BODY MASS ESTIMATION: PRELIMINARY POPULATION SPECIFIC EQUATIONS FOR SOUTH TEXAS MIGRANT HISPANICS AND AN EVALUATION OF GEOGRAPHIC VARIATION WITHIN A POPULATION

by

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DEDICATION

For my mother.

Here's to following in your footsteps.

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LIST OF ABBREVIATIONS

Abbreviation	Description
BM	Body Mass
BMI	Body Mass Index
ENSANUT	Encuesta Nacional de Salud y Nutrición
FACTS	Forensic Anthropology Center at Texas State University
FDB	Forensic Anthropology Data Bank
INS	Immigration and Naturalization Service
FH	Femoral Head Diameter
INS	Immigration and Naturalization Service
LBIB	Living bi-iliac breadth
NamUs	National Missing and Unidentified Persons System
NCHS	National Center for Health Statistics
NHANES	National Health and Nutrition Examination Survey
NHANES III	Third National Health and Nutrition Examination Survey
OpID	Operation Identification
ORPL	Osteology Research and Processing Laboratory
SBIB	Skeletal Bi-iliac Breadth
ST	Stature
WC	Waist Circumference
WtHR	Waist-to-Height Ratio

I. INTRODUCTION

Problem and Purpose

Establishing a biological profile is one of the main tasks for a forensic anthropologist, which includes the estimation of age, sex, ancestry, and stature. Previous research has shown a need for population specific formulae for estimating the biological profile from skeletal remains (Gocha et al. 2013; Pomeroy and Stock 2012; Tallman and Winburn 2015). The majority of techniques used in the United States were developed using skeletal samples of predominately American Whites and American Blacks (Spradley et al. 2008). According to the U.S. Census Bureau (2016), there was a two-percent increase in the Hispanic population from 2015 to 2016, totaling an estimated 57.5 million Hispanics living in the United States. It is important to note that the term "Hispanic" is not a social race category, but an ethnicity that can be self-defined (Passel and Taylor 2009). Therefore, it is important for forensic anthropologists to continue updating and refining their methods to reflect everchanging American demographics. While Hispanics account for 17.8 percent of the current American population (U.S. Census Bureau 2016), biological profile techniques for this group are limited by the low number of available skeletal samples.

The goal of estimating age, sex, ancestry, and stature for unidentified remains is to ultimately result in an identification. Information provided in a traditional biological profile may not be sufficient to lead to an identification in situations of mass disaster, such as the migrant deaths along the US-Mexico border, where the Hispanic population is most heavily affected. Under these circumstances, estimating body mass may help narrow the number of missing persons because living weight is often included in missing persons reports.

This study examines the accuracy of the stature-bi-iliac breadth method of body mass estimation introduced by Ruff et al. (1997) in estimating body mass in Hispanic individuals. Preliminary population specific body mass estimation equations for migrant Hispanics are created using three methods: 1) stature-bi-iliac breadth, 2) stature-waist circumference, and 3) waist-to-height ratio. Living body mass data from the National Health and Nutrition Examination Survey and the Encuesta Nacional de Salud y Nutrición were used to generate the equations. The accuracy rate and applicability of each body mass estimation method is addressed. Finally, this study also explores geographic variation in body mass within the Hispanic population by comparing the average weight of each demographic population (e.g. American Hispanics, migrant Hispanics, and Mexican Hispanics).

Migrant Hispanic Issues

Starting in 1993, the Clinton administration introduced border policy shifts which included increasing the budget for the Immigration and Naturalization Service (INS) for border enforcement, as well as a concentration of enforcement in urban areas with high levels of migrant crossings (Cornelius 2001). Four distinct operations resulted in this initiative: Operation Hold-the-Line in El Paso, Texas; Operation Gatekeeper in San Diego, California; Operation Safeguard along the Arizona border; and Operation Rio Grande in the south Rio Grande Valley of Texas. The implementation of these policies caused a shift in border-crossing attempts towards the east (Hinkes 2008). From 1993 to

1997, these policies distributed migrant traffic into more rural areas, where detection by Border Patrol was less likely (Eschbach et al. 2003).

Through these policies, the INS claims that the number of apprehensions has greatly decreased (Cornelius 2001). Though the rate of apprehension may have decreased, the increased number of migrant deaths since the mid-1990s is an unintended consequence (Eschbach et al. 2003). To avoid apprehension, migrants are choosing hazardous routes that are more physically demanding (Sapkota et al. 2006). A possible correlation between an increase in migrant deaths and intensified border-control policies is evident in the sharp increase of recorded migrant deaths from 1994 to mid-2001 (1,700 deaths) and October 1997 to May 2001 (1,013 deaths) (Cornelius 2001).

Brooks County, Texas, has seen an intensified increase in migrant deaths due to attempts to bypass the nearby United States Border Patrol checkpoint (Anderson and Spradley 2016). Each county along the US-Mexico border has their own procedures on how to handle migrant deaths despite state laws. In Texas, the process for handling migrant deaths has been standardized but widely unfollowed, and many individuals are buried without any efforts for identification (Spradley 2014). Later identification efforts are often hindered by missing paperwork and a lack of context for when and where the individuals were discovered. Therefore, any information that can be gleaned from a set of remains is crucial for identification – including the estimation of body mass.

