CRANIAL BASE HEIGHT AS AN INDICATOR OF DEVELOPMENTAL STRESS IN NATIVE MEXICAN AND AMERICAN-BORN MEXICAN POPULATIONS

by

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DEDICATION

To Karen,

You are my sunshine.

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ABSTRACT

Cranial base height, much like stature, has been used as an indicator of developmental stress in human populations since J. Lawrence Angel first proposed the idea in 1976. Previous research on the cranial base has involved the study of secular change in historic populations, but it has not often been used to explore differences in developmental stress in modern populations. Current views of Mexican migrants often hold that this population is impoverished, malnourished, and under a high disease load during growth and development. The present research allows for an empirical analysis of this viewpoint by comparing the height of the cranial base in a Mexican-born population (n=137) from the Pima County Office of the Medical Examiner and Xoclan and Zimapán documented collections, and an American-born population of Mexican descent (n=16) from the Texas State University Donated Skeletal Collection and the University of New Mexico Documented Skeletal Collection.

Landmark data were collected using a Microscribe® G2 3D digitizer and 3Skull software. Data were analyzed with an ANOVA in Excel, using the Real Statistics Add-in. Males and females were analyzed separately in order to control for size differences associated with sex. Cranial base height was not significantly different in females ($p=0.1238$), but significant in males ($p=0.03541$). These findings indicate that the levels of developmental stress in American-born Mexicans and native Mexicans are not drastically different for females, but are different for males. This result has broader social

implications for understanding the environments from which migrants leave and those to which they migrate.

CHAPTER I

INTRODUCTION

This thesis explores differences in cranial base height, or basion radius (BAR), in two populations of Mexican descent to examine health and nutrition differences between native Mexicans and American-born individuals of Mexican ancestry. The purpose of this project is to understand whether living conditions during growth and development of the native Mexican sample, which have been considered “low-income” and “rural,” (Birkby et al., 2008) are detectable skeletally. In this case, a shorter cranial base in the Mexican-born population would imply that these individuals were under a higher disease load, experienced an inadequate nutritional environment during their growth and development, or both.

The present study is critical for several reasons: it fills gaps in the literature, provides a new perspective for assessing health issues in modern populations, and may ultimately help shift our culture’s perception of migration. Previous research has addressed nutritional deficiencies in migrant and non-migrant samples using stature as a proxy for stress (Malina et al., 1986) and, more recently, studies have explored secular change in Mexico from the late 1960s-2000 with respect to stature and craniofacial dimensions (Little et al., 2006, Malina et al., 2009). These studies have laid the framework for the present research by showing that anthropometrics and craniometrics can be successfully used in a Mexican population to explore developmental stress. As yet, however, no study has used cranial base height to explore the nutritional status of a Mexican vs. American developmental environment with an aim to apply the results to issues of human rights. The present research will fill this gap in the literature, providing empirical instead of anecdotal evidence to corroborate the notion that developmental stress is higher in Mexico than in America, and to help show why some individuals may choose to make the dangerous trek across the U.S.-Mexico border.

This project can contribute to a social understanding of the types of people who attempt to illegally cross the border into the United States, which has the potential to shift public opinion regarding American treatment of undocumented immigrants. Additionally, the results of this study can be used to better understand why immigrant groups are coming to America and to attempt to solve the problem at its origin, instead of after people try to migrate to the United States without documentation. For example, if one can show that native Mexicans have a lower cranial base height, then one can show that developmental stress is higher in Mexico than it is in the United States. While this idea currently exists as a stereotype, the empirical demonstration of stressful childhoods in Mexico may allow us to better assist native Mexicans with health-related issues. With further research, scientists can make changes to the way that the general public views ethnicity, language, and cultural groups, which will hopefully influence the way Americans view people of different ethnicities within our country.

Cranial Plasticity

Craniometrics, or measurements of the human cranium, are an ideal proxy for exploring immigration because these measurements reflect both environmental factors, such as developmental stress, as well as genetic influences. Boas used the cranial index to suggest that cranial measurements are extremely plastic. That is, that the size and shape of the skull are primarily influenced by environment (1912). Specifically, he notes that American-born children of immigrant parents have significantly different cranial indices than their parents, owing to a general improvement in living conditions after immigration to America.

In the intervening years, the strength of Boas' claims has been tested, most notably by Sparks and Jantz (2002, 2003) and Gravlee and colleagues (2003a, 2003b). Using modern statistical techniques unavailable to Boas, Gravlee et al. have suggested that, as Boas demonstrated, subtle changes in cranial size and shape do manifest in first-generation immigrants to America (2003a, 2003b). On the other hand, Sparks and Jantz propose that Boas' data do not support the broad notion of cranial plasticity that has been traditionally accepted by anthropologists (2002, 2003). They conclude that the cranium has high heritability, serving as a record of an individual's genetics and population affinity, and that Boas' results have consistently been overstated in anthropology throughout the last century. Sparks and Jantz do not argue that the cranium does not exhibit any plasticity; they simply show that the genetic component of these measurements is more significant than most anthropologists have realized prior to their reevaluation of Boas' data (2002).

Although these conclusions may seem incompatible, the primary difference comes in the authors' readiness to accept Boas' conclusions about cranial plasticity as overarching and significant (Gravlee et al., 2003a, 2003b), or as a less important factor in cranial variation than genetics (Sparks and Jantz, 2002, 2003). Regardless, neither set of authors denies that cranial plasticity occurs. The present research aligns with Sparks and Jantz's conclusions and uses cranial plasticity as both a measure of environmental influence while simultaneously controlling for population differences in cranial size and shape by sampling only individuals of Mexican ancestry. This thesis will first utilize a geometric morphometric cranial shape analysis comparing the American-born and Mexican-born groups to confirm that they are genetically similar, based on the idea that craniometrics follow the same isolation-by-distance model as genetics (Relethford, 2004b). If the two groups are not statistically distinct with respect to cranial shape, then any differences in size can be more confidently attributed to environmental differences as opposed to population differences, consistent with expectations derived from Sparks and Jantz (2002, 2003).

In the last decade, further research has supported the conclusion that the skull acts to simultaneously track environmental changes while retaining population genetic information. Relethford, in a discussion of the aforementioned studies, notes that he also agrees that cranial plasticity occurs, but that its significance is smaller in importance than Boas originally stated (2004a). He suggests that plasticity can change cranial size and shape, but not to the degree that it would entirely obscure underlying genetic relationships. Relethford concludes that craniometeric variation on the whole tends to follow a neutral model of genetic drift and gene flow, with plasticity mediating environmentally-driven differences in certain parts of the cranium. Given ample research on the environmental impacts on the human cranial base (Cameron et al., 1990, Wescott and Jantz, 2005, Rewekant, 2001, Senator et al., 2009, Weisensee and Jantz, 2011, Angel, 1976), there is evidence that this portion of the skull is influenced, to some degree, by the environment.

