Second		16.1360	1.60131	0.71613		
TrmLTrdScaF	Original	5	19.0040	1.38347	0.61424	-5.431	0.006
	Second		19.8500	1.46062	0.65321		
TrmWScaF	Original	5	8.3080	1.34728	0.60252	-3.246	0.031
	Second		8.5880	1.28972	0.57678		

The P-value (P>0.05) indicates that two of the trapezium measures are significant. These measures are the length of the trapezoid and scaphoid facet (TrmLTrdScaF) and the width of the scaphoid facet (TrmWScaF) with P-values of 0.006 and 0.031 respectfully.

Table 9. Trapezoid paired t-test results.

Measurement	Pairing	N	Mean	Standard Deviation	Standard Error Mean	t	Sig. (P)
TrdH	Original	2	19.6050	1.87383	1.32500	-0.788	0.575
	Second		20.4250	3.34462	2.36500		
TrdLDS	Original	2	8.9200	0.49497	0.35000	-0.301	0.814
	Second		9.3550	2.53851	1.79500		
TrdLPS	Original	2	16.1650	1.30815	0.92500	-5.000	0.126
	Second		16.3150	1.35057	0.95500		
TrdWPS	Original	2	11.0750	0.06364	0.04500	0.579	0.666
	Second		10.9650	0.33234	0.23500		
TrdMdW	Original	2	10.0900	1.45664	1.03000	-3.769	0.165
	Second		10.3350	1.54856	1.09500		
TrdLTrmF	Original	2	15.3400	0.12728	0.09000	4.744	0.132
	Second		14.4150	0.14849	0.01500		
TrdWTrmF	Original	2	9.6600	2.07889	1.47000	-0.776	0.580
	Second		11.3600	1.01823	0.72000		

The P-value (P>0.05) indicates that none of the trapezoid measures are significant.

The results of the paired t-test show that 48 out of the 51 measurements had a P-value greater than 0.05. Of the three values that were significant, two were on the trapezium and one was on the hamate. The range of the measurements with non-significant P-values was 0.052, measured on the scaphoid, to 0.970, measured on the trapezium.

Results of the discriminant function analysis indicate this population does show sexual dimorphism in the carpals and through the use of discriminant function analysis, the carpals can be sorted into two groups. Tables 10-17 show the results of the analysis for each carpal. These analyses were done using only those specimen's data that every measure was able to be obtained. There were a total of nine specimens excluded from the final discriminant function analysis out of the 213 individual specimens that were sampled.

Table 10. Discriminant function analysis results of the lunate.

Variable	Measurement	Unstandardized Coefficient	Constant	Demarking Point (mm)	Group Centroid	Accuracy (%)
Lunate	LunL	0.412	-11.340	0.0615	Female= -1.045 Male= 0.922	87.5
	LunW	-0.215				
	LunWDoH	0.466				
	LunWTF	0.262				
	LunHTF	0.221				

Results yield a single constant, a demarking point, an accuracy percentage as well as one group centroid per group and an unstandardized coefficient for each measurement.

Table 11. Discriminant function analysis results of the scaphoid.

Variable	Measurement	Unstandardized Coefficient	Constant	Demarking Point (mm)	Group Centroid	Accuracy (%)
Scaphoid	ScaL	0.327	-16.204	-0.167	Female= -1.502 Male= 1.168	93.8
	ScaW	-0.339				
	ScaLRF	-0.196				
	ScaLScaT	-0.020				
	ScaLCF	0.79				
	ScaWCF	0.540				

Results yield a single constant, a demarking point, an accuracy percentage as well as one group centroid per group and an unstandardized coefficient for each measurement.

Table 12. Discriminant function analysis results of the triquetral.

Variable	Measurement	Unstandardized Coefficient	Constant	Demarking Point (mm)	Group Centroid	Accuracy (%)
Triquetral	TriL	0.102	-14.729	-0.1705	Female= -1.877	100.0
	TriH	0.065			Male= 1.536	
	TriW	0.255				
	TriLLunF	0.584				
	TriWLunF	0.419				
	TriLPisF	0.024				
	TriWPisF	0.890				
	TriHHamF	0.103				
	TriWHamF	-0.682				

Results yield a single constant, a demarking point, and an accuracy percentage as well as one group centroid per group and an unstandardized coefficient for each measurement. The accuracy percentage of 100% is based on the grouping method used and not based on grouping by known sexes of the individuals.

Table 13. Discriminant function analysis results of the capitate.

Variable	Measurement	Unstandardized Coefficient	Constant	Demarking Point (mm)	Group Centroid	Accuracy (%)
Capitate	CapH	-0.179	-7.046	0.00	Female= -0.664	72.2
	CapMiWHd	1.573			Male= 0.664	
	CapMaWHd	-0.136				
	CapLDiB	-0.248				
	CapWDiB	0.308				
	CapLT	-0.215				

Results yield a single constant, a demarking point, and an accuracy percentage as well as one group centroid per group and an unstandardized coefficient for each measurement.

Table 14. Discriminant function analysis results of the hamate.

Variable	Measurement	Unstandardized Coefficient	Constant	Demarking Point (mm)	Group Centroid	Accuracy (%)
Hamate	HamH	0.383	-20.388	-0.1625	Female= -1.411	87.0
	HamW	0.624			Male= 1.086	
	HamHBd	0.419				
	HamMaWHa	-0.387				
	HamWDiF	-0.229				
	HamHMe5F	0.137				
	HamHMe4F	-0.005				

Results yield a single constant, a demarking point, and an accuracy percentage as well as one group centroid per group and an unstandardized coefficient for each measurement.

Table 15. Discriminant function analysis results of the pisiform.

Variable	Measurement	Unstandardized Coefficient	Constant	Demarking Point (mm)	Group Centroid	Accuracy (%)
Pisiform	PisL	-0.317	-10.847	0.0	Female= -0.769	75.0
	PisW	0.369			Male= 0.769	
	PisHTriF	1.018				
	PisWTriF	0.425				

Results yield a single constant, a demarking point, and an accuracy percentage as well as one group centroid per group and an unstandardized coefficient for each measurement.

Table 16. Discriminant function analysis results of the trapezium.

Variable	Measurement	Unstandardized Coefficient	Constant	Demarking Point (mm)	Group Centroid	Accuracy (%)
Trapezium	TrmL	-0.008	-21.356	0.0	Female= -1.319	92.3
	TrmH	0.248			Male= 1.319	
	TrmLMe1F	0.841				
	TrmWMe1F	-0.652				
	TrmLTrdF	0.144				
	TrmLTrdScaF	0.672				
	TrmWScaF	-0.150				

Results yield a single constant, a demarking point, and an accuracy percentage as well as one group centroid per group and an unstandardized coefficient for each measurement.

Table 17. Discriminant function analysis results of the trapezoid.

Variable	Measurement	Unstandardized Coefficient	Constant	Demarking Point (mm)	Group Centroid	Accuracy (%)
Trapezoid	TrdH	0.511	-6.617	0.055	Female= -0.989 Male= 1.099	89.5
	TrdLDS	-0.907				
	TrdLPS	0.945				
	TrdWDS	-0.122				
	TrdMdW	-0.821				
	TrdLTrmF	-0.190				
	TrdWTrmF	0.265				

Results yield a single constant, a demarking point, and an accuracy percentage as well as one group centroid per group and an unstandardized coefficient for each measurement.

The range in accuracy is 72.2% to potentially 100%. The triquetral returned a 100% accurate grouping result. This remarkably high accuracy is a result of the way the groups were divided by the sum of the measurements. Because the biological sex is not known, the 100% accuracy cannot be verified. The next highest is the scaphoid at 93.8% accuracy. The lowest accuracy score belongs to the capitate. These accuracy percentages are based on the calculations from the measurements of the carpals of this specific sample. The issue of chipping in regard to error in the measurement as well as grouping the carpals into male or female groups based on a sum of measures rather than known biological sex, are two factors that play a role in limiting the certainty of these results.

A univariant stepwise discriminant function was not performed and therefore the single most diagnostic measure is not known nor to what percent it would be accurate to. Beta weights for each carpal do presumptively show what measure would likely to be most diagnostic for each carpal. For the lunate, it was the length; for the scaphoid, it was the length of the capitate facet;

for the triquetral, it was the height; for the capitate, it was the minimum width of the capitate head; for the hamate, it was the width; for the pisiform, it was the width; for the trapezium, it was the length of the metacarpal 1 facet; for the trapezoid, it was the length of the palmar surface. Further analysis could also yield which measurements for this population are not discerning. This information is important because it is different depending on the population. Sulzmann et al. (2008) found that the pisiform, as a whole, was not useful in sex determination and the hamate width, specifically of the left hand, was most diagnostic. Mastrangelo et al. (2011b) found that the maximum width of the scaphoid was the single most sexually dimorphic measurement. Mastrangelo et al. (2011a) found the most sexually dimorphic measurement to be the height of the triquetral facet on the lunate.