Body Mass Estimation

Body mass is often left out of the biological profile because it is highly variable among populations, and has a minimal correlation to the skeleton (Pomeroy and Stock 2012). Even so, the unique situation of unidentified migrant deaths in South Texas benefits from any additional information that can be added to each case report. Methods of body mass estimation also cannot account for individuals who fall on the extreme ends of the body mass spectrum (Lorkiewicz-Muszyńska et al. 2013). There are currently four established methods of body mass estimation, three of which are identified as *mechanical*, and one which is considered *morphometric* (Auerbach and Ruff 2004). The mechanical equations use strictly femoral head diameter (FH) (Grine et al. 1995; McHenry 1992; Ruff et al. 1991) while the morphometric method uses stature (ST) in conjunction with living bi-iliac breadth (LBIB) (Ruff et al. 1997). Each method makes use of different skeletal collections of varying populations and body sizes, resulting in different formulae.

Auerbach and Ruff (2004) conducted a comparison between results of the morphometric method and the individual results of the mechanical methods of body mass estimation. The femoral head diameters, statures, and bi-iliac breadth dimensions used for this comparison come from a geographically diverse sample of 1173 adult Holocene individuals (Auerbach and Ruff 2004). Bivariate scatters of estimated body mass were conducted over the entire pooled sample and the correspondence of the three mechanical methods were individually evaluated, with Ruff et al. (1997) used as the baseline equation for comparison. Because all four equations are derived from different skeletal collections that represent different types of populations, the results provided evidence for body-size related variation (Auerbach and Ruff 2004). These results indicate a need for population-specific equations, as the variability between the four body mass estimation methods are due to the difference in samples from which each method was derived.

Pomeroy and Stock (2012) estimated stature and body mass of coastal and mid-altitude Andean skeletal populations. Based on the study published by Auerbach and Ruff (2004), Pomeroy and Stock used the morphometric method as "true" body mass and evaluated the accuracy of the body mass estimates derived from the mechanical methods. Overall, the combined average body mass from the three mechanical equations resulted in the most statistically similar body mass estimates when compared against the morphometric method (Pomeroy and Stock 2012).

Schaffer (2016) evaluated Ruff's (1997) stature-bi-iliac breadth method on non-Hispanic U.S. Whites, non-Hispanic U.S. Blacks, and Mexican Americans reported in NHANES III. Additional criteria for the study included individuals who fell within "normal" ranges of BMI and were between the ages of 20-39 years-old. The study generated population specific body mass estimation equations for males and females of the aforementioned population groups. Schaffer (2016) found a strong, positive correlation (0.853) between estimated and actual body mass using the newly generated equations. Limitations to this study include the exclusive use of a narrow age range that may not be suitable for most cases in forensic anthropology. Moreover, Schaffer (2016) focused on classifying individuals based on body mass index, which has been found to poorly estimate total body mass.

Measures of Total Body Mass

Body mass index classifies individuals with high ratios of skeletal muscle to be obese, and many professional athletes are classified as underweight. As an alternative to using body mass index as a measure of body fat, the U.S. Army has recently proposed using waist-to-height ratio instead (Bernstein et al. 2017). Waist-to-height ratio is calculated as waist circumference divided by stature. Research has shown that waist-to-height ratio is a more accurate indicator of obesity and related health issues, with a universal threshold of 0.5 (Ashwell and Hsieh 2005). One advantage to using waist-to-height ratio is that it standardizes body size, which means it is free of sex, age, or populational biases. This allows for research focusing on the effects of economic and environmental factors to be conducted. Most research has cited complications with estimating body mass for individuals who are either underweight or obese according to their body mass index. This study will explore the relationship between waist-to-height ratio and body mass and evaluate whether a more accurate method of body mass estimation can be created using methods similar to Schaffer (2016) without limitations on body mass index.

Variation within the Hispanic Population

In addition to generating body mass estimation equations for migrant Hispanics, this study will explore the effect of environment on body size variation within the Hispanic population. Bogin and Loucky (1997) explored the concept of plasticity in humans and the effect that environmental, political, and social conditions have on growth and development. They sought to quantify these effects by comparing the differences in height, weight, and body composition of native Mayan children living in Latin America and their counterparts living in the United States. The authors found that the American born or raised Mayan children were statistically larger than their native Guatemalan counterparts (Bogin and Loucky 1997). On average, they weighed 4.7 kilograms heavier and were 5.5 centimeters taller. Results strongly suggest that biological variation in body size due to geographic location is quantifiable within ancestry groups.

Spradley et al. (2008) tested biological profile methods of estimating sex, stature, and ancestry on Hispanic individuals from the Forensic Anthropology Data Bank (FDB). On average, Hispanics have smaller body size than the American Whites and Blacks used to establish biological profile methods. Therefore, this study found that traditional methods used by forensic anthropologists to estimate the biological profile do not perform well on Hispanic individuals (Spradley et al. 2008). In particular, Spradley et al. (2008) evaluated mean stature between American Whites and Blacks, and Hispanics self-reporting to be from Cuba, Mexico, and Puerto Rico, from the National Health and Nutrition Examination Survey. Results indicate not only differences in sitting and standing height between American Whites and Blacks and the Hispanic groups, but also marked differences in average height by birth year for Cubans, Mexicans, and Puerto Ricans.

Both Bogin and Loucky (1997) and Spradley et al. (2008) identified a need for further exploration into body size variation within the Hispanic population. This current study explores patterns in average body mass between American Hispanics, migrant Hispanics, and Mexican Hispanics from three different reference groups.