A comprehensive understanding of cranial plasticity is critical to this research. The present study rests on the assumption that an individual's environment can have a small but significant impact on his or her cranial size and shape. However, it is also important to remember that the cranium can record genetic relationships and population history. Therefore, this thesis controls for population differences in cranial size by using only individuals of Mexican descent.

Cranial Base Height

The first anthropologist to use cranial base height as an indicator of developmental stress was J. Lawrence Angel in 1976. Angel compared changes from the colonial period to the 20th century in porion-basion height and showed that skull base height increases with improved healthcare and better nutrition. Angel argued that if the bones in the skull base are weak, due to nutritional deficiency during growth, then the skull base can become compressed under the weight of the brain (1982). In fact, the region surrounding the foramen magnum experiences the greatest pressure in the body during development. The weight of the brain is carried by the occipital condyles, and this weight is balanced near basion (Senator et al., 2009).

Other researchers have suggested, instead, that an improvement in health over time leads to larger brains, which requires a higher cranial base (Wescott and Jantz, 2005). Therefore, an increase in brain size due to good health is the cause of a higher cranial base. In a study of sagittal midline tomographs of 70 children aged two months to 14 years, Bradac and Simon determined that most of brain development occurs prior to ten years of age (1971). It is during this period when the cranial base is most susceptible to environmental disruptions, such as malnutrition (Bradac and Simon, 1971).

Following Angel's lead, Cameron et al. studied secular change, or skeletal change over time in response to a changing environment, in South African black male crania, showing that cranial base height can actually decrease in times of resource stress (1990). This change is known as a negative secular trend (Cameron et al., 1990). Rewekant also found that a medieval Polish group of higher socioeconomic status had greater cranial base heights than a group with lower socioeconomic status (2001). Additionally, cranial base height has been used to assess living conditions in European, Australian, and African populations, following the idea that lower cranial bases indicate poor nutritional status or high disease load during development (Senator et al., 2009).

Recently, Weisensee and Jantz conducted a geometric morphometric study of craniofacial morphology, including cranial base height, in a Portuguese population and showed that the cranial base moves inferiorly and anteriorly over time with better nutrition in the population (2011). In 2005, Wescott and Jantz showed that basion moved inferiorly and posteriorly and that lambda moved superiorly in American Blacks and Whites between the 19^{th} and 20^{th} centuries. This data corroborates the idea that cranial base height is exhibiting a positive secular trend in the United States. The authors attribute this positive secular trend to better infant health and nutrition over the course of the last two centuries (Wescott and Jantz, 2005). Similarly, in 2001, Jantz showed a correlation between cranial vault height and birth year, with an increase in vault height over the 125-year study period. He also attributed these changes to an increase in cranial base height due to an improved American environment between 1850 and 1975. These changes are caused by a combination of cranial plasticity and genetic change, according to Jantz (2001).

The wealth of research on both secular change in general and changes in cranial base height, specifically, has shown that analyses of cranial base size and shape provide an excellent indication of developmental stress in a population.

Developmental Stress

According to Angel, developmental stress is defined as inadequate nutrition, unsanitary living conditions, limited sun exposure, and high disease load during development (1982). The effects of poor nutrition can be complicated by infectious disease load, which in turn stunts growth in both urban and rural children of lower socioeconomic status (Gray et al., 2006, Uauy et al., 2008, Prentice et al., 2006, Yarbrough et al., 1975).

More specifically, nutrition status can be characterized by malnutrition, which "refers to all deviations from adequate and optimal nutritional status, including energy undernutrition and overnutrition" (Shetty, 2003, pg. 18). Malnutrition is caused by nutrient deficiency. For example, inadequate iron intake causes a form of malnutrition known as anemia. According to Shetty, stunting, or the failure of children to reach their growth potential, is caused by malnutrition during the first two years of life (2003).

Under the umbrella of malnutrition falls undernutrition, which refers to inadequate energy intake, and overnutrition, which occurs in cases of obesity (Shetty, 2003). Undernutrition can be caused by starvation or semi-starvation due to poverty or political conflict, or can be caused by disorders or parasites that inhibit the body's ability to absorb nutrients. Overnutrition is an underlying cause of obesity, which is steadily increasing in Mexico (Rivera et al., 2009). Both forms of malnutrition are present in Mexico, and both can contribute to developmental stress, as defined by Angel (1982).

Comprehensive nutrition surveys have been performed three times during the last 30 years in Mexico: in 1988, 1999, and 2006. The results have shown an overwhelming decline in the prevalence of undernutrition, of which stunting is a component, and anemia, and an increase in prevalence of overweight and obesity (Rivera et al., 2009). However, Rivera and colleagues suggest that undernutrition and anemia are still significant issues in Mexico, despite their decline (2009). In addition, they propose that the most significant nutritional issue facing Mexicans is the drastic increase in obesity, or overnutrition. It is important to remember that overnutrition can still result in an inadequate intake of necessary vitamins and minerals, leading to stunting in much the same way that undernutrition does. I anticipate that the high level of malnutrition present in Mexico will manifest skeletally as a lower cranial base height in the Mexican-born sample.

Cranial Base Development

The primate cranial base has been the subject of a number of studies seeking to explore how the development of this part of the skull can illuminate evolutionary relationships (Lieberman et al., 2000a, 2000b, Nevell and Wood, 2008). For the present study, it is important to understand the basics of the timing and growth trajectory in the human cranial base in order to make connections between developmental patterns and nutrition. Lieberman and colleagues are in agreement with Wescott and Jantz when they note that brain size, not weight, appears to be the most important factor in understanding variation in the cranial base (Lieberman et al., 2000a, 2000b, Wescott and Jantz, 2005).

The chondrocranium, or cartilaginous precursor to the cranial base, begins to develop during the second month in utero. The chondrocranium is composed of 41 ossification centers that eventually form the ethmoid, sphenoid, occipital, and temporal bones in adults. The center of the cranial base reaches adult size and shape first, and the anterior and posterior cranial base develop independently from one another and the central cranial base. After birth, the cranial base grows quickly during the first six to eight years of life while the brain grows and develops. In terms of cranial base height, the cranial base tends to shift inferiorly in relation to the size of the occipital lobes, cerebellum, and brain stem (Lieberman et al., 2000a).

Growth and Development in Mexican Populations

The present research relies on a foundational understanding of human growth and development, as well as its relationship to nutrition. Nutrition can be assessed by proxy of growth rate, the change in size over a set period of time, or growth status, the final size attained. Growth rate can be used to explore present nutritional conditions, while growth status can be used to assess an individual's past nutritional environment (Little et al., 1988). Cranial base height in adults explores growth status, as opposed to growth rate, and can be examined using a cross-sectional sampling strategy, as is used presently. Delayed growth in children living in less developed nations has been used to indicate poor health conditions in those areas (Little et al., 1988).