DISCUSSION

The initial question this research aimed to answer was whether or not discriminant function analysis would show any sexual dimorphism of the carpal bones in this specific population. The results of this study indicate the probability that this method can be used to show sexual dimorphism in this population. Six out of eight carpals had an accuracy of over 80% of splitting the two groups as they were originally input.

There were some key differences and limitations in this study compared to previous ones. Previous studies using this method by Sulzmann et al. (2008) and Mastrangelo et al. (2011a; 2011b) used populations with known biological sex and Mastrangelo et al. (2011a; 2011b) used this knowledge to group the samples. This was not an option for this current study as that information was largely not known. Williams and White (2006) and Williams et al. (2009) also used samples from the MASC and through these studies, some samples of this current study were able to be matched up by catalogue number and tentatively identified as male or female.

The biological sex of the individuals being unknown made it impossible to verify the validity of the results. These results, therefore, show that six out of eight carpals can be separated out into two groups with an accuracy of eighty percent or greater; not that one group is indeed, or highly probably, male or female. Mastrangelo et al. (2011a; 2011b) concluded that the female carpals were smaller than males and this led to the conclusion that the dimorphism seen in this study is because of the two biological sexes, the smaller dimensioned group being those of females. Mastrangelo et al. (2011a; 2011b) also brings up the fact that within a population, there is overlap between the two biological sexes and this makes the middle range sexually indistinct morphologically. Without records from crypts, cemeteries, or medical collections, or more

complete skeletons to assess the sex of specific individuals with skulls and/or pelvis bones, the results can only be certain that this method has separated out two groups, one larger and one smaller, with a middle that is morphologically ambiguous.

Along with not knowing the sex before hand for grouping purposes, or being able to verify results after the calculations were done, there was the condition of the actual bones to consider. While the previously mentioned studies used remains from medical collections, crypts and graveyards, the remains housed in the Maya Archaeological Skeletal Collection have been recovered from excavations. Some bones were worn or chipped on facet edges making measurements less certain. Other bones were outright broken. This was a common occurrence with the hamulus of the hamate, likely because it protrudes from the body of the bone and is not especially thick. The measurements used for discriminant function analysis should be as precise as possible and with facet edges chipped away, there is a window of error due to the exact dimension being unknown and only approximated when necessary. While the paired t-test may show that the measurements were taken the same both times, it still doesn't account for the dimensions being physically incomplete. This is an inherent issue with recovery of archaeological remains and can also be an issue when recovering forensic remains depending on the circumstances they are recovered in. Overall, the less than ideal condition of the carpals makes the results, and any future calculations based on these results, less certain than other studies that use individuals that have been well preserved. The Sulzmann et al. (2008) and Mastrangelo et al. (2011a; 2011b) studies all state that any specimens showing signs of pathology or damage were excluded from their studies.

The carpals were used because the size and shape of them make them less likely to be broken when recovered in archaeological or forensic remains. Unfortunately, the irregular, compact shape that lend to this preservation is also likely a reason some carpals are mistaken for rocks and not collected. Archaeological remains are often discolored and can be similar in shade to the dirt and rocks around them. If the person collecting on an archaeological dig is not familiar with anatomy or is concerned instead with artifacts, these bones could easily be missed. The same logic can be applied to forensic remains. The remains of an individual can also be scattered by elements of nature, intentional placement by a human, or scavenger activity placing the carpals outside the search perimeter and therefore being missed in collection.

The limited number of samples vs the number needed to accurately do a discriminant function analysis made for uncertain analysis when assessing dimorphism of the left and right sides. For this reason, this study was unable to obtain any results or draw any conclusion regarding dimorphism of the sides other than a larger sample is needed than what was present for this analysis. Sulzmann et al. (2008) found there was a size difference between the two sides. Mastranglo et al. (2011a; 2011b) did not find this difference between left and right sides. If a size difference exists in this population it could further improve the ability to sex an individual with a discriminant function analysis if it were accounted for in the calculations.

Future work on discriminant function analysis of carpals in this population would aim to have a more robust sample size. Ideally, a multivariant stepwise discriminant function would be performed as well as the univariant method that was used here. Knowing the most and least sensitive measurements could help assessments, especially with damaged elements that only a couple of measurements can be obtained. More important than the sample size would be to know

the biological sex of the individuals included in the sample. This would allow for the groupings to initially be sexed and then for the results to be assessed based on what is known versus what the calculations predict. As stated previously, populations have a middle range that can be sexually indistinct morphologically. Knowing the biological sex of an individual and comparing the discriminant score with the demarking point would allow for an assessment on how accurate the demarking point is compared to reality.

A population with a large sample of individuals with known biological sex could also lead to more precise studies, such as variation between left and right sides. Sulzmann et al. (2008) found there was a size dimorphism between left and right carpals even after they were grouped by male and female and that one side had the potential to be more diagnostic due to a larger range of dimorphism than the other side. This could play a factor in the specificity of the demarking point. Future work should attempt to take this into account for the most accurate calculations possible.

CONCLUSIONS

While this method is susceptible to variation within a population, its validity is supported as long as the parameters are addressed for each population prior to analysis. This method also indicates a probability of belonging to a group, not a definitive yes or no. As such, the results need to be considered with regards to how close the discriminant score is to the demarking point, if vital measurements were unobtainable, and how sensitive the particular bone is to assessing sexual dimorphism.

Future studies of sexual dimorphism in carpals using discriminant function analysis should aim for as large a sample size as possible. The combination of some bones having multiple measurements and some bones having a small representation in the collection may have made the outcome of this analysis less specific than is ideal. Discriminant function analysis works best with a large sample from a single population. This larger sample could also better assess if there is dimorphism between the left and right hand, if it is possible to detect handedness, and maybe even if there are specific measurements related to handedness that are specific to males or females only.

The use of a collection that has individuals from 300 BC, is another large difference between this study and the studies of Sulzmann et al. (2008) and Mastangelo et al. (2011a; 2011b). The individuals used in these studies were, at most, a few hundred years old. The age of the bones themselves could be a contributing factor to preservation but due to the nature of preservation of the collections, age is a likely less of a factor than the burial and recovery of archaeological remains. Because this method is based on variation within a population, time also becomes a component of the population itself. Immigration and emigration can cause variation

and changed morphology that this method could be sensitive to. The sensitivity regarding the change in a population over time has not been evaluated yet but for the purpose of using this method for archaeological remains, would be useful to know.

A further interest for future studies aimed towards forensics would be looking at the carpals of remains found in contemporary settings but of possible unknown origin populations. In today's mobile society, people often travel to areas where they would be considered a foreigner. In America alone, there are many distinct, as well as mixed, ancestries that could yield varied results with a discriminant function analysis. Though this could be a good tool in the instances where few skeletal elements are recovered, the issue of population specificity would have to be addressed first to render an accurate probability result.

APPENDIX A
CARPAL ACRONYMS

Acronyms used in measurements.

