CRANIAL SEXUAL DIMORPHISM IN HISPANICS USING GEOMETRIC MORPHOMETRICS

by

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DEDICATION

To my Mother and Father.

You have both shaped my life equally.

ACKNOWLEDGEMENTS

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ABSTRACT

Hispanics comprise the second largest population group in the US. Further, 63% of U.S. Hispanics are of Mexican origin with 37% foreign born (Motel and Patten, 2012). Sex estimation is an important component of the forensic anthropological profile and is considered population specific in that human groups differ in size. Sexual dimorphism in the cranium has been explored in American Whites and Blacks (Kimmerle et al., 2008), but little is understood concerning sexual dimorphism in Hispanics; the fastest growing US population (Martinez and Ariosto, 2011). A better understanding of sexual dimorphism among US population groups will facilitate more accurate sex estimation techniques within forensic anthropological practice.

Therefore, the purpose of this thesis is to explore cranial size and shape sexual dimorphism in Hispanics when compared to American Blacks and American Whites using geometric morphometric methods. Landmark data for American Blacks (N=75) and Whites (N=384) was obtained from the Forensic Anthropology Data Bank. The Hispanic sample was obtained from multiple sources, including two populations from Mexico (n=128), the Forensic Databank (n=93), the Pima County Office of the Medical Examiner (n=227), the Maxwell Museum of Anthropology (n=10) and the Texas State Donated Skeletal Collection (n=5). All individuals used in this research have 20th century birth years. A total of 35 landmarks were chosen to maximize sample size and represent

overall craniofacial morphology.

A MANOVA indicates no significant differences in the expression of sexual size dimorphism among the groups, however significant sex-specific differences in size among the groups were detected. Shape differences using the Procrustes coordinates in a canonical variates analysis demonstrate differences in the areas of the cranium that provide the most information of differentiation between the sexes. In the American Black sample, cranial differences between sexes lied mainly in the posterior and superior vault shape, with some differences also arising from the nasal and orbit area. The Hispanic sample differed mainly in vault shape, including the posterior, superior and lateral vault, as well as the basicranium and the glabellar region. The differences in the American White sample were focused in the midface (nasal, cheek and orbit areas) and the basicranium.

CHAPTER I

Introduction

Within forensic anthropology, sex estimation is an important first step in the identification process since many other elements of the biological profile are dependent on sex. After the pelvis, the long bones have proven to be the most valuable in sex estimation (Spradley and Jantz, 2011). However, in instances of advanced decomposition, as is common with undocumented border crossing fatalities into the United States (Anderson, 2008), the skull may be only item available for analysis. When developing new methods or criteria for sex estimation, an understanding of population specific levels of sexual dimorphism is necessary. Numerous studies have examined sexual dimorphism in American Blacks and Whites (Kimmerle et al. 2008, Garvin and Ruff 2012, Giles and Elliot 1963), but currently in the United States there are few skeletal collections that contain individuals considered Hispanic. Therefore, sex estimation methods for Hispanics have not developed as fast as methods for other groups (American Black and White).

Frequently, the gracile nature of Hispanic individuals causes males to be misclassified as females (Spradley et al., 2008; Kimmerle et al., 2008). This discrepancy highlights the need for a better understanding of sexual dimorphism in individuals considered Hispanic in order to create and apply population-specific methods for estimation of components of the biological profile, including sex, age, and stature.

The purpose of this thesis is to explore size and shape sexual dimorphism in modern Hispanic crania as compared to American Whites and Blacks, the three largest demographic groups in the United States.

Growing numbers of individuals are crossing into the U.S. through Mexico. Many of these individuals make it across the border, but succumb to the elements (Anderson, 2008) and die of heat exhaustion. This creates an issue for the identification of an individual who may not have been carrying any form of identification on them and may not have any family members searching for them. Further complicating identification, the arid to semi-arid desert environment of the southern United States causes rapid decomposition and tissue desiccation, which can impede identification based on soft tissue (finger prints, facial recognition). The southern United States is also home to many scavengers that can act as taphonomic agents, such as canids, rodents, and vultures (Galloway et al. 1986, Spradley et al. 2012, Ubelaker 1997). The number of border fatalities has risen from 263 in 1998 to 445 in 2013 (TABLE 1).

Further, 16% of the U.S. population considered themselves Hispanic when filling out the 2010 Census (Ennis et al, 2011). In addition, as of 2010, the U.S. Census reported, "41% of Hispanics lived in the West and 36 percent lived in the South" (Ennis et al., 2010 p. 4). With the growing Hispanic population (12.5% in 2000, 16.3% in 2010; Ennis et al.) and the high concentration of Hispanics in the Southwest, this topic is pertinent for forensic anthropology practitioners not only in border-states with a high concentration of Hispanic individuals and border-crossers, but also to practitioners in non-border states.

Identification Criteria for Hispanics

There have been a limited number of publications for estimating the biological profile for Hispanics mainly pertaining to ancestry and sex estimation (Hurst, 2012; Spradley et al., 2008; Spradley 2013; Tise et al., 2013). Hurst (2012) narrowed down eight morphoscopic cranial traits from a total of 26 that are best used for distinguishing Southwest Hispanics from Afro-American and Euro-American samples, providing guidelines for ancestry estimation. Many of the morphoscopic traits used in the Hurst study were taken from the Birkby et al. (2008) study, which outlined a group of non-metric skeletal traits used in identifying individuals of Southwest Hispanic ancestry. Birkby et al. (2008) also proposed to outline a method they found useful in the identification of Hispanic individuals: the "cultural profile", which they describe as "geographic context, personal effects, condition of the teeth, stature and cultural accouterments" (Birkby, 2008 p. 31; Anderson, 2008). This profile is used to differentiate documented American citizen Hispanics from undocumented immigrants attempting to cross the border. This is important for identification of individuals as foreign-born Hispanics even if they are unable to be definitively matched to a known missing person, as is often the case (Anderson 2008, Birkby et al., 2008).

In addition to morphological or contextual estimation of ancestry, sex estimation is important to establish prior to subsequent elements of the biological profile (Kimmerle et al. 2008, SWGANTH, 2010). A firm understanding of variation between and among the sexes is imperative to assessing the sex of unknown skeletal remains. Spradley et al. (2008) used metric data from the Forensic Anthropology Data Bank, which includes many different ancestral groups, to explore the problems associated with applying

American White skeletal measurements to those of Hispanic individuals in order to estimate sex, stature and ancestry in unidentified remains. This study found that American Blacks and Whites tended to be taller than Hispanic individuals based on postcranial measurements, and there was variation among Hispanic groups. When American White humeral head diameter was used to classify Hispanic females, 100% were correctly identified, but when used to classify Hispanic males, the humeral head diameter identified 47%. Femoral head diameter provided similar classification results. This study highlights the need for a more thorough exploration into Hispanic sexual dimorphism in comparison to American Blacks and Whites.

The majority of research on sex estimation for Hispanics comes from the post-cranial skeleton (Tise et al. 2013, Spradley 2013). Tise et al. 2013 and Spradley 2013 found that specific postcranial elements, (e.g. the scapula) had high rates of sexual dimorphism in Hispanics, and provided sectioning points for sex estimation using these elements. Additionally, Figueroa Soto (2012) explored levels of post-cranial sexual dimorphism in Mexican migrants and non-migrants as compared to American Blacks and Whites. Although Figueroa Soto found that there was no differences in the levels of sexual dimorphism between any groups, she did find that Mexican migrants and non-migrants were had significantly shorter long bone dimensions.

Sexual Dimorphism

Frayer and Wolpoff (1985) describe sexual dimorphism (the difference between males and females of the same species) as the effects of pubertal hormones on certain biological traits. This review of sexual dimorphism explains that males are more affected by nutrition deficiencies than females, therefore lowering the sexual dimorphism in a species when males scale down in size. This effect is known as the "female buffering hypothesis". The reason for the more gracile nature of males considered Hispanic (as described by Spradley et al., 2008) might be due to nutrition deficiencies, as evidenced by the effects of poor health that can be seen in many of the border crossing fatalities at the Pima County Office of the Medical Examiner, Tucson, Arizona (Birkby at al. 2008).

