2010

Ancestral determination from foramen magnum

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ANCESTRAL DETERMINATION FROM FORAMEN MAGNUM

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Arts

in

The Department of Geography and Anthropology

by
Stephanie Marie Crider
B.A. University of California Santa Cruz, 2005
May 2010

ACKNOWLEDGEMENTS

I would like to thank my entire thesis committee for their help, support, and encouragement through this process. I am extremely grateful for time and effort Ms. Mary Manhein put into my thesis to help it become the best possible product. Ms. Manhein has been not only an excellent advisor, but an outstanding mentor that has pushed me to do the best possible work I can; for that I am eternally thankful. Dr. Dydia DeLyser has been especially helpful with her insightful comments and continuing support. Dr. DeLyser’s encouragement has been endless and is very much appreciated. I would like to thank Dr. Robert Tague for his support and willingness to help with my questions regarding osteology and statistical methods as applied in biological anthropology. Finally, I would like to thank Dr. Kristine DeLong for her enthusiasm, statistical knowledge, and ability to interpret my very scattered emails asking for guidance. My entire thesis committee has provided me unparalleled support and guidance, without which I would never have been able to complete my research.

This research would not be possible without the generous funding from the Robert C. West Travel grant and the Department of Geography and Anthropology at Louisiana State University. The department’s continuing support for graduate students has been the driving force behind this research. I would like to thank Ms. Mary Lee Eggart for her beautiful cranial base drawings used in this thesis.

I would like to thank the Pima County Office of the Medical Examiner, Dr. Bruce Anderson, and Dr. Bruce Parks for allowing me to use their facilities and access to the remains of Undocumented Border Crossers who perished in the Sonoran desert attempting to enter the United States. I would also like to thank the University of Tennessee at Knoxville and Dr. Lee Meadows Jantz for access to the William M. Bass Donated Skeletal Collection. Thank you to the University of New Mexico and Dr. Heather Edgar for access to the Maxwell Museum of

Anthropology's Osteology Laboratory. Finally, I would like to thank Ms. Mary Manhein for her generosity in allowing me to study the Louisiana State University's Forensic Anthropology and Computer Enhancement Services (FACES) Laboratory's Donated Skeletal Collection.

I need to thank Ms. Madalina Hanes, Dr. Renée Renegar and the Louisiana State University's Graduate School for their constant support and flexibility with my assistantship. I thank Ms. Nicki Smith for her constructive comments during the editing process and her endless support. I would also like to thank my fellow graduate students, Ms. Sophia Renke, Ms. Teresa Wilson, Ms. Michelle Whipp, and Ms. Lauren Pharr, for their encouragement and suggestions throughout the entire thesis process. Special thanks to Ms. Leigh-Anne Lawton for her willingness to check references.

I am forever thankful for the encouragement, support and love that my entire family provided me. Their constant, never-ending support pushed me to do my best even when I was questioning myself.

Lastly, I would like to thank all of the individuals who donated their bodies for the study and advancement of science. Without their generosity and willingness to allow others to learn from their physical remains, I would never have been able to complete my research.

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ABSTRACT

Ancestry estimation is a crucial part of the biological profile creation in forensic anthropology. Without proper classification of ancestry, other aspects of the biological profile, such as stature, can be affected. Several techniques are used by forensic anthropologists to determine ancestry of unidentified remains. Some anthropologists believe the cranium to be an excellent indicator of ancestry (Rhine 1990). The focus of this research was to determine the utility of the foramen magnum region on the cranial base as a positive indicator of ancestry.

Previous studies have explored the effectiveness of using the cranial base's occipital condyles for ancestry assignment of an individual. Holland (1986a) studied the Terry Collection, housed at the Smithsonian, to develop five multiple-regression equations. Using the same measurements as Holland (1986a) for the current research, four modern skeletal collections consisting principally of whites, blacks, and Hispanics were documented and measured. A total of 465 cranial bases comprised the sample.

The hypothesis of this research stated correlations exist between the shape of the foramen magnum and ancestry of an individual. The null hypothesis stated ancestral groups are not visually and metrically different from each other.

Localized changes on the cranial base have occurred. The Maximum Distance between Occipital Condyles increased in length and the Maximum Interior Distance between Occipital Condyles decreased in length.

Five different foramen magnum shape categories were defined to classify each foramen magnum: Arrowhead, Circle, Diamond, Egg, and Oval. No correlations were found between foramen magnum shapes and positive assignment of ancestry or sex. However, the Egg shaped foramen magnum has the potential to be used as an eliminating non-metric characteristic for

Hispanics; no individuals of presumed Hispanic ancestry possessed an Egg shaped foramen magnum.

A Pearson's chi-square showed a significant relationship between blacks, whites, and Hispanics, and foramen magnum shape ($p = 0.05$). Metric variation of the foramen magnum width among blacks, whites, and Hispanics is significant ($p = 0.05$). Also, variation between sexes was significant in eight of the 12 measurements ($p = 0.05$).

Ultimately, the null hypothesis for shape variation could not be rejected, while the null hypothesis for metric variation could be accepted.

CHAPTER 1 – INTRODUCTION

Forensic anthropology is an applied discipline of physical anthropology. A forensic anthropologist must be versed in many areas in order to assess human remains properly. Some of the areas of knowledge required are human osteology, human growth and development, and skeletal pathology. Each of these specialties is essential to construct a biological profile successfully. A biological profile in forensic anthropology consists of an educated assessment of age, sex, living stature, and ancestry (Byers 2008). Correct determination of ancestry is necessary for the positive identification of unknown skeletal remains. Numerous studies have shown the cranium to be an excellent indicator of ancestry based on metric and non-metric characteristics (Rhine 1990). The cranial base has been studied on several different occasions to determine ancestral similarities and dissimilarities, and is the focus for this research project.

The primary goal of this research project is to document and analyze the foramen magnum shape (with consideration of the occipital condyles) to determine if there is a correlation between the shape and ancestral groups. Modern documented skeletal collections from throughout the country, as well as a substantial collection from the Pima County Office of the Medical Examiner, comprised the main sample for this project. Visual assessment involved categorizing each foramen magnum into one of five shape categories. Metric assessment involved descriptive statistics, as well as other statistical methods, to compare and contrast each of the twelve measurements.

The hypothesis of this research is that correlations exist between the foramen magnum shape and ancestral groupings. This hypothesis will be accepted if the null hypothesis that ancestral groups are not visually and metrically different from each other is rejected.

CHAPTER 2 – LITERATURE REVIEW

The cranial base is a complex structure with several different significant bony landmarks that forensic anthropologists utilize on a regular basis. In order to examine the foramen magnum shape and to try to determine if there is a correlation between the shape and ancestry, one must first understand the different structures surrounding the foramen magnum on the cranial base and on the adjacent cervical vertebrae.

2.1 Cranial Base Evolution

The interesting and complex evolution of the cranial base is well represented in the fossil record (Nevell and Wood 2008). Nevell and Wood (2008) extensively studied hominin cranial bases in order to document the changes that occurred to as a result of evolution (May and Sheffer 1999). They state, “the cranial base undergoes significant change within the hominin clade” (Nevell and Wood 2008:455). The entire cranial base underwent change from our early hominin ancestors to modern *H. sapiens sapiens*. In order for one cranial structure to change during evolution (ie. enlargement of the brain), the different bones of the cranial base flex to allow for the required expansion (Strait 2008).

Some of the osteological features that have undergone evolutionary changes include: the petrous portion, the postglenoid process, the tympanic bone, the squamosal portion of the temporal bone (Nevell and Wood 2008), and the foramen magnum (Nevell and Wood 2008; Schaefer 1999; Scott 1958). Nevell and Wood found *H. sapiens sapiens* were the first species to have an unossified petrous apex, while antecedent hominins (*P. aethiopicus*, *P. boisei*, *A. africanus* and *H. habilis*) possessed an ossified petrous apex (Nevell and Wood 2008). Also, the tubular tympanic bone in *Pan* and early *Homo* is significantly different from the tympanic bones that modern humans possess (Nevell and Wood 2008). The postglenoid process has undergone a reduction in size as seen through "the *Paranthropus – Kenyanthropus – Australopithecus – Homo* clade" (Nevell and Wood 2008:460).

Bruner (2008) compared the endocranial casts (endocasts) of modern humans and Neandertals using geometric superimposition to examine the differences between the two groups. Bruner found substantial differences exist between modern human and Neandertal endocasts. Bruner stated "bulging of the parietal and posterior cerebellar areas" (Bruner 2008:100) was among the biggest differences between modern humans and Neandertals. He suggested these changes are a result of the evolution for advanced cerebral complexity in modern humans (Bruner 2008).

Finally, the foramen magnum has also undergone significant change throughout hominin history. While it is unusual for foramen magnums to be preserved on fossilized remains, techniques have been developed to determine the original location. Triangulation of osteological landmarks around the occipital condyles (basion, nasion, and opisthocranion) can provide insight as to the original location of the foramen magnum (Luboga and Wood 1990). Once this location is identified, paleoanthropologists have found no backward migration of the foramen magnum position throughout evolution (Scott 1958). In fact, the foramen magnum is situated more anteriorly in hominins than in apes (Scott 1958). However, it is situated posteriorly in early hominins compared to modern humans (Nevell and Wood 2008; Schaefer 1999). For example, KNM-ER 1813 has a more anterior foramen magnum than that of Sts 5 (Luboga and Wood 1990) which are both posterior to modern humans.

Studies have been conducted on the growth of the cranial base. Angel (1982) compared two distinctive skeletal collections: the Terry Collection and a modern forensic/willed specimen collection. Angel (1982) found an increase in size had occurred in modern forensic/willed collections when compared to the early 20th century Terry Collection. He also found that the greatest growth was seen in the region of the skull base height.

2.2 The Cranial Base

The cranial base is a complex structure (Figure 2.1). The foramen caecum is considered the most anterior portion of the cranial base (Lestrel and Roche 1986). The development of the cranial base begins during early fetal growth as a cartilaginous mass with multiple centers of ossification. The foramen magnum alone is one such center. The growth of the cranial base during fetal development is most rapid between the "14th and 32nd week[s]" (Scott 1958:323). Within the first nine months of life, an increase in angulation occurs for all angles of the cranial base (George 1978). After those first nine months, a sharp decrease occurs in angulation between one year nine months, and three years of age. By age 13, the cranial base will reach 90% of its adult size (Scott 1958).

Both cranial vault morphology and capacity are shaped by the size of the cranial base. Taylor and Dibennardo (1980) suggest cranial base length and brain size are correlated positively with one another, while facial length and cranial base length are not. Jantz (2001) suggests increased nutritional quality and quantity, over the last hundred years, possibly contributed to the increase in the cranial vault size in both blacks and whites, thus resulting in a lengthening of the foramen magnum.

Many studies have been performed on the cranial base to determine whether or not sexual dimorphism can be assessed. By measuring specific bony landmarks on the cranial base, such as axial length of the occipital condyle, the apex of the mastoid process to the outermost lateral point of the foramen magnum, and the jugular foramen to the temporomandibular joint, one can determine whether or not the unknown skull belongs to a male or female (Çìçekçsi et al. 2004). Lestrel et al. (2005) conducted a study to determine sexual dimorphism within specific ancestral groups based solely on the cranial base. Sexual dimorphism of the cranial base was measured with wavelet transformation on a population of Japanese individuals (Lestrel et al. 2005). Some

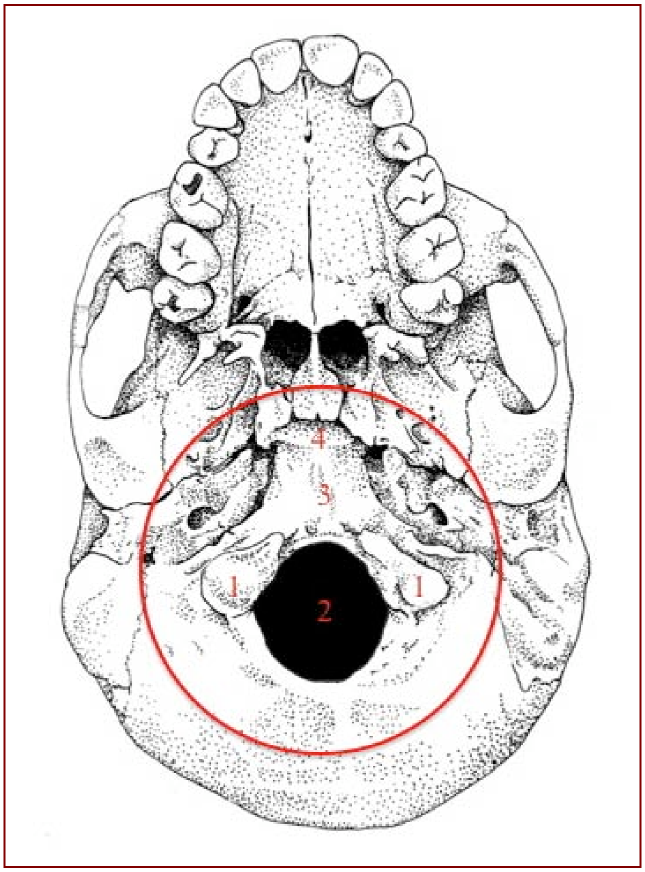


Figure 2.1. Inferior view of the cranial base (courtesy of Mary Lee Eggart); 1) occipital condyles, 2) foramen magnum, 3) basilar process, 4) hormion.

dimorphic differences between sexes were recorded; however, not enough were observed to positively suggest strong sexual dimorphism. Finally, Snow et al. (1979) tested the Giles and Elliot discriminant function analysis of cranial features. While the Giles and Elliot test has been somewhat useful for determining sex (about 85% accurate), the various formulae do not take into consideration growth changes in modern populations. Lestrel and Roche (1986) used Fourier analysis, a curve-fitting model, to examine the changes in shape to the cranial base during four specific age categories: “infants, juveniles, adolescents and adults” (Lestrel and Roche 1986:533). Lestrel and Roche found a significant growth spurt associated with puberty. This growth spurt is the point when the cranial base changes from its form as an infant to the final adult shape (Lestrel and Roche 1986). They found that the location of present osteological features moved positions during the growth period between the different age groups. An example of this feature migration is the superior movement of the hypophyseal fossa and the anterior-inferior movement of the dorsum sellae (Lestrel and Roche 1986).