Carpal	Acronym	Meaning
Lunate	LunL	Length of Lunate
	LunW	Width of Lunate
	LunWDoH	Width of Dorsal Horns of Lunate
	LunWTF	Width of Triquetral Facet of Lunate
	LunHTF	Height of Triquetral Facet of Lunate
Scaphoid	ScaL	Length of Scaphoid
	ScaW	Width of Scaphoid
	ScaLRF	Length of Radius Facet of Scaphoid
	ScaLScaT	Length of Scaphoid Tubercle of Scaphoid
	ScaLCF	Length of Capitate Facet of Scaphoid
	ScaWCF	Width of Capitate Facet of Scaphoid
Triquetral	TriL	Length of Triquetral
	TriH	Height of Triquetral
	TriW	Width of Triquetral
	TriLLunF	Length of Lunate Facet of Triquetral
	TriWLunF	Width of Lunate Facet of Triquetral
	TriLPisF	Length of Pisiform Facet of Triquetral
	TriWPisF	Width of Pisiform Facet of Triquetral
	TriHHamF	Height of Hamate Facet of Triquetral
	TriWHamF	Width of Hamate Facet of Triquetral
Capitate	CapH	Height of Capitate
	CapMiWHd	Minimum Width of Capitate Head
	CapMaWHd	Maximum Width of Capitate Head
	CapLDiB	Length of Distal Base of Capitate
	CapWDiB	Width of Distal Base of Capitate
	CapLT	Length of Tuberosity of Capitate
Hamate	HamH	Height of Hamate
	HamW	Width of Hamate
	HamHBd	Height of Body of Hamate
	HamMaWHa	Maximum Width of Hamulus of Hamate
	HamWDiF	Width of Distal Facet of Hamate
	HamHMe5F	Height of Metacarpal 5 Facet of Hamate
	HamHMe4F	Height of Metacarpal 4 Facet of Hamate
Pisiform	PisL	Length of Pisiform
	PisW	Width of Pisiform
	PisHTriF	Height of Triquetral Facet of Pisiform
	PisWTriF	Width of Triquetral Facet of Pisiform

Trapezium	TrmL	Length of Trapezium
	TrmH	Height of Trapezium
	TrmLMe1F	Length of Metacarpal 1 Facet of Trapezium
	TrmWMe1F	Width of Metacarpal 1 Facet of Trapezium
	TrmLTrdF	Length of Trapezoid Facet of Trapezium
	TrmLTrdScaF	Length of Trapezoid and Scaphoid Facet of Trapezium
	TrmWScaF	Width of Scaphoid Facet of Trapezium
Trapezoid	TrdH	Height of Trapezoid
	TrdLDS	Length of Dorsal Surface of Trapezoid
	TrdLPS	Length of Palmar Surface of Trapezoid
	TrdWDS	Width of Dorsal Surface of Trapezoid
	TrdMdW	Mid Width of Trapezoid
	TrdLTrmF	Length of Trapezium Facet of Trapezoid
	TrdWTrmF	Width of Trapezium Facet of Trapezoid

APPENDIX B
RAW DATA

Lunate raw data measurements.

Specimen	LunL	LunW	LunWDoH	LunWTF	LunHTF
SP-11-2/5	14.99	17.51	10.94	8.41	8.91
SP-11-2/5	16.14	18.3	11.85	8.53	7.73
SP-1A	16.17	17.97	11.87	8.66	8.7
SP-1B	15.98	16.83	11.46	7.28	9.87
SP-1B	14.65	16.91	11.57	7.24	9
SP-11-2/6	12.03	15.06	8.81	6.66	7.61
SP-1A	17.26	17.7	12.14	10.34	9.99
SP-11-3/4	14.61	15.88	9.87	6.08	7.91
SP-11-3/4	14.66	16.59	10.43	--	--
SP 11 3/1	13.07	15.53	8.78	--	7.84
LAM YDL1 85-97 box 1	14.56	17.36	8.35	6.31	8.15
LAM YDL1 85-97 box 1	13.96	16.83	8.94	6.79	7.78
LAM N N10-4/29 (45)	13.22	15.49	9.12	5.1	5.92
LAM N10-1/1?	17.7	19.23	13.03	9.09	9.74
LAM YDL-1 85-92 (60)	13.77	16.03	9.89	5.96	6.37
LAM YDL-1 85-92 (60)	12.4	15.83	10.41	6.94	6.25
LAM N N12-11 gr burial ind 19	14.39	15.31	10.98	7.76	8.96
LAM N10-1/2	17.47	18.34	11.16	8.55	8.93
LAM N10-4/46C	12.18	12.65	9.57	7.27	8.83
LAM N12-11/5A	14.47	16.74	9.53	7.07	7.98
LAM N10-9/10	18.64	21.15	11.57	7.59	8.47
LAM N10-/18	15.24	17.47	10.91	8.36	7.22
LAM N10-2/42A	16.53	17.97	10.03	8.55	8.79
LAM N10 2/20 MN1-1+	17.47	18.41	10.86	7.6	10.11
LAM N10 2/20 MN1-1+	13.47	16.02	8.65	7.19	8.29
LAM N10 2/20 MN1-1+	16.97	17.95	10.96	8.27	9.04
LAM N10 4/45	17.18	17.38	11.26	9.12	8.83
LAM N10 4/45	17.7	17.84	12.04	9.6	9
LAM N 12-11/3	11.9	13.62	8.89	8.1	9.35
LAM N 12-11/3	14.6	16.59	11.95	10.08	9.84
LAM YDL1 85-97 Box 1 (65)	14.54	17.26	8.42	5.96	8.49
LAM N10-4/9A	14.27	17.23	9.71	7.3	8.76
LAM N10-4/9A	13.92	16.88	9.45	8.15	9.52
LAM N10-2/42A	15.28	18.69	9.08	7.02	10.55

Scaphoid raw data measurements.

Specimen	ScaL	ScaW	ScaLRF	ScaLST	ScaLCF	ScaWCF
SP-11-2/5	24.42	17.16	17.02	17.04	13.7	11.69
SP-11-2/5	26.09	14.84	18.02	18.72	13.47	10.59
SP-1A	27.83	17.35	17.77	16.39	15.4	11.82
SP-11-2/6	23.63	14.36	15.86	18.1	13.94	10.21
SP-1-3/1	21.79	14.01	14.86	10.9	12.93	8.22
SP-1A	26.58	16.35	--	15.39	14.7	11.44
SP-11-3/4	24.55	14.7	14.22	12.57	10.84	8.74
SP 11-2/6	25.14	14.35	16.65	13.44	14.58	9.24
SP R6A and B	23.42	14.86	15.97	14.43	11.61	9.61
LAM N N12-11 GP 18	26.45	15.84	15.69	15.5	13.9	8.76
LAM N N12-11 GP 18	26.65	15.15	15.29	14.49	12.8	8.78
LAM YDL1 85-97 box 1	23.72	13.87	16.68	13.52	14.04	9.41
LAM YDL1 85-97 box 1	23.28	14.66	16.56	13.73	13.09	9.96
LAM N N10-4/19 (45)	19.73	13.46	15.82	11.43	12.01	8.69
LAM N N10-4/19 (45)	21.55	13.96	15.86	12.15	12.79	9.21
LAM N10-1/1?	28.36	16.03	19.58	--	15.64	12.39
LAM N10-1/1?	27.89	16.47	19.45	14.68	15.62	12.38
LAM YDL-1 85-92 (60)	25.78	14.55	16.45	12.85	12.2	9.8
LAM N N12-11 gr burial ind 19	--	--	16.31	--	14.34	9.48
LAM N10-1/2	29.22	18.95	18.58	17.53	16	11.92
LAM N10-4/46C	21.93	12.81	14.46	11.9	12.23	8.69
LAM N12-11/5A	24.48	15.64	16.71	14.74	13.98	11.28
LAM N12-11 Bur ?	26.82	16.43	16.12	14.03	12.73	11.02
LAM N12-11 GP Ind 24	25.87	15.58	18.15	15.48	14.44	10.1
LAM N12-11 GP Ind 24	24.86	15.15	16.66	13.35	14.86	10.75
LAM N12-11 GP Ind 2	27.07	15.5	17.85	16.23	13.9	11.76
LAM/Chultun P8-1	21.7	14.69	14.12	13.47	13.09	9.81
LAM N10 2/20 MN1-1+	27.71	17.29	18.41	17.25	15.29	12.8
LAM N10 4/45	28.25	16.46	18.71	18.41	14.37	9.87
LAM N10 4/45	27.73	17.5	18.26	18.03	14.72	10.65
LAM N10 4/46A	29.8	19.26	19.83	17.53	15.43	13.21
LAM N10 4/46A	30.26	17.93	18.24	16.76	13.55	13.13
LAM N10-4/9A	26.25	15.77	16.21	14.48	14.15	11.4
LAM N10-4/46B	27.09	17.56	17.69	17.07	15.91	11.93

Triquetral raw data measurements.