The human cranium has been shown to express sexual dimorphism (Williams et al., 2006; Franklin et al., 2005; Rosas et al., 2002 Kimmerle et al., 2008; Pretorius et al., 2006; Frayer et al., 1985; Giles et al., 1963; Hunter et al., 1972). Described as the effects of pubertal hormones, nutrition, body composition, energetic intake, genetics and sexual selection on aspects of biology (Frayer et al., 1985; Kimmerle et al., 2008), sexual dimorphism can be expressed both by size and shape differences between the sexes. Body size differences between the sexes of a species can often be difficult to quantify since environment also influences body size (Frayer et al., 1985). The relationship between body size, and subsequently cranial size, and environment is not linear; Cranial shape has been analyzed by numerous authors: Bigoni et al., 2010; Franklin et al., 2005; Kimmerle et al., 2008; Pretorius et al., 2006; Rosas et al., 2002; many of who have been able to successfully separate size differences from shape differences.

In the U.S., most studies of modern sexual dimorphism have been conducted on American Black and White collections. Garvin et al. (2012) found that there are significant differences in size and shape in the brow ridge and chin areas in American Blacks as compared to American Whites. Kimmerle et al. (2008) found significant differences in cranial size and shape for American Blacks and Whites, but no size effect on shape for either group. Both Garvin et al. (2012) and Kimmerle et al. (2008) used geometric morphometric methods to explore size and shape differences. Geometric morphometric methods utilize landmark data and can capture areas of the cranium not captured by traditional craniometric variables or by visual assessments of sex (Buikstra and Ubelaker 1994). Since the skull may be the only portion of the skeleton recovered and there have been no studies on cranial size and shape dimorphism of Hispanics that could inform the estimation of sex, it is important to quantify sexual dimorphism in size and shape in this population group as compared to American Blacks and Whites.

Therefore, the purpose of this research is to evaluate cranial size and shape sexual dimorphism in individuals considered Hispanic, using three dimensional craniometric measurements and geometric morphometric methods. The specific questions this thesis will address are:

1. Are there differences in cranial size and shape between Hispanic males and females?

   If differences in size and shape exist between Hispanic males and females, it should be possible to estimate sex of Hispanic crania.

2. Are there differences in the levels of sexual size dimorphism among the three groups?

   If differences in the levels of sexual size dimorphism exist among the three groups, particularly if the Hispanic sample displays lower levels of sexual dimorphism, sex estimation may be difficult.

3. Are there differences in cranial size and shape among male and female Hispanics, American Blacks, and American Whites?

If differences exist among male and female Hispanics, American Blacks, and American Whites, it should be possible to ascertain where these differences exist for future exploration of the creation of population specific sex estimation criteria.

TABLE 1: Southwest Border Deaths by Fiscal Year (United States Border Patrol 2013)

Fiscal Year	Big Bend *(formerly Marfa)*	Del Rio	El Centro	El Paso	Laredo	Rio Grande Valley *(formerly McAllen)*	San Diego	Tucson	Yuma	Southwest Border Total
2013	3	18	3	2	56	156	7	194	6	445
2012	1	29	11	1	90	151	5	180	9	477
2011	2	18	5	6	65	66	15	195	3	375
2010	0	23	14	4	35	29	8	251	1	365
2009	3	29	27	5	58	68	15	212	3	420
2008	3	22	20	8	32	92	32	171	5	385
2007	0	20	12	25	52	61	15	202	11	398
2006	4	34	21	33	36	81	36	169	40	454
2005	4	28	30	28	53	55	23	219	52	492
2004	0	21	36	18	22	35	15	142	39	328
2003	0	23	61	10	17	39	29	137	22	338
2002	4	29	64	8	15	30	24	134	12	320
2001	3	41	96	10	28	37	21	80	24	340
2000	3	48	72	26	47	40	34	74	36	380
1999	0	30	56	15	37	36	25	29	21	249
1998	3	28	90	24	20	26	44	11	17	263

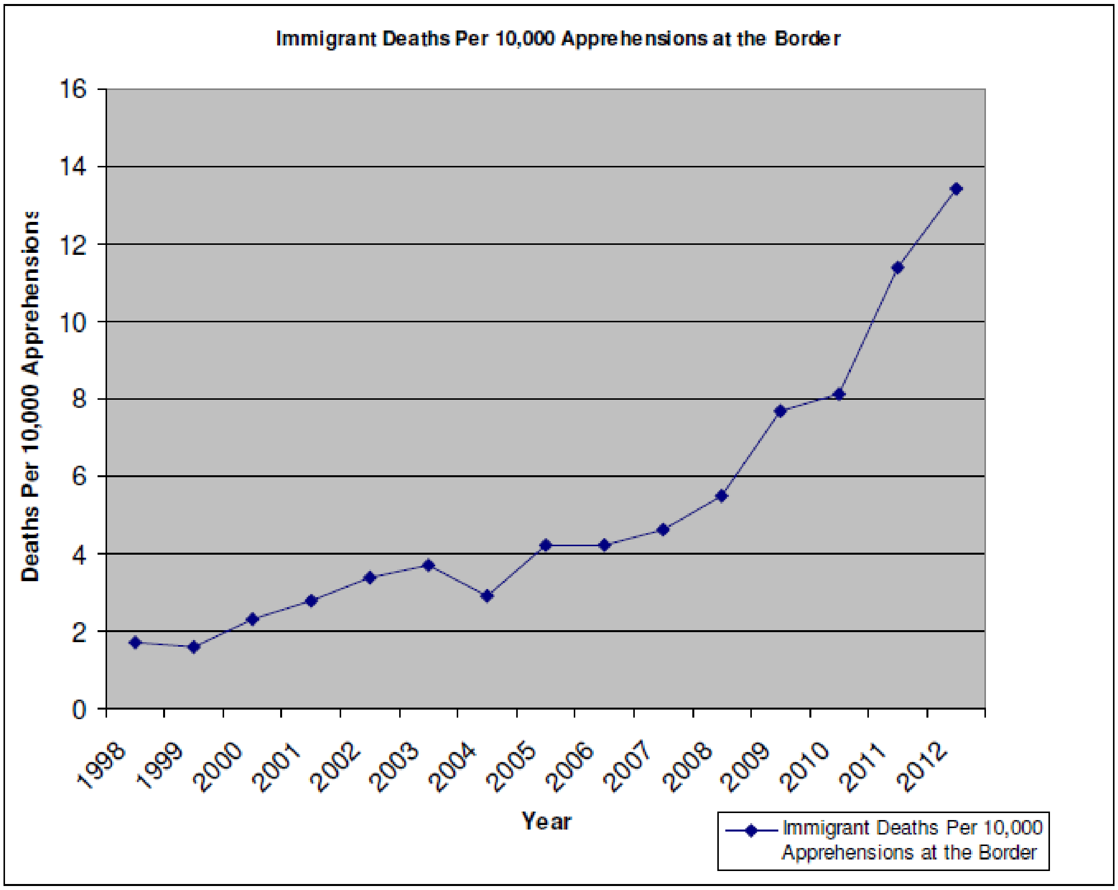

FIGURE 1: Immigrant Deaths per 10,000 Apprehensions at the Border (Anderson 2013).

CHAPTER II

Materials and Methods

For the present research, the general term Hispanic will be used as defined by the United States Census Bureau: "A person of Cuban, Mexican, Puerto Rican, South or Central American or other Spanish culture or origin regardless of race" (Ennis et al., 2011 p. 2). Although this term is arbitrary, for purposes of continuity and reference, it will be used in this research. The designation of Hispanic is more inclusive rather than exclusive as there is no current standard to distinguish among groups considered Hispanic using skeletal morphology. The program FORDISC does distinguish between Guatemalans and Hispanics, but these are the only two of the many groups that are considered Hispanic in the US and the Guatamalan sample within FORDISC only contains male individuals.

Reference Samples

Hispanic Sample

The Hispanic study sample was compiled from multiple institutions and contains individuals from Mexico (n=128), Honduras (n=1), Peru (n=1), Guatemala (n=78) and El Salvador (n=5), as well as positively identified Hispanic U.S. citizens (n=55). In addition, 132 unidentified individuals from the Pima County Office of the Medical Examiner were added to the Hispanic sample. These individuals were estimated to be Hispanic based on craniometric analysis, contextual evidence, location of recovery and the cultural profile (Birkby et al. 2008; TABLE 2). Sex was estimated for the unidentified individuals using the pelvis in most cases, but for cases where no pelvis was available for sex estimation, postcranial measurements and the cranium were used to estimate sex.

These Hispanic data were obtained from the Forensic Anthropology Data Bank (FDB) (n=93) (Jantz and Moore-Jansen, 1988), the Pima County Office of the Medical Examiner (PCOME) located in Tucson, Arizona (n=227; Spradley 2013), two modern skeletal collections in Mexico (n=65; Spradley, 2013), individuals from the Maxwell Museum of Anthropology at the University of New Mexico (n=10) and individuals from the Texas State Donated Skeletal Collection (TSDSC; n=5), for a total of 400 Hispanic individuals (TABLE 3).