As helpful as the cranial base is in determining sex, the endocranial base can also aid in the understanding of age, sex, handedness, and ancestral characteristics. Attempts to use the basilar synchondrosis to determine age at death (Kahana et al. 2003) based on the degree of closure present were not successful because of weak correlation between chronological age and closure. Kahana et al. (2003) found no link exists in males between basilar synchondrosis closure and age, while females, some differences are present. However, the authors acknowledge their female sample size is small and therefore, suggest further research before any definitive statements can be made regarding the correlation of closure and age in females (Kahana et al. 2003).

Additionally, the jugular foramen has been examined to determine if there is a correlation between asymmetry and handedness (Glassman and Dana 1992). The authors suggest asymmetry of the jugular foramen is due to an excessive blood supply and increase musculature on the dominant side. Yet, no association between the asymmetry of the jugular foramen and handedness has been established. Finally, Bruner and Ripani (2008) examined the endocranial base to see if any morphological relationships between the various landmarks exist. Using 3D configurations, superimpostion, and morphometrics, they found that allometry can explain a large portion of the differences between the sexes (Bruner and Ripani 2008).

2.3 The Cervical Vertebrae

The cranial base and endocranial base are directly affected by the cervical vertebrae, which play a substantial role in the development and modification of the foramen magnum. Cervical vertebrae continually increase in size until the age of two, where development slows to a moderate pace (Roche 1972). Occipitalization of the atlas is the ossification of the atlas to the occipital condyles on the cranial base. Occipitalization of the atlas is rare, affecting less than one percent of the overall population, but is a debilitating pathology for the cervical vertebrae that severely reduces range of motion (Al-Motabagani and Surendra 2006).

The growth of the cervical vertebrae is sexually dimorphic (Roche 1972; Katz et al. 1975; Cooke and Wei 1988; Huggare 1992; Marino 1995). Elongation of the cervical vertebrae is greater in males than females during the teen years, causing a longer trunk in males (Roche 1972). By examining lateral radiographs of living individuals, Katz et al. (1975) determined males have an increased vertebral body height compared to females because males have larger heads than females.

Head posture is integral in understanding features of the cervical vertebrae and the function of the cranial base. Solow and Tallgren (1973) found a correlation exists between the head posture and the allowance for flexion of the cranial base. Flexion is a result of the elongation of the cranial base, which is directly responsible for the elongation of the foramen magnum. The elongation of the foramen magnum causes the first two cervical vertebrae to elongate and allow for increased flexion. All aspects of the cranial base and cervical vertebrae work together to better allow for upright head posture.

In females, the angle of the cervical vertebrae has been found to be more forward than males because females tend to hold their heads higher (Cooke and Wei 1988). By holding their heads higher, women are prone to having a more elongated cervical vertebral portion of their overall vertebral column as adults (Huggare 1992). Similar to these findings, Huggare (1992) found individuals living in colder climates are more likely to have more developed dorsal and ventral arches on the first cervical vertebra, the atlas, due to increased musculation. This musculation is directly related to individuals holding their heads at different angles in order to protect their faces from the cold temperatures (Huggare 1992).

The first cervical vertebra has been studied for sexually dimorphic characteristics. Using eight different locations on the atlas, as well as visual methods, Marino (1995) found a 60-80% cause to rely on the atlas for sexually dimorphic characteristics. After creating seven multiple regression formulae, Marino stated the vertebral foramen in the atlas is the most sexually dimorphic trait. The morphology of the second cervical vertebra's articular process, the axis, has been found to be more variable than that of any other cervical vertebrae (Ludwiczak and Wackenheim 1975).

Finally, Saunders and Popovich (1978) researched the bridging of the atlas to determine if it is an inherited trait. Radiographs taken of both parents and their children led the researchers to conclude that atlas bridging is an inherited trait (Saunders and Popovich 1978).

2.4 The Styloid Process

The styloid process is a small cylindrical bone on the base of the temporal bone that projects anteriorly (Gonçales et al. 2003 and Sikanjic et al. 2008) (Figure 2.2). Three muscles and two ligaments attach to the styloid process (Eagle 1962). The three muscles attach to the styloid process toward the tongue, the hyoid, and posterior pharyngeal wall (Eagle 1962). The stylomandibular ligament attaches the styloid process near the angle of the mandible on the inner surface, and the stylohyoid ligament attaches the styloid process to the hyoid bone (Eagle 1962). Feldman (2003) and Sikanjic and Vlak (2008) state the typical mean length of a styloid process is between two and one-half, and three centimeters (cm). If the styloid exceeds three cm in length, it is considered elongated (Gonçales et al. 2003; Kim et al. 2008; Sikanjic and Vlak 2008). The styloid can become elongated for several reasons: increased musculation of the vertebral column, calcification of the stylohyoid ligament (Gonçales et al. 2003), and fusion of an ossified stylohyoid ligament to the apex of the styloid process (Sikanjic and Vlak 2008). Typically, in modern populations an elongated styloid process is linked with Eagle's syndrome (Eagle 1937). Eagle's syndrome occurs in four to 23% of modern populations and is characterized by the ossification of the stylohyoid and stylomandibular ligaments (Restrepo et al. 2000; Gonçales et al. 2003). During their 2008 study, Sikanjic and Vlak studied 448 x-rays, 102 of which presented with Eagle's syndrome. Of the 102 patients with Eagle's syndrome, 66 were females (Sikanjic and Vlak 2008).

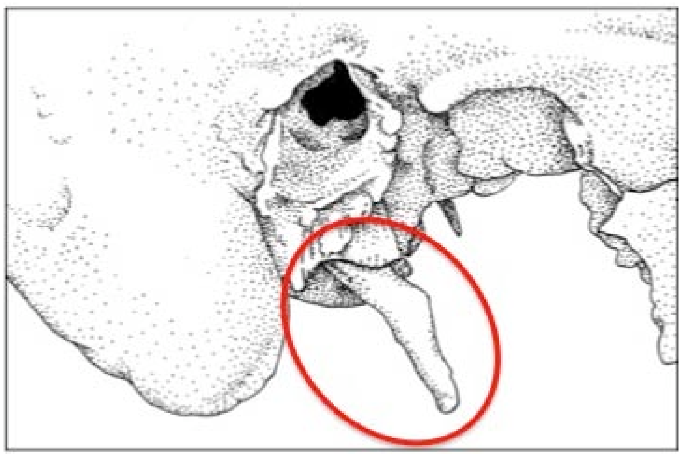


Figure 2.2. Lateral view of the temporal bone with a circle around the styloid process (courtesy of Mary Lee Eggart).

Individuals with Eagle's syndrome usually have a styloid process length ranging from three and three-hundredths to ten and one-half centimeters (cm) (Gonçales et al. 2003; Sikanjic and Vlak 2008). Most individuals with Eagle's syndrome do not present with symptoms indicating Eagle's syndrome until they have a mild neck injury (Restrepo et al. 2000). Patients are most commonly diagnosed over the age of 30 and are more likely to be females than males (Feldman 2003; Sikanjic and Vlak 2008).

2.5 The Occipital Condyles

Occipital condyles (Figure 2.3) can be helpful in determining the sex of an individual. Gapert et al. (2008) created regression formulae for sex determination from six measurements on the occipital condyles from a historic population. While the formulae lack the statistical strength necessary for regular use, they do provide some insight for the utility of occipital condyles for sexual dimorphism. Sex determination from occipital condyles could be used in conjunction with other techniques.

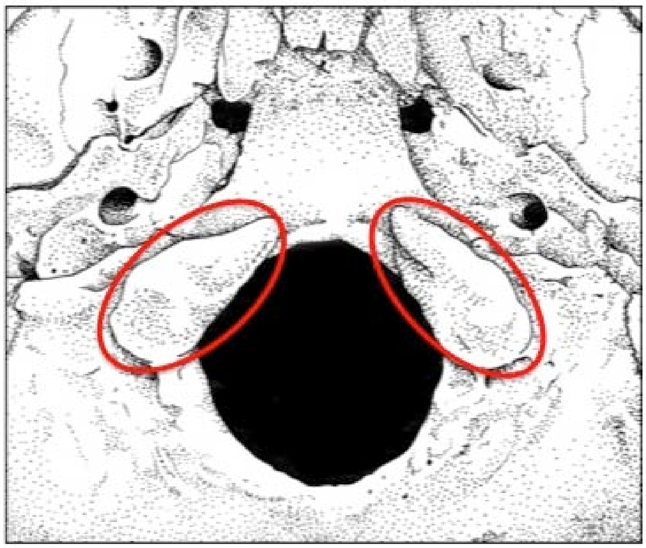


Figure 2.3. Detailed inferior view of the cranial base with the occipital condyles circled (courtesy of Mary Lee Eggart).

Several types of anomalies and traumas are associated with the occipital condyles. Occipital condyle syndrome (OCS) does not necessarily involve the occipital condyle itself, rather the twelfth cranial nerve. OCS occurs when the twelfth cranial nerve is compressed by the occipital condyle, often stemming from sports or car injuries (Capobianco et al. 2002).

Though rare, occipital condyle fractures are more common than OCS. These fractures tend to be a result of the compression of the occipital condyles by the cervical vertebrae (Cartmill et al. 1999). Occipital condyle fractures are serious and can cause extreme neurological damage due to the proximity to cranial nerves, more specifically, the twelfth cranial nerve (Cartmill et al. 1999; Momjian et al. 2003).

2.6 The Foramen Magnum

The foramen magnum is one of the primary centers of ossification on the cranial base during growth and development, and is located inferior to the sagittal suture, on the cranial base (Figure 2.4).

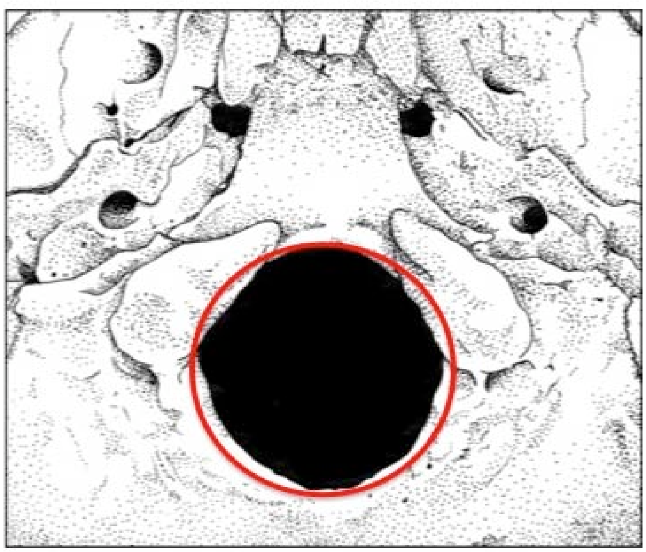


Figure 2.4. Inferior view of the cranial base with a circle around the foramen magnum (courtesy of Mary Lee Eggart).

There is a small incidence for tubercle formation on the anterior aspect of the foramen magnum (Vazquez et al. 1996). The foramen magnum tubercle is important because it is located on the anterior portion of the foramen magnum, in the midline (Vazquez et al. 1996). In the case of a fragmentary cranial base, a foramen magnum tubercle can aid in the orientation of the fragmented pieces. A foramen magnum tubercle is more frequently found in Southeast Asian populations (about 15%) than in white populations (about one and three-tenths percent) (Vazquez et al. 1996).

The measurements for both the length and width of the foramen magnum vary depending on their sources, sex, and ancestry of the samples. Listed in Table 2.1 are the measurements of eight authors who have studied the foramen magnum extensively. When available, the sample information is included. When comparing these measurements, the historical samples have smaller measurements; the transverse width of the foramen magnum was always less than that of the sagittal width (Catalina-Herrera 1987).

Table 2.1. Comparison of Foramen Magnum Means from Various Studies.

Author(s) & Date	Foramen Magnum Length (mm)	Foramen Magnum Width (mm)	Sample Size
"Classic" (reported in Murshed et al. 2003)	35	30	--
Schmeltzer et al. (reported in Murshed et al. 2003)	35	30	--
Zaragoza (reported in Murshed et al. 2003)	38	28	--
Murshed et al. (2003)	37.2 (males) and 34.6 (females)	31.6 (males) and 29.3 (females)	100 living patients (Turkey)
Sendemir el al. (1993)	36.4	30.0	23 subjects
Wackenheim (reported in Murshed et al. 2003)	35	30	--
Catalina-Herrera (Catalina-Herrera 1987)	35.2	30.3	100 skulls (Universidad de Sevilla)
Holland (1986a & b)	37.6 (males) and 34.7 (females)	31.4 (males) and 29.4 (females)	100 subjects (Terry Collection)

Several articles have been published on the usefulness of the foramen magnum and cranial base for identification purposes (Holland 1986a and b; Holland 1989). Since the skull is highly susceptible to fracture, it may not always be intact when given to a forensic anthropologist. Using this rationalization, Holland (1986b) created a regression equation that uses nine measurements from the cranial base to determine sex of fragmented crania. Holland's sex discriminant function identified the sample population with 71-90% accuracy. When tested against more crania from the Terry Collection, the accuracy drops to 85% at most (Holland 1986b).