A number of studies have been performed on Mexican and Mexican-American adults and children in order to assess nutritional status in these populations. Historically, stature has been used as a proxy for nutrition (Malina et al., 1986). In a study of the growth rate of Zapotec children, Little and colleagues suggested that the delayed growth rate and growth status of Mexican children was likely caused in the first six years of life (1988). They suggest that adult stature is related to deficits developed from prenatal growth through childhood. They emphasize the importance of targeting community health initiatives towards mothers and young children in order to combat adult deficiencies in stature. According to the authors, "The cumulative effect of small mothers, poor health, and inadequate nutritional conditions pre- and postnatally is small children who are eventually small adults. Better nutrition appears to result in taller children with longer trunks, and possibly an earlier onset adolescent growth spurt." (Little et al., 1988 pg. 5).

Yarbrough and colleagues considered stature, of which cranial base height is a component, to be "a reasonably sensitive indicator of nutritional status" (1975, pg. 439). Additionally, the authors found that Guatemalan children were smaller than their American counterparts from Denver, and that these changes were most notable between birth and two years of age, as well as between five years of age and seven years of age (Yarbrough et al., 1975). In a study of stature of American-born children of Mexican immigrants by Chase et al., the children were shown to have an overall lower stature between birth and seven years of age relative to the United States Growth Grid, which was correlated with low vitamin A, alkaline phosphatase, and total serum protein levels in the same population (1971).

In a study of migrant and non-migrant Mexican American children, Dewey et al. found that the migrant children (born in Mexico) had significantly lower statures than the non-migrants (born in America) (1984). Dewey also found that, for adolescents, the longer the individual spent in Mexico, the less likely they would be to attain the age-matched stature of an American-born, non-migrant individual. Lasker suggested that the differences between migrants and *sedentes*, or non-migrants, was related to age at migration (1952, 1954). According to Malina, et al., if environmental conditions improve upon migration, and an individual migrates at a young age, there is greater potential for the individual to change in body size such that size matches the new, better, environment (1986).

A 1967 study by Paradis found that statures of White, Black, and Mexican-American boys were not significantly different, when socioeconomic status is controlled. That is, differences in socioeconomic status seem to play a more important role in stature than do differences in ancestry. According to Malina and colleagues, there is variation in stature within Mexican-Americans adults in San Antonio, relating to their socioeconomic status (1983). Those males who are of higher socioeconomic status were also significantly taller than their ancestry-matched counterparts of lower socioeconomic status.

The wealth of research in the fields of secular change and health outcomes of native Mexicans and Mexican migrants provides a foundation for the present research. A general consensus in the field is that inadequate nutrition during the period of cranial base development (the first six to ten years of life) leads to lower stature; this difference is even more obvious in Mexican migrants (Malina et al., 1986). As cranial base height is a component of stature, it is also a useful proxy for exploring the developmental environment of native Mexican and American-born Mexicans to compare their levels of nutrition and disease load during childhood. This will, in turn, allow for a better understanding of the motivation behind migration from Mexico to the United States, and will show how conditions in the United States differ from those in Mexico.

Research Question

This research focuses on a two questions. First, and most fundamentally, do the two groups have similar cranial shapes? If so, then do native Mexicans and American-born Mexicans show a difference in cranial base height, indicating a difference in developmental stress?

Given the fact that craniometrics follow an isolation-by-distance model (Relethford, 2004b) and that these two samples are of Mexican descent, I expect that the two samples will not be significantly different with respect to cranial landmark locations. This will allow for an unbiased assessment of cranial base height.

Based on previous research suggesting that nutritional deficiencies can lead to lower stature, and that migrants tend not to reach the age-matched stature of non-migrants, I hypothesize that there will be significant difference in cranial base height between native Mexicans and American-born Mexicans. My null hypothesis is that there is no significant difference in cranial base height between native Mexicans and American-born Mexicans.

CHAPTER II

MATERIALS AND METHODS

The study population includes individuals from a native Mexican sample, who were born and raised in Mexico, as well as individuals from an "American-born Mexican" sample who were either born OR raised in the United States. Due to a dearth of skeletal remains of self-identified American individuals of Mexican descent, it is necessary to broaden the definition to people who spent most of the first 10 years of their lives in the United States. Numerous studies have shown that the place of birth is less important than where an individual spends the first six to ten years of his or her life in terms of developmental stress (Lieberman et al., 2000a, 2000b, Bradac and Simon, 1971, Little et al., 1988).

Reference Samples

American-Born Sample

The sample of American-born individuals (n=16) is drawn from the Texas State University Donated Skeletal Collection (TSDSC) and the Maxwell Museum of Anthropology at the University of New Mexico. The sample of American-born individuals includes 9 males (n=9) and 7 females (n=7).

The TSDSC is housed at the Grady Early Forensic Anthropology Research Laboratory (GEFARL). The collection contains eight individuals who are either self-reported as American-born of Mexican ancestry, or have been reported by their next-of-kin as American-born of Mexican ancestry. American-born here refers either specifically to individuals born in the United States, or those who spent approximately the first ten years of their lives in the United States. Studies have shown that it is not necessarily the environment of birth, but the environment wherein an individual grows and develops that affects his or her growth trajectory (Lieberman et al., 2000a, 2000b, Bradac and Simon, 1971, Little et al., 1988). One individual was excluded due to the presence of cranial trauma, making for a total of 7 individuals (n=7) from the TSDSC. These individuals were measured by the author.

The Maxwell Museum of Anthropology Documented Skeletal Collection is a donated skeletal collection located at the University of New Mexico and curated by Dr. Heather Edgar. This collection includes health, occupation, and demographic data on its individuals. This collection contains 9 individuals (n=9) of "Hispanic" ancestry. These individuals were measured by Hailey A. Duecker. Data were used with permission of Ms. Duecker.

Mexican-Born Sample

The sample of Mexican-born individuals includes 29 positively-identified deceased Mexican migrants from the Pima County Office of the Medical Examiner (PCOME) (n=29), 65 individuals from the Xoclán documented skeletal collection (n=65), and 43 individuals from the Zimapan documented skeletal collection (n=43). This makes for a total sample of 137 Mexican-born individuals (n=137), of which 95 are male (n=95) and 42 are female (n=42).

Deceased undocumented border-crossers (UBCs) in parts of southern Arizona are given a forensic analysis at the PCOME in an effort to identify the individuals and return the remains to their families. The remains from Xoclán and Zimapan are documented cemetery collections consisting of Mexicans born between the early 1800s and 1980. However, the data collected for the present research consists only of individuals with birth years after 1900. The Zimapan collection is housed at the Universided Nacional Autónoma de México (UNAM) and represents individuals whose families could not afford reburial during a cemetery relocation. The Xoclán collection represents individuals who have been disinterred from the cemetery and who have been positively identified. These individuals were measured by Dr. Kate Spradley (2013). Data were used with permission of Dr. Spradley.