Forensic Anthropology Data Bank

The Forensic Anthropology Data Bank is a collection of data that have been compiled by practicing forensic anthropologists since its creation in 1988 (Jantz and Moore-Jansen, 1988). When a forensic case is received, the forensic anthropologist will then take the standardized measurements and enter them into the data bank.

Hispanic individuals from the FDB (n=93) consist of 88 positively identified males and five positively identified females; 71 of these 93 are Guatemalan nationals (m=68, f=3) and 22 are Hispanic individuals from the U.S. with no specific country of origin (m=20, f=2). See TABLES 2 and 3 for further explanation.

Pima County Office of the Medical Examiner (PCOME)

Hispanic individuals from the PCOME consist of 197 male and 30 female US/Mexico border crossing fatalities. The individuals comprised in this sample are either positively identified or open forensic cases that remain unidentified (n=132). These unidentified border crossers were considered to be Hispanic through contextual evidence (Birkby et al. 2008), but specific place of origin remains unknown**.** Clothing, personal effects, location of recovery of the remains, currency, religious artifacts are among the contextual clues used to classify an unidentified border crosser as Hispanic in addition to ancestry estimation using FORDISC 3.1 (Jantz and Ousley, 2005). The 197 PCOME males consist of 55 Mexicans, six Guatemalans, three El Salvadorans, one Honduran (all positively identified) and 132 unidentified individuals (Spradley 2013). The 30 PCOME females consist of eight Mexicans, one Guatemalan, two El Salvadorans and one Peruvian, all of which are positively identified. The remaining 18 Hispanic females are unidentified. See TABLES 2 and 3 for further explanation.

Mexican Skeletal Collections

The two modern Mexican samples contained within the Hispanic sample were collected by Dr. Kate Spradley, and come from two separate skeletal collections located in Zimapán, Hidalgo (n=16) and Xoclán, Merida, Yucatán (n=49) (Spradley 2013) for a total of 65 non-migrant Mexicans. The Zimapán sample consists of 11 males and five females, while the Xoclán sample (Spradley, 2013) consists of 33 males and 16 females. See TABLES 2 and 3 for further explanation.

Documented Skeletal Collections

Hispanic individuals from the Maxwell Museum of Anthropology (n=10) consist of six males and four females. The individuals curated at the Maxwell Museum were willingly donated to the body donation program run by Dr. Heather Edgar within the Department of Anthropology at the University of New Mexico. These modern individuals of known biological profile were measured by the author. Hispanic individuals from the TSDSC (n=5) consist of four males and one female. The TSDSC comes from the Willed Body Donation Program run by the Forensic Anthropology Center at Texas State (FACTS). These modern individuals of known biological profile were also measured by the author. See TABLES 2 and 3 for further explanation.

TABLE 2: Hispanic Sample Description by Country of Origin

Group	**Male**	**Female**	**Total**
El Salvadoran	3	2	5
Guatemalan	74	4	78
Honduran	1	0	1
Mexican	99	29	128
Peruvian	0	1	1
Hispanic*	162	25	187
Total	339	61	400

*In this case, the “Hispanic” portion of the sample consists of individuals from the U.S. that were either: 1) unidentified and estimated to be Hispanic based on the cultural profile (n=132; Birkby et al. 2008), or 2) identified Hispanic U.S. citizens (n=55).

TABLE 3: Hispanic Sample Description by Collection

Sample	Male	Female	Total
FDB	88	5	93
Maxwell Museum	6	4	10
PCOME	197	30	227
TSDSC	4	1	5
Xoclán, Merida, Yucatán, Mex.	33	16	49
Zimapán, Hidalgo, Mex.	11	5	16
Total	339	61	400

American Black and White Samples

For comparative purposes, craniometric data for American Blacks (m=60, f=15) and Whites (m=250, f=134) (TABLE 4) were obtained from the Forensic Anthropology Data Bank (Jantz and Moore-Jansen, 1998) with the permission of Dr. Richard Jantz.

TABLE 4: Sample Description by Group

Group	Male	Female	Total
American Black	60	15	75
American White	250	134	384
Hispanic	339	61	400
Total	649	210	859

Data Collection

Thirty five standard craniometric landmarks (TABLE 5; APPENDIX A) representing overall craniofacial morphology were obtained following definitions outlined in Howells (1973) using a Microscribe 3D Digitizer along with "Threeskull" (2010), a program developed by Stephen D. Ousley.

TABLE 5: Craniometric Landmarks
(Buikstra and Ubelaker 1994, Howells 1973, Moore-Jansen et al. 1984)

No.	Landmark	No.	Landmark	No.	Landmark
1,2	Alare	15	Glabella	24	Parietal Subtense Point
3,4	Asterion	16	Lambda	25,26	Porion
5	Basion	17	Metopion	27	Prosthion (Howells)
6	Bregma	18	Nasion	28,29	Frontotemporale
7,8	Dacryon	19,20	Inf Nasal Border	30	Cheek Height Inf
9,10	Ectoconchion	21	Occipital Subtense Point	31	Cheek Height Sup
11,12	Eurion	22	Opisthocranion	32,33	Nasomaxillary Suture Pinch Point
13,14	Frontomalare Ant.	23	Opisthion	34,35	Zygion

Prior to collection of three-dimensional landmarks, various instrumentally determined points were marked slightly with a pencil with the help of spreading and sliding calipers. These include: eurion, ectoconchion, zygion, stephanion, alveolon, alare and frontotemporale. Various Type I landmarks (Bookstein, 1991), which are those occurring at the intersection of two sutures, were also marked with a pencil to facilitate their location during digitizing and to determine their location in the event of a complex suture intersection or obliteration. The cranium was then placed on three pillars of modeling clay. This stabilizes the cranium and allows the researcher access to the basicranium for inferior measurements such as basion and hormion (FIGURE 2). Stabilization of the cranium is incredibly important when digitizing, since the Microscribe cannot be moved once one has begun taking measurements. If the cranium is moved at any point while digitizing, all landmarks previously taken are useless. Once the cranium was stabilized, the Microscribe was then connected to the computer being used, homed (zeroed out and calibrated) and landmark collection then began.

FIGURE 2: Photograph of a cranium stabilized for digitization using a Microscribe 3D digitizer.

The stylus at the end of the wand, which is connected to the movable jointed arm, was then placed on each craniometric landmark and that coordinate point (X, Y and Z) was recorded to create a three-dimensional image of the cranium. Instead of calculating the measurements by hand using sliding and spreading calipers, the Threeskull program (Ousley, 2010) calculates these interlandmark distances and is therefore much more precise. After all coordinate points were obtained, cranial arcs were calculated by tracing the contour of the skull. This is normally done using a contour gauge, but the Threeskull program is able to collect these data by recording the three-dimensional semi-landmark coordinates along the arc in a predetermined distance interval. For this research, arc coordinate points were collected every 0.5 millimeters.

Some bilateral points, such as the superior and inferior cheek pinch points, were only taken on the left side of the cranium. In the event of fragmentation of the crania on the left side, points were taken at the corresponding point on the right side. If both sides of the cranium were fragmentary at a given bilateral point or an area on a midline point was damaged, the point was usually not taken. Some points, however, are crucial to the calculation of many craniometric measurements and dimensions, and were estimated. Points estimated included the inferior and anterior prosthion, subspinale and dacryon, and were only done so in the presence of minor bone loss or resorption. With significant damage, resorption or healed antemortem fractures, points were not taken; for example, ectomolare. Once all points were recorded, any pencil marks remaining on the cranium were erased and the cranium was returned to its box.

The collected three dimensional coordinates were then organized using a program called 3DILDOut (developed by Steve Ousley). This program does two things: 1) it condenses a craniometric data set and organizes coordinate points by those that every individual in the sample has in common, and 2) it puts the data into a format (Morphologika, in this case) that can be transferred into MorphoJ (Klingenberg, 2011) for statistical analysis. Methods for obtaining three-dimensional coordinates using a microscribe digitizer and Threeskull are standard for collecting these data and are the same methods used by the researchers who collected the FDB, PCOME, and Mexican samples.

Statistical Analyses

Three dimensional landmark data were analyzed using the program MorphoJ 1.06a (Klingenberg, 2011). Before any statistical analyses were performed, the raw three-dimensional data were brought into a common coordinate system through Procrustes superimposition. This procedure translates, rotates and scales each individual's landmarks into a common coordinate system (Zelditch et. al., 2012). The Procrustes coordinates were then used in subsequent analyses for both size and shape sexual dimorphism.