Murshed et al. (2003) pointed out that, statistically, foreman magnum measurements in males are greater because they tend to have larger heads than females. Uysal et al. (2005) used Computed Tomography (CT) scans of living individuals to examine the cranial base and foramen magnum for sexually dimorphic characteristics. CT scans were taken and measured digitally to determine if previous research on sex determination from the foramen magnum is accurate (Uysal et al. 2005). Uysal et al. (2005) found all dimensions were larger in males than females, with the length and width of the right occipital condyle and the width of the foramen magnum reflecting the greatest differences.

Few studies have been conducted to determine ancestry from the foramen magnum. By specifically defining the features on and around the foramen magnum, Holland (1986a) created five multiple-regression equations to assign the ancestry to individuals of black or white origin. Having a slightly lower accuracy rate than his research on sexual dimorphism, Holland (1986a) found the foramen magnum could be used with about 90% accuracy on the sample population. Allaire and Manhein (2008) found that when a modern population is tested using this equation (Holland's #4 regression equation), the accuracy dropped by a third to 57%.

Finally, one study addresses the variation of shapes of the foramen magnum. Murshed et al. (2003) used x-rays of living individuals and measured the foramen magnum from ventral to dorsal, and lateral-edge-to-lateral-edge. After examining each of the x-rays, Murshed et al. (2003) suggested a total of eight different shapes for the foramen magnum: oval, egg, round, tetragonal, pentagonal, hexagonal, irregular A, and irregular B. While Murshed et al. (2003) do designate different types of foramen magnum shapes, they do not use statistics to explain or draw connections between the shape categories, sex, and ancestry.

CHAPTER 3 – THE SONORAN DESERT AND THE PIMA COUNTY OFFICE OF THE MEDICAL EXAMINER

One of the major skeletal collections utilized in the current study represents individuals whose remains were found in the Sonoran Desert area. An overview of that geographical region, and cases associated with that region, provides insight into the extreme environmental challenges faced by people wishing to enter the United States.

3.1 Sonoran Desert Demographics

The Sonoran desert is one of the four major deserts in North America (Figure 3.1) (Houk 2000) and is approximately 120,000 square miles (Broyles 2003) of rugged mountainous terrain

Figure 3.1. Map of Sonoran desert. Courtesy of the Western National Parks Association.

(Figure 3.2). Two-thirds of the desert is in Mexico and the other third lies between southern Arizona and southeastern California. Elevation of the Sonoran desert ranges from sea level to approximately 4,000 feet (Houk 2000). Temperatures can reach as high as 119^{o}F in the summer months (Western Regional Climate Center – Yuma Weather Station – http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?azyuva) and as low as six degrees Fahrenheit in the winter months (Western Regional Climate Center – University of Arizona at Tucson Weather Station - http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?aztucs). Rainfall is extremely scarce, with recorded minimums of two inches a year (Houk 2000).

Figure 3.2. Photograph of rugged terrain in the Sonoran desert. Taken by S. Crider in Southwest Tucson, Az.

3.2 Undocumented Border Crossers and Mexico-U.S. Illegal Immigration

The United States shares approximately 2,000 miles of borderland with Mexico along the states of California, Arizona, New Mexico and Texas (Anderson 2008; Hinkes 2008). Tucson, Arizona (Pima County), is one of the primary ports of entry for illegal immigration into the United States. With 281 miles of shared border (Anderson 2008), Tucson, Arizona, and the Pima County Office of the Medical Examiner (PCOME) have seen an increase in the number of Undocumented Border Crosser (UBC) cases. The PCOME conducts anthropological exams on approximately 200 individuals each year who are classified as UBCs (Anderson 2008). Between 2001 and the spring of 2007, the PCOME reported seeing over 1,000 cases (Anderson and Parks 2008).

A unique population used for this research is a collection of UCB skeletal remains from the PCOME. The PCOME defines UBCs as undocumented migrants who perished in transit attempting to enter the United States illegally (Anderson 2008). This definition does not include individuals of foreign origin who have established legal residency within the United States (Anderson 2008). The PCOME uses several different criteria to determine the designation of UBC for unidentified remains. Some of the circumstantial evidence taken into consideration for the UBC designation are personal effects (Anderson and Parks 2008), such as "Mexican voter registration cards, birth and marriage certificates; address books and scraps of paper with telephone numbers (both foreign and domestic); foreign currency; and cultural accoutrements" (Anderson 2008:12) as well as clothing, shoes, and religious icons indicative of Latin American culture (Anderson and Parks 2008; Birkby et al. 2008).

Of the approximately 200 cases of UBCs the PCOME sees on a yearly basis, the cause of death is attributed to the extreme environmental elements of the Sonoran desert. The Sonoran desert is the hottest of the four deserts in North America (Weiss and Overpeck 2005).

Hyperthermia, or the elevation of the body temperature, has been reported as one of the leading causes of death from the extreme heat during the summer months of May through September (Anderson 2008). This cause of death has been verified from remains found in the desert that were well preserved (not skeletonized) and underwent an autopsy (Anderson and Parks 2008). Sun exposure and dehydration are also common causes of death for UBCs (Fulginiti 2008; Hinkes 2008). Along the California-Mexico border, there has been an increase in weather-related causes of death (hyperthermia and hypothermia) over the past two decades (Hinkes 2008). Due to the extreme climatic conditions, decomposition rates are greatly accelerated in the Sonoran, and surrounding deserts (Anderson 2008; Hinkes 2008). Hinkes (2008) reports the rate of decomposition in a desert is so accelerated that a body can be reduced to a skeleton with only a few ligaments remaining within two weeks time.

3.3 Immigration in the Sonoran Desert

Between 1985 and 1998, the PCOME averaged 19 UBC deaths per year; however, in the past few years, this number has jumped to almost 200 per year (Anderson 2008). This increase in UBC deaths in Arizona can be linked partially to several governmental policies regarding border patrol and the reduction of illegal entry into the United States from Mexico at certain points. Unlike most of the areas that share a border with Mexico, San Diego, California, has observed a decrease in the quantity of UBC anthropological exams (Hinkes 2008). This has been directly correlated with Operation Gatekeeper, which was enacted in 1994 by the Clinton Administration (Hinkes 2008). Operation Gatekeeper's main goal is to lower the number of undocumented individuals immigrating illegally into the United States through the California-Mexico border, and, more specifically, in San Diego county (Hinkes 2008). While this has been successful in San Diego for reducing the number of illegal immigration attempts, many areas east of San Diego have experienced an increase in illegal immigration (Hinkes 2008). This increase has resulted in a challenge in anthropological identification of ancestry for those states, especially since anthropometric information for individuals of Hispanic/Southwest Hispanic ancestry is still in collection stages. Along with Operation Gatekeeper, several other federal and state immigration policies are currently in place: Operation Hold the Line for El Paso, Texas, established in 1994 and Operation Safeguard to secure Nogales, Arizona, in 1995 (Anderson 2008) are just two.

For forensic anthropologists working in states bordering Mexico, the increased number of UBCs has presented a need for reevaluation of traditional ancestral determination. Attempts to immigrate illegally into the United States through the deserts in the southwest region of America can be fatal. Human smuggling rings, headed by *coyotes* (human smugglers) that promise to transport individuals safely into the United States for a large fee are a major problem. The average cost for such transportation can be between $1,400 (Fulginiti 2008) and $2,000 (Hinkes 2008). For individuals wanting to be transported from Central America, Asia, or Europe, the costs can range from $4,000 to $50,000 per person (Fulginiti 2008). While the leading cause of death among UBCs tends to be heat exposure (Anderson and Parks 2008), over the last several years an increase in violent acts against individuals illegally immigrating has occurred, often resulting in homicide (Fulginiti 2008). Fulginiti (2008) explains that the *coyotes* will agree to help individuals with their immigration into the United States for a set price but often have ulterior motives. Instead of releasing them once they have crossed successfully into the United States, the immigrants are held for ransom. If the ransom is not paid, they are killed. Common and mass graves of UBCs who were unable to provide the *coyotes* with their elevated crossing fees have also been reported throughout the Southwest (Fulginiti 2008).

3.4 Identification Methods for Southwest Hispanic Ancestry

An increase in deaths in the American Southwest requires new identification techniques for the positive identification of UBC skeletal remains. Rhine (1990) described the non-metric skeletal traits of Hispanic ancestry as being a combination of European and American Indian traits. Some of these traits consist of the following "slight alveolar prognathism, nasal aperture of intermediate width…tented nasals…slight nasal depression…rounded or sloping orbits…and a curved zygomaxillary suture" (Birkby et al. 2008:30). While Rhine documented significant non-metric traits for Hispanic ancestry, the PCOME has also documented common non-metric traits to aid in the successful identification of peoples of Hispanic/Southwest Hispanic ancestry (Birkby et al. 2008). One of the most significant distinguishing characteristics of Hispanic/Southwest Hispanics is that they are generally smaller in stature than individuals of black and white ancestry (Spradley et al. 2008). Non-metric characteristics specific to the Hispanic/Southwest Hispanic ancestry include "shoveled anterior teeth, anterior malar projection, short posterior occipital shelf, less elaborate nasal sill (tending toward dull), oval window visualization between zero and partial, enamel extensions on molars, nasal overgrowth, wide frontal process of the zygomatic, platymeria of the subtrochanteric region of the femur and sharp medial crest" (Birkby et al. 2008:30). Measurements are taken on UBCs during anthropological examination, but the data are still lacking in comparison to those of blacks and whites in the Forensic Data Bank (Spradley et al. 2008).

Both Hinkes (2008) and Anderson (personal communication 2009) have stated that the vast majority of UBCs are male. By tracking their identifications, the PCOME has been able to create a profile for the typical UBC. Anderson (2008) states that a typical UBC examined by his office "is a Mexican National between 21 and 30 years old, three times more likely to be male" (Anderson 2008:13). In addition to using the non-metric traits summarized by Birkby, the

PCOME uses several other resources in order to create a comprehensive biological profile of the UBCs (Table 3.1).

The PCOME has two distinct levels of identification that their office will accept for UBCs: positive and circumstantial (Anderson 2008; Table 3.1). Positive identifications require an individual familiar with the presumed decedent to provide materials (such as antemortem medical or dental records, or DNA) for medico-legal professionals to supplement the initial anthropological exam (Anderson 2008). A combination of medical, dental records, and DNA provide the strongest identification; however, these are not always available for comparison. If unavailable, then PCOME's second level of identification, circumstantial identification, becomes important. For the PCOME, a circumstantial identification is established when no unexplainable inconsistencies exist between the presumed decedent and the actual decedent (Anderson 2008). Depending upon the level of uniqueness of circumstantial evidence provided, the PCOME can make a circumstantial identification of the decedent (Anderson 2008). Even with all of the above-mentioned methods being used at the PCOME, the percentage of successful identifications of UBCs still ranges between only 70-75% (Table 3.1) (Anderson 2008; Anderson and Parks 2008; Birkby et al. 2008.

Table 3.1. Methods of Identification and Percent Identified by the PCOME (Anderson 2008)

Methods of Identification	2001	2002	2003	2004	2005	2006	Total
Visual	23	66	44	51	55	51	290
Circumstantial	29	29	36	37	35	22	188
Fingerprints	4	20	20	24	40	22	130
DNA	0	3	13	14*	13*	8*	51*
Dental	0	2	0	2	1	0	5
Radiography	0	0	1	2	0	0	3
Total identified	56	120	114	130*	142*	96*	667*
Total UBCs	75	147	156	170	196	174	918
%Identified	75	82	73	77	74	59	73
*More identifications pending							

With every positive identification obtained by the PCOME, demographic information is recorded to document the range of countries of origin for the identified individuals. Individuals of Mexican origin comprise the majority (92% overall) of the UBC remains examined by the PCOME (Table 3.2).

Table 3.2. Anderson (2008) Summary of Nationalities of Identified Undocumented Border Crossers from 2001 Through 2006.

UBC nationalities	2001	2002	2003	2004	2005	2006	Total
Mexican	56	117	98	114	133	93	611
Guatemalan	0	0	7	6	6	6	25
Salvadoran	0	0	4	4	2	0	10
Brazilian	0	1	1	1	1	0	4
Honduran	0	0	1	1	1	1	4
Ecuadoran	0	0	0	2	0	1	3
Unknown	0	0	1	0	0	2	3
Colombian	0	1	0	1	0	0	2
Dominican	0	0	2	0	0	0	2
Costa Rican	0	1	0	0	0	0	1
Chilean	0	0	0	1	0	0	1
Peruvian	0	0	0	0	1	0	1
Total	56	120	114	130	144	103	667
% Mexican	100	98	86	88	92	92	92

3.5 PCOME Skeletal Collection

The skeletal materials made available for this research from the PCOME consisted of 36 cranial bases. Of these 36 cranial bases, 21 were capable of being assessed metrically (see criteria for metric assessment in Section 4.2). Ancestry is represented in Table 3.3 listed below. The PCOME provided more skulls of Southwest Hispanic and Native American ancestry for this research than any other ancestries.

Table 3.3. PCOME Sample Ancestry Demographics.