Research Questions

There are currently no population specific methods in estimating body mass for Hispanic individuals, and we do not fully understand the biological variation of groups considered Hispanic. The current study will generate preliminary population specific body mass estimation equations for the migrant Hispanic population, evaluate the accuracy of the established stature-bi-iliac breadth method on the migrant Hispanic population, as well as explore geographic variation within the Hispanic population. The estimated body mass data of the unidentified migrants housed at the Forensic Anthropology Center at Texas State University (FACTS) will be utilized and compared to living body mass data for American Hispanics from the National Health and Nutrition Examination Survey (NHANES) and for Mexican Hispanics from the Encuesta Nacional de Salud y Nutrición (ENSANUT) will be used to explore the following questions:

1. Can accurate population specific body mass estimation methods for skeletal remains be created using anthropometric data from NHANES and ENSANUT?
2. Does the morphometric stature-bi-iliac breadth method published by Ruff et al. (1997) accurately estimate body mass of Hispanic individuals?
3. Are there patterns in average body mass between American Hispanics, migrant Hispanics, and Mexican Hispanics?

II. MATERIALS AND METHODS

This study will first calculate preliminary population specific equations for body mass estimation using anthropometric data of Hispanic individuals from NHANES and ENSANUT ("reference sample") and applied to the identified and unidentified migrants. Second, the accuracy of the stature-bi-iliac breadth body mass estimation method will be analyzed when applied to the combined demographic and anthropometric data comprised of the reference sample as well as the positively identified migrants from Operation Identification. Data pulled from the reference sample includes sex, age, living body mass, stature, living bi-iliac breadth, waist circumference, and waist-to-height ratio. Finally, this study will use the actual body mass information from the health surveys and the estimated body mass information from the unidentified migrants to navigate the questions laid out in the introduction.

Sample Descriptions

American Hispanics. The National Health and Nutrition Examination Survey III (NHANES) is a survey that was conducted from 1988-1994 by the National Center for Health Statistics (NCHS), which is a branch of the Center for Disease Control and Prevention (CDC) (National Center for Health Statistics 1994). The goal of the survey is to document and assess the health and nutritional state of all people in the United States. There is both an interview portion and a physical examination included in the survey. Around 30,818 individuals were interviewed and examined to make up a representative sample of the United States. To account for often under-representation, the program over-sampled certain groups such as African Americans, Mexican-Americans, and Hispanics (National Center for Health Statistics 1994). Sample demographics used for this study are outlined in Table 1. Individuals who were under the age of 20 or over the age of 80 were excluded from the data set for this study. A total of 4,481 individuals from the survey were used.

Mexican Hispanics. The Encuesta Nacional de Salud y Nutrición (ENSANUT) is a similar study to NHANES but is conducted by the Mexican government (Romero-Martínez et al. 2013). A representative sample of the urban and rural distribution of Mexico was generated using multi-stage and stratified sampling. To correct for under-represented entities, oversampling was conducted for those groups (Romero-Martínez et al. 2013). The most recent data was collected in 2012, and sample demographics are reported in Table 1. Individuals who were under the age of 20 or over the age of 80 were excluded from the data set. In total, 35,919 individuals were identified as fitting the criteria for this study.

Table 1. Summary of the average demographics of the NHANES and ENSANUT samples. Standard deviations are reported in parentheses.

	Sex	Age
NHANES (N = 4,481)	Male (n = 2208)	41.58 (16.47)
	Female (n = 2273)	41.35 (16.09)
ENSANUT (N = 35,919)	Male (n = 15526)	43.84 (15.65)
	Female (n = 20393)	43.68 (14.78)

Migrant Hispanics. Operation Identification (OpID) is an initiative started by Dr. Kate Spradley at Texas State University "to locate, identify, and repatriate unidentified migrants found on or near the South Texas border through community outreach, forensic anthropological analysis, and collaboration with governmental and non-governmental organizations" (Operation Identification 2017). The roughly 200 individuals in OpID were exhumed in 2013 and 2014, involving collaboration between Dr. Lori Baker (Baylor University), Dr. Krista Latham (University of Indianapolis), and Dr. Kate Spradley (Texas State University) (Anderson and Spradley 2016). In 2017, another exhumation took place as a joint effort by Drs. Latham and Spradley. The unidentified remains are housed at the Osteology Research and Processing Laboratory (ORPL), which is a FACTS laboratory in San Marcos, Texas.

The cases in OpID are regarded as a mass disaster situation, in which efforts to identify and repatriate take precedence. Biological profiles are created for each individual, meaning that information such as estimated sex, age, height, and other distinguishing factors have been collected. This information is periodically compared to missing persons reports in the National Missing and Unidentified Persons System (NamUs), an online database containing information for missing persons, unidentified deceased, and unclaimed persons cases for potential identifications (Heurich 2014). Additional cross-referencing occurs with non-governmental databases. Most of the individuals have yet to be positively identified. Any addition of information, such as an estimation of body mass, could be beneficial in narrowing the number of possible identifications for each migrant.

This study required that skeletal bi-iliac breadth and anatomical stature could be measured. Any individuals with fragmentary remains of the os coxae, sacrum, or vertebral bodies were excluded from the study. Skeletal bi-iliac breadth was measured by first articulating the pelvic girdle using putty (see Appendix). Reported weight obtained from NamUs for the positively identified individuals was included for analysis of accuracy for body mass estimation methods. In total, 8 positively identified individuals and 60 unidentified individuals from OpID were measured, and their body masses were estimated for this study.

Data Collection

Skeletal Measurements. 68 individuals in OpID were measured for skeletal bi-iliac breadth and stature using sliding calipers, spreading calipers, and an osteometric board. Individuals were excluded if any measurements could not be taken due to fragmentation or missing elements. The measurements are defined as follows:

Maximum skeletal bi-iliac breadth (SBIB): The maximum medio-lateral breadth of the pelvis after first articulating the innominates and the sacrum (Ruff 2000). Osteometric board. Examples in Appendix.