Size

A MANOVA was performed using SAS 9.3 (SAS Institute, Cary NC), to test for significant differences in centroid size for population group, sex, and an interaction between population groups and sex with a Tukey post-hoc test. The Tukey post-hoc test is beneficial to this data set, due to small sample sizes of some of the groups, such as the small number of American Black females (n=15) in comparison to the robust size of the Hispanic male sample (n=339). These analyses serve to test for differences in cranial size between Hispanic males and females, differences in cranial size among males and females of all three groups, and differences in the levels of sexual size dimorphism among the three groups.

Shape

Procrustes coordinates were used in a canonical variates analysis (CVA) in MorphoJ to address shape differences by sex and group. Wireframe graphs were used to compare the mean shape averages between the sexes within each group and among groups. This procedure also produced Mahalanobis distances as a measure of the shape sexual dimorphism between the sexes of each group. This was done to assess whether the shape differences expressed between the sexes of each group differed, and which areas held the most information for sex estimation.

CHAPTER III

Results

Size

The results of the ANOVA, which was testing for overall differences in centroid size by sex, show that significant differences in size exist for males and females in all groups at the $p<0.001$ level (TABLES 6 and 7). The Tukey results indicate that, at the $p<0.05$ level of significance, Hispanic males are significantly smaller in centroid size from American Black and American White males, as were Hispanic females from their American Black and American White counterparts. The significant negative difference between the means of Hispanic males and Hispanic females when compared to the other two groups can be seen in TABLES 8 and 9.

TABLE 6: ANOVA Results for Males

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	40512.9424	20256.4712	127.07	<.0001
Error	630	100428.5141	159.4103		
Corrected Total	632	140941.4565			

TABLE 7: ANOVA Results for Females

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	9691.1989	4845.59945	30.36	<.0001
Error	207	33040.44391	159.61567		
Tukey Corrected Total	209	42731.64281			

TABLE 8: ANOVA Tukey Post-Hoc Test Results for Males

Group Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
W - B	-1.9684	-6.2325	2.2956	
H - B	-17.5539	-21.7237	-13.3842	***
H - W	-15.5855	-18.0841	-13.0869	***
Comparisons significant at the p<0.05 level are indicated by ***				

TABLE 9: ANOVA Tukey Post-Hoc Test Results for Females

Group Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
W-B	-3.735	-11.855	4.385	
H-B	-18.177	-26.772	-9.581	***
H-W	-14.442	-19.048	-9.835	***
Comparisons significant at the p<0.05 level are indicated by ***				

The results of the MANOVA show that there are significant size differences between groups. However, the interaction between sex and population group is not significant, indicating there is no significant difference (p=.8829) in the expression of sexual size dimorphism among the groups (TABLES 10, 11, FIGURE 3).

TABLE 10: MANOVA Results Comparing Male and Female Centroid Size by Group

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	114945.6517	22989.1303	144.17	<.0001
Error	837	133468.9580	159.4611		
Corrected Total	842248414.6097				

TABLE 11: MANOVA Results Comparing Group, Sex and Group/Sex

Source	DF	Type III SS	Mean Square	F Value	Pr>F
Group	2	32255.70095	16127.85048	101.14	<.0001
Sex	1	42132.80707	42132.80707	264.22	<.0001
Group*Sex	2	62.17852	31.08926	0.19	0.8229 (Wilks' Lambda)

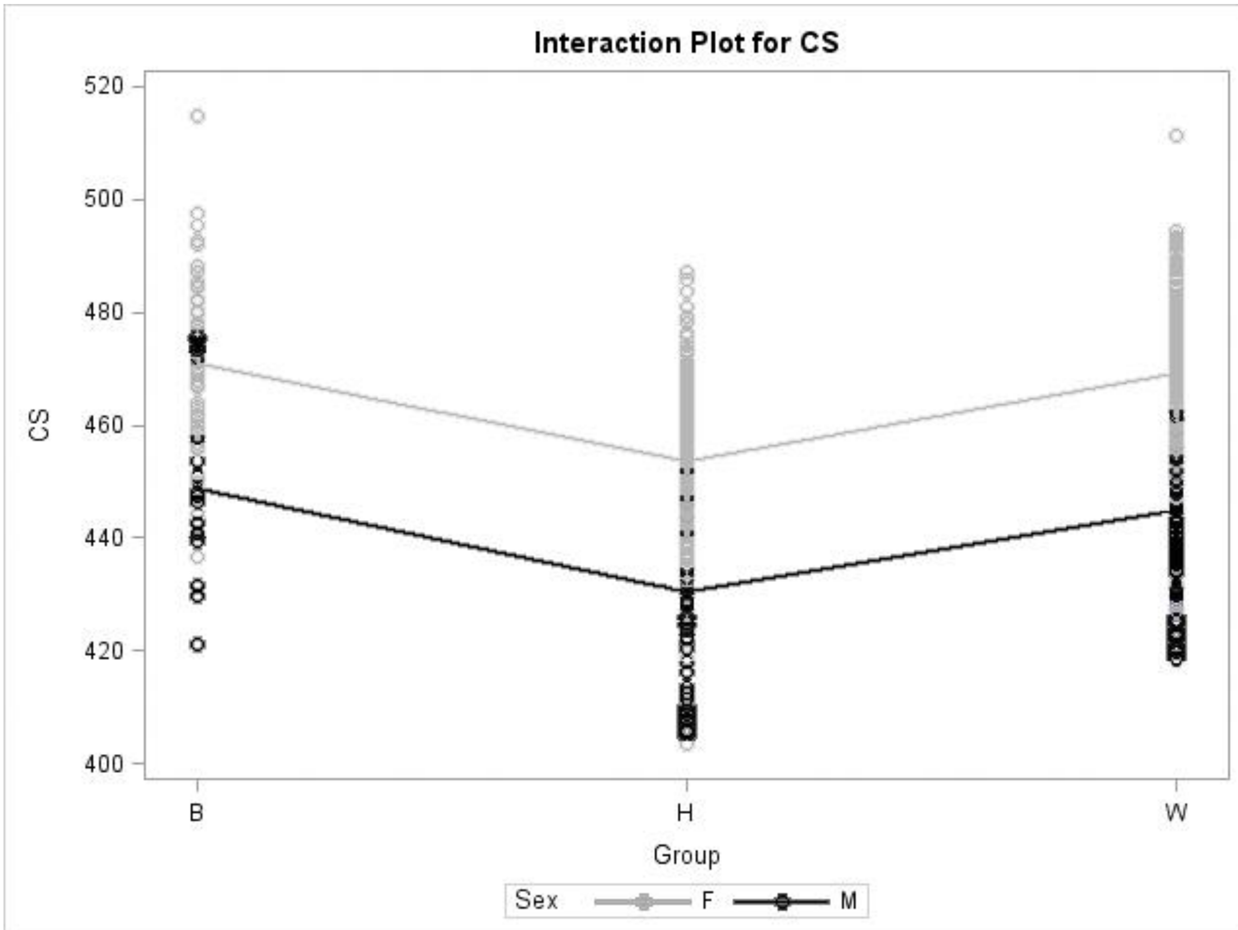

FIGURE 3: Plot of average centroid size by group and sex.

Shape

Wireframe graphs allow for the visualization of shape changes shown in units of Mahalanobis distances. The wireframes represent positive and negative changes from the mean shape in 10 Mahalanobis distance units along the first Canonical Variates (CV) axis.

American Black Sample

In the American Black sample, cranial differences between the sexes lied mainly in the posterior and inferior vault shape, with some differences also arising from the nasal and orbit area (FIGURE 4). CV1 separation is visualized in the histogram FIGURE 5.