Specimen	TriL	TriH	TriW	TriLunLF	TriWLunF	TriLPisF	TriWPisF	TriHHamF	TriWHamF
SP-11-2/5	19.15	15.91	14.7	9.72	6.53	9.93	7.26	11.9	13.83
SP-1A	19.74	15.82	13.67	9.41	7.75	11.93	7.62	12.07	11.44
SP-1B	19.46	16.56	13.73	9.68	6.4	8.61	7.1	13.82	10.51
SP-11-2/6	18.3	15.49	12.23	8.93	6.13	8.67	6.81	12.41	9.29
SP-1A	18.78	15.48	13.87	--	--	11.71	7.44	13.09	11.02
SP-11-3/4	17.93	14.37	13.18	8.1	6.01	7.49	5.85	11.56	11.59
SP 11 3/1	16.79	14.06	11.5	8.31	6.55	8.71	5.92	11.85	8.94
LAM N N12-11 GP 18	11.56	11.42	9.11	8.37	5.38	9.54	6.06	12.94	10.29
LAM N N10-4/19 (45)	17	14.94	12.14	7.05	6.24	7.21	6.29	11.22	10.03
LAM N N10-4/19 (45)	16.56	14.44	11.59	6.23	7.49	8.76	7.03	11.03	11.13
LAM YDL-1 85-92 (60)	16.6	13.93	12.41	8.48	5.93	8.28	7.54	12.51	11.33
LAM YDL-1 85-92 (60)	15.71	14.62	11.25	7.49	6.31	12.44	6.78	11.49	11.06
LAM N10-1/2	20.83	16.35	15.77	9.05	8.19	10.2	8.99	14.38	10.03
LAM N10-/18	18.32	16.33	13.73	9.23	6.58	9.64	8.98	13.26	12.16
LAM N10 2/20 MN1-1+	19.59	15.89	14.74	8.32	9.25	10.63	7.5	--	10.9
LAM N10 2/20 MN1-1+	20.21	15.91	14.43	9.65	9.27	10.61	7.08	11.54	11.23
LAM N10 4/45	20.24	16.11	14.68	9.35	7.34	10.61	7.39	13.95	11.28
LAM N10 4/45	20.39	16.37	13.73	9.16	8.65	11.33	8.93	14.63	13.17
LAM N10-4/28	20.41	15.82	13.32	9.38	7.48	9.88	8.04	13.2	10.62
LAM N10 4/46A	20.29	18.65	15.93	8.21	6.08	10.5	9.01	15.31	10.85
LAM N10-4/9A	18.59	15.1	13.63	8.95	5.97	8.81	7.13	14.73	11.86
LAM N9 56/1	20.58	14.92	18.75	6.73	6.22	11.1	8.66	14.84	12.4

Capitate raw data measurements.

Specimen	CapH	CapMiWHd	CapMaWHd	CapLDiB	CapWDiB	CapLT
SP-11-2/5	26.31	10.63	14.8	19.46	12.06	15.88
SP-11-2/5	26.66	11.48	14.75	18.2	10.72	16.83
SP-1A	27.69	12.15	14.49	19.94	13.22	15.55
SP-1B	26.82	11.97	14.68	18.26	13.81	14.44
SP-11-2/6	23.42	9.62	12.08	19.57	13.1	11.49
SP-1A	27.16	12.12	14.96	20.35	11.16	12.31
SP-11-3/4	23.74	9.52	13.8	16.83	12.67	11.6
SP 11-2/6	23.52	10.61	12.65	19.77	13.01	15.17
SP 11 3/1	22.27	9.39	12.51	17.04	10.48	13.84
LAM N N 12-11 GP 18	23.72	10.68	14.12	17.6	13.3	15.39
LAM YDL1 85-97 box 1	24.75	10.34	11.54	18.72	14.16	12.54
LAM YDL1 85-97 box 1	24.76	10.21	11.63	17.69	13.44	12.56
LAM N N10-4/19 (45)	22.15	8.5	11.37	16.11	12.98	12.9
LAM N N10-4/19 (45)	22.56	9.29	12.68	16.44	11.71	13.3
LAM N10- 1/1?	27.38	12.28	15.07	20.34	16.12	15.14
LAM YDL-1 85-92 (60)	24.38	10.69	13.59	18.25	12.94	12.49
LAM YDL-1 85-92 (60)	24.85	10.85	13.5	18.23	14.26	14.67
LAM N N12-11 gr burial ind 19	21.76	8.9	12.94	16.4	13.54	14.27
LAM N10-1/2	27.43	12.4	14.45	19.65	17.85	15.54
LAM N10-1/2	27.65	11.29	14.19	21.26	17.94	15.09
LAM N10-4/46C	21.04	9.2	11.64	15.97	12.38	13.26
LAM N10-4/46C	21.98	9.38	11.83	15.18	12.03	13.56
LAM N12-11/5A	24.12	10.68	13.77	19.83	14.05	11.3
LAM N12-11 Bur ?	22.42	9.84	13.01	17.08	11.06	12.83
LAM N12-11 GP Ind 24	25.9	11.77	15.76	20.22	14.95	17.01
LAM N12-11 GP Ind 24	24.51	11.22	14.98	19.34	14.26	15.24
LAM N12-11 GP Ind 2	27.21	10.82	13.66	20.49	12.71	16.02
LAM/Chultun P8-1	23.29	11.62	14.12	17.65	14.46	15.12
LAM N10 2/20 MN1-1+	27.08	10.11	13.68	19.33	17.21	13.99
LAM N10 2/20 MN1-1+	27.38	10.96	13.74	20.89	16.9	14.66
LAM N10 4/45	28.05	11.44	14.3	19.1	16.52	15.14
LAM N10 4/45	27.07	11.75	12.9	19.03	16.14	14.48
LAM YDL1 85-07 Box 1 (65)	24.82	10.19	11.42	18.56	11.87	16.43
LAM N10 4/46A	29.8	12.16	17.64	21.72	17.08	17.47
LAM N10 4/9B	27.56	12.09	15.4	21.14	14.43	16.33
LAM N10-4/46B	27.78	11.64	15.49	19.59	16.56	15.62

Hamate raw data measurements.

Specimen	HamH	HamW	HamHBd	HamMWHa	HamWDiF	HamHMe5F	HamHMe4F
SP-11-2/5	24.16	19.51	13.9	10.53	14.85	10.2	10.4
SP-1A	21.74	19.8	12.85	6.26	14.97	9.17	9.58
SP-11-2/4	18.91	20.97	13.37	4.93	15.79	10.24	11.71
SP-1B	22.28	21.28	12.45	7.1	15.11	10.61	10.57
SP-1B	23.18	20.59	12.6	8.4	14.92	11.86	11.72
SP-11-2/6	23.16	17.23	12.53	7.77	12.58	8.8	9.85
SP-1A	22.72	20.76	13.7	9	14.71	10.14	9.68
SP-11-3/4	17.43	17.74	11.82	6.54	14.04	8.88	7.79
SP 11-2/6	21.03	18.56	12.71	9.75	12.58	9.19	9.39
SP 1 3/1	19.77	17.42	11.56	6.8	13.11	9.92	10.19
LAM N N 12-11 GP 18	21.59	19.81	12.62	8.81	12.94	10.41	8.82
LAM YDL1 85-97 box 1	18.73	17.19	12.53	6.64	12.8	9.5	10.69
LAM YDL1 85-97 box 1	21.44	16.87	8.72	7.75	14.09	10.44	10.91
LAM N N10-4/19 (45)	19.41	18.1	10.9	8.18	11.43	9.91	7.68
LAM N N10-4/19 (45)	18.84	18.45	11.27	6.22	12.11	10.14	8.4
LAM N N10-1/1?	23.93	19.59	13.03	9.34	15.22	10.99	10
LAM YDL-1 85-92 (60)	21.79	18.24	12.7	7.46	14.2	10.18	10.5
LAM N N12-11 gr burial ind 19	17.75	15.84	13.16	4.58	14.87	10.63	9.94
LAM N10-1/2	24.96	21.82	15.51	10.57	--	--	--
LAM N12-11/5A	21.92	17.61	13.87	6.96	11.72	9.72	10.67
LAM N 12-11 Bur ?	23.71	19.2	13.43	8.74	14.89	11.03	10.14
LAM N12-11 GP Ind 24	18.21	18.37	10.11	5.97	13.94	8.23	8.37
LAM N10 4/45	22.54	22.71	13.57	8.96	15.2	11.23	10.4
LAM N10 4/45	23.92	21.91	13.78	9.26	16.51	11.96	11.82

Pisiform raw data measurements.