Revised Fully Stature (ST): Summation of the following measurements: Basion-bregma height of the cranium; Maximum height of the corpus of the C2-L5 vertebrae measured separately; Anterior height of the first sacral segment; Physiological length of the femur; Maximum length of the tibia without the spine and including the malleolus; Articulated height of the talus and calcaneus, from the most superior point on the talus to the most inferior point on the calcaneus (Raxter et al. 2006). Sliding calipers, spreading calipers, and osteometric board.

Measurements required for body mass estimation were either conducted by the author or by previous researchers. As part of standardized protocol for OpID, sex is estimated using DNA when available, or a combination of craniometric and morphologic features. A tissue-correction equation was used to convert skeletal bi-iliac breadth (SBIB) to living bi-iliac breadth (Ruff et al. 1997). The tissue-correction equation and stature-bi-iliac breadth body mass estimation method published by Ruff et al. (1997) are outlined in Table 2.

Table 2. Summary of the equations from Ruff et al. (1997) utilized for this study.

Tissue-correction Equation:
LBIB(cm) = (1.17 x SBIB(cm)) – 3(cm)

Body Mass Estimation Equations		
Male	BM(kg) = (0.373 x ST(cm)) + (3.033 x LBIB(cm)) – 82.5 ± 3.6(cm)[ǂ]	r = 0.898[ǂ]
Female	BM(kg) = (0.522 x ST(cm)) + (1.809 x LBIB(cm)) – 75.5 ± 4.1(cm)[ǂ]	r = 0.816[ǂ]

[ǂ]R and standard error values were retrieved from Ruff (2000)

Statistical Analyses

All statistical analyses for this thesis were calculated in R.

Preliminary population-specific methods. To explore whether population specific body mass estimation methods could be created using anthropometric data, three different preliminary population specific methods were established using a Bayesian approach with an informed prior of living Hispanic individuals reported in the reference sample. A similar approach was used for stature estimation by Ross and Konigsberg (2002). A Bayesian approach was utilized for this study because the use of large health datasets provides a larger sample than can be achieved skeletally for Hispanic individuals. Additionally, the potential for translating anthropometric data to skeletal data opens the possibilities for larger-scale research to be conducted in biological anthropology regarding demographics and body size. The variables selected for this study were sex, body mass, stature, living bi-iliac breadth, waist circumference, and waist-to-height ratio.

Estimating living bi-iliac breadth and waist circumference. The relationships between the variables selected for this study were tested to see whether they would be suitable for estimating body mass. Because ENSANUT does not measure living bi-iliac breadth in their study, a Pearson's correlation was used to evaluate the relationship between living bi-iliac breadth and waist circumference. Following the analysis, equations estimating living bi-iliac breadth from waist circumference was created using NHANES for males, females, and pooled individuals using linear regression. To test for accuracy, living bi-iliac breadth was estimated for all individuals in NHANES and a Mann-Whitney test was conducted to determine whether there was a statistically significant difference between actual living bi-iliac breadths and estimated living bi-iliac breadths. The resulting equation was used to estimate living bi-iliac breadth of the ENSANUT individuals before the two datasets were combined.

Linear regression was then used to create equations to estimate waist circumference from living bi-iliac breadth for males, females, and a pooled sample, to be used for the skeletal OpID individuals. To test for accuracy of these equations, waist circumference was estimated for the NHANES individuals using the equations and a Mann-Whitney test was conducted to test whether there was a statistically significant difference between the estimated waist circumference values and the actual waist circumference values. The equations were then applied to the OpID individuals to estimate waist circumference from the converted living bi-iliac breadth values.

Method A: Stature and living bi-iliac breadth. The first set of equations are a population specific version of the stature-bi-iliac breadth method published by Ruff et al. (1997). To generate the final body mass estimation equations, a Pearson's correlation was first conducted on the reference sample to explore the relationship between body mass and the interaction of living bi-iliac breadth with stature. Following the analysis, linear regression was used to create body mass estimation equations using the reference sample for males, females, and pooled samples. Standard errors produced by the equations allow for a body mass estimation range to be used. Accuracy of the first method of body mass estimation was evaluated by the percentage of correct body mass estimations for the measured living body mass of the reference sample. The same analysis was conducted on the 8 identified OpID individuals using reported body mass from missing persons reports.

The body mass estimations were considered accurate if the reported body mass fell within the estimated body mass range.

Method B: Stature and waist circumference. The second set of equations make use of the relationship between body mass and a combination of stature and waist circumference. First, a Pearson's correlation was used to explore the relationship between body mass and the combination of waist circumference and stature. Second, linear regression was used to generate body mass estimation equations using the reference sample for males, females, and pooled samples. Standard errors produced by the equations allow for a body mass estimation range to be used. Finally, accuracy was determined by the percentage of living body mass values that fell within the estimated body mass ranges produced by the second method of body mass estimation for the reference sample. The same analysis was conducted on the 8 identified OpID individuals.

Method C: Waist-to-height ratio. The third set of equations use the relationship between body mass and waist-to-height ratio. A Pearson's correlation was used to evaluate the relationship between body mass and waist-to-height ratio. Linear regression was used to generate body mass estimation equations using the reference sample for males, females, and pooled samples. Standard errors produced by the equations allow for a body mass estimation range to be used. The accuracy of these equations was demonstrated by the percentage of living body mass values that fell within the estimated body mass ranges produced by the third method of body mass estimation for the reference sample. The same analysis was conducted on the 8 identified OpID individuals.

Accuracy of the stature-bi-iliac breadth method. To address the second research question, which tests the accuracy of the body mass estimation equations published by Ruff et al. (1997), the stature-bi-iliac breadth equations were used to estimate body mass ranges for males and females in the combined health dataset using standard error provided by Ruff (2000). The estimated body mass ranges were compared to measured living body mass from the reference sample. If the living body mass fell within the estimated body mass range, the estimation was considered accurate. The same process of body mass estimation and accuracy evaluation was conducted on the 8 positively identified OpID individuals using reported living weight from missing persons reports.