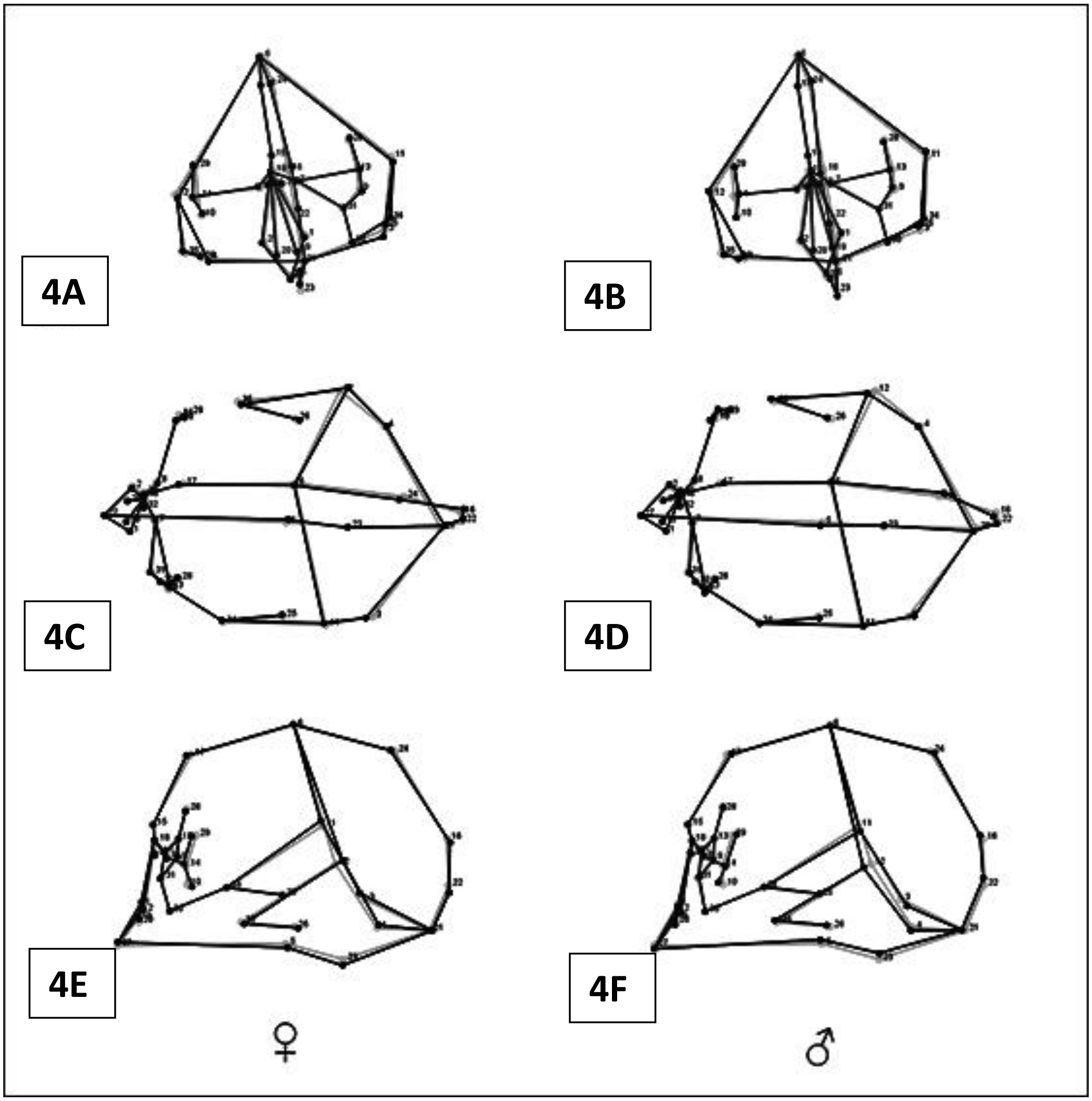

FIGURE 4: Wireframe graphs of American Black females (4A, 4C, 4E) and American Black males (4B, 4D, 4F) compared to the mean shape for all American Blacks. Grey represents the mean shape, black represents a negative difference of 10 Mahalanobis distance units for females and a positive difference of 10 Mahalanobis distance units for males.

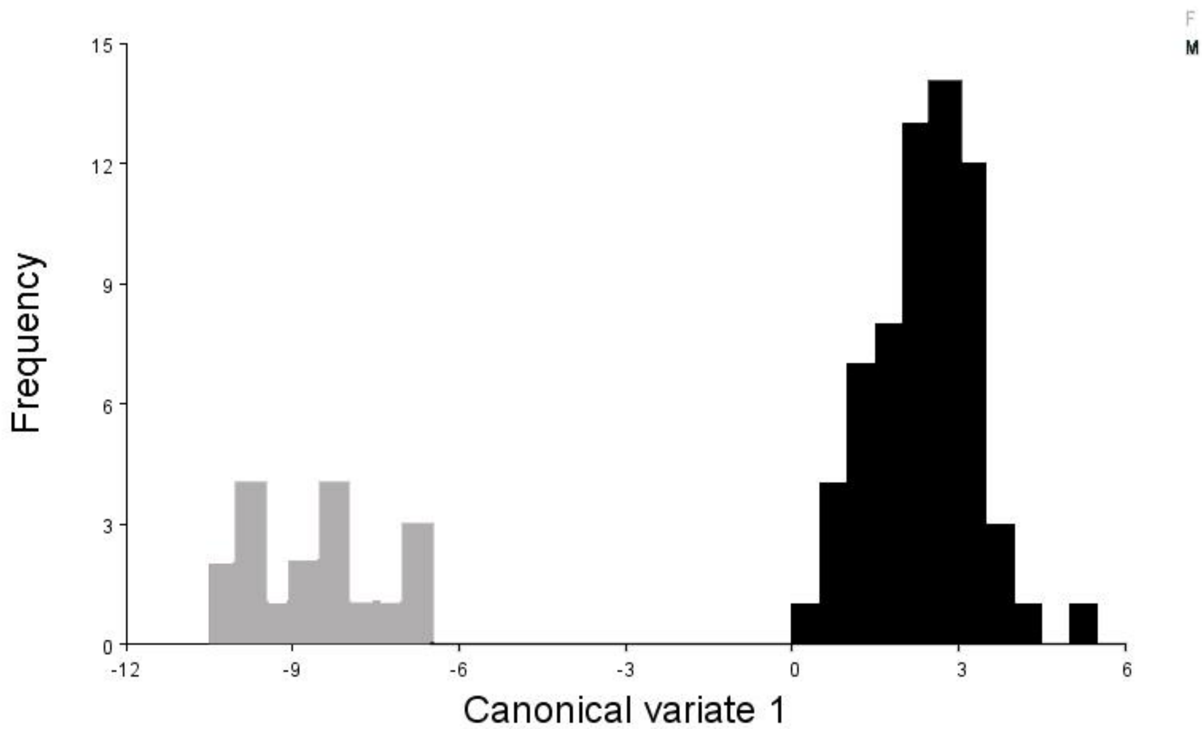

FIGURE 5: CV 1 histogram for American Black males and females showing shape differences. Note the lack of overlap in male and female shape.

Mahalanobis distances produced during the CV analysis show that the expression of sexual shape dimorphism is significantly stronger in the American Black sample (Mahal. D=10.99), than the American White (Mahal. D=3.21) and Hispanic samples (Mahal. D=3.02; TABLE 12). The larger Mahalanobis distance, when American Black males are compared to females, means that the males of this group are the most dissimilar of to their female counterparts than all other groups. Significant results were achieved in the comparison of Mahalanobis distances, with a p=<.0001.

The first CV axis accounts for the 100% of the variation between the males and females. In this sample, the posterior, inferior and lateral vault, nasal height and width, orbit width, and frontal bossing versus a more posterior sloping forehead in males. The complete lack of overlap shown in the histogram of CV1 (FIGURE 5), tells us that the likelihood for misclassification in this sample is very low.

Hispanic Sample

The Hispanic sample differed mainly in vault shape, including the posterior, superior and lateral vault, as well as the basicranium and the glabellar region (FIGURE 6). The first canonical variate (CV1) separation is visualized in the histogram below (FIGURE 7).