Specimen	PisL	PisW	PisHTriF	PisWTriF
SP-11-2/5	14.43	8.51	8.31	9.59
SP-11-2/5	15.02	9.64	8.45	10.75
SP 11 2/6	12.53	8.35	7.25	8.91
LAM N N 12-11 GP 18	13.73	8.09	7	8.06
LAM N N 12-11 GP 18	13.75	17.92	7.11	8.07
LAM YDL1 85-97 box 1	11.99	8.74	7.27	8.73
LAM N N10-4/19 (45)	13.3	8.92	7.55	8.72
LAM YDL-1 85-92 (60)	10.8	7.27	6.51	8.48
LAM N10-1/2	15.45	9.88	8.37	11.22
LAM N12-11 GP Ind 2	15.35	9.5	8.37	10.47
LAM N10-1/42A	12.01	7.59	6.05	8.99
LAM N10 2/20 MN1-1+	13.97	8.54	7.09	8.64
LAM N10 2/20 MN1-1+	14.85	9.29	8.58	9.82
LAM YDL1 85-97 Box 1 (65)	12.52	8.27	6.79	8.79
KAM N10 4/46A	13.33	9.72	8.55	11.02
SP-11-2/10	13.59	9.11	7.7	10.12

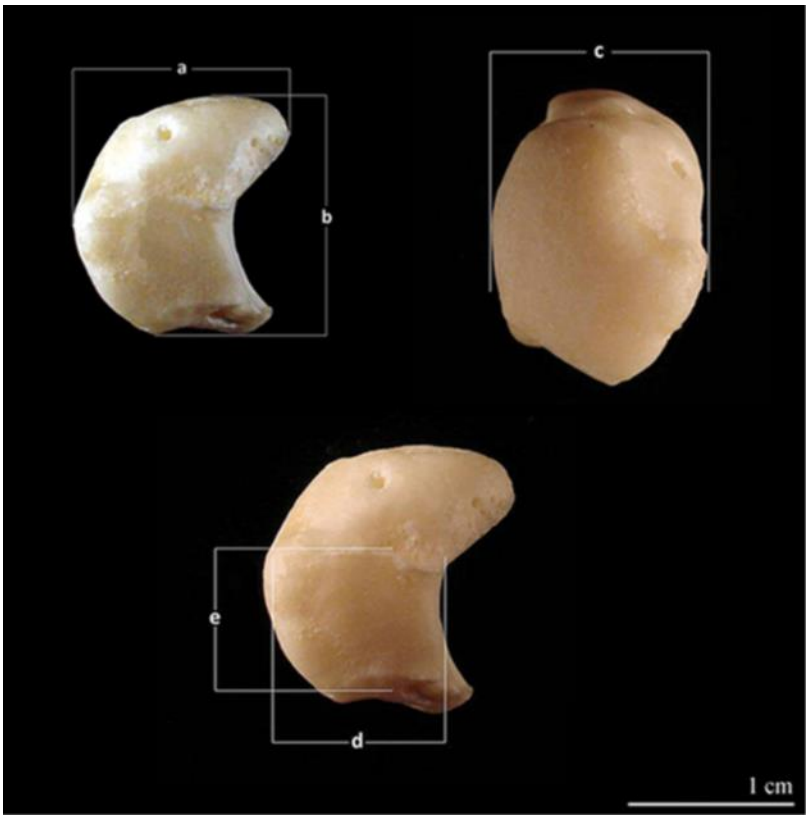
Trapezium raw data measurements.

Specimen	TrmL	TrmH	TrmLMe1F	TrmWMe1F	TrmLTrdF	TrmLTrdScaF	TrmWScaF
SP-11-2/5	24.3	17.08	15.97	12.31	14.74	17.39	7.84
SP-11-2/5	23.9	11.24	15.1	12.7	13.97	17.54	7.88
SP-1A	25.26	17.12	14.45	11.81	15.65	20.78	8.2
SP-1B	21.13	16.42	14.75	12.08	15.1	19.09	8.58
SP-1B	24.76	17.21	15.04	10.17	15.43	19.24	8.01
SP-11-2/6	22.3	16.45	13.92	10.34	13.96	17.72	8.27
SP-1A	25.08	17.04	14.13	11.25	15.85	19.66	7.29
SP 11-2/6	22.8	16.6	--	11.01	14.22	15.4	7.9
LAM N N 12-11 GP 18	18.36	16.38	13.15	10.95	13.26	16.39	7.78
LAM N N 12-11 GP 18	21.12	16.39	13.45	11.34	14.45	17.65	7.56
LAM YDL1 85-97 box 1	21.74	14.57	12.09	10.7	13.94	18.09	8.55
LAM YDL1 85-97 box 1	22.21	15.4	13.01	10.1	13.89	17.62	8.91
LAM N N10-4/19 (45)	21.86	13.41	11.28	8.69	12.98	15.7	6.24
LAM YDL-1 85-92 (60)	21.83	15.2	13.8	10.8	13.62	17.47	8.57
LAM N10-4/46C	16.88	13.66	12.04	8.74	13.37	15.61	7.67
LAM N12-11/5A	19.6	15.21	11	10.5	15.26	17.89	7.59
LAM N12-11 Bur?	23.18	16.05	15.54	10.91	13.9	17.66	7.78
LAM N12-11 GP Ind 2	23.51	16.25	15.06	11.14	14.77	16.99	7.28
MG 14/16 a+b	21.34	15.69	13.38	10.11	13.51	17.61	8.82
LAM/Chultun P8=1	22.5	14.37	13.28	9.72	12.31	16.28	7.3
LAM N10-9/10	24.87	17.69	15.39	12.24	16.07	20.32	8.39
LAM N10-/18	25.62	15.59	14.82	10.87	14.32	18.69	8.48
LAM N10 2/20 MN1-1+	24.66	17.03	17.85	13.12	14.13	16.85	7.84
LAM N10 4/45	24.17	16.14	14.43	10.96	15.98	19.99	10.6
LAM N 12-11/3	23.16	16.21	14.73	12.27	14.19	18.26	9.37
LAM YDL1 85-97 Box 1 (65)	22.27	14.66	13.73	10.57	13.29	17.64	8.35
LAM N10 4/46A	25.89	17.23	16.36	11.56	16.89	19.1	8.94

Trapezoid raw data measurements.

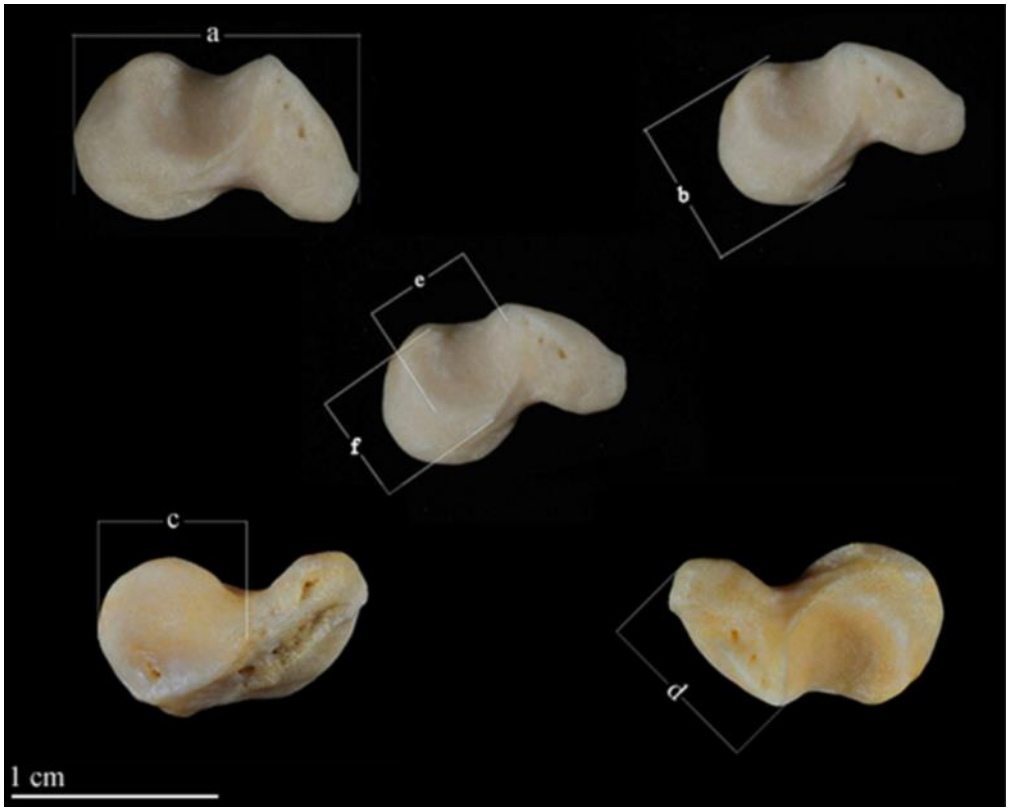
Specimen	TrdH	TrdLDS	TrdLPS	TrdWDS	TrdMdW	TrdLTrmF	TrdWTrmF
SP-11-2/5	18.28	8.57	15.24	11.03	9.06	15.43	8.19
SP-11-2/5	18.3	8.99	14.22	9.85	9.43	10.17	--
SP-1A	20.5	9.42	18.2	12.96	10.8	17.13	11.39
SP-11-2/4	21.77	8.86	--	12.37	11.26	17.12	11.23
SP-1B	20.29	8.64	15.27	11.47	8.62	15.23	8.78
SP-1B	20.09	7.49	16.64	10.8	9.45	17.08	10.07
SP-11-2/6	16.18	6.78	13.38	8.44	7.68	11.02	7.65
SP-1A	20.93	9.27	17.09	11.12	11.12	15.25	11.13
SP-11-2/6	17.08	6.94	13.52	8.83	--	--	--
LAM N N 12-11 GP 18	17.44	8.43	14.5	9.21	9.05	13.18	7.85
LAM N N 12-11 GP 18	17.48	7.83	14.53	10.51	8.76	13.41	9.01
LAM YDL1 85-97 box 1	16.85	8.59	13.15	9.26	9.57	11.68	8.36
LAM N N12-11 gr burial ind 19	17.23	6.94	13.3	8.72	9.75	13.26	7.29
LAM N10-4/46C	16.09	6.75	11.58	7.63	7.51	12.11	6.3
MG 14/16 a+b	16.97	8.32	15.33	9.38	8.8	14.03	9.11
LAM N10 2/20 MN1-1+	18.83	9.77	14.93	8.57	9.25	12.26	10.43
LAM YDL1 85-97 Box 1 (65)	16.91	8.72	13.01	9.38	9.52	12.28	8.24
LAM N10-4/28	20.6	8.86	14.55	10.16	10.51	12.25	7.72
LAM N10-4/28	19.83	8.84	14.5	10.62	10.48	10.76	7.22
LAM N10 4/46A	19.57	8.86	15.76	13.02	8.33	9.29	5.26
LAM N10-4/9A	17.45	9.37	14.95	9.92	10.17	9.7	8.26
SP-11-2/10	18.62	7.66	14.25	11.68	9.14	11.15	7.82