Geographic variation. The final research question addresses patterns in body mass observed between the following three geographically separate groups: American Hispanics, migrant Hispanics, and Mexican Hispanics. To explore how populational variance in body mass is affected by geographic location, average body mass of males and females of the American Hispanics (NHANES), migrant Hispanics (OpID), and Mexican Hispanics (ENSANUT) was calculated. A Kruskal-Wallis test was used to evaluate whether there are statistically significant differences between stature and the average body masses of American Hispanics, migrant Hispanics, and Mexican Hispanics for males, females, and a pooled sample. A pairwise Wilcoxon ranked sum test was then conducted to further evaluate the relationships between the three groups.

III. RESULTS

A summary of the available information provided by the reference sample and OpID dataset used for this study are presented in Table 3.

Table 3. Summary of mean values for body mass (if actual is known), stature, living bi-iliac breadth, waist circumference, and waist-to-height-ratio for the reference sample and OpID. Standard deviations are provided in parentheses.

	N	BM (kg)	ST (cm)	LBIB (cm)	WC (cm)	WtHR
Reference sample	40400	71.55 (15.58)	158.6 (9.781)	29.32 (2.294)	93.70 (13.09)	0.5925 (0.0903)
OpID	68	-	156.5 (11.04)	30.34 (1.535)	112.3 (4.608)	0.7206 (0.0579)

Preliminary population-specific methods. To generate preliminary population-specific equations for migrant Hispanics, relationships were first tested between the selected variables: living bi-iliac breadth, waist circumference, stature, and waist-to-height ratio.

Estimating living bi-iliac breadth and waist circumference. Results of the Pearson's correlation between living bi-iliac breadth and waist circumference using the NHANES data showed a strong positive relationship (0.7332 – 0.7989). Three equations were generated to estimate living bi-iliac breadth from waist circumference. A Mann-Whitney test comparing actual living bi-iliac breadth from NHANES to estimated living bi-iliac breadth using the created equations showed that there were no statistically significant differences between the mean values ($p > 0.05$). The three equations were used to estimate living bi-iliac breadth for the ENSANUT dataset and are summarized below in Table 4.

Table 4. Equations for estimating living b-iliac breadth from waist circumference for the Mexican Hispanic sample.

Estimating Living Bi-iliac Breadth (LBIB) from Waist Circumference (WC)	
Male	LBIB(cm) = (0.165 x WC(cm)) + 13.641
Female	LBIB(cm) = (0.173 x WC(cm)) + 13.312
Pooled	LBIB(cm) = (0.168 x WC(cm)) + 13.577

Three equations were then generated to estimate waist circumference from living bi-iliac breadth for the skeletal sample from OpID. A Mann-Whitney test comparing actual waist circumference from NHANES to estimated waist circumference using the created equations showed that there were no statistically significant differences between the mean values ($p > 0.05$). The three equations were then used to estimate waist circumference for the OpID individuals using living bi-iliac breadth. The equations are summarized below in Table 5.

Table 5. Equations for estimating waist circumference from living bi-iliac breadth for the OpID skeletal sample.

Estimating Waist Circumference (WC) from Living Bi-iliac Breadth (LBIB)	
Male	WC(cm) = (3.864 x LBIB(cm)) – 18.425
Female	WC(cm) = (3.106 x LBIB(cm)) + 1.122
Pooled	WC(cm) = (3.389 x LBIB(cm)) – 5.855

Method A: Stature and living bi-iliac breadth. The relationship between body mass and a combination of living bi-iliac breadth and stature was tested using a Pearson's correlation on the reference sample. The results of this correlation (0.5819 – 0.6519) show a moderately positive relationship between body mass and living bi-iliac breadth with stature.

Method B: Stature and waist circumference. A Pearson's correlation was also conducted to explore the relationship between body mass and waist circumference with stature using the reference sample. Results show a high positive correlation between body mass and waist circumference with stature (0.8870 – 0.9023).

Method C: Waist-to-height ratio. Finally, a Pearson's correlation tested the relationship between body mass and waist-to-height-ratio using the reference sample. The resulting correlation (0.5872 – 0.6859) indicates a moderately positive relationship between body mass and waist-to-height ratio.

After strong positive relationships between variables were established, linear regression was used to generate body mass estimation equations for males, females, and pooled sex for each method. The preliminary population specific body mass estimation equations are reported below in Tables 6, 7, and 8, for methods A, B, and C respectively.

Table 6. Summary of the three body mass estimation equations using Method A.

	Equation	Statistics
Male	BM(kg) = (0.642 x ST(cm)) + (5.421 x LBIB(cm)) – 189.2	r^2 = 0.7915, SEE = 6.977
Female	BM(kg) = (0.650 x ST(cm)) + (4.783 x LBIB(cm)) – 171.8	r^2 = 0.7305, SEE = 7.702
Unknown	BM(kg) = (0.591 x ST(cm)) + (5.075 x LBIB(cm)) – 170.9	r^2 = 0.7708, SEE = 7.460

Table 7. Summary of the three body mass estimation equations using Method B.

	Equation	Statistics
Male	BM(kg) = (0.658 x ST(cm)) + (0.951 x WC(cm)) – 123.1	r^2 = 0.8271, SEE = 6.354
Female	BM(kg) = (0.688 x ST(cm)) + (0.902 x WC(cm)) – 117.9	r^2 = 0.7801, SEE = 6.957
Unknown	BM(kg) = (0.586 x ST(cm)) + (0.922 x WC(cm)) – 107.8	r^2 = 0.8115, SEE = 6.766

Table 8. Summary of the three body mass estimation equations using Method C.