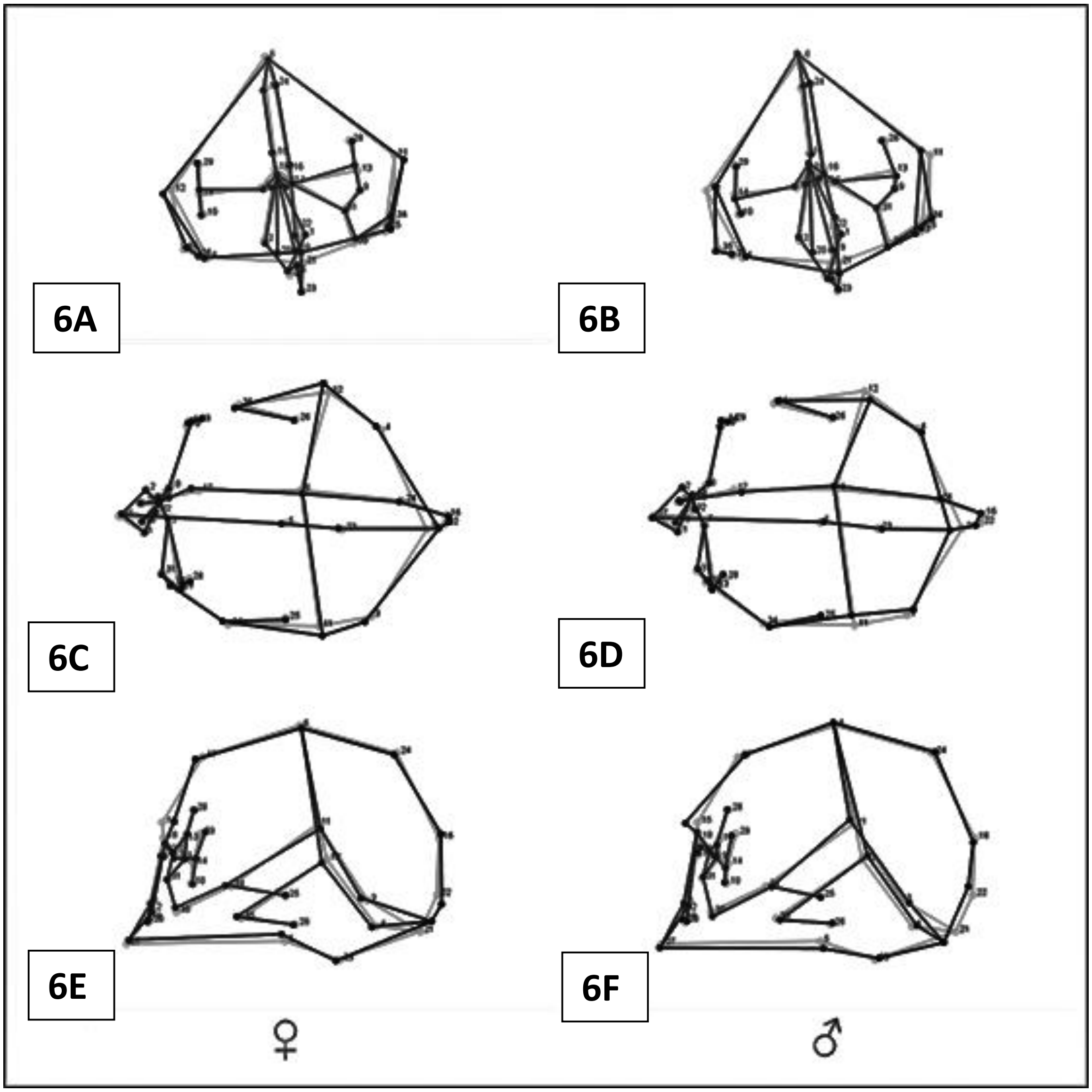

FIGURE 6: Wireframe graphs of Hispanic females (3A, 3C, 3E) and Hispanic males (3B, 3D, 3F) compared to the mean shape the pooled Hispanic sample. Grey represents the mean shape, black represents a negative difference of 10 Mahalanobis distance units for females and a positive difference of 10 Mahalanobis distance units for males.

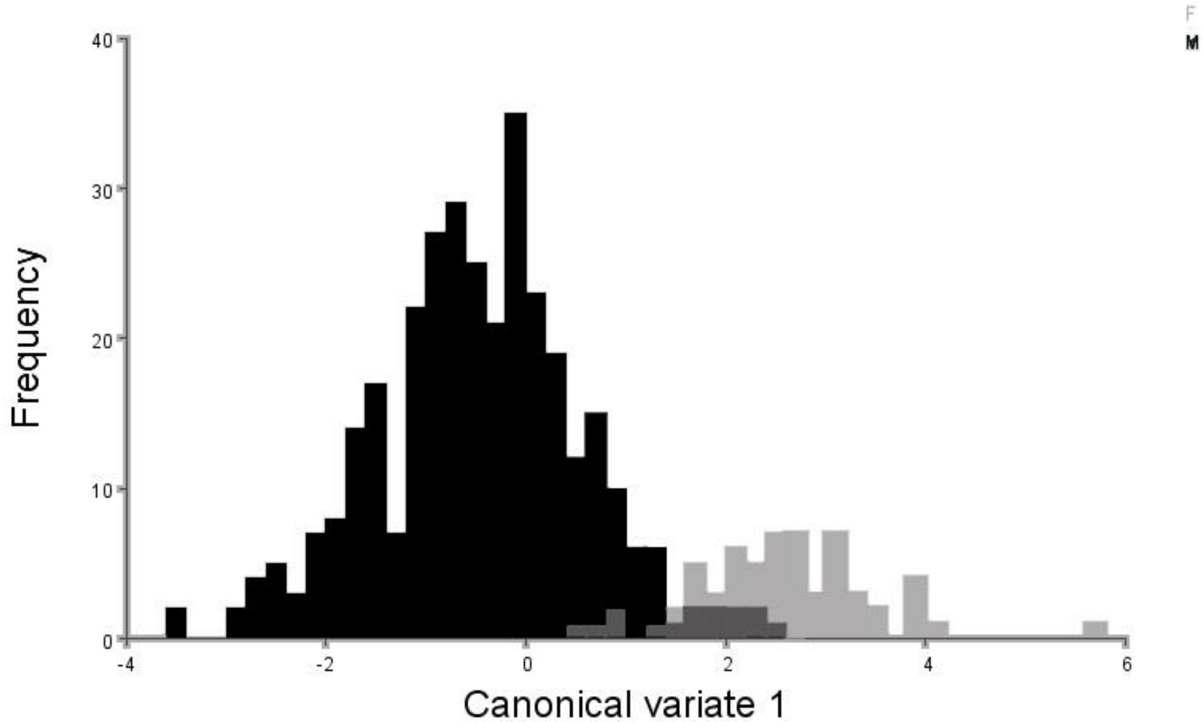

FIGURE 7: CV 1 histogram for Hispanic males and females showing shape differences.

Mahalanobis distances produced during the CVA show that the expression of sexual shape dimorphism is the lowest in the Hispanic sample, with a Mahalanobis distance of 3.02 (TABLE 12). The amount of sexual shape dimorphism in the Hispanic sample is very similar to that of the American White sample. Significant results were still achieved in the comparison of Mahalanobis distances in the Hispanic sample, with a p=<.0001.

The first canonical variate (CV) axis accounts for 100% of the variation between the males and females. In this sample, the vault holds the most shape information between the sexes. The posterior, superior and lateral vault are most informative for sex.

Females generally have a wider and shorter vault, while males had a taller and narrower vault. Males typically have a much flatter cranial base and a much more sloping forehead compared to a more anteriorly projecting frontal area in females. Males also tend to have a much more robust glabellar region than females. Orbit height and nasal height were also valuable in differentiating Hispanic males from females.

FIGURE 7 shows that Hispanic males and females very similar in shape. While the cranial vault best separates males and females, there is still a great deal of overlap between the sexes.

American White Sample

The differences in the American White sample were focused in the midface (nasal, maxillary, cheek and orbit areas) and the basicranium (FIGURE 5). The first canonical variate (CV1) separation is visualized in the histogram (FIGURE 6).