	Black	White	Asian	Southwest Hispanic	Native American	Total
Male	0	1	0	12	4	17
Female	0	0	0	3	1	4
Total	0	1	0	15	5	21

Unlike the other collections used for this research, the PCOME rarely knew the exact age and sex of every individual that they provided. The anthropological examination estimations of age, sex and ancestry were provided for each of the individuals documented. Table 3.4 lists the summary of the age ranges and sex estimations for the PCOME collection. As demonstrated in

Table 3.4 the majority of the skulls examined from PCOME are estimated to fall into the Young Adult range and Middle Adult Categories. No individuals over the age of 50 years were present at the PCOME.

Table 3.4. PCOME Sample Age Range Demographics

	Juveniles (19 and under)	Young Adult (20-34 years)	Middle Adult (35-49 years)	Old Adult (50+ years)	Total
Males	2	8	7	0	17
Female	1	2	1	0	4
Total	3	10	8	0	21

Not every measureable skull belongs to an identified individual; in fact, only two of the measureable skulls have been (as of publication) positively identified (Anderson personal communication 2009). Several of the skulls documented were extremely fragile at the time of data collection. The fragility was due to exposure of the cranium to the extreme elements - mainly the harsh Sonoran desert sun, as well as damage caused by scavenging animal activity.

CHAPTER 4 – MATERIALS AND METHODS

4.1 Sample

A blind study was conducted on 465 human cranial bases. All 465 of these cranial bases were assessed visually for foramen magnum shape classification; 435 were capable of being assessed metrically (Section 4.2). All skeletal materials were collected from the William M. Bass Donated Skeletal Collection at the University of Tennessee at Knoxville (UT), the Maxwell Museum of Anthropology's Laboratory of Human Osteology Skeletal Collection at the University of New Mexico (UNM), the Forensic Anthropology and Computer Enhancement Services (FACES) Laboratory at Louisiana State University, and the Pima County Office of the Medical Examiner (PCOME) in Tucson, Arizona (Table 4.1).

Table 4.1. Total Sample Size.

Collection	Assessed Visually	Assessed Metrically
UT	255	244
UNM	144	141
FACES	30	29
PCOME	36	21
Totals	465	435

The ancestry distribution for the total sample is skewed, with the majority of the individuals being of white ancestry and only one individual represented from both Asian and Mixed (known) ancestry. Additionally, more than half of the overall sample is over the age of 50 years. The least represented age group is that of juveniles with ages of 19 years and younger (Table 4.2).

4.2 Measureable Sample

Every cranial base was measured, regardless of the completeness of the base. To be considered part of the measurable sample, a cranial base needed to be intact for all 12 measurements to be taken (see Section 4.3). If even one measurement could not be taken, that particular cranial base was removed from the measureable sample. Along with eliminating cranial bases that were not fully intact, cranial bases of skulls without complete biographical data (age, sex, and ancestry) were eliminated from the study. Since the cranial base reaches 90% of its adult size by the age of 13 (Scott 1958), skulls of individuals under the age of 13 were not included in this study. Finally, any cranial base that had been deformed intentionally was eliminated, as such deformation is known to elongate the foramen magnum in the anterior-posterior aspect (Anton 1989), or can cause a posterior shift if the skull is subjected to anterior-posterior restriction (McNeill and Netwon 1965).

Like the overall sample, the measureable sample was skewed with the vast majority of individuals being of white ancestry and over the age of 50 years. Native Americans and Asians were the least represented ancestries in the measureable sample (Table 4.3).

Table 4.2. Total Sample: Age and Ancestry Distribution.

	Asian	Black	Hispanic/Southwest Hispanic	Mixed (Known)	Native American	Unknown	White	Totals
Juvenile (16-19 years)	0	2	3	0	0	0	5	10
Young Adult (20-34 years)	0	12	15	1	5	0	27	60
Middle Adult (35-49 years)	0	25	13	0	3	0	64	105
Old Adult (35-49 years)	1	27	4	0	2	3	239	276
Unknown	0	5	3	0	0	6	0	14
Totals	1	71	38	1	10	9	335	465

Table 4.3. Measureable Data Age and Ancestry Distribution.

Ancestry	Asian	Black	Hispanic/Southwest Hispanic	Native American	White	Totals
Juvenile (16-19 years)	0	2	0	0	5	7
Young Adult (20-34 years)	0	12	7	3	26	48
Middle Adult (35-49 years)	0	24	13	2	64	103
Old Adult (50+ years)	1	27	9	2	238	277
Totals	1	65	29	7	333	435

4.3 Measurements

A total of 12 measurements was taken from each intact cranial base with sliding calipers. Each measurement was taken in millimeters (mm) to an accuracy of 0.5 mm to allow for instrument error (Robinson et al. 2005) and recorded in an Excel spreadsheet corresponding to the skull and collection number unique to that particular skull. The following measurements were taken following Holland (1986a):

1. Foramen magnum length – maximum internal length of the foramen magnum along the midsagittal plane, from opisthion to basion (White 2000) (Figure 4.1);
2. Foramen magnum width – maximum internal width of the foramen magnum along the transverse plane (Figure 4.2);
3. Right occipital condyle maximum width – maximum width of the right occipital condyle taken along the articular surface perpendicular to the right occipital condyle length (Figure 4.3);
4. Right occipital condyle minimum width – minimum width of the right occipital condyle taken along the articular surface perpendicular to the right occipital condyle length (Figure 4.4);
5. Right occipital condyle length – maximum length of the right occipital condyle taken along the articular surface perpendicular to the right occipital condyle width (Figure 4.5);
6. Left occipital condyle maximum width – maximum width of the left occipital condyle taken along the articular surface perpendicular to the left occipital condyle length (Figure 4.6);
7. Left occipital condyle minimum width – minimum width of the left occipital condyle taken along the articular surface perpendicular to the left occipital condyle length (Figure 4.7);

8. Left occipital condyle length – maximum length of the left occipital condyle taken along the articular surface perpendicular to the left occipital condyle width (Figure 4.8);
9. Length of the basilar process – maximum length of the basilar process measured from basion to hormion (White 2000) (Figure 4.9);
10. Maximum distance between occipital condyles – maximum distance between the lateral edges of the articular surfaces of the occipital condyles perpendicular to the midsagittal plane (Figure 4.10);
11. Minimum distance between occipital condyles – minimum distance between the lateral edges of the articular surfaces of the occipital condyles perpendicular to the midsagittal plane (Figure 4.11);
12. Maximum internal distance of the occipital condyles – maximum distance between the medial margins of the occipital condyles perpendicular to the midsagittal plane (Holland 1986a) (Figure 4.12).

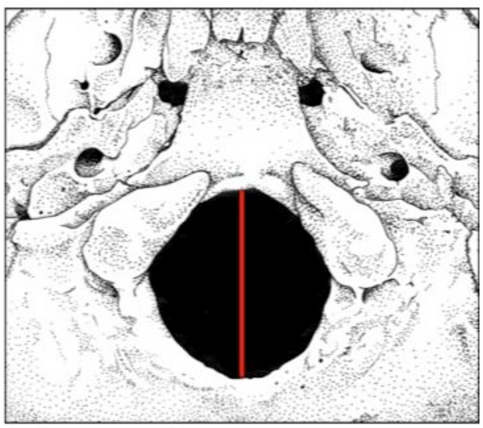


Figure 4.1. Foramen Magnum Length

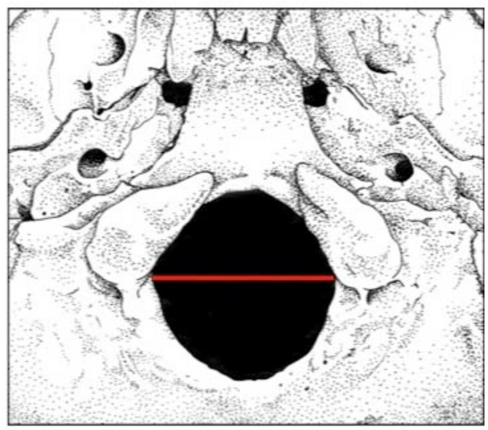


Figure 4.2. Foramen Magnum Width

Figure 4.3. Right Occipital Condyle Maximum Width

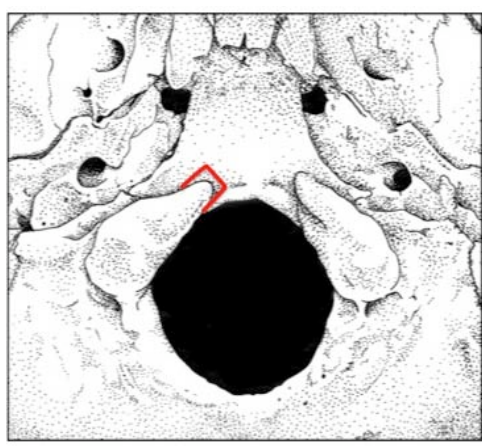


Figure 4.4. Right Occipital Condyle Minimum Width

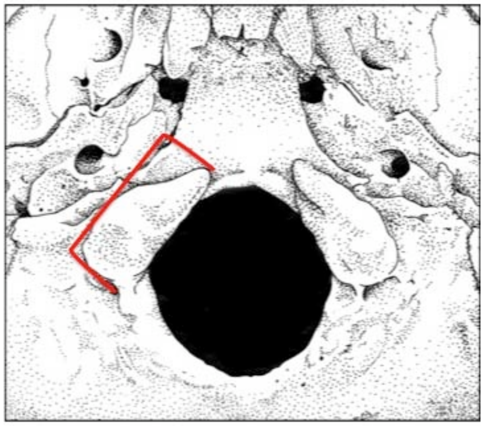


Figure 4.5. Right Occipital Condyle Length

Figure 4.6. Left Occipital Condyle Maximum Width

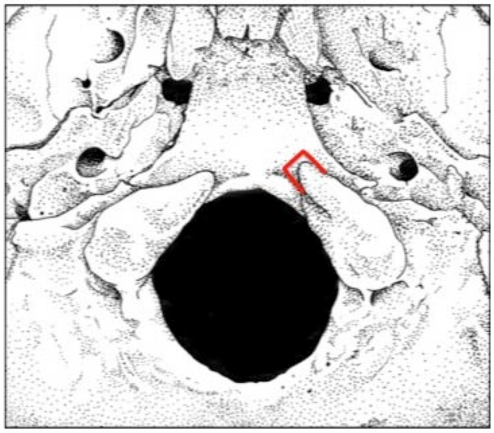


Figure 4.7. Left Occipital Condyle Minimum Width

Figure 4.8. Left Occipital Condyle Length

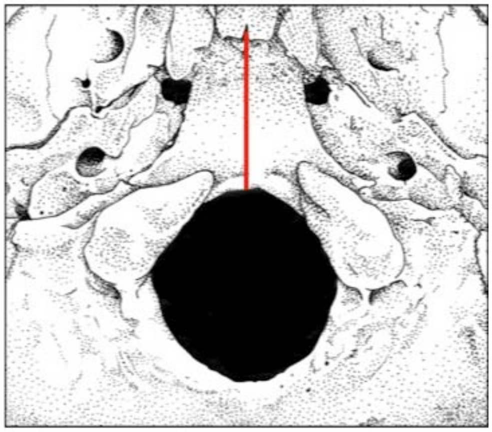


Figure 4.9. Basilar Process Length

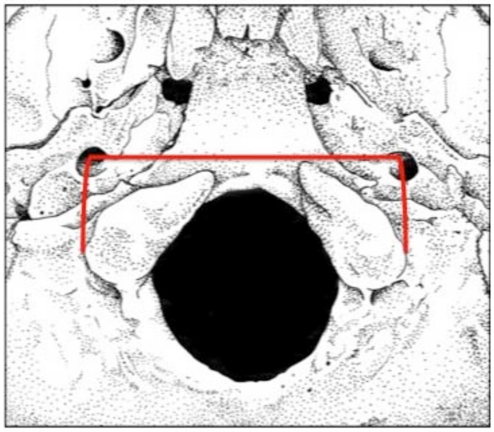


Figure 4.10. Maximum Distance Between Occipital Condyles

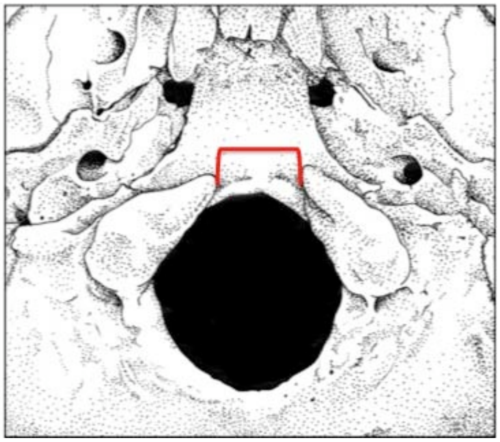


Figure 4.11. Minimum Distance Between Occipital Condyles

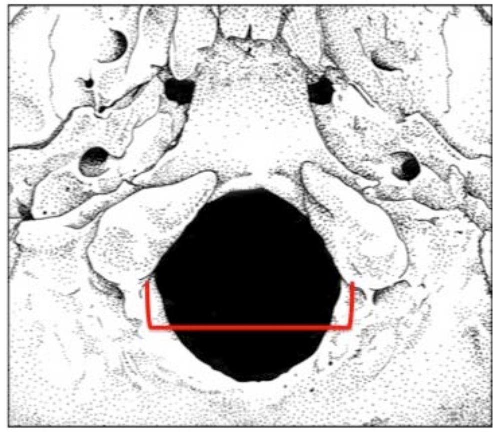


Figure 4.12. Maximum Interior Distance Between Occipital Condyles

After all measurements were taken, three digital photographs of each region were taken with a Nikon D60 10.2 megapixel digital camera to ensure maximum pixelation. The skull was placed on a foam surface with black fabric underneath. A scientific ruler was placed in the field of vision with the occipital condyles and foramen magnum in each picture. Each image was imported into ImageJ, a Java platform image-processing program available from the National Institute of Health, and saved in JPEG format. The clearest image out of the three was used to measure the cranial bases digitally.