APPENDIX C
CARPAL MEASUREMENTS



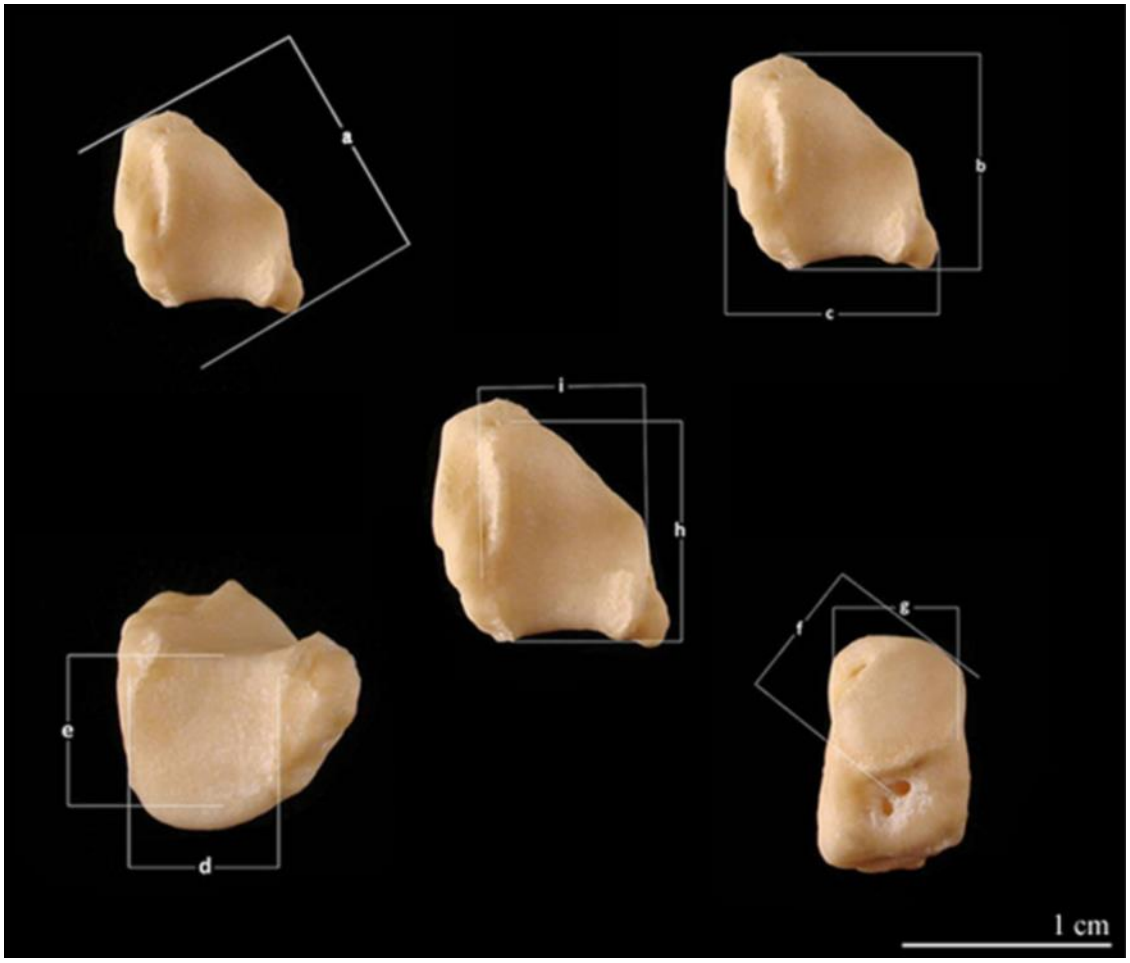
Lunate measurements. Measurements assessed on the lunate were: a, maximum length; b, maximum width; c, maximum width of dorsal horns; d, width of the triquetral facet; and e, height of the triquetral facet.

Source: Mastrangelo, P., De Luca, S., Sanchez-Mejorada, G. (2011b). Sex Assessment from Carpal Bones: Discriminant Function Analysis in a Contemporary Mexican Sample. *Forensic Science International*, 209(196), 196.e1-196.e15. Doi:10.1016/j.forsciint.2011.04.019



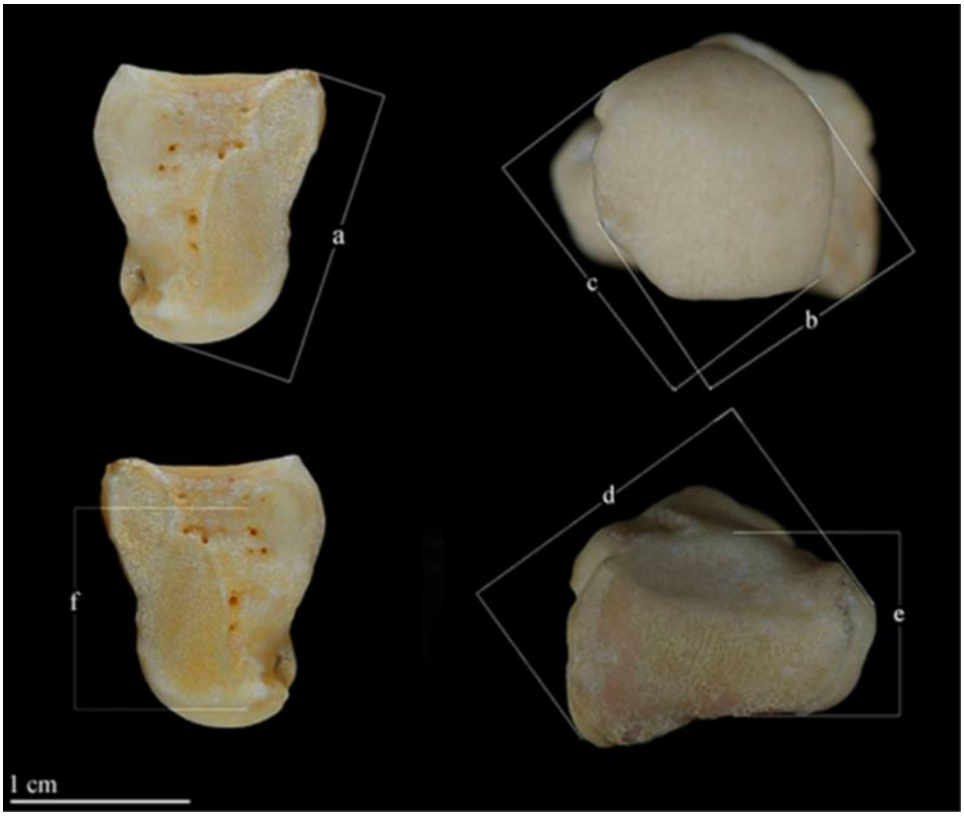
Scaphoid measurements. Measurements assessed on the scaphoid were: a, maximum length; b, maximum width; c, maximum length of radius facet; d, maximum length of scaphoid tubercle; e, maximum length of capitate facet; and f, maximum width of capitate facet.