TABLE 1: Sample Sizes by Source

Source	**Group**	**Male**	**Female**	**Total**
PCOME	Mexican-Born	24	5	**29**
Zimapan	Mexican-Born	27	16	**43**
Xoclán	Mexican-Born	44	21	**65**
UNM	American-Born	5	4	**9**
TSDSC	American-Born	4	3	**7**

TABLE 2: Sample Sizes by Group

Group	**Male**	**Female**	**Total**
Mexican-Born	95	42	**137**
American-Born	9	7	**16**

Data Collection

Cranial Landmarks

This thesis involves the collection of cranial landmark data from human crania. Cranial landmarks are defined points on the human skull used to standardize measurements across individuals. Theoretically, these landmarks are homologous across all individuals, allowing for a comparison of landmark locations across a sample (Howells, 1973). This study utilized Howells' definitions of landmarks (1973), as well as landmarks defined in the 3Skull software package.

Although a full suite of craniometric landmarks was collected on each cranium in my samples, there are 9 landmarks that are of particular interest in this study: left and right porion, basion, bregma, left and right asterion, nasion, and left and right radiometer points. The first seven landmarks are used in a geometric morphometric shape analysis of the crania in this sample. The latter two landmarks and basion are used in the analysis of cranial base height. These landmarks are important because they capture the size and shape of the cranial base, as well as cranial vault height. Please see Appendix A for the definitions of these landmarks and Appendix B for an illustration of these landmarks.

Microscribe Data Collection Method

Landmark data from the crania in the TSDSC, at the University of New Mexico, and at the PCOME were recorded using a Microscribe 3D digitizer and entered into the program 3Skull (Ousley, 2004). The Microscribe digitizer records x, y, and z spatial coordinates for each landmark. These coordinates are imported through the program 3Skull into an Excel spreadsheet. 3Skull then calculates interlandmark distances from these coordinates. The interlandmark distance data are exported into a different Excel spreadsheet and are recorded in millimeters.

Before a cranium is digitized, several instrumentally-determined landmarks are measured with sliding or spreading calipers and marked with a pencil. These landmarks are ectoconchion (L and R), upper orbital border (L when possible), cheek height superior point (L when possible), cheek height inferior point (L when possible), zygion (L and R), eurion (L and R), frontotemporale (L and R), maximum frontal point (L and R), glabella, and ectomolare (L and R). Additionally, certain points are not instrumentally determined, but are marked for ease of identification during the digitizing process. These landmarks are sphenion (L and R), krotaphion (L and R), stephanion (L and R), asterion (L and R), opisthion, and basion.

Once these landmarks have been located and marked, the cranium is set on three pedestals of acid-free clay and secured so that it is immovable (FIGURE 1). Small pieces of clay are also used to secure the Microscribe to the table. Once the digitizing process begins, neither the cranium nor the Microscribe can move. The digitizer is set to the home position, with the arm turned all the way to the left, and then powered on. The 3Skull program is then opened, and the CatKey (ID number), Individual (male or female, where the information is available), recorder's initials, and an indication of whether cranial reshaping was present, are entered. Additionally, there is a "comments" box that allows the recorder to make note of any important issues with a particular cranium. Typically, these comments include information about resorption, breakage, or abnormality at certain landmarks. At this point, digitizing can begin.

FIGURE 1: Cranium stabilized on clay pillars, prepared for digitizing.

The 3Skull software package prompts the recorder for each landmark, as shown in FIGURE 2 below. When a particular landmark is requested, the recorder places the point of the Microscribe's stylus on the landmark and presses the attached foot pedal to record the point. Once the coordinates of a landmark have been collected, 3Skull automatically moves to the next landmark and the recorder repeats the process. If landmarks are not present, due to resorption or breakage, and cannot be estimated, they can be skipped. 3Skull also allows the recorder to move forward and backward in the list of landmarks in order to retake points that may have been recorded in error.

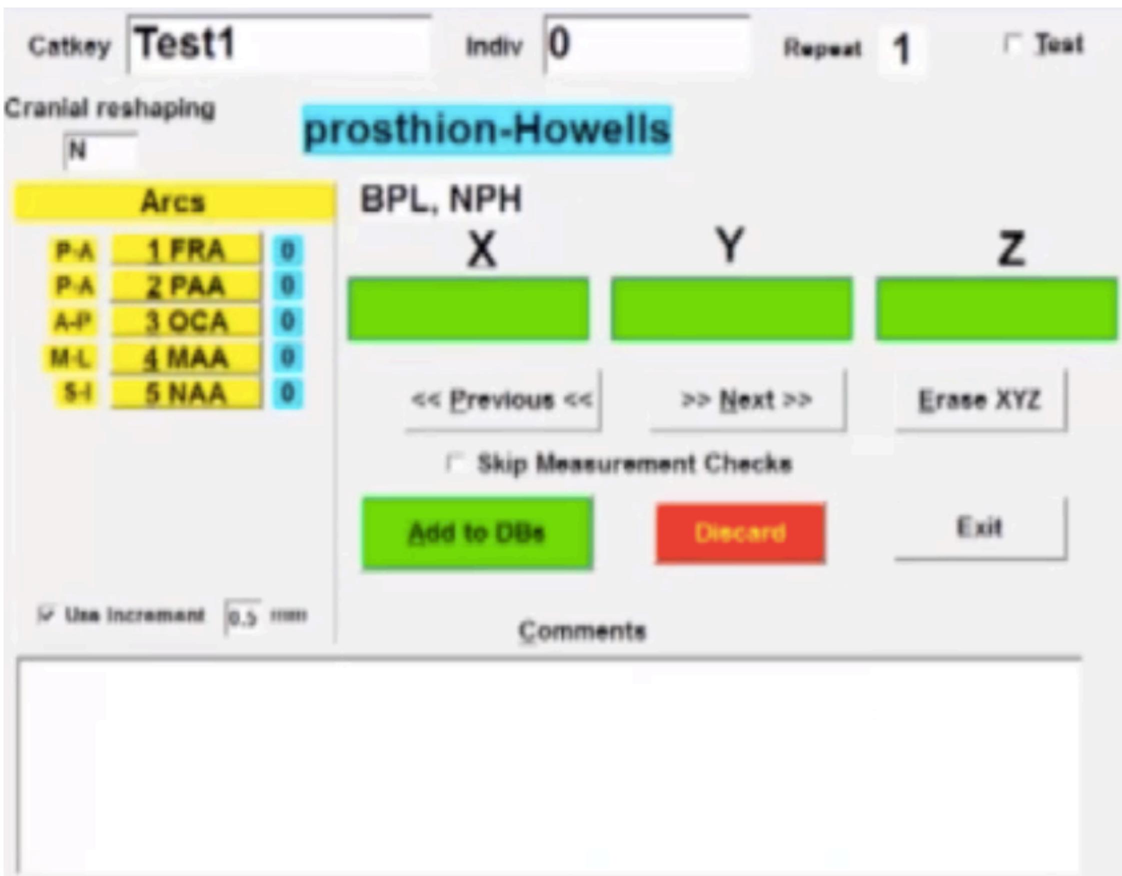

FIGURE 2: 3Skull entry form. The microscribe automatically inputs coordinates into the green fields. The teal box denotes the landmark being measured.