4.4 Error Rate

Of the 465 measured cranial bases, every sixth cranial base, 15.6% (n = 73), was measured a second time in order to determine the intra-observer error rate. Not all cranial bases used for error rate calculation had 12 measurements. If a broken cranial base happened to be the sixth skull documented in the set it was used for intra-observer error calculation. Measurement error is considered any measurement difference over $^{+/-}$0.5 mm.

Error rate is calculated by subtracting the duplicate measurement from the original measurement; any difference over $^{+/-}$0.5 is then marked as an error. Each error was counted, added together, and divided by the total number of possible errors (Table 4.4), providing an overall error rate of 5.3%. The average measurement error was 1.1 mm.

Table 4.4. Error Rate Calculation.

Collection	Total Errors (ΣE)	Possibilities for Error (P_E)	Percentage of Error
UT	20	468	4.2%
UNM	6	288	2.0%
FACES	9	62	12.5%
PCOME	13	72	18.0%
Totals	48	890	5.3%

4.5 Foramen Magnum Shape Classification

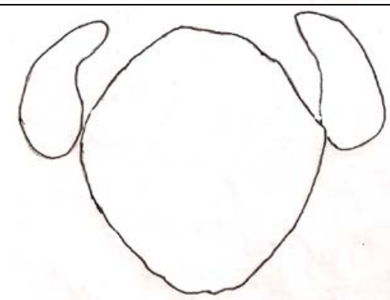
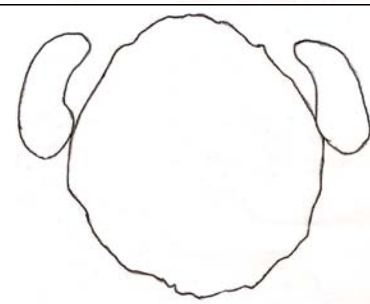
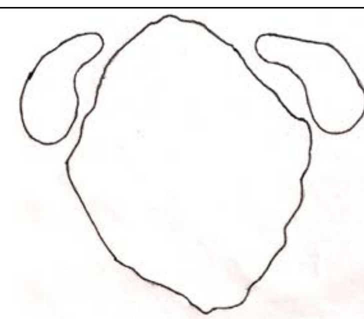
A visual classification and categorization were made for all foramen magnums in this study (n = 465). After importing all the photographs into ImageJ, each foramen magnum was then classified into one of five categories: Arrowhead, Circle, Diamond, Egg, and Oval (Table 4.5).

A Pearson's chi-square test was conducted to determine if there was a relationship among foramen magnum shape and the three largest ancestral categories (blacks, whites, and Hispanics). The level of significance was set at $p \leq 0.05$.

4.6 Survey

Every measureable cranial base was classified into one of these five categories. The subjectivity of these categories was then tested at the 62nd Annual Meeting of the American Academy of Forensic Scientists held in Seattle, Washington, in February 2010. A poster with explanations of how to classify the different foramen magnum shapes as well as picture examples were on display for all participants to observe. Once the participants examined the different foramen magnum shapes, they were handed a separate sheet of paper with examples of the shapes, unclassified, and were asked to classify the foramen magnums into one of the five categories based on their own interpretations. A total of 110 surveys were collected. The results

Table 4.5. Foramen Magnum Shapes: Descriptions and Examples.

Category	Criteria for Inclusion	Example (anterior is at the top of the square)
Arrowhead	Four distinct points, three of which are equidistance from each other, and the fourth (at the base) is half the distance of all other points, creating a compressed section	
Egg	Elongated shape with a clear base where the curvature rounds out to form a wider region then the opposing end that is almost pointed, yet still rounded	
Circle	Round shape with consistently smooth curvature; throughout the curvature of the foramen magnum are no points formed; symmetrical	
Oval	Elongated shape with a smooth curvature, without any pointed regions	
Diamond	Classic diamond shape is based on a nearly symmetrical four points equidistance from each other	

of this survey were then compared to the original classifications of the author and marked as either correct (the same as that of the author) or incorrect (different from that of the author). Percentages of accuracy were calculated for each foramen magnum shape classification by dividing the number of correct classifications by the total number of classifications, and dividing the number of incorrect classifications by the total number of classifications.

4.7 Comparison of Foramen Magnum Lengths and Widths

The mean measurements for the length and width of the foramen magnum were compared for blacks, whites, and Hispanics. A two-tailed Student's t-test was conducted in MatLab version R2009a to compare the sample means of each group to the others at the 95% confidence level. To compare each measurement for all three ancestries, a t-test was calculated a total of three times per measurement (resulting in 36 separate t-tests for the entire sample). The t-tests compared blacks and whites, blacks and Hispanics, and whites and Hispanics.

4.8 Comparison of Sex and Foramen Magnum Shape

A total of 12 two-tailed Student's t-tests were conducted in MatLab to compare the mean measurements of all males and all females. The percentage of each foramen magnum shape category was calculated for each sex by dividing the number in each specific shape category by that of the overall sample.

4.9 Comparison of Samples

Holland's (1986a and 1986b) data were compared to the same measurements documented by this researcher. For the two categories where there was a substantial difference between the mean measurements, the difference was calculated and documented. Holland's measurements were subtracted from this researcher's measurements, and the absolute value of the results was used.

A Student's t-test was conducted to compare the sample means for the Minimum Distance between Occipital Condyles and Maximum Interior Distance between Occipital Condyles. These categories showed the greatest differences between Holland's sample and this researcher's sample. This type of t-test (ttest2 in MatLab) is able to test for significance between two samples of unequal sample variances. Holland had a total of 25 data points in each sub-sample, while the sub-sample for this researcher's ranges from 15 to 108 data points.

4.10 Holland's Ancestry Chart

Holland (1986a) developed five separate multiple-regression equations from eight different measurements on the cranial base to determine the ancestry of a skull (Table 3.8). These formulae can be used by multiplying each measurement by the assigned constant and adding together the results, then adding the constant to get a result between 0 and 1 (Holland 1986a). All five of these multiple-regression equations were tested in an Excel spreadsheet to determine if they could accurately assign ancestry to the modern populations recorded for this study.

4.11 Digital Measurements

Of the 435 cranial bases measured, 171 cranial bases (38%) were also measured digitally from photographs with ImageJ. These digital measurements were entered into a separate Excel spreadsheet with all of the skull and collection information, as well as photograph number from the digital camera. All 12 measurements that were taken manually were taken digitally.

First, images were opened in ImageJ and a scale was set from known distances in the image (from a ruler in focus placed in the field of vision of the cranial base). A distance of 10 mm was set and ImageJ converted the measurements to pixels.

Table 4.6. Holland (1986a) Multiple-Regression Equation for Predicting the Ancestry of Fragmentary Crania.

Equation Number	**1**	**2**	**3**	**4**	**5**
Number of Measurements	6	5	5	4	3
Length of occipital condyle	-0.0224	…	-0.0095	-0.0420	…
Width of occipital condyle	…	…	…	0.0806	…
Minimum distance between condyles	0.0345	0.0338	0.0347	…	0.0239
Maximum distance between condyles	-0.0236	-0.0329	-0.0063	…	…
Maximum interior distance between condyles	-0.0161	-0.0159	-0.0428	…	-0.0536
Length of foramen magnum	…	…	…	0.0284	…
Width of foramen magnum	-0.0185	-0.0200	-0.0201	-0.0650	…
Length of basilar process	0.0777	0.0756	…	…	0.0712
Constant	0.669	0.706	2.87	1.48	0.425
Sectioning Point	0.5	0.5	0.5	0.5	0.5
Percent accuracy: Group 1 (*N*=100)	86.0	82.0	72.0	70.0	80.0
Percent accuracy: Group 2 (*N*=20)	90.0	85.0	75.0	75.0	80.0

Once the scale was set, the specific points on the foramen magnum, occipital condyles, and basilar process were selected for their corresponding measurements, and ImageJ measured the length. Once all measurements were recorded, they were then subtracted from the manual measurements of the corresponding cranial base measurement. The differences between these measurements were then averaged in Excel (Σdifferences/N). The standard deviation (σ) of each average was calculated in Microsoft Excel ($\sigma = \sqrt{\Sigma(x- \bar{x})^2/N-1}$) to determine the average distance from the mean for each measurement. A two-tailed Student's t-test was conducted in MatLab R2009a to test the significance between the means of the manual and digital measurements for each of the 12 measurements.

4.12 Collection Demographics

By collecting measurements and biographical information from four different skeletal collections representing broad geographical areas, the opportunity for a more inclusive database was possible. The skeletal collections used for this research were: the Pima County Office of the

Medical Examiner (PCOME), the University of Tennessee at Knoxville's William M. Bass Donated Skeletal Collection (UT), the University of New Mexico's Maxwell Museum of Anthropology's Laboratory of Osteology Skeletal Collection (UNM), and Louisiana State University's Forensic Anthropology and Computer Enhancement Services (FACES) Laboratory.

The 2000 United States (U.S.) Census results from the cities where each skeletal collection resides were compared to the demographic information provided by the skeletal collection records. The six ancestral categories used by the U.S. Census Bureau were also the six categories reported in this study: white, black, American Indian, Asian, Hispanic, and Mixed ancestry. The ratios of men to women were compared in both the census and skeletal collections. Finally, the total percentage of people over the age of 65 was compared between the U.S. Census and each skeletal collection. Importantly, the U.S. Census Bureau defines Hispanics as a self-identified category that contains people of the following origins: "Mexican, Puerto Rican, Cuban, Central or South American or some other Hispanic origin" (http://www.census.gov/population/www/socdemo/hispanic/hispdef.html).

Compared to the U.S. Census report, the skeletal material examined from UNM (Appendix A, Table A1) had a higher percentage of individuals from white ancestry, a much smaller percentage of individuals of Hispanic ancestry, and a higher percentage of people over the age of 65 (http://quickfacts.census.gov/qfd/states/35/3502000.html). The number of individuals of white ancestry at PCOME was different from the results of the U.S. Census report (Appendix A, Table A2). While Hispanic ancestry is well represented in the entire PCOME sample, black ancestry was not represented at all. Additionally, women and individuals over the age of 65 years were underrepresented in the PCOME sample compared to the report for Tucson, Arizona (http://quickfacts.census.gov/qfd/states/04/0477000.html).

The skeletal collection from UT closely mirrored the demographics reported in the U.S. Census Bureau's report for Knoxville, Tennessee. Black, white, and Hispanic ancestry representation was different by only four percent. The largest difference between UT and the Census report was the amount of women in the overall Knoxville population versus the amount of women collected from the UT skeletal collection (Appendix A, Table A3) (http://quickfacts.census.gov/qfd/states/47/4740000.html).

Finally, the FACES skeletal collection had the exact percentage of blacks as the U.S. Census report for Baton Rouge, Louisiana. The percentage of women in the Census report was also close to that of the FACES. The one category where FACES was not reflective of the Census report was that of people over 65 years old (Appendix A, Table A4) (http://quickfacts.census.gov/qfd/states/22/2205000.html).

Overall, the skeletal collections used for this research were dissimilar to the U.S. Census report, and, therefore, potentially non-reflective of the populations at large. The number of women was underrepresented in all skeletal collections except that of FACES. Also, in two of the larger samples, UT and UNM, the number of people over the age of 65 years was far greater than that of the Census reports from their respective cities. Overall, the comparison between the U.S. Census report from 2000 and the skeletal collections used showed that the skeletal collections were not as diverse as their respective geographical areas.

CHAPTER 5 – RESULTS

5.1 Foramen Magnum Shape Classifications

Table 5.1 details the number of specimens which were placed in the various shape categories. Overall, the Arrowhead shape was the most common, while no individuals of Hispanic ancestry were categorized as having an Egg shaped foramen magnum.

Table 5.1. Foramen Magnum Shape Categories and Ancestries in Total Sample.

	Arrowhead	Circle	Diamond	Egg	Oval	Total
Blacks	29	2	13	19	8	71
Hispanics	20	7	6	0	4	37
Whites	155	19	59	66	36	335
American Indian	6	1	2	1	0	10
Asian	1	0	0	0	0	1
Unknown	4	1	4	0	1	10
Mixed (Known)	0	0	1	0	0	1
Total	215	30	85	86	49	465
Percentage	46.2	6.5	18.3	18.5	10.5	100

Using the samples of blacks, whites, and Hispanics, a Pearson's chi-square test comparing ancestry with foramen magnum shape showed a significant relationship ($\chi^2 = 21.17$, df=8; $p = 0.007$).

Table 5.2 breaks down the distribution of the different foramen magnum shapes within the various collections. Notably, the PCOME collection contained no individuals with Egg shaped foramen magnums, while UT had a high number of Egg shaped foramen magnums.

Table 5.2. Collection Distribution of Foramen Magnum Shapes.

	Arrowhead	Circle	Diamond	Egg	Oval	Total
UNM	68	6	25	29	16	144
UT	120	17	41	49	28	255
PCOME	20	5	8	0	3	36
FACES	7	2	11	8	2	30
Total	215	30	85	86	49	465
Percentage	46.2	6.5	18.3	18.5	10.5	100

When separated by sex, the Arrowhead shape is the most common shape for both females (48.4%) and males (45.0%). A Circle shaped foramen magnum is the least common for both females (five percent) and males (seven and one-tenth percent) (Table 5.3).