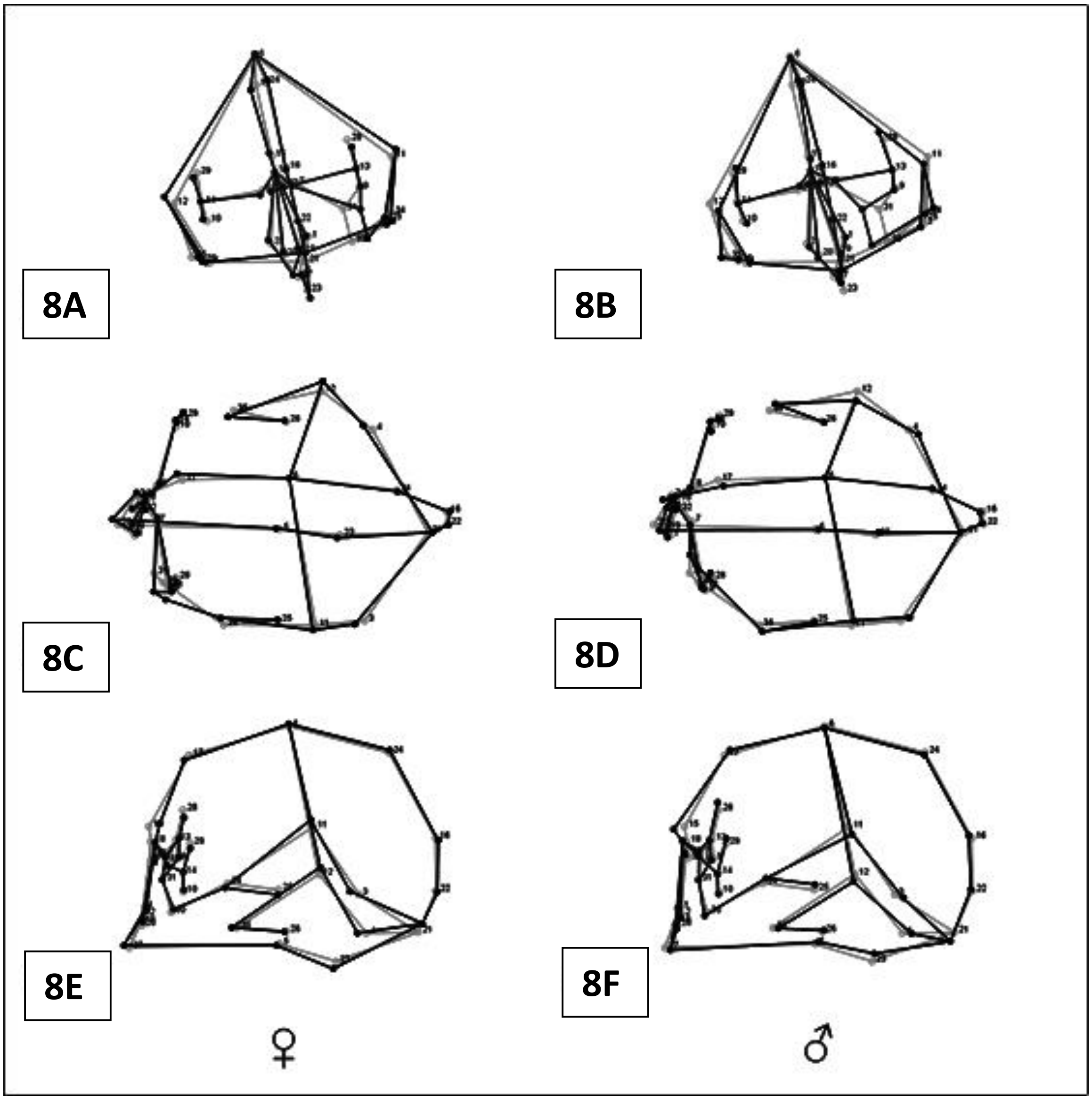

FIGURE 8: Wireframe graphs of American White females (5A, 5C, 5E) and American White males (5B, 5D, 5F) compared to the mean shape for all American Whites. Grey represents the mean shape, black represents a negative difference of 10 Mahalanobis distance units for females and a positive difference of 10 Mahalanobis distance units for males.

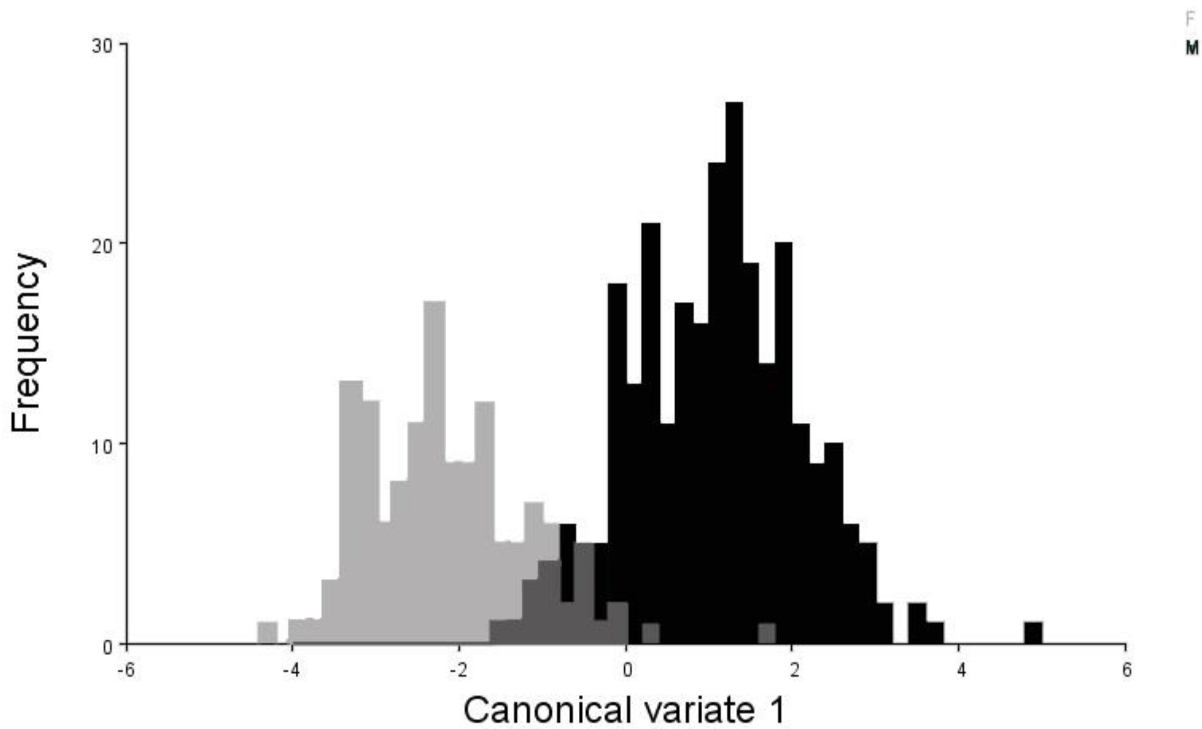

FIGURE 9: CV 1 histogram for American White males and females showing shape differences.

Mahalanobis distances produced during the CVA show that the expression of sexual shape dimorphism in the American White sample (Mahal.D=3.21) is slightly higher than that of the Hispanic sample (Mahal. D=3.02; TABLE 12). Significant results were still achieved in the comparison of Mahalanobis distances, with a p=<.0001.

The first canonical variate (CV) axis accounts for 100% of the variation between the males and females. In American White, most of the shape variation between the sexes lies in the midface. Orbit shape, orbit height, nasal height, nasal width, zygomatic shape and anterior malar projection contribute a significant amount of shape differentiation between the sexes. The location and size of the cheek pinch, which would change the overall shape of both the orbit, the maxilla and the zygomatic, also contribute to midface sexual dimorphism. Maxillary prognathism is seen to be more pronounced in females, leading to a flatter midface in males. Vault width is also slightly narrower in females, and males, and males tend to have a flatter cranial base and a more posteriorly projecting nuchal region.

TABLE 12: Mahalanobis Distance Values from Canonical Variates Analysis

American Black Female – Male	10.99
Hispanic Female – Male	3.02
American White Female – Male	3.21

CHAPTER IV

Discussion

The results of the present research can be used to inform research and development of new methods of sex estimation for individuals considered Hispanic by demonstrating the areas of the cranium that are most sexually dimorphic. The findings of the present research are consistent with previous findings of sexual dimorphism in other American population groups (Figueroa-Soto and Spradley 2012, Kimmerle et al. 2008, Tise et al. 2013) and expand on previous research involving the postcranial skeleton.

Size

Previous research using postcrania have shown that when American Black or American White data are used to identify individuals considered Hispanic, classifications are low most likely due to smaller size (Spradley et al. 2008, Tise et al. 2013 Figueroa-Soto and Spradley 2012). In the current study, when the centroid sizes of each group were compared by sex, a significant difference was found. This study demonstrated that Hispanic crania analyzed in this study also differ significantly in size from the American White and American Black population (Figueroa-Soto and Spradley 2012). Spradley and Jantz (2011) found that, postcranially, American Blacks were generally larger in size than American Whites and had higher rates of sexual size dimorphism. This study also found that the crania of American Blacks are more sexually size dimorphic than American Whites and Hispanics.

Shape

Commonly, forensic anthropologists estimate sex using morphological traits of the cranium outlined in Buikstra and Ubelaker's Standards for Data collection from Human Skeletal Remains (1994). These traits, described by Walker (2008), may not be universally applicable across all populations. As has been found in this research, the most valuable area for sex estimation in Hispanic crania is the vault, which is not taken into account in these five morphological traits (nuchal crest, mastoid process, supraorbital margin, glabella, mental eminence).

The results of the canonical variates analysis show the areas of the cranium that best separate males from females in each group. The Hispanic sample expressed cranial sexual shape dimorphism in areas different from the American Black and American White samples, and the CVA showed that the vault holds the most information of shape differences between the sexes in Hispanics. Mahalanobis distances produced during the CVA show that the expression of sexual shape dimorphism is the strongest in the American Black sample (TABLE 12).