Once all cranial landmark coordinates have been collected, the recorder collects points on 5 arcs: the frontal arc, parietal arc, occipital arc, malar arc, and nasal arc. This process involves tracing the contour of the skull with the stylus. Coordinates are recorded every 0.5 mm in order to provide an accurate and fine-grained image of shape of the cranium.

Finally, the recorder presses the "Add to DB" button, which compiles and stores the coordinates for a particular cranium in two separate databases: one for the coordinates and one for the interlandmark distances. At this time, 3Skull automatically notifies the recorder if any of the measurements are outside a normal range, and the recorder can retake certain landmark points if necessary.

Statistical Analyses

Geometric Morphometric Analyses

Prior to analysis of cranial base height, it is important to establish that the two samples in this study are similar with respect to cranial shape. If the two groups do not have significantly different cranial shapes, then it can be concluded more confidently that any size differences are due to environment, not population differences. Geometric morphometric cranial shape assessments can provide information about the placement of important landmarks, such as porion, basion, asterion, nasion, and bregma, which may or may not be statistically different between the populations.

Geometric morphometric analysis, which is the quantitative analysis of size and shape variables and spatial relationships among structures, has been used in biological anthropology to study shape differences in human crania (Slice, 2005). A 3D geometric cranial shape analysis was performed using the MorphoJ statistical package (Klingenberg 2011).

A Procrustes superimposition was used, which minimizes the sum of squared distances of each sample from the mean shape of all individuals in the sample, allowing for a study of how much the shape of an individual cranium differs from the sample average (Slice, 2005). A Procrustes superimposition combines information gleaned from all the landmarks on a particular skull into a common coordinate system where each point on the coordinate grid is a shape variable (Slice, 2005). Shape differences are visualized and resulting Procrustes coordinates are transformed into principal components for additional multivariate statistics.

Geometric morphometric methods have been utilized in similar studies to explore craniofacial morphology (Jonke et al., 2007, Weisensee and Jantz, 2011, Wescott and Jantz, 2005, Jantz, 2001). Geometric morphometric methods have been used to analyze how Austrian facial shape changes over the last 100 years (Jonke et al., 2007). Geometric morphometric methods have also been used to study shape and placement of the cranial base to explore how cranial morphology has changed over time in a population from Lisbon, Portugal between 1806 and 1954 (Weisensee and Jantz, 2011).

Analysis of Variance (ANOVA)

In order to explore the difference in basion radius (BAR), the proxy used here for cranial base height, a one-way Analysis of Variance (ANOVA) is used. One-way ANOVA is a statistical method utilized to compare means of two samples to determine whether or not they are significantly different. The null hypothesis tested by one-way ANOVA is that the means of two or more samples are not statistically different.

In this case, males and females are analyzed separately in order to avoid confounding the results with size variations due to sex. ANOVA was run in Excel using the Real Statistics Add-in. A p-value less than 0.05 is considered a significant result.

CHAPTER III

RESULTS

Cranial Shape

A Multiple Analysis of Variance (MANOVA) was performed using the Real Statistics Add-On in Excel in order to explore cranial shape differences between the Mexican-born and American-born samples. The MANOVA results were insignificant (p=0.2272) (TABLE 3), suggesting that the American-born and Mexican-born samples do not differ significantly in cranial shape (FIGURE 3).

Subsequently, ANOVAs for each principal component score were performed, showing significance in only one case: Principal Component 11 (p=0.003896).

TABLE 3: MANOVA Results

	stat	*F*	*df1*	*df2*	*p-value*	*eta-sq*
Pillai Trace	0.041257472	1.263323014	14	411	0.227187061	0.041257472
Wilk's Lambda	0.958742528	1.263323014	14	411	0.227187061	0.041257472
Hotelling Trace	0.043032901	1.263323014	14	411	0.227187061	0.041257472
Roy's Lg Root	0.043032901					
Hotelling's T2	18.2459499					

Cranial Base Height

A one-way ANOVA test was used to explore the difference in BAR, or cranial base height, between American-born Mexicans and native Mexicans. Males and females were separated in this analysis because the cranial base is sexually dimorphic (Holland, 1986). The results show that cranial base height differs significantly (p=0.0354) in males, but not in females (p=0.1238) at α=0.05. Results can be seen in TABLE 4 for males and

TABLE 5 for females. For the males, the American-born Mexicans have a greater average cranial base height (BAR) at 16.0mm, than do the native Mexicans at 12.895mm. While not statistically significant, females do follow the same pattern as males, with American-born females having a higher cranial base at 14.29mm compared with 12.09mm for the Mexican-born females.

TABLE 4: ANOVA Results for Males

DESCRIPTION

Groups	*Count*	*Sum*	*Mean*	*Variance*
BAR (Mex)	95	1225	12.89473684	18.13773796
BAR (Am)	9	144	16	9.25

ANOVA

Sources	*SS*	*df*	*MS*	*F*	*P value*
Between Groups	79.27378543	1	79.27378543	4.545343081	**0.035409609**
Within Groups	1778.947368	102	17.44066047		
Total	1858.221154	103	18.04098208		

TABLE 5: ANOVA Results for Females

DESCRIPTION

Groups	*Count*	*Sum*	*Mean*	*Variance*
BAR (Mex)	42	508	12.0952381	12.23461092
BAR (Am)	7	100	14.28571429	8.238095238

ANOVA

Sources	*SS*	*df*	*MS*	*F*	*P value*
Between Groups	28.78911565	1	28.78911565	2.45548368	**0.123823939**
Within Groups	551.047619	47	11.72441743		
Total	579.8367347	48	12.07993197		