Table 5.3. Foramen Magnum Shape Counts for Females and Males.

	Arrowhead	Circle	Diamond	Egg	Oval	Total
Females	77	8	36	23	15	159
Males	138	22	49	63	34	306
Total	215	30	85	86	49	465

5.2 Survey

The survey demonstrates that the subjectivity of the foramen magnum shape categories is high. Those classifications that were inconsistent with the author's categorization were marked as misclassified. Of the 766 classifications collected from the survey, only 398 (51.9%) were categorized in the same manner as the author. The most commonly correct classified foramen magnum shape was the Circle shape, with 185 (84.1%) correct classifications. The least correctly classified foramen magnum shape was the Diamond shape, with only 27 (24.5%) correct classifications.

The most commonly misclassified foramen magnum shapes were the Diamond and Arrowhead shapes. Several survey participants stated that these two shapes were very similar to each other; therefore, the two categories were combined to determine whether or not accuracy would improve. When the Diamond and Arrowhead foramen magnum shape categories were combined, 232 (70.9%) foramen magnums were classified correctly. The overall accuracy then increased to 519 (67.6%) correct classifications.

5.3 Statistical Analysis of Three Ancestral Groups

A statistical analysis of the three most represented ancestries (blacks, whites, and Hispanics) revealed differences among the mean measurements. The difference in length for the Maximum Interior Distance between Occipital Condyles was the largest out of all 12 measurements for these ancestral groups. This difference is not statistically significant (Table 5.4). The mean measurements for whites, blacks, and Hispanics are reflected in Table 5.5, Table 5.6, and Table 5.7, respectively.

Table 5.4. Significance Testing of All Ancestries and the Maximum Interior Distance between Occipital Condyles.

	Black	White
White	$p = 0.0605$	
Hispanic	$p = 0.3070$	$p = 0.3148$

5.4 Significance Testing for Foramen Magnum Length and Width

A Student's t-test was performed to assess mean differences among the foramen magnum lengths of blacks, whites, and Hispanics. The results for foramen magnum length indicate no statistically significant difference exists among blacks, whites, and Hispanics at the 95% confidence level (Table 5.8).

The results of the Student's t-test comparing the mean differences of the foramen magnum width among blacks, whites, and Hispanics showed significant differences exist between whites and blacks, and between Hispanics and whites (Table 5.9). Hispanic and black foramen magnum widths are not significantly different from each other.

Table 5.5. Summary Statistics for Individuals of White Ancestry (in mm).

	LOC Length	LOC Max Width	LOC Min Width	Max Distance Between Condyles	Min Distance Between Condyles	Max Interior Distance Between Condyles	ROC Length	ROC Max Width	ROC Min Width	Length of Foramen Magnum	Width of Foramen Magnum	Length of Basilar Process
Mean	23.8	11.3	5.5	50.8	35.6	35.1	24.5	11.0	5.5	36.1	30.5	29.7
St Dev	3.0	1.4	1.5	3.5	4.1	3.2	3.0	1.4	1.4	2.6	2.2	3.0
Min	13.5	5.5	2.5	38.5	24.0	24.5	14.5	3.5	1.5	26.5	22.5	20.5
Max	33.5	17.0	11.5	60.0	49.0	45.5	35.0	15.0	10.0	44.5	37.0	39.0

LOC = Left Occipital Condyle
ROC = Right Occipital Condyle

Table 5.6. Summary Statistics for Individuals of Black Ancestry (in mm).

	LOC Length	LOC Max Width	LOC Min Width	Max Distance Between Condyles	Min Distance Between Condyles	Max Interior Distance Between Condyles	ROC Length	ROC Max Width	ROC Min Width	Length of Foramen Magnum	Width of Foramen Magnum	Length of Basilar Process
Mean	23.6	12.0	6.5	48.5	35.9	31.8	23.7	12.4	6.6	35.5	29.1	31.7
St Dev	2.7	1.7	1.6	3.3	3.8	3.3	2.3	1.8	1.6	2.0	2.0	2.4
Min	15.0	7.5	3.0	40.0	28.5	25.5	19.0	9.5	2.0	30.0	24.5	27.0
Max	31.5	16.0	12.0	58.0	45.5	42.5	31.0	19.5	10.5	40.0	35.0	37.0

LOC = Left Occipital Condyle
ROC = Right Occipital Condyle

Table 5.7. Summary Statistics for Individuals of Hispanic Ancestry (in mm).

	LOC Length	LOC Max Width	LOC Min Width	Max Distance Between Condyles	Min Distance Between Condyles	Max Interior Distance Between Condyles	ROC Length	ROC Max Width	ROC Min Width	Length of Foramen Magnum	Width of Foramen Magnum	Length of Basilar Process
Mean	22.6	12.2	6.5	49.5	35.4	32.7	23.7	11.4	6.0	35.1	29.6	30.2
St Dev	3.5	2.0	2.0	3.5	4.6	4.5	3.2	1.4	1.5	2.8	2.01	2.8
Min	12.5	9.0	2.5	41.0	28.0	24.5	15.0	8.0	3.5	31.0	25.5	25.0
Max	28.0	19.5	10.5	55.5	46.5	40.5	29.0	15.0	9.5	42.0	33.5	37.0

LOC = Left Occipital Condyle
ROC = Right Occipital Condyle

Table 5.8. Student's t-test for Differences Among Ancestry and Foramen Magnum Length

	Black	White
White	p = 0.1092	
Hispanic	p =0.3826	p = 0.0504

Table 5.9. Student's t-test for Differences Among Ancestry and Foramen Magnum Width

	Black	White
White	p = <0.0001	
Hispanic	p =0.3163	p = 0.0258

5.5 Comparison of Sexes and Foramen Magnum Shape

A Student's t-test was performed to assess the variation between each of the 12 measurements and sex. Four of the 12 measurements were not significantly different at the 95% confidence internal between all males and all females: Left Occipital Condyle Minimum Width, Maximum Distance between Occipital Condyles, Maximum Interior Distance between Occipital Condyles, and Right Occipital Condyle Minimum Width (Table 5.10). The remaining eight measurements were significantly different between all males and all females (Table 5.10).

5.6 Accuracy of Manual Measurements versus Digital Measurements

As a final test, digital measurements were taken from 171 cranial bases and compared to their respective manual measurements. This study demonstrated that using digital measurements on the cranial base does not accurately reflect the manual measurements for all sites. A two-tailed Student's t-test was conducted on all 12 measurements comparing the differences between the means of both manual and digital measurements (Tables 5.11). Table 5.11 also shows that manual and digital measurements were significantly different for six measurements and not significantly different for the other six measurements.

5.7 Comparison of Crider and Holland (1986a) Measurements

The following measurements were compared between Holland (1986a) and this researcher's sample: Length of Condyle (left), Width of Condyle (left), Minimum Distance between Occipital Condyles, Maximum Distance between Occipital Condyles, Maximum Interior Distance between Occipital Condyles, Length of the Foramen Magnum, Width of the Foramen Magnum, and Length of the Basilar Process (Table 5.12). The greatest variation in differences between Holland's (1986a) means and this researcher's means are the Minimum Distance between Occipital Condyles and Maximum Interior Distance between Occipital Condyles (Table 5.12).

A Student's t-test was conducted to determine if there were significant differences between Crider's and Holland's populations. The Minimum Distance between Occipital Condyles for all four groups (white females and males, and black females and males) is significantly different. The Maximum Interior Distance between Occipital Condyles is significantly different for white females, blacks females, and black males (Table 5.13). Only white males are not significantly different.

5.8 Holland's (1986a) Multiple-Regression Equations Tested on Modern Populations

All measureable blacks and whites were tested for ancestry assignment in Holland's (1986a) five multiple-regression equations. Equation 4 had the highest percent of accurately classified crania with 263 crania (65.1%) (Table 5.14). For all equations except Formula 4, blacks were classified correctly more often than whites.

Table 5.10. Comparison of All Male and All Female Measurements (in Measureable Sample) in mm.

	Left Occipital Condyle Length	Left Occipital Condyle Maximum Width	Left Occipital Condyle Minimum Width	Maximum Distance Between Occipital Condyles	Minimum Distance Between Occipital Condyles	Maximum Interior Distance Between Occipital Condyles	Right Occipital Condyle Length	Right Occipital Condyle Maximum Width	Right Occipital Condyle Minimum Width	Length of Basilar Process	Foramen Magnum Length	Foramen Magnum Width
Female Mean (n=152)	22.3	10.9	5.8	49.0	34.8	33.8	22.9	10.8	5.7	28.6	35.2	29.7
Female St Dev	2.8	1.5	1.6	3.7	4.0	3.6	3.6	1.6	1.5	2.7	2.5	2.2
Male Mean (n=274)	24.4	11.8	5.7	51.0	36.1	34.8	25.2	11.5	5.9	30.8	36.4	30.5
Male St Dev	2.9	1.5	1.6	3.3	4.0	3.4	2.8	1.4	3.2	2.8	2.5	2.1
p-value	<0.0001	<0.0001	0.6591	0.1356	<0.0001	0.1727	<0.0001	<0.0001	0.3254	<0.0001	<0.0001	<0.0001

Table 5.11. Comparison of Means and Standard Deviations for Manual versus Digital Measurements.

LOC		LOC Max		LOC Min		Max Dist		Min Dist		Max Int.		ROC		ROC Max		ROC Min		LFM		WFM		LBP	
M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D
Means																							
22.7	23.0	10.8	10.4	4.8	3.0	49.4	51.6	34.4	32.9	34.5	35.2	23.3	23.3	10.6	10.8	4.8	3.3	36.2	36.4	30.1	31.2	29.8	28.8
Standard Deviations																							
3.1	3.3	1.6	1.6	1.4	0.8	3.4	4.2	4.1	4.5	3.6	3.8	3.2	3.1	1.4	1.6	1.4	0.8	2.5	3.0	2.0	2.5	2.8	3.1
p-value																							
0.5066		0.0365		0		<0.0001		0.0027		0.1051		0.9874		0.2071		0		0.3845		<0.0001		0.0027	

M – Manual

D – Digital

LOC – Left Occipital Condyle Length

ROC – Right Occipital Condyle Length

LOC Max – Left Occipital Condyle Maximum Width

ROC Max – Right Occipital Condyle Maximum Width

LOC Min – Left Occipital Condyle Minimum Width

ROC Min – Right Occipital Condyle Minimum Width

Max Dist – Maximum Distance Between Condyles

LFM – Length of the Foramen Magnum

Min Dist – Minimum Distance Between Condyles

WFM – Width of the Foramen Magnum

LBP – Length of the Basilar Process

Table 5.12. Comparison Between Crider and Holland (1986a) Means (mm) and Standard Deviations

	Length of Condyle mm		Width of Condyle mm		Minimum Distance mm		Maximum Distance mm		Maximum Interior Distance mm		Length of Foramen Magnum mm		Width of Foramen Magnum mm		Length of Basilar Process mm	
	Crider	Holland	Crider	Holland	Crider	Holland	Crider	Holland	Crider	Holland	Crider	Holland	Crider	Holland	Crider	Holland
White Females	23.1	23.9	10.8	11.4	34.9	18.0	49.6	50.3	34.3	45.1	35.4	34.7	29.9	30.4	28.3	25.4
White Males	25.4	25.7	12.2	12.6	37.2	20.0	52.8	52.9	36.0	46.2	36.6	38.0	31.2	31.8	30.9	27.2
Black Females	22.5	21.8	11.1	11.8	34.8	18.2	46.4	46.9	31.1	41.3	35.2	34.6	28.5	28.4	31.6	28.0
Black Males	24.0	25.0	12.4	13.1	36.2	22.0	49.1	50.5	32.1	44.0	35.7	37.1	29.3	31.1	31.8	30.0
Standard Deviations																
White Females	2.2	2.8	1.4	1.1	1.5	2.0	3.5	3.9	3.3	3.4	2.5	2.7	2.1	2.2	2.6	1.9
White Males	2.9	2.8	1.4	1.4	3.8	3.2	3.0	3.4	2.8	2.8	2.7	2.5	2.1	1.9	2.9	1.8
Black Females	2.7	1.9	1.2	1.0	3.3	2.2	3.8	3.0	3.6	3.8	2.3	3.0	2.9	2.5	2.3	2.2
Black Males	2.7	2.0	1.7	1.7	3.9	4.4	2.9	3.1	3.2	2.7	1.9	2.2	1.7	1.8	2.5	3.7

Table 5.13. Student's t-test for Crider and Holland Measurements (mm).

	White Females		White Males		Black Females		Black Males	
Minimum Distance (Between Occipital Condyles)	Crider	Holland	Crider	Holland	Crider	Holland	Crider	Holland
	34.9	18.0	37.2	20.0	34.8	18.2	36.2	22.0
	p = <0.0001		p = <0.0001		p = <0.0001		p = <0.0001	
Maximum Interior Distance (Between Occipital Condyles)	Crider	Holland	Crider	Holland	Crider	Holland	Crider	Holland
	34.3	45.1	36.0	46.2	31.1	41.3	32.1	44.0
	p = <0.0001		p = 0.0586		p = <0.0001		p = <0.0001	

Table 5.14. Results of Correctly Classified Crania from Testing Holland (1986a) Formulae

	Formula 1	Formula 2	Formula 3	Formula 4	Formula 5	Total
Blacks Classified	69	70	70	46	70	325
Whites Classified	4	4	0	217	3	228
Total Correctly Classified	73	74	70	263	73	553
Total Sample Size	404	404	404	404	404	2020
Percent Correctly Classified	18.0	18.3	17.3	65.1	18.0	27.3

CHAPTER 6 – DISCUSSION AND CONCLUSIONS

The shape of the foramen magnum is highly variable. A total of five shape categories were identified in this study: Arrowhead, Circle, Diamond, Egg, and Oval. Since 46.2% of the crania were classified into only one of the five shapes (Arrowhead), it appears that the foramen magnum shape is not indicative of ancestry (Table 5.1). If Arrowhead shapes are removed from each sample, a minor difference exists among the ancestral groups. The three ancestral groups with the greatest sample size change from Arrowhead dominance to: Egg (blacks), Circle (Hispanics), and Circle (whites). However, these secondary categories are not distinctive enough to use as ancestry classificatory methods. Also, because the Arrowhead shape is the most common shape for both males and females, it appears that the foramen magnum shape is not a positive indicator of sex either (Table 5.3).