Source: Mastrangelo, P., De Luca, S., Sanchez-Mejorada, G. (2011b). Sex Assessment from Carpal Bones: Discriminant Function Analysis in a Contemporary Mexican Sample. *Forensic Science International*, 209(196), 196.e1-196.e15. Doi:10.1016/j.forsciint.2011.04.019



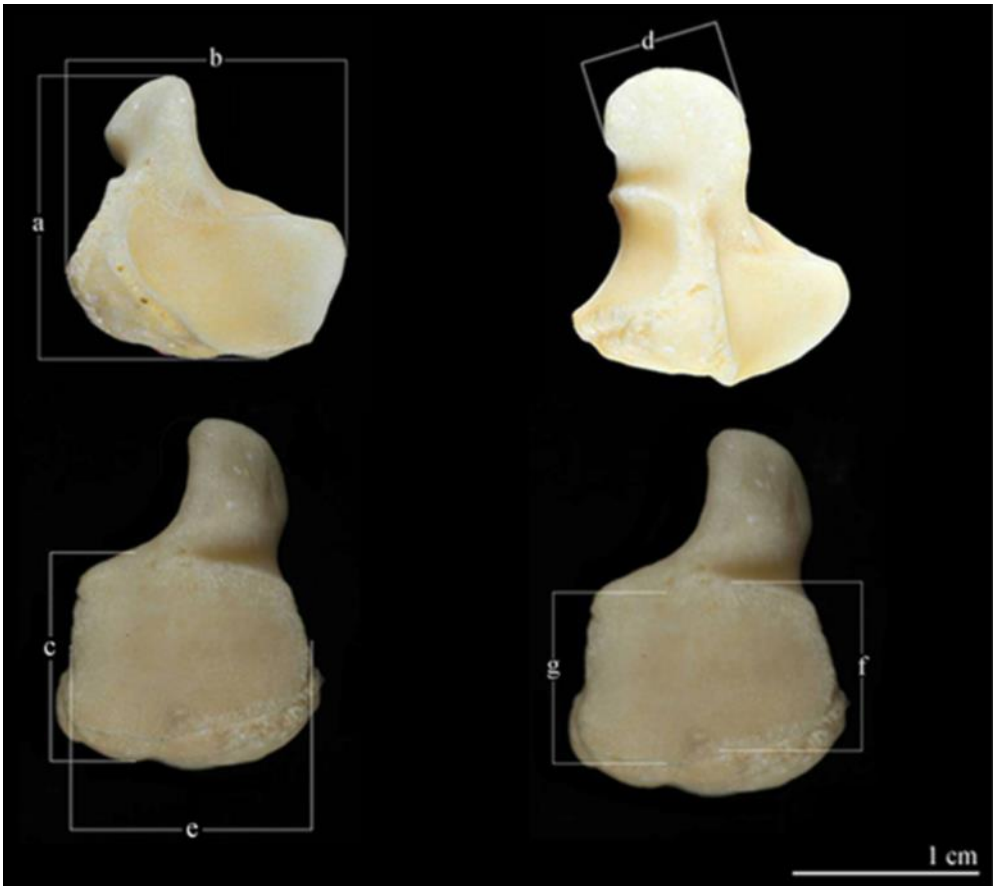
Triquetral measurements. The measurements assessed on the triquetral were: a, maximum length; b, maximum height; c, maximum width; d, maximum length of lunate facet; e, maximum width of lunate facet; f, maximum length of pisiform facet; g, maximum width of pisiform facet; h, maximum height of hamate facet; and i, maximum width of hamate facet.

Source: Mastrangelo, P., De Luca, S., Sanchez-Mejorada, G. (2011b). Sex Assessment from Carpal Bones: Discriminant Function Analysis in a Contemporary Mexican Sample. *Forensic Science International*, 209(196), 196.e1-196.e15. Doi:10.1016/j.forsciint.2011.04.019



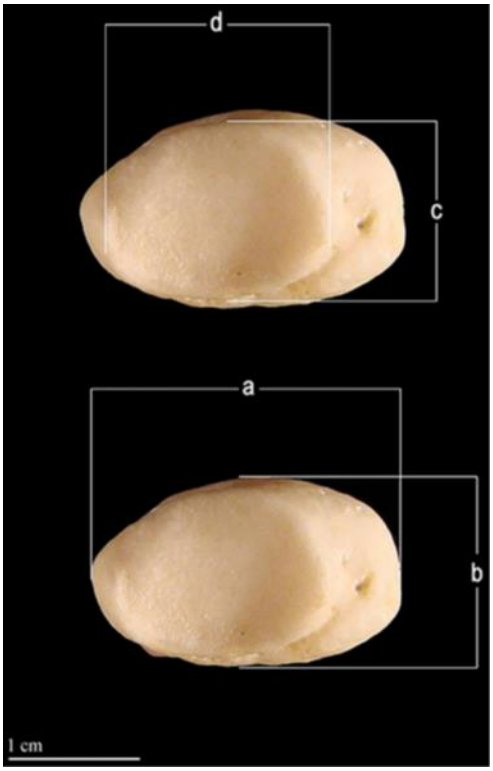
Capitate measurements. Measurements assessed on the capitate were: a, maximum height; b, minimum width of head; c, maximum width of head; d, maximum length of distal base; e, maximum width of distal base; and f, length of tuberosity.

Source: Mastrangelo, P., De Luca, S., Sanchez-Mejorada, G. (2011b). Sex Assessment from Carpal Bones: Discriminant Function Analysis in a Contemporary Mexican Sample. *Forensic Science International*, 209(196), 196.e1-196.e15. Doi:10.1016/j.forsciint.2011.04.019



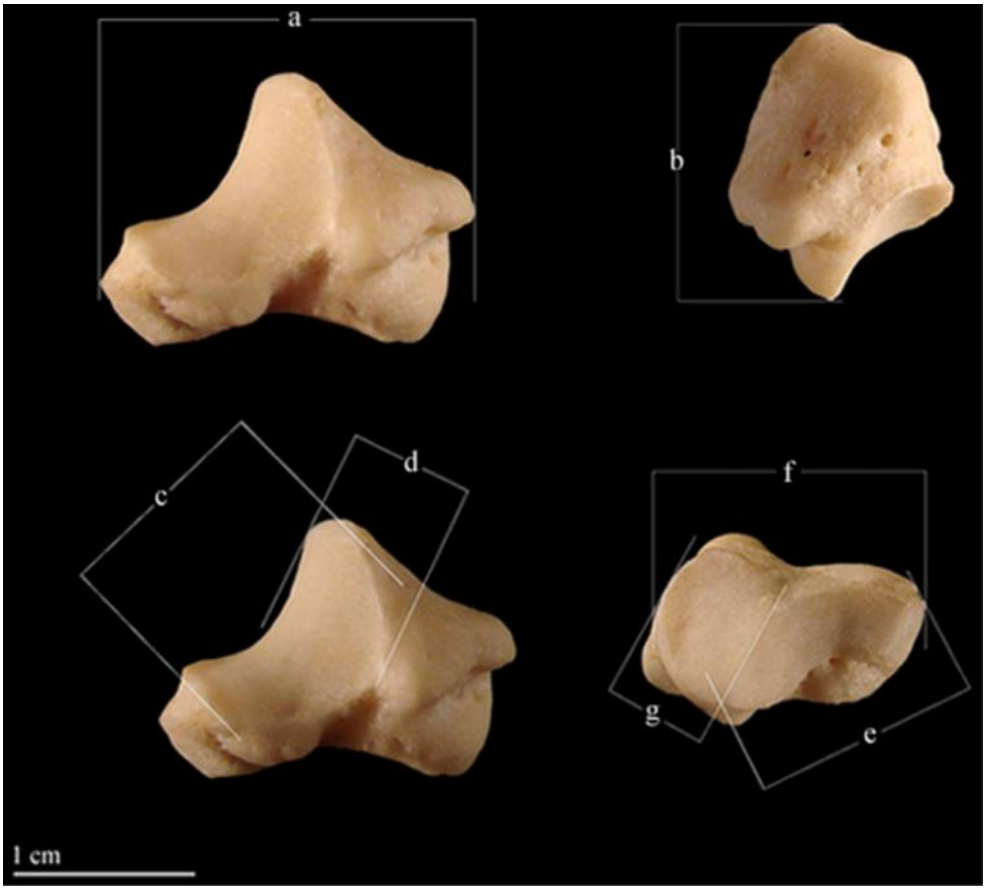
Hamate measurements. Measurements assessed on the hamate were: a, maximum height; b, maximum width; c, height of the body; d, maximum width of the hamulus; e, maximum width of the distal facets; f, height of metacarpal 5 facet; and g; height of metacarpal 4 facet.