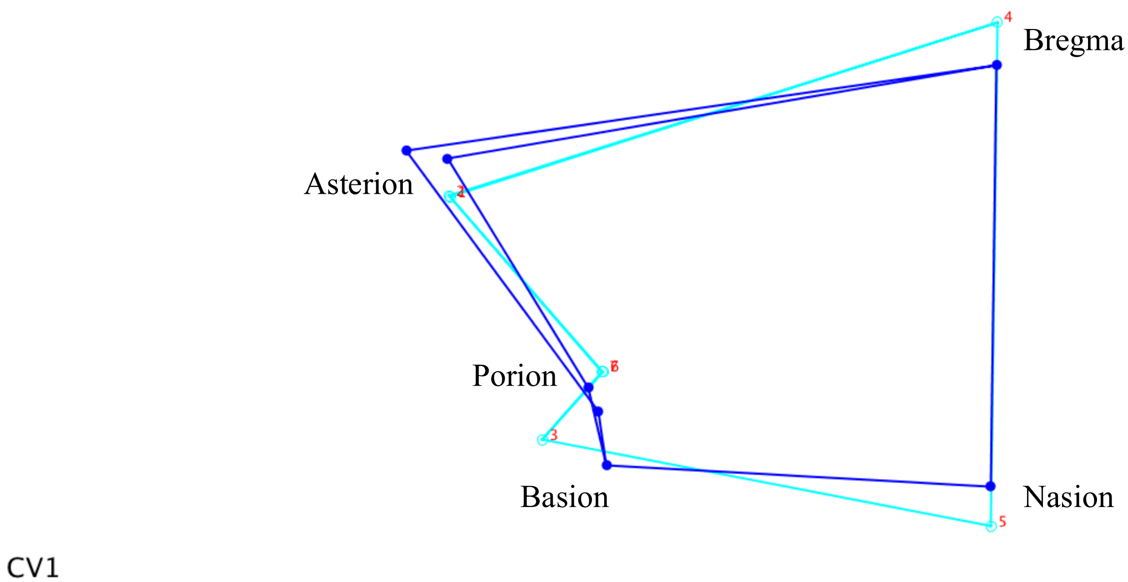

FIGURE 3: Wireframe graph showing relative locations of asterion, basion, bregma, nasion, and porion. American mean denoted in light blue, Mexican mean denoted in dark blue.

CHAPTER IV

DISCUSSION

The results suggest that males experience different environments, in terms of developmental stress, in Mexico and the United States, while females either experience more similar environments or are better adapted to buffer changes in their environments somewhere else (Frayer and Wolpoff, 1985). The present research is consistent with previous research (Yarbrough et al., 1975) that suggests that being born in America, as opposed to South and Central America, leads to increased stature, of which cranial base height is a component. This discussion will explore the cranial shape analysis, then will consider males and females separately in terms of cranial base height. Finally, it will focus on the implications for immigration, limitations of the materials and methods of the present research, and future research directions.

Cranial Shape Analysis

Given the insignificant MANOVA between Mexican-born and American-born samples, it is clear that the two samples do not differ significantly with respect to landmark location and cranial shape. This result is probably due to the fact that these samples are both of Mexican ancestry, and that craniofacial shape is similar in populations that are genetically and geographically similar. In fact, studies have shown that craniometrics tend to follow an isolation-by-distance model, which suggests that geographically close populations also tend to be genetically similar (Relethford, 2004b). Given this basis of craniometric variation, it is not surprising that the two samples in this study do not differ significantly in terms of cranial shape. All the individuals are of Mexican ancestry, and the question in this study essentially comes down to whether or not an individual was born in one of two neighboring countries. Therefore, the insignificant results of the cranial shape analysis make sense in the context of the ancestral and geographic continuity seen in this study. This result also provides a foundation for understanding cranial base height, as it can now be more confidently asserted that any differences seen in cranial base height can be explained by environmental differences, as opposed to population differences. This result follows Sparks and Jantz' conclusions that the human cranium primarily records genetic information, but also exhibits a small degree of plasticity (2002, 2003).

Males

The results of this study indicate that males who are born in America have significantly higher cranial bases than do males who are born in Mexico. Previous studies have suggested that a low cranial base indicates a high level of developmental stress (Cameron et al., 1990, Wescott and Jantz, 2005, Rewekant, 2001, Senator et al., 2009, Weisensee and Jantz, 2011, Angel, 1976). Therefore, the significant difference in this study implies that males experience greater levels of developmental stress in Mexico than they do in America. This result confirms the original hypothesis: better living conditions in America may provide motivation for individuals to migrate from Mexico to the United States.

Poverty is a significant issue in Mexico, with 9.8% of urban and 34.1% of rural households having income levels below what was necessary for minimum calorie intake in the year 2000 (Hanson, 2007). According to Birkby and colleagues, poor dental health and a lower stature also characterize a significant portion of migrants who die crossing the US/Mexico border (2008). Additionally, evidence from several national nutrition surveys in Mexico during the last thirty years have shown that malnutrition, in the form of undernutrition (wasting, stunting, and anemia), and overnutrition (overweight and obesity) are still significant public health issues that can contribute to developmental stress in this population (Rivera et al., 2009).

The sum of the evidence suggests that, in certain parts of Mexico at least, there are environments high in developmental stressors, such as high levels of poverty and malnutrition. This is corroborated by a lower cranial base height in individuals born in Mexico versus those born in America. The results indicate, however, that these stressors are ameliorated for males born in the United States.

Females

The story behind female emigration from Mexico is quite different from that of the males, which leads to a very interesting set of possible conclusions. The fact that females do not differ significantly in cranial base height when born in Mexico vs. America could have one or a number of potential causes. First, women might experience low levels of developmental stress in both Mexico and the United States. Second, women might experience high levels of developmental stress in both Mexico and the United States. Finally, women may be better "buffered" to handle changes in environment, suggesting that they may be experiencing different levels of developmental stress in

Mexico and the United States but that these differences may not manifest skeletally (Frayer and Wolpoff, 1985).

The most parsimonious explanation for the results in females comes in the form of the "female buffering hypothesis," or the idea that females are better able to adapt to different environments without significantly decreasing in body size. There is evidence that males are more susceptible to nutritional deficiencies than females, at least when it comes to the skeletal manifestation of these deficiencies in terms of low stature. In a review of sexual dimorphism, Frayer and Wolpoff suggest that, in evolutionary terms, nutritional stress leads to a decrease in body size (1985). Males and females have less sexual dimorphism during times of nutritional stress, and are able to rebound to greater levels of sexual dimorphism after the stress dissipates. In terms of more proximate cause, Frayer and Wolpoff propose that females are better adapted to handling fluctuations in nutrition, or developmental stress, because of their adaptations to reproduction, increased fat storage, and a smaller body, which has a lower absolute energy requirement (1985). The present research is consistent with Frayer and Wolpoff's hypothesis.

Interestingly, some evidence exists that suggests urban females from Mexico may actually be "positively selected" for migration (Rubalcava et al., 2008). That is, women who leave urban areas in Mexico for the United States may actually have self-reported better health. Urban female migrants were more likely to migrate if they have greater stature and self-reported good health (Rubalcava et al., 2008). This particular study suggests that, at least for some Mexican women, the ability to migrate is actually correlated with better health. This provides evidence for the hypothesis that, perhaps, Mexican women who migrate and have children in the United States are experiencing low levels of developmental stress in both Mexico and the United States. However, this only accounts for urban females, and, in the present research, a distinction was not made between urban and rural environments.