The Pearson's chi-square test revealed that there is an association between foramen magnum shape and the three largest ancestral groups in the study. The pattern revealed by the chi-square is that the distribution of foramen magnum shapes for individuals of Hispanic ancestry varies from that of blacks and whites (see Section 5.1). The lack of an Egg shaped foramen magnum for any individuals of Hispanic ancestry is significantly different from both blacks and whites. This supports the findings described below.

Using the foramen magnum shape as a classifier of ancestry will not work. Yet, using the shape as an eliminating non-metric characteristic may have utility in ancestry determination. The example of this is the Egg shape classification. Out of the 37 Hispanic foramen magnums in this study, not even one was classified as an Egg shape. Even though this study involved a small sample size, the absence of an Egg shape foramen magnum in the Hispanic ancestry category may have some importance. Further research examining the foramen magnum shapes of Hispanics is needed to confirm these results.

This study involved multiple skeletal collections from several geographical locations. After comparing the demographic information from the United States Census Bureau to that from the skeletal collections used for this research, concerns arise. The main concern is the overall underrepresentation of peoples from non-white ancestries. The United States is a diverse country, and research involving the use of donated skeletal collections, ideally, should strive to reflect that diversity.

To aid in evaluating the utility in using the foramen magnum shape as an ancestry designation, a survey was conducted at the 62nd annual American Academy of Forensic Sciences conference. The survey demonstrated that the foramen magnum shape categories developed for this research are subjective. Low classification accuracy is a manifestation of the subjectivity. One of the possible explanations for the low accuracy is the disproportionate amount of instruction given to each survey participant. The participants who had the author explain the survey to them did better than those that were handed the survey without instruction. Another possible explanation for the low accuracy can be attributed to the amount of time each participant gave the survey. Some participants took the survey quickly, ignoring the reference poster, while others examined the accompanying poster carefully prior to completing the survey.

One way to decrease the subjectivity of this classification method is to combine the Diamond and Arrowhead categories. Combining the Diamond and Arrowhead categories into one category not only increases the classification accuracy, but also could reduce confusion between the two categories. This combined category could be referred to as Diamond. The written description of the Diamond category would remain the same as the previous description.

Another aspect of this thesis included comparing all 12 measurements taken for each of the three main ancestral groups with one another. The results revealed that Hispanic measurements often were smaller than those of blacks and whites. Overall, Hispanics have smaller measurements than both blacks and whites in every category except those of the Left Occipital Condyle's Maximum Width and Left Occipital Condyle's Minimum Width, which were the largest. Therefore, generally speaking, it can be implied that the smaller body size of Hispanics, as compared with that of blacks and whites, correlates with a smaller cranial base. Unfortunately, assessing whether blacks and whites typically have a larger cranial base compared to one another is difficult, since the sample means are very similar to each other. Out of the 12 measurements taken, whites had the largest in six of the 12 measurements, while blacks had the largest in four of the 12 measurements.

Significance testing among the three main ancestral groups in this study revealed that no significant differences in foramen magnum length exists. However, testing of the foramen magnum width did reveal significant differences between whites and blacks, and Hispanics and whites. The mean measurements of Hispanics and blacks were too similar to each other to be significantly different. In addition, testing for mean differences between males and females further confirms the general consensus that males have significantly larger cranial bases than females.

As noted in Chapter 5, minor differences exist between digital and manual measurements of the cranial base; the differences range from 0.26 mm to 1.80 mm. While most differences are small, several were significantly different (Table 5.11), and might have an impact on some research. However, certain advantages for the use of digital measurements over manual measurements exist. Digital measurements allow for more fragile skeletal materials to be documented without the threat of further damage. This benefit has application to charred remains when the bones have been leached of their organic substances and become highly fragile. Finally, one of the greatest advantages to digital measurements is it allows researchers to closely pinpoint certain osteological landmarks that various metric formulae require.

While advantages for measuring skeletal materials digitally have been found, disadvantages also exist. One of the main disadvantages to measuring digitally is that it is a very time consuming process, compared to measuring by hand. In this researcher's experience, measuring digitally takes at least three times longer than measuring by with sliding calipers. Each picture has to be calibrated to the ruler that was set into the field of vision when the skull was photographed. Along with calibrating each picture, every image needs to be enlarged to provide the clearest view of the osteological markers. Also, one must resolve the problem regarding the 2D nature of a photograph. Photographs are flat and do not show the various bumps and ridges of the skeleton. Bone has a natural curvature that does not necessarily translate to photographs. Therefore, the differences between digital and manual measurements may be a result of the removal of the natural curvature of the cranial base. For the most accurate digital measurements from photographs, each researcher needs to manually measure a few specimens and then compare those measurements to his or her digital measurements. This will allow the researcher to determine a line of best fit (or correction formula) for the measurements, ensuring the digital measurements will reflect manual measurements.

The final component of this research project was to compare the cranial base measurements taken by Holland (1986a) to those of this researcher. Both Holland and Crider utilized skeletal collections from different eras. Holland's use of the Terry Collection, which has recorded death dates ranging from 1920 to 1965 (Hunt and Albanese 2005), comes from an earlier era than that of the UT, UNM, FACES, and PCOME collections, which have recorded death dates ranging from 1980 to the present. The modern skeletal collections used in this sample represent individuals who were older in age than those from the Terry Collection.

For the most part, both Holland's and this researcher's measurements were similar in size. However, the variances for two of the measurements were significantly different from each other: the Minimum Distance between Occipital Condyles and the Maximum Interior Distance between Occipital Condyles. The decrease in the Maximum Interior Distance between Occipital Condyles and the increase in the Minimum Distance between Occipital Condyles may suggest localized changes on the cranial base over the last 59 years.

Holland also used the Terry Collection to create five multiple-regression equations for assigning ancestry from measurements on the cranial base. The testing of Holland's ancestry formulae revealed four of the five equations are more likely to assign accurate ancestry to blacks than whites, and will miss-classify whites as blacks more often. Only Equation 4 assigned white ancestry over black ancestry correctly. These equations are not likely to assign the correct ancestry to unknown remains from modern populations. These findings support those found by Allaire and Manhein (2008).

This research was multi-faceted, with several important questions. The hypothesis for this research stated that a correlation exists between the foramen magnum shape and ancestral groupings. The null hypothesis stated ancestral groups are not visually and metrically different from each other. The findings of this research showed that the Arrowhead foramen magnum shape was the most common shape regardless of ancestry. Thus, the null hypothesis for shape variation could not be rejected. However, the null hypothesis for metric variation can be accepted. There are minor differences between the mean measurements of blacks, whites, and Hispanics; some of these differences are significant (i.e. the Foramen Magnum Width), while many are not. An expanded sample size of blacks and Hispanics can allow for further significance testing for samples of approximately equal size.

Several other findings have been recorded. Of all of the individuals of Hispanic ancestry in this study, none possessed an Egg shape foramen magnum. While the Hispanics sample size is very small (n = 37), this finding is important. The absence of an entire shape category, for any ancestry, could be used as a non-metric characteristic that can eliminate an unknown skull from possible inaccurate ancestry assignment. With an expanded sample of Hispanics, these initial results can either be confirmed, or possibly rejected. By adding another non-metric trait to the list of traits noted by Birkby et al. (2008) and Rhine (1990), forensic anthropologists working in states bordering Mexico will have another tool to help them with their identification processes.

Further, Holland's (1986a) five multiple-regression equations are not likely to assign the correct ancestry to unidentified cranial bases from modern populations. With an expanded sample size of black individuals, updated multiple-regression equations can be created. By updating the multiple-regression equations, forensic anthropologists will have another tool to help with ancestry assessment, especially with fragmentary cranial bases.

Also, by comparing and testing the differences between Holland's and this researcher's measurements, it appears localized change has occurred on the cranial base. These results are also preliminary. Possible future research comparing historic collections, such as the Hamman-Todd Collection, to modern skeletal collection measurements, could further confirm these results.

In conclusion, future research is needed to further confirm preliminary results acquired with this study. First, both the black and Hispanic samples need to be expanded from modern skeletal collections. Secondly, with the expanded skeletal collection, updated multiple-regression equations could be made similar to that of Holland (1986a). Also, a comparative study, with measurements from historic and modern skeletal collections is necessary to determine the extent of localized cranial change that has occurred. Overall, this study shows the shape of the foramen magnum is not indicative of a specific ancestral group; however, the Egg shape potentially can act as an exclusionary non-metric characteristic.

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APPENDIX A – 2000 UNITED STATE CENSUS REPORT COMPARED TO SKELETAL COLLECTION DEMOGRAPHICS

Table A1. Comparison between U.S. Census Bureau for the city of Albuquerque, New Mexico, and UNM

Census Category	City of Albuquerque (%)	UNM Demographics (%)	Differences (Census minus Skeletal Collection)
White	71.6	90.2	-18.6
Black	3.1	3.4	-0.3
American Indian	3.9	0	3.9
Asian	2.3	0	2.3
Hispanic	39.9	4.1	35.8
Mixed	4.3	0	4.3
Men	Not Recorded	65.2	Cannot Calculate
Women	51.4	34.7	16.7
65+	12	48.6	-36.6

Table A2. Comparison between U.S. Census Bureau for the city of Tucson, Arizona, and PCOME

Census Category	City of Tucson (%)	PCOME Demographics (%)	Differences (Census minus Skeletal Collection)
White	70.2	5.5	64.7
Black	4.3	0	4.3
American Indian	2.3	2.7	-0.4
Asian	2.7	0	2.7
Hispanic	35.7	55.5	-19.8
Mixed	3.8	36.1	-32.3
Men	Not Recorded	83.3	Cannot Calculate
Women	51	16.6	34.4
65+	11.9	0	11.9

Table A3. Comparison between U.S. Census Bureau for the city of Knoxville, Tennessee, and UT

Census Category	City of Knoxville (%)	UT Demographics (%)	Differences (Census minus Skeletal Collection)
White	79.7	73.7	6.0
Black	16.2	20	-3.8
American Indian	0.3	0.7	-0.4
Asian	1.5	0.3	1.2
Hispanic	1.6	4.7	-3.1
Mixed	1.6	0.3	1.3
Men	Not Recorded	65.8	Cannot Calculate
Women	52.6	34.1	18.5
65+	14.4	26.6	-12.2

Table A4. Comparison between U.S. Census Bureau for the city of Baton Rouge, Louisiana, and LSU FACES

Census Category	City of Baton Rouge (%)	LSU FACES Demographics (%)	Differences (Census minus Skeletal Collection)
White	45.7	50	-4.3
Black	50	50	0
American Indian	0.2	0	0.2
Asian	2.6	0	2.6
Hispanic	1.7	0	1.7
Mixed	1	0	1
Men	Not Recorded	46.6	Cannot Calculate
Women	52.5	53.3	-0.8
65+	11.4	0	11.4

APPENDIX B – GRAPHIC COMPARISION OF MANUAL MEASUREMENTS TO DIGITAL MEASUREMENTS

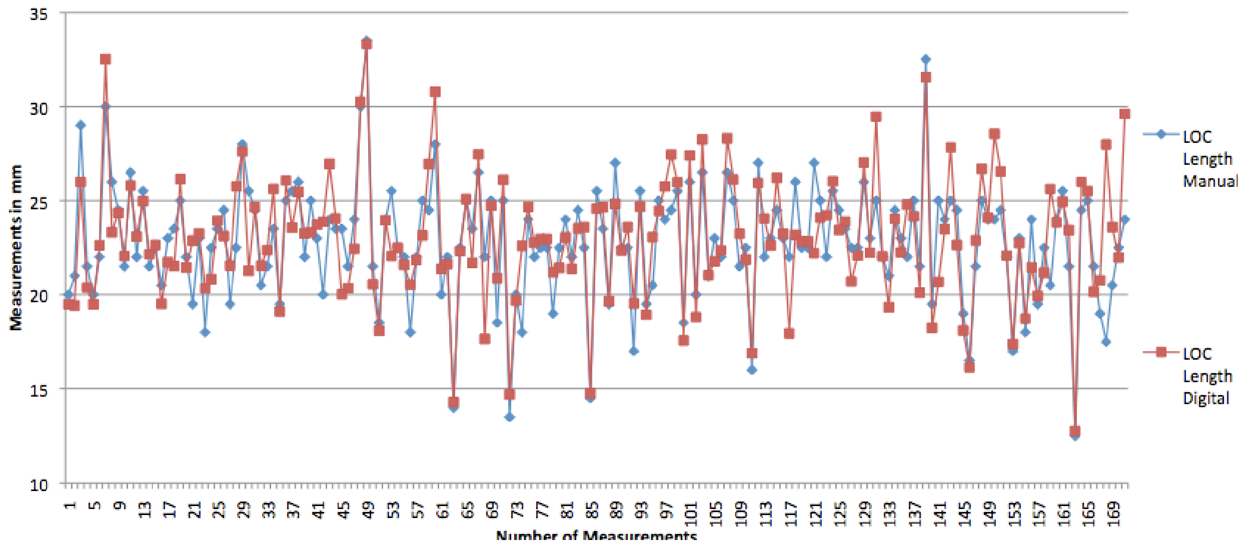

Figure B1. Comparison of Manual and Digital Measurements for Left Occipital Condyle Length.