	Equation	Statistics
Male	BM(kg) = (138.2 x WtHR) – 3.000	r^2 = 0.4705, SEE = 11.12
Female	BM(kg) = (111.2 x WtHR) – 0.304	r^2 = 0.4589, SEE = 10.91
Unknown	BM(kg) = (106.3 x WtHR) + 8.549	r^2 = 0.3447, SEE = 12.61

Accuracy of the stature-bi-iliac breadth method. The accuracy rates for all four methods of body mass estimation are summarized in Table 9. The stature-bi-iliac breadth method published by Ruff et al. (1997) performed the worst with estimation accuracy rates ranging from 23.55% (males) to 26.76% (females). The population specific stature-bi-iliac breadth method performed the best with estimation accuracy rates ranging from 76.39% (females) to 76.66% (males).

Mean difference between actual body mass and the point estimates from each method were calculated to explore the magnitude and directionality of error for each method of body mass estimation. A visual comparison of the over- and under-estimation of body mass by the four methods compared to actual body mass from the reference sample and reported living body mass from missing persons reports are shown in Figure 1 for males and females.

Table 9. Summary of the body mass estimation methods with estimation accuracy rates for males and females of the reference sample and the identified OpID individuals.

	Ruff et al. (1997)	Method A	Method B	Method C
Males	26.67%	76.39%	75.98%	70.72%
Females	23.55%	76.66%	68.01%	72.22%

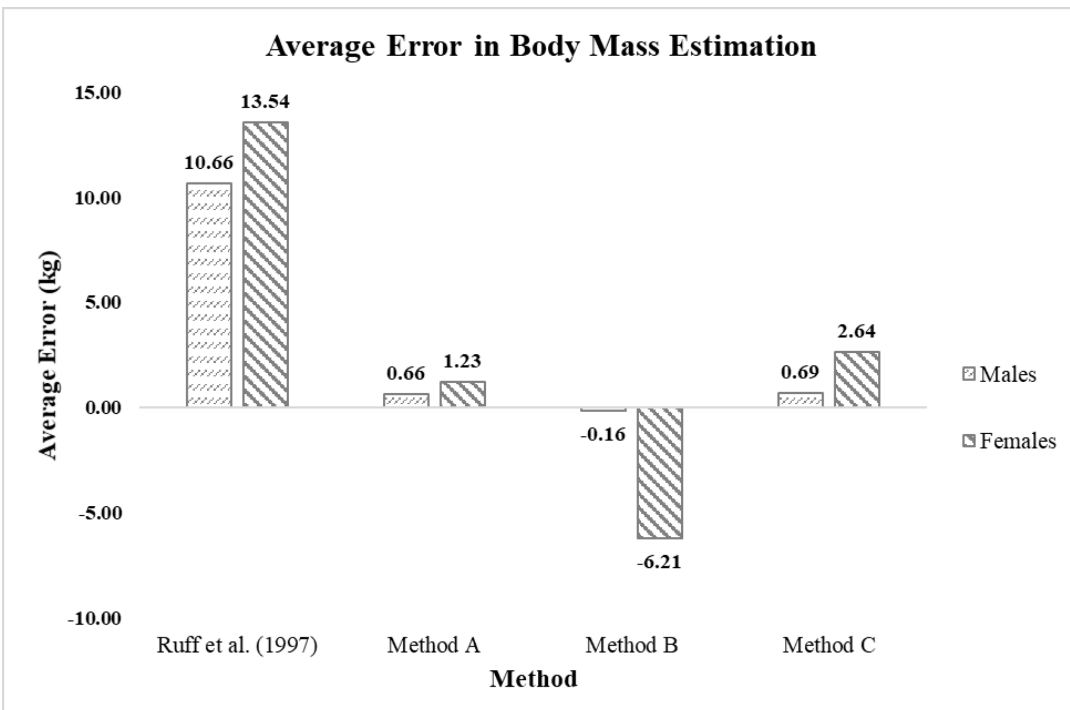

Figure 1. Average error in estimation of the four methods for males and females. (Method A: stature-living bi-iliac breadth, Method B: stature-waist circumference, Method C: waist-to-height ratio)

Geographic variation. Method A performed with the highest accuracy rates and was used to estimate body mass for the OpID individuals to explore geographic variation. Averages for all demographic categories were calculated to evaluate differences between American Hispanics, migrant Hispanics, and Mexican Hispanics. A summary of the three geographic regions evaluated in this study are provided in Table 10. The Kruskal-Wallis test comparing average stature and average body mass of the three regional groups separated by sex showed statistically significant differences ($p<0.05$) for all relationships except for average body mass of females ($p=0.06$). Results of the pairwise Wilcoxon ranked sum tests are presented in Tables 11 and 12.

Table 10. Summary of average demographics and anthropometry for the three geographic regions. Standard deviations are provided in parentheses.

	Sex	Age	BM (kg)	ST (cm)	LBIB (cm)	WC (cm)	WtHR
NHANES (N = 4,481)	Male (n = 2208)	41.58 (16.47)	77.42 (14.73)	169.3 (6.43)	29.29 (2.58)	94.77 (12.49)	0.560 (0.074)
	Female (n = 2273)	41.35 (16.09)	68.87 (15.59)	156.5 (6.26)	29.20 (3.36)	91.82 (14.22)	0.588 (0.094)
ENSANUT (N = 35,919)	Male (n = 15526)	43.84 (15.65)	76.01 (15.35)	165.4 (7.66)	21.46 (3.33)	94.95 (12.70)	0.575 (0.076)
	Female (n = 20393)	43.68 (14.78)	67.82 (14.75)	152.5 (7.11)	20.99 (3.24)	94.85 (13.21)	0.610 (0.090)
OpID (N = 68)	Male (n = 3)	N/A	79.75 (12.21)	161.5 (11.55)	30.49 (1.56)	112.68 (4.64)	0.702 (0.066)
	Female (n = 5)	N/A	69.77 (9.21)	149.8 (5.43)	30.15 (1.50)	111.68 (4.59)	0.746 (0.032)

Table 11. Summary of the pairwise Wilcoxon ranked sum test p-values for stature.