While not statistically significant, females do follow the same pattern as males. That is, American-born females have higher cranial bases than do Mexican-born females. The lack of statistical significance may very well represent a biological difference, but it may also be simply an artifact of small sample size. Although this discussion focuses on why females may experience stress differently from males, it is important to remember that statistical and biological significance are two distinct concepts. When considering the implications of this research, in terms of public health for example, it will be critical to ensure that females are not forgotten.

Immigration Implications

The present study has some interesting implications for understanding migration between Mexico and the United States, as its results show that levels of developmental stress are higher for males in Mexico as compared to the United States. Coupled with empirical evidence about poverty (Hanson, 2007) and poor health (Birkby et al., 2008), this study sheds light on the potential reasons Mexican males migrate to the United States. For females, the picture is less clear. It is not yet understood whether they experience similar conditions in the United States and Mexico, whether their bodies are simply better at adapting to different environments without decreasing in stature, or whether a pattern more similar to males may become evident if more females were sampled. Additional research on cultural aspects of immigration will provide insight into this issue.

Limitations

This study is not without limitations. The first, and most significant, is the small sample size. In anthropology, we are often limited by what material is available. In order to work with deceased individuals, we must have access to their remains in skeletal collections. For this study in particular, I was limited even further by working only with Hispanic individuals who self-reported birth in Mexico or the United States, leaving me with a sample of only 16 American-born individuals. While this number is low, it represents the total number of individuals who met these criteria in skeletal collections to which I have access. It is unfortunate that there are so few American-born Hispanics who donate their skeletons because those remains are integral to understanding ancestry estimation, health, and immigration in an underrepresented population.

An additional limitation of this study is that, for some individuals in the Texas State Donated Skeletal Collection, information about their birthplace was provided by next of kin. While there is no reason to believe that this information is false, it would be better if this data were self-reported.

Future Directions

There are a number of additional directions that could be taken to strengthen this research. The first is that sample size could be improved through the use of cranial CT scans. Initially, this project was proposed to include cranial CT scans of self-reported

American-born Mexicans from the University of Texas Health Science Center at Houston (UTHSC). However, time limits precluded the use of this data. Moving forward, it will be useful to continue to collaborate with the UTHSC to collect additional data on the American-born Mexican sample to increase sample size and, thus, the validity of the results.

Additionally, this research would be strengthened by the use of a survey, either completed by the individual or their next of kin, noting specific details about the first ten years of their life. Potential survey questions might ask whether the individual was raised in an urban or rural environment, whether they lived below the poverty line for any length of time, what socioeconomic status they grew up in, from what diseases, if any, they suffered during childhood, and detailed information about which cities and countries they lived in and for how long they resided in each location. This information would allow me to tease out the urban vs. rural differences that are noted in other studies (Rubalcava et al., 2008), it would illuminate how large an impact socioeconomic status has on the results, and could provide more accurate assessment of how developmental stress (disease load, poverty) impacted cranial base height.

It will also be interesting, going forward, to compare the results obtained from this study to White and Black Americans of varying socioeconomic statuses. This further avenue of research will allow for a comparison of both ancestry and developmental stress to corroborate the idea that a lower cranial base height is correlated to a lower socioeconomic status across ancestries.

CHAPTER V

CONCLUSION

The present research is consistent with previous studies (Malina et al., 1986, Yarbrough et al., 1975), which suggest that being born in America, as opposed to South and Central America, leads to increased stature. Additionally, this research corroborates Angel's idea that developmental stress leads to a low cranial base height (Angel, 1976, Wescott and Jantz, 2005, Weisensee and Jantz, 2011). The results of this study show that cranial base height in males born in Mexico is significantly lower than those born in America. There is no significant difference in cranial base height for females.

These results indicate that developmental stress in males in Mexico is significantly greater than that of those who are born in America. This may be a result of increasing drug violence (Shirk, 2010), poverty, and infectious disease load in Mexico that is not as prevalent as it is in the United States. Females, however, do not differ significantly in cranial base height. This is likely a result of females' ability to deal with environmental transitions without changing significantly in body size (Frayer and Wolpoff, 1985). However, there is some evidence that females who leave Mexico may actually be already be in good health and of higher socioeconomic status (Rubalcava et al., 2008), suggesting that some women may not experience a drastic difference in developmental stress between Mexico and American.

Additionally, the Mexican-born and American-born samples differ more in terms of cranial base height than they do in cranial shape. This result suggests that the two groups are genetically similar, and that the difference we see in cranial base height is likely a function of different environments during growth and development.

Future research directions include an improvement of sample size through the use of cranial CT scans, a comprehensive survey that will provide accurate information about birthplace and stressors during childhood, and a comparison with American Blacks and Whites to explore the interaction between ancestry, socioeconomic status, and cranial base height. There is also potential for this research to illuminate the cultural and biological environments that may cause individuals to migrate from Mexico, which has led in part to the human rights crisis we currently face on the Texas/Mexico border.

In all, the present study provides an empirical framework for understanding how and why Mexican migrants may choose to risk their lives to cross the border into the United States. While this research can shed light on the fact that, for males in particular, developmental stress is higher in Mexico than in America, it is more than likely that Mexican individuals who are deciding to migrate do not need the results of this study to know that they are leaving in search of a healthier environment. The present research lends support to the idea that these individuals are attempting to escape a country in which they cannot adequately provide for themselves and their developing children. This study shows that, at least for men and possibly for women as well, the hope of an improved life in the United States is an earnest one. Now the question must become, "what can we do?" It is my hope that studies like this will provide a basis for empathy towards Mexican migrants and will be used to improve America's treatment of the human beings who choose to cross our border.

APPENDIX SECTION

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A. List of Craniometric Landmarks 36

B. Illustration of Craniometric Landmarks 38

APPENDIX A: LIST OF CRANIOMETRIC LANDMARKS

Asterion as

"The common meeting point of the temporal, parietal, and occipital bones, on either side. If the meeting point is occupied by a wormian bone (os astericum), extend the lambdoid suture onto its surface, and then extend the other two sutures (temporo-parietal, temporo-occipital) to the first line, finding asterion as the point midway between the intersections if these do not coincide (BM). Use only the part of the last two sutures (ca. 1 cm) which is nearest the point, in finding these directions.

If the lambdoid (or other) suture is complex or composed of wormian bones, trace a pencil line along the center of the area covered by the complexity, as well as can be done, to find the main axis of the suture. If the sutures gape at this point, leaving an open space, find asterion on the edge of the occipital bone." (Howells, 1973)

Basion ba

"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. Mark carefully with a pencil. In the most usual specimen the border of the foramen will have a thickness of 1-2 mm and a rounded edge. The position chosen will be about half way between the inner border directly facing the posterior border (opisthion) and the lowermost point on the border, i.e., between the points usually designated endobasion and hypobasion respectively.