In the American Black sample, cranial differences between sexes lay mainly in the posterior and superior vault shape, with some differences also arising from the nasal and orbit area. In the Hispanic sample the sexes differed mainly in vault shape, including the posterior, superior and lateral vault, as well as the basicranium and the glabellar region. The differences between males and females in the American White sample were focused in the midface (nasal, cheek and orbit areas) and the basicranium. In the present research, vault shape was estimated to hold the most information in sex estimation of individuals considered Hispanic.

The CV results represented in the histograms (FIGURES 5, 7, 9) show the amount of overlap in similarity between the sexes of each group. The American Black sample has a high amount of separation and no overlap in shape. This means that there would be very low misclassification rates when using shape to estimate sex in this population. This could, however, be a result of a low sample size. The Hispanic and American White samples both show higher levels of overlap in shape between the sexes. Additionally, both the Hispanic and American White samples have more males similar to the average female shape than vice versa. As a result, Hispanic and American White males would misclassify as females at higher rates than the American Black sample.

The most likely reasoning for the differences in the amount of sexual shape dimorphism, and the areas that are the most dimorphic among these three populations, is a complex combination of long-term adaptation to different environments, population health, secular change and genetic admixture.

These differences in the areas of shape dimorphism may highlight differences in population-wide adaptations to different environments (Beals et al. 1972, 1983, 1984, Roseman 2004). It has been established that interregional differences in climate are highly correlated with variation in cranial form, with brachycephalization in the crania of individuals adapted to colder climates. These adaptations to differing climates could manifest in the sexes in differing ways based on other factors, such as nutrition or secular trends.

The differences could also be an indication of the overall health of a population (Carson 2008, Charisi et al. 2011, Gray and Wolfe 1980, Greulich 1951, 1957, Rickland and Tobias 1986, Stini 1969, Stinson 1985,). As discussed in Stinson's 1985 publication, males are more effected by environmental stressors such as poor nutrition, or a diet high low in protein and high in carbohydrates. These nutritional deficiencies lead to long-term morphological changes, such as delayed skeletal maturation, smaller stature, smaller body size, which all tend to effect males more so than females. Socioeconomic status may also have an effect on the overall health of a population (Carson 2008, Figueroa-Soto and Spradley 2012, Greulich 1951), which would therefore have a negative correlation with stature, body size and subsequently cranial size or shape. When Mexican-American populations were compared to Mexican populations, it was shown that Mexicans were smaller in stature than there Mexican-American counterparts, which is believed to be due to a better diet and higher socioeconomic status in America (Carson 2008, Figueroa-Soto and Spradley 2012).

Another explanation for the variation in cranial shape between sexes among the three groups is the effects of secular trends for different populations over time. It has been established that general growth trends exist in populations over time (Fogel et al. 1983, Jantz and Jantz 2000, Spradley and Hefner 2012, Wescott and Jantz 2005). These trends may be due to positive or negative changes in nutrition, sampling biases based on age or sex, environmental conditions, mechanical stress, physical activity patterns, or genetic admixture (Jantz and Jantz 2000, Wescott and Jantz 2005).

In addition, population admixture will have an effect on the general shape of the cranium. It has been shown that cranial variation is consistent with global genetic variation (González-José et al. 2004, Relethford 1994, 2002). Given the high genetic component of craniometric traits, the craniometric complexity of a given population based on genetic admixture is highly variable. Hispanic populations in the U.S. and Central and South America are composed of differing levels of admixture from three general populations: European, African and Native American (Bertoni et al. 2003).

CHAPTER V

Conclusion

These findings are consistent with previous findings of sexual dimorphism in other American population groups (Figueroa-Soto and Spradley 2012, Kimmerle et al. 2008, Tise et al. 2013) and expand on previous research involving the postcranial skeleton. While differences in cranial size and shape among the three groups were significant, no differences in the expression of sexual size dimorphism were found. Sexual shape dimorphism in the cranium was evident in the Hispanic sample mainly in the vault, basicranium and glabellar regions. When compared to the American Black and White samples, the Hispanic sample exhibited the smallest level of sexual shape dimorphism.

Differences in the areas of the cranium that are the most sexually shape dimorphic will aid practicing forensic anthropologists in sex estimation of the crania of individuals considered Hispanic. Emphasis on vault shape in metric sex estimation is recommended. In addition, it was found that the midface holds the most information for differentiating between American White individuals, and the nasal, orbit and portions of the vault hold the most information for American Black individuals.

These results can also aid in the identification of Hispanic individuals when compared to other populations, since both males and females tend to be smaller in size. If it is suspected that an unknown cranium is Hispanic, metric analysis of ancestry estimation is optimal over visual morphological assessment. Along with contextual clues and the cultural profile (Anderson 2008, Birkby et al. 2008), these results can help the forensic anthropologist identify Undocumented Border Crossers into the United States when developing a biological profile. In light of recent publications on the rising numbers border crossing deaths in the southern United States, the issue of sex estimation of Hispanic individuals is a problem that must be investigated further.

Future avenues of expansion on this research include a further analysis of the craniometric variation within Hispanic populations. Data collection in Central American countries, such as El Salvador, Honduras, Guatemala, and Mexico would greatly benefit the forensic anthropological community. In addition, further exploration of the effects of socioeconomic on within-group variation would help shed light on how Hispanic populations should or should not be pooled for analysis.

APPENDIX SECTION

Craniometric Landmarks

1, 2: Alare – Instrumentally determined as the most lateral points on the nasal aperture in a transverse plane (bilateral; Buikstra and Ubelaker 1994).

3, 4: Asterion – The common meeting point of the temporal, parietal, and occipital bones, on either side (bilateral: Howells 1973).

5: Basion – On the anterior border of the foramen magnum, in the midline, at the position pointed to by the apex of the triangular surface at the base of either condyle, i.e., the average position from the crests bordering this area (Howells 1973).

6: Bregma – The posterior border of the frontal bone in the median plane (Howells 1973).

7, 8: Dacryon – The apex of the lacrimal fossa, as it impinges on the frontal bone (bilateral; Howells 1973).

9, 10: Ectoconchion – The intersection of the most anterior surface of the lateral border of the orbit and a line bisecting the orbit along its axis (bilateral; Howells 1973).

11, 12: Eurion – Instrumentally determined ectocranial points on opposite sides of the skull that form the termini of the line of greatest cranial breadth (bilateral; Buikstra and Ubelaker 1994).

13, 14: Frontomalare Anterior – The most anterior point on the fronto-malar suture (bilateral; Howells 1973).

15: Glabella – The most anterior midline point on the frontal bone, usually above the frontonasal suture (Buikstra and Ubelaker 1994).

16: Lambda – The apex of the occipital bone at its junction with the parietals, in the midline (Howells 1973).

17: Metopion - Point where the line that connects the highest points of the frontal eminences crosses the sagittal plane (Martin and Saller 1928).

18: Nasion – The intersection of the fronto-nasal suture and the median plane (Howells 1973).

19, 20: Inferior Nasal Border – The lowest point on the border of the nasal aperture on either side (bilateral; Howells 1973).

21: Occipital Subtense Point – Instrumentally determined as the most prominent point on the basic contour of the occipital bone in the midplane (Howells 1973).

22: Opisthiocranion – Instrumentally determined most posterior point of the skull not on the external occipital protuberance (Buikstra and Ubelaker 1994).

23: Opisthion – The interior edge of the posterior border of the foramen magnum in the midline (Howells 1973).

24: Parietal Subtense Point – Instrumentally determined as the highest point on the convexity of the parietal bones in the midplane, to the bregma-lambda chord (Howells 1973).

25, 26: Porion - The most lateral part of the superior margin of the external auditory meatus. It is used to define the Frankfort Plane and to measure mastoid length (bilateral; Moore-Jansen et al. 1984).

27: Prosthion – The most anteriorly prominent point, in the midline, on the alveolar border, above the septum between the central incisors (Howells 1973).

28, 29: Frontotemporale – The point where the temporal line reaches its most anteromedial position on the frontal (bilateral; Buikstra and Ubelaker 1994).

30: Cheek Height Inferior – Instrumentally determined as the inferior point of the minimum distance, in any direction, from the lower border of the orbit to the lower margin of the maxilla, mesial to the masseter attachment (Howells 1973).

31: Cheek Height Superior - Instrumentally determined as the superior point of the minimum distance, in any direction, from the lower border of the orbit to the lower margin of the maxilla, mesial to the masseter attachment (Howells 1973).

32, 33: Nasomaxillary Suture Pinch Point – Instrumentally determined bilateral points between the naso-maxillary sutures at their closest approach (Howells 1973).

34, 35: Zygion – Instrumentally determined points at the maximum breadth across the zygomatic arches, wherever found, perpendicular to the median plane (Howells 1973).

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