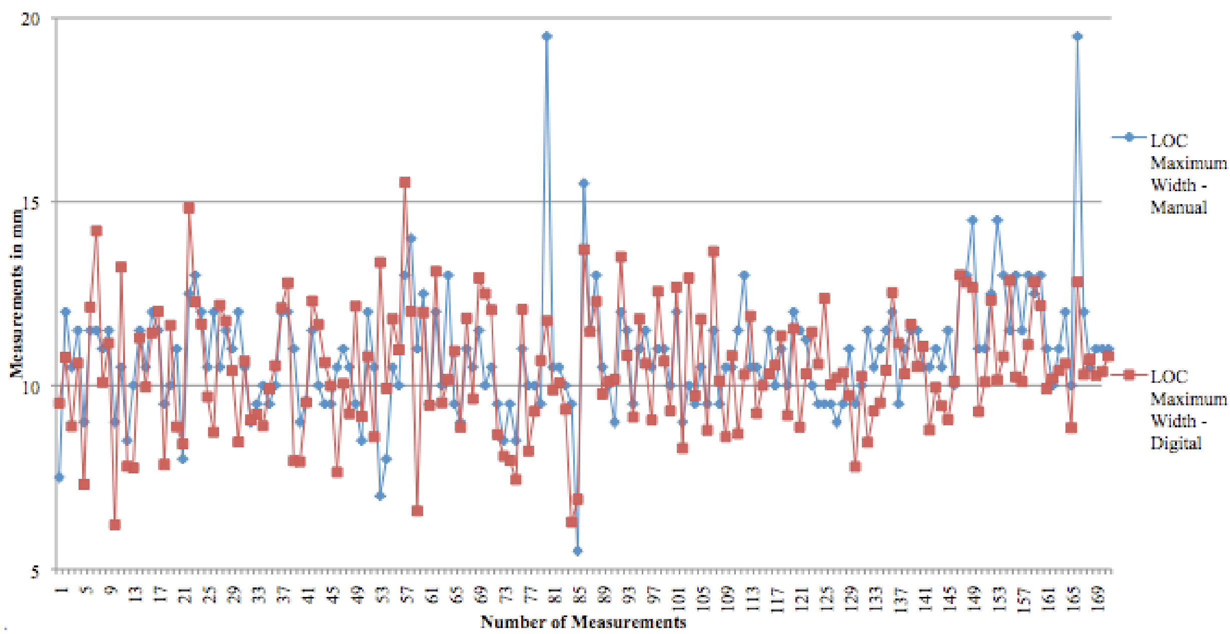

Figure B2. Comparison of Manual and Digital Measurements for Left Occipital Condyle Maximum Width.

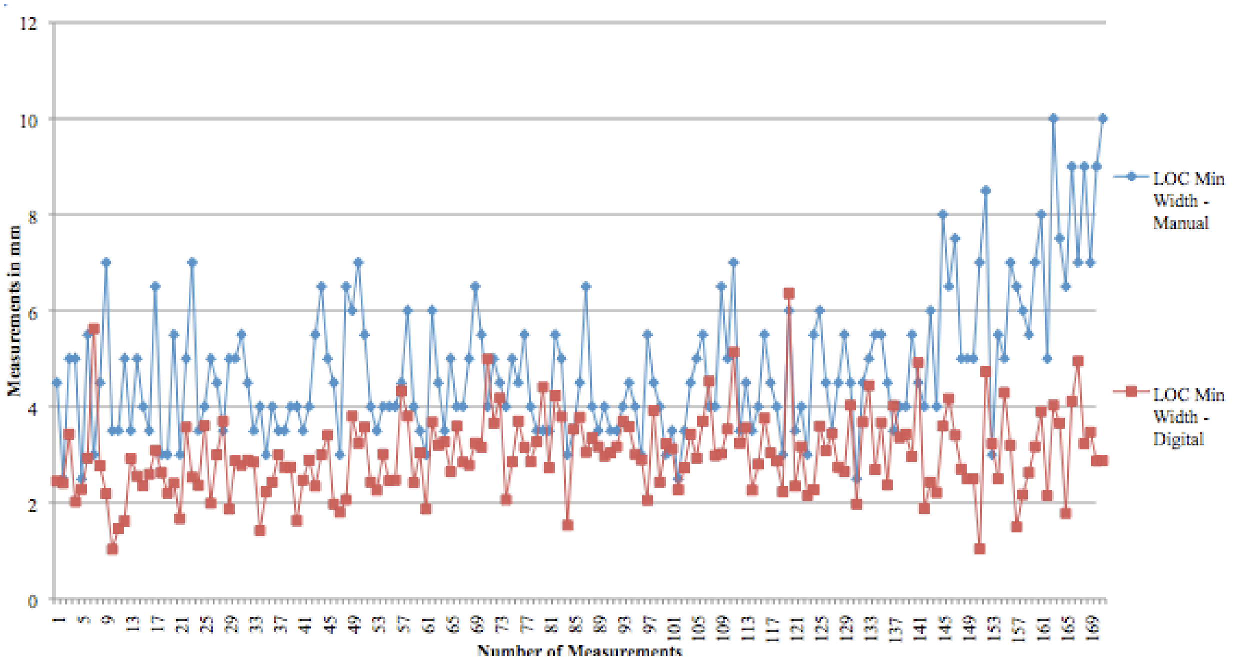

Figure B3. Comparison of Manual and Digital Measurements for Left Occipital Condyle Minimum Width.

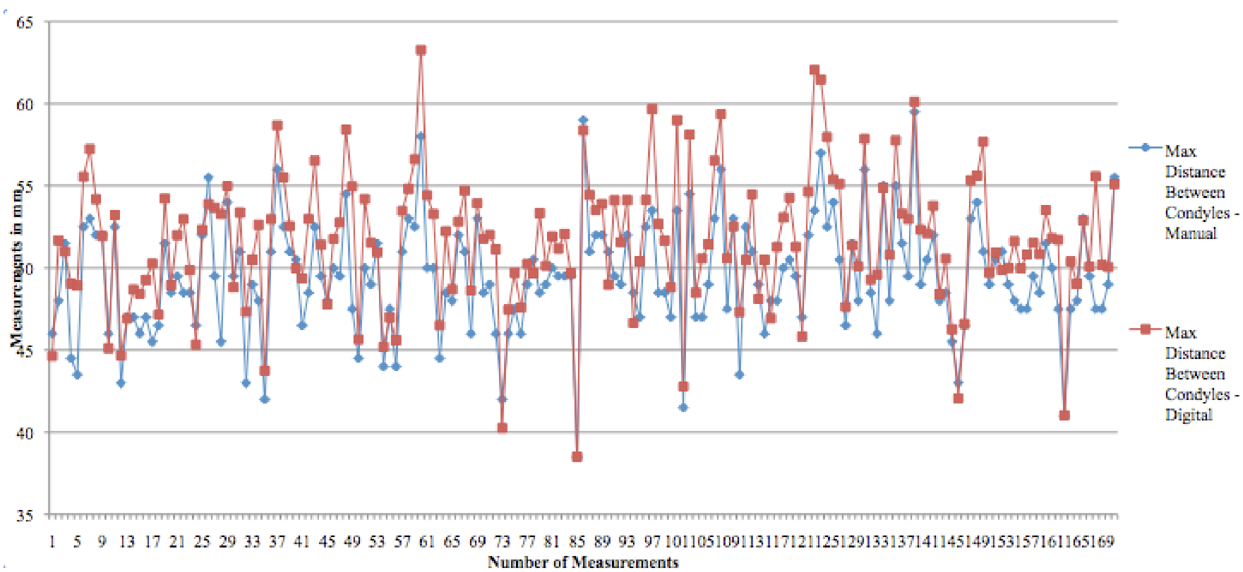

Figure B4. Comparison of Manual and Digital Measurements for the Maximum Distance Between Occipital Condyles.

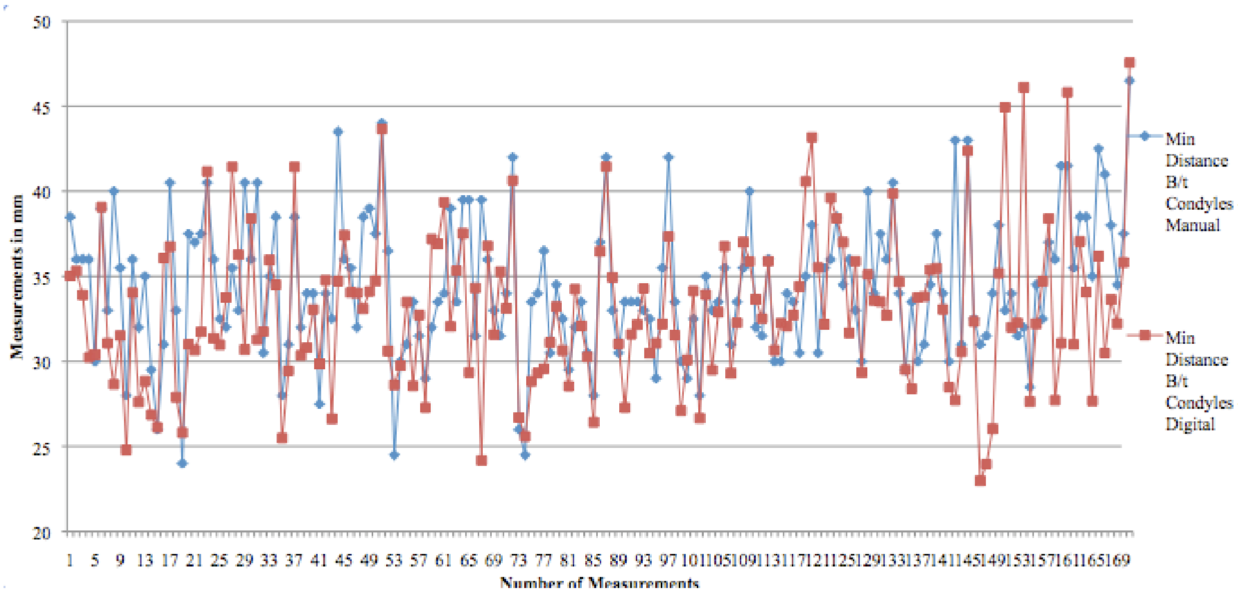

Figure B5. Comparison of Manual and Digital Measurements for the Minimum Distance Between Occipital Condyles.

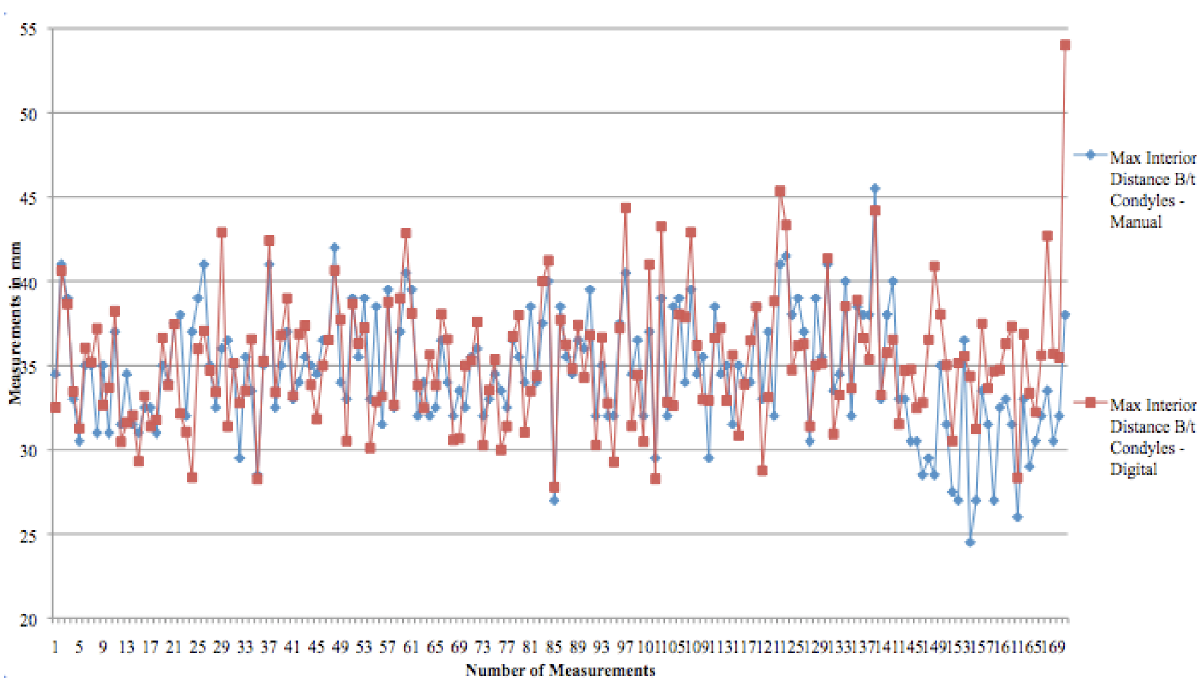

Figure B6. Comparison of Manual and Digital Measurements for the Maximum Interior Distance Between Occipital Condyles.