As a practical matter, the point will almost always be the endpoint of the basion-nasion length if the caliper is applied here so as to find a maximum. It will correspond with endobasion only if there is a thin, sharp border to the foramen. The variation in structure here is considerable: in thickness of the border, and in the presence of a small tubercle or a larger articular surface. In the case of the former, displace basion to one side or the other; in the case of an articular surface, place the point on this, trying to estimate the position from directions above. To estimate basion in a damaged skull, use a transverse line connecting the posterior limits of the bases of the spinous processes on either side. The elevation of basion in such a case can, however, be only guessed at." (Howells, 1973)

Bregma br

"The posterior border of the frontal bone in the median plane. Normally this is the meeting point of the coronal and sagittal sutures. The latter may diverge from the midline here, however, and should not then be followed. (Metopic sutures should be disregarded.)

More commonly, the coronal suture may project slightly backward in a small point here, from the general smooth curve of the suture on either side; or the two halves of the suture may meet in a short antero-posterior line, i.e., one half may lie forward of the other where they reach the midline. In these and similar cases, the general course of the suture as a whole should be lightly drawn with a pencil, and the bregma established on this. The point should mark the limits of the frontal and parietal segments of the vault generally, not minor sutural variations.

If the coronal suture is nearly obliterated, its course must be established from any remaining traces: if it is completely obliterated, there is nothing to do but estimate the position of bregma.

The sutures may meet with rounded external edges, resulting in a cleft or depression at their junction. Bregma is then to be established "in the air" (BM), i.e., in its correct position but at the level of the general surface of the bone and not, by sinking the caliper point into such a fissure in measuring, below this surface. Some device, such as displacing bregma slightly to one side in the same transverse plane, may be followed.

In any other questionable case where such a choice may be necessary, bregma is considered to be on the frontal bone." (Howells, 1973)

Nasion na

"The intersection of the fronto-nasal suture and the median plane. Mark with a pencil. This does not refer to the internasal suture in any way. If there is irregularity near the midline, rectify the general curve of the fronto-nasal suture with a pencil so as to find the correct level for nasion.
Except for this last, a general rule is to consider nasion as on the frontal bone (BM, V). I.e., if the fronto-nasal suture forms a cleft or gap, locate nasion on the midline just at the angle between the facial and sutural surfaces of the frontal bone itself." (Howells, 1973)

Porion po

"The most lateral part of the superior margin of the external auditory meatus." (Moore-Jansen et al., 1984)

Radiometer Point

This point is taken with the digitizer wand hovering in the center of the external auditory meatus, without touching bone.

APPENDIX B: ILLUSTRATION OF CRANIOMETRIC LANDMARKS

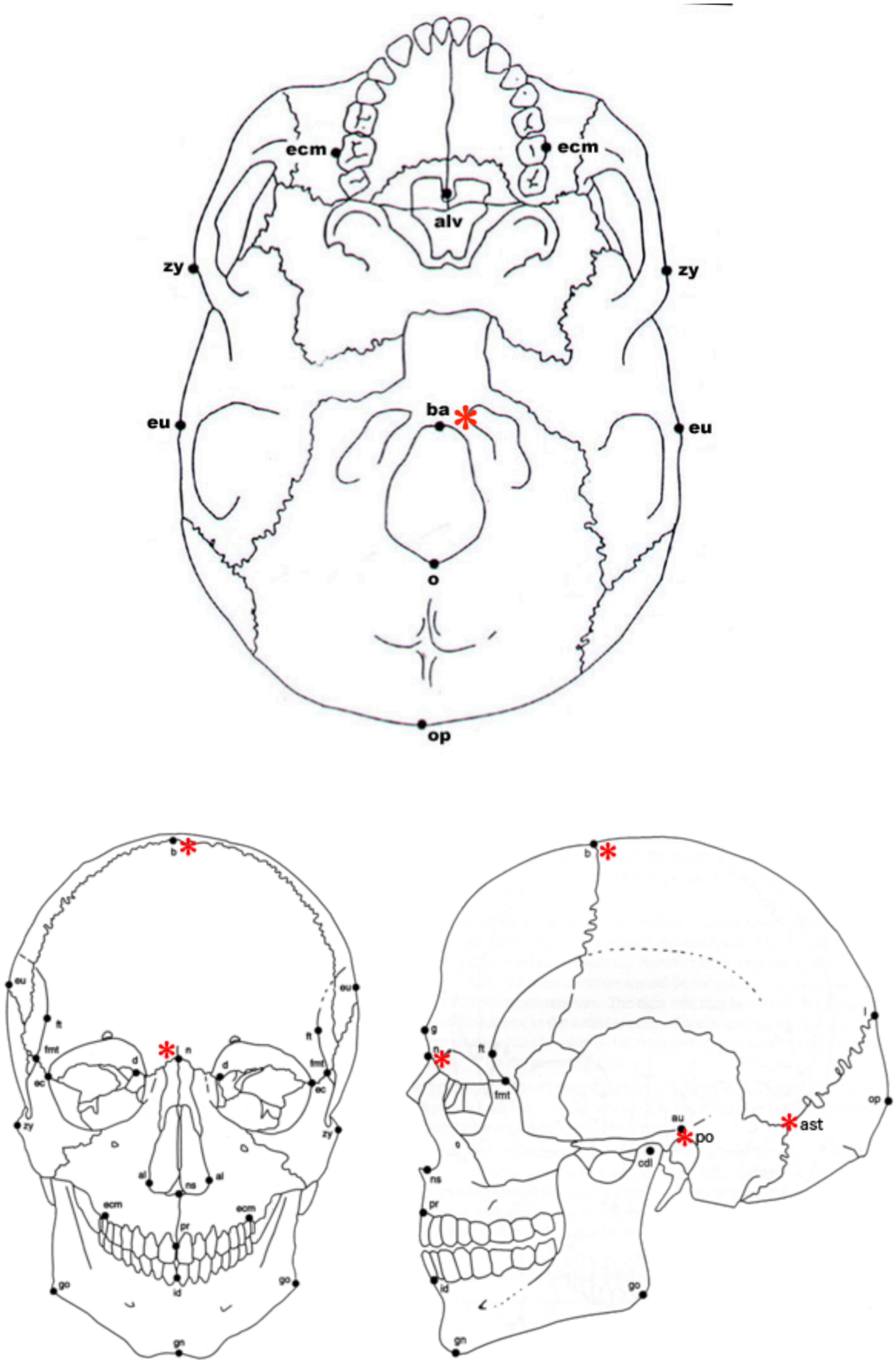

FIGURE 4: Illustration of cranial landmarks with landmarks of interest denoted with red asterisks. Modified from Moore-Jansen et al. (1994).

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