	Males			Females	
	ENSANUT	NHANES		ENSANUT	NHANES
NHANES	<0.05	-	**NHANES**	<0.05	-
OpID	0.089	<0.05	**OpID**	<0.05	<0.05

Table 12. Summary of the pairwise Wilcoxon ranked sum test p-values for body mass.

	Males			Females	
	ENSANUT	NHANES		ENSANUT	NHANES
NHANES	<0.05	-	**NHANES**	0.060	-
OpID	0.034	0.124	**OpID**	0.136	0.206

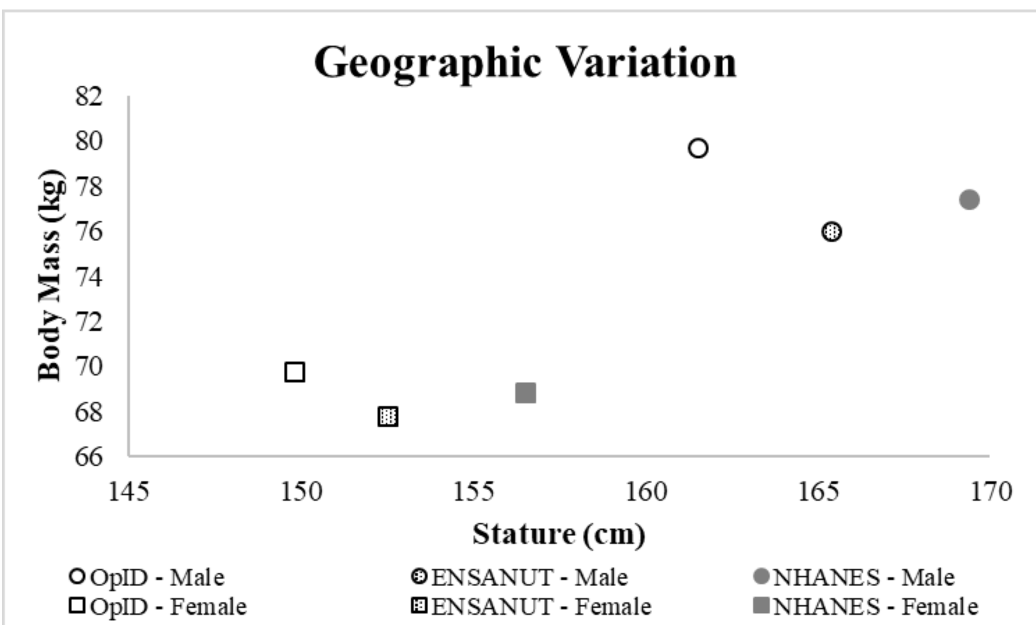

Figure 2. Relationship between average height and weight from NHANES, ENSANUT, and OpID samples.

Figure 2 shows differences in height and weight between the three regional groups. Males are represented as dots, while females are represented as squares. General trends indicate migrant Hispanic body mass to be overall higher than average body mass reported by NHANES and ENSANUT, being 2.33 kg heavier for males and 0.9 kg heavier for females than American Hispanics, and 3.74 kg heavier for males and 1.95 kg heavier for females than Mexican Hispanics.

In contrast, OpID individuals are on average 7.79 cm shorter for males and 6.69 cm shorter for females than American Hispanics, and 3.89 cm shorter for males and 2.69 cm shorter for females than Mexican Hispanics. These results show that migrant Hispanics tend to be heavier but shorter than their American and Mexican counterparts.

IV. DISCUSSION

Preliminary population-specific methods. Three different methods of body mass estimation were generated to explore this research question. Method A was created as a population specific version of Ruff et al. (1997), while the other two methods were generated after using a Bayesian approach to explore correlations between other anthropometric measurements and body mass. The author hypothesized Method B to perform better than the stature-bi-iliac breadth method because it adds a three-dimensional component to body mass estimation by using waist circumference instead of bi-iliac breadth. Instead, this study observed the combination of waist circumference and stature to estimate body mass less accurately. The findings could be due to estimating waist circumference in the skeletal sample.

An interesting result from this study finds that Method C is a better body mass estimation method than waist circumference paired with stature. This could be due to the standardizing nature of WtHR, which does not carry sex, age, or populational biases. Because of marginal accuracy rates between Method A and Method C, it may be best to utilize one of the two methods depending on circumstances. Since the stature-bi-iliac breadth method regards the human body as two-dimensional while WtHR accounts for the three-dimensional nature of the human body, it is theoretically the preferable method.

It is also important to note here the small sample of identified OpID individuals, which may have affected the overall accuracy rates of the body mass estimation methods. Future research should utilize larger skeletal samples of known body mass. Additionally, previous research has indicated the problematic nature of using self-reported height and weight instead of actual height and weight values. Fernandez-Rhodes et al. (2017)

recently found that although there was a positive correlation between self-reported weight and actual weight, US-born Hispanics/Latinos typically underestimated their weight, while foreign-born Hispanics/Latinos typically overestimated their weight. Such discrepancies in over- or under-estimation of body weight may be due to stigmatization of higher body fat content in the United States when compared to Mexico and Central American countries, which are traditionally fat-positive societies (Brewis et al. 2011). Accuracy of the weight and height of the identified OpID individuals as provided in missing persons reports may be affected by next-of-kin reporting, as well as extended time since last contact.