Source: Mastrangelo, P., De Luca, S., Sanchez-Mejorada, G. (2011b). Sex Assessment from Carpal Bones: Discriminant Function Analysis in a Contemporary Mexican Sample. *Forensic Science International*, 209(196), 196.e1-196.e15. Doi:10.1016/j.forsciint.2011.04.019



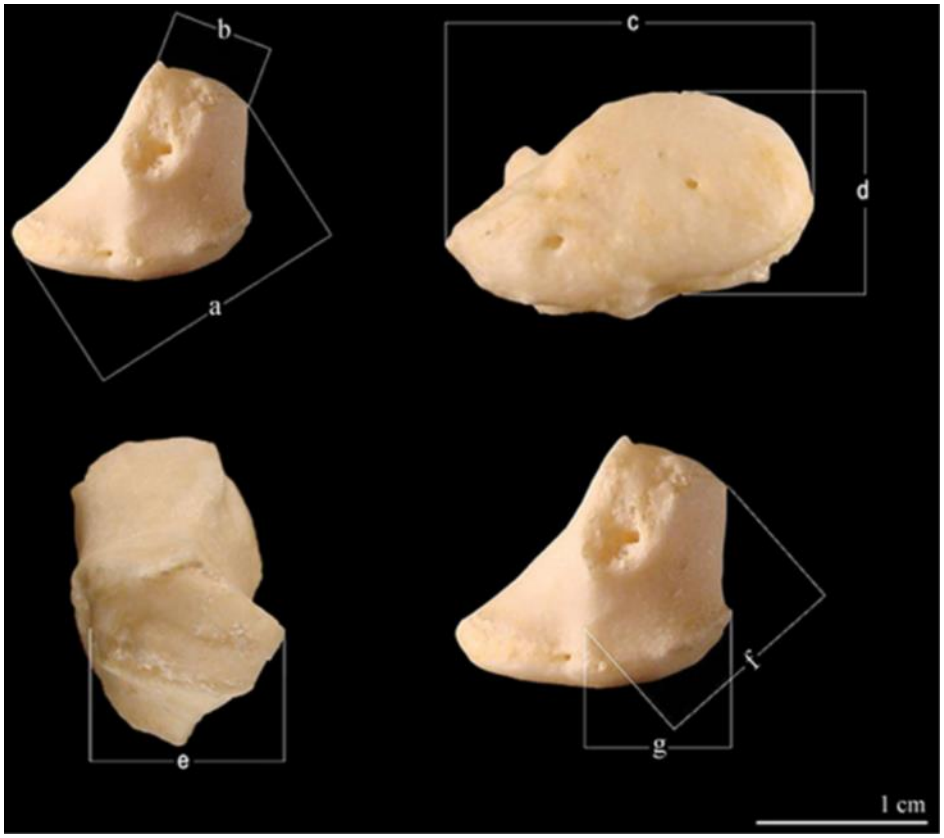
Pisiform measurements. The measurements assessed on the pisiform were: a, maximum length; b, maximum width; c, height of triquetral facet; and d, width of triquetral facet.

Source: Mastrangelo, P., De Luca, S., Sanchez-Mejorada, G. (2011b). Sex Assessment from Carpal Bones: Discriminant Function Analysis in a Contemporary Mexican Sample. *Forensic Science International*, 209(196), 196.e1-196.e15. Doi:10.1016/j.forsciint.2011.04.019



Trapezium measurement. Measurements assessed on the trapezium were: a, maximum length; b, height; c, maximum length of metacarpal 1 facet; d, maximum width of metacarpal 1 facet; e, maximum length of trapezoid facet; f, maximum length of trapezoid and scaphoid facet; and g, width of scaphoid facet.

Source: Mastrangelo, P., De Luca, S., Sanchez-Mejorada, G. (2011b). Sex Assessment from Carpal Bones: Discriminant Function Analysis in a Contemporary Mexican Sample. *Forensic Science International*, 209(196), 196.e1-196.e15. Doi:10.1016/j.forsciint.2011.04.019



Trapezoid measurements. Measurements assessed on the trapezoid were; a, maximum height; b, length of dorsal surface; c, length of palmar surface; d, width of dorsal surface; e, mid width; f, maximum length of trapezium facet; and g, maximum width of trapezium facet.

Source: Mastrangelo, P., De Luca, S., Sanchez-Mejorada, G. (2011b). Sex Assessment from Carpal Bones: Discriminant Function Analysis in a Contemporary Mexican Sample. *Forensic Science International*, 209(196), 196.e1-196.e15. Doi:10.1016/j.forsciint.2011.04.019

RESOURCES

Didi, A., Azman, R., Nazri, M. (2016). Sex Determination from Carpal Bone Volumes: A Multi Detector Computed Tomography (MTCT) Study in a Malaysian Population. *Legal Medicine*, 20, 49-52. Doi: http://dx.doi.org/10.1016/j.legalmed.2016.04.002

Evans, S. (2013). Ancient Mexico and Central America: Archaeology and Culture History. London: Thames and Hudson

Hoover, K. and Berbesque, J. (2018). Early Holocene Morphological Variation in Hunter-Gatherer Hands and Feet. *PeerJ*, 6:e5564. Doi: 10.7717/peerj.5564

Joshi, A., Leahy, R., Badawi, R., Chaudhari, A. (2016). Registration-Based Morphometry for Shape Analysis of the Bones of the Human Wrist. *IEEE Transactions on Medical Imaging*, 35(2), 416-427. Doi: 10.1109./TMI.2015.2476817

Kivell, T., Guimont, I., Wall, C. (2013). Sex-Related Shape Dimorphism in the Human Radiocarpal and Midcarpal Joints. *The Anatomical Record*, 296(1), 19-30. Doi: http://doi.org/10.1002/ar.22609

Loten, H. (1985). The Northern Lowlands: Lamanai Postclassic, pp 85-90.

Mastrangelo, P., De Luca, S., Aleman, I., Botella, M. (2011a). Sex Assessment from the Carpal Bones: Discriminant Function Analysis in a 20th Century Spanish Sample. *Forensic Science International*, 206(216), 216.e1-196.e10. Doi:10.1016/j.forsciint.2011.01.007

Mastrangelo, P., De Luca, S., Sanchez-Mejorada, G. (2011b). Sex Assessment from Carpal Bones: Discriminant Function Analysis in a Contemporary Mexican Sample. *Forensic Science International*, 209(196), 196.e1-196.e15. Doi:10.1016/j.forsciint.2011.04.019

Pendergast, D. (1981). Lamanai, Belize: Summary of Excavation Results, 1974-1980. *Journal of Field Archaeology*, 8(1), 29-53. Retrieved from http://www.jstor.org/stable/529781

Sulzmann, C., Buckberry, J. Pastor, R. (2008). The Utility of Carpals for Sex Assessment: A Preliminary Study. *American Journal of Physical Anthropology*, 135, 252-262. Doi: 10.1002/ajpa.20738

White, C., Pendergast, D., Longstaffe, F., Law, K. (2001). Social Complexity and Food Systems at Altun Ha, Belize: The Isotopic Evidence. *Latin American Antiquity*, 12(4), 371-393. Doi: 10.2307/972085

Williams, J. and White C. (2006). Dental Modification in the Postclassic Population from Lamanai, Belize. *Ancient Mesoamerica*, 17, 139-151. Doi: 10.1017/S0956536106050267

Williams, J., White, C., Longstaffe, F. (2009). Maya Marine Subsistence: Isotopic Evidence from Marco Gonzalez and San Pedro, Belize. *Latin American Antiquity* 20(1), 37-56. Retrieved from http://www.jstor.org/stable/40650075