Additional confounding factors include the limitation of estimating anthropometric data from skeletal measurements, and the temporal difference in data collection between NHANES and ENSANUT. By estimating stature, living bi-iliac breadth, and waist circumference, the potential for error is compounded at each step, thus increasing the error in body mass estimation. The twenty-year time lapse between the collection of NHANES and ENSANUT data can also contribute to error, given the effect of globalization and ever-increasing obesity rates around the world. Therefore, further studies that use contemporary data to improve methods of converting skeletal to anthropometric data can benefit body mass estimation.

Accuracy of the stature-bi-iliac breadth method. Results show that the stature-bi-iliac breadth method published by Ruff et al. (1997) estimates the body mass of Hispanic individuals with only 20.43% - 26.76% accuracy. The accuracy rates produced by Ruff et al. (1997) are substantially lower than those produced by Methods A and C from this study, and further support the necessity of population specific methods for estimating body size. There are clear differences in average estimation error between the four body mass estimation methods as well as marked differences in the over- and under-estimation of body mass between males and females. The results show that on average, the Ruff et al. (1997) method grossly over-estimates (>10 kilograms) body mass when compared to the three population specific body mass estimation methods.

Geographic variation. Results for exploring the third research question confirm that while not all statistically significant, there are discernable differences in average body mass between American Hispanics, migrant Hispanics, and Mexican Hispanics. To summarize, migrant Hispanics are on average heavier but shorter than their American and Mexican counterparts.

Bogin and Loucky (1997) found that Guatemalan Maya children still living in Guatemala were on average smaller than their American-raised counterparts. The findings from this study support the findings of Bogin and Loucky (1997), indicating that the Mexican Hispanic sample from ENSANUT is shorter and weighs less than the American Hispanic group from NHANES. The migrant Hispanic sample from OpID is found to be the shortest of the three groups and on average weighs more.

This study provides evidence for the effects of globalization and urbanization on body mass. The WtHR for all three geographic categories, both male and female, are above the established 0.5 threshold for obesity, meaning that all three groups are generally obese. Malik et al. (2012) found that North and Central America were among the countries with the highest increase in obesity among men and women. Lack of nutritional education and access to nutritious foods were some of the cited causes of obesity. The findings published by Malik et al. (2012) could explain why the OpID sample is estimated to be the heaviest group. Additionally, Creighton et al. (2011) found that migrant children in the United States were found to have higher frequencies of obesity than American or Mexican children.

The average short stature of the migrant Hispanics can also be inferred as an effect of poor nutrition and low socio-economic status. Peck and Lundberg (1995) found that short stature is attributed to disadvantageous conditions in childhood, including economic hardship and familial disputes. Research has also shown a marked decrease in stature for groups that have experienced violence or war-like conditions (Akresh et al. 2012). Many migrants are forced to immigrate due to factors that prevent them from remaining in their home countries (Torres and Wallace 2013). Therefore, migrant Hispanic individuals may not reach their full height potential compared to their American and Mexican counterparts due to the economy, structural violence, actual violence, and limited access to proper nutrition.

V. CONCLUSION

Estimating body mass from skeletal remains can aid in situations where a large number of unidentified and missing persons come from a single population, such as the migrant deaths along the US-Mexico border. The first aim of this study was to generate population specific body mass estimation methods for migrant Hispanics using contemporary health data. This study found that population specific equations for body mass estimation are more accurate than the previously published method by Ruff et al. (1997), which only accurately estimated body mass 23.55% - 26.76%. Method A, which uses a stature-bi-iliac breadth approach, produced the most accurate body mass estimations performing at 76.39% - 76.66% accuracy. Method C, which uses a waist-to-height ratio approach, produced comparable results performing at 70.72% - 72.22% accuracy.

After estimating the biological profile, Methods A and C from this study can be utilized by migrant identification projects such as Operation Identification to narrow the number of missing persons. While estimating body mass may assist in mass disaster situations such as the migrant deaths along the US-Mexico border, the lower accuracy rates (<80%) suggest that body mass estimation may not be suitable for typical forensic contexts where there is a single unidentified individual.

The second aim of this study was to expand on research into biological variation within the Hispanic population by exploring geographic variation in body mass. Results found marked differences in height and weight based on geographic group. The migrant Hispanic individuals were found to be the shortest and heaviest, the American Hispanics were the tallest and lightest, and the Mexican Hispanics fell in the middle for both height and weight. Variation between these three groups emulate the effects of the environment on body size, such as having access to adequate nutrition and healthcare.

Results of this study have implications for the forensic anthropology community by providing further evidence for establishing more population specific methods of estimating the biological profile. Additionally, this research shows the potential for body mass estimation to assist in the identification efforts of mass disaster situations. Exploration into geographic variation of body mass within the Hispanic population has reflected changes in body size due to economic and environmental factors, such as globalization and urbanization, in the United States and Mexico. The same economic and environmental factors affecting the Hispanic population also influence other populations. Therefore, biological anthropologists must be aware of the demographic changes occurring within the United States. Finally, this research showed the value of using a multidisciplinary approach to answering questions of biological variation by using large anthropometric datasets and cultural approaches to explain observed relationships.

APPENDIX SECTION

Measurement Figures

Figure 1. Maximum skeletal bi-iliac breadth (SBIB). View is anterior.

Figure 2. Maximum skeletal bi-iliac breadth (SBIB). View is superior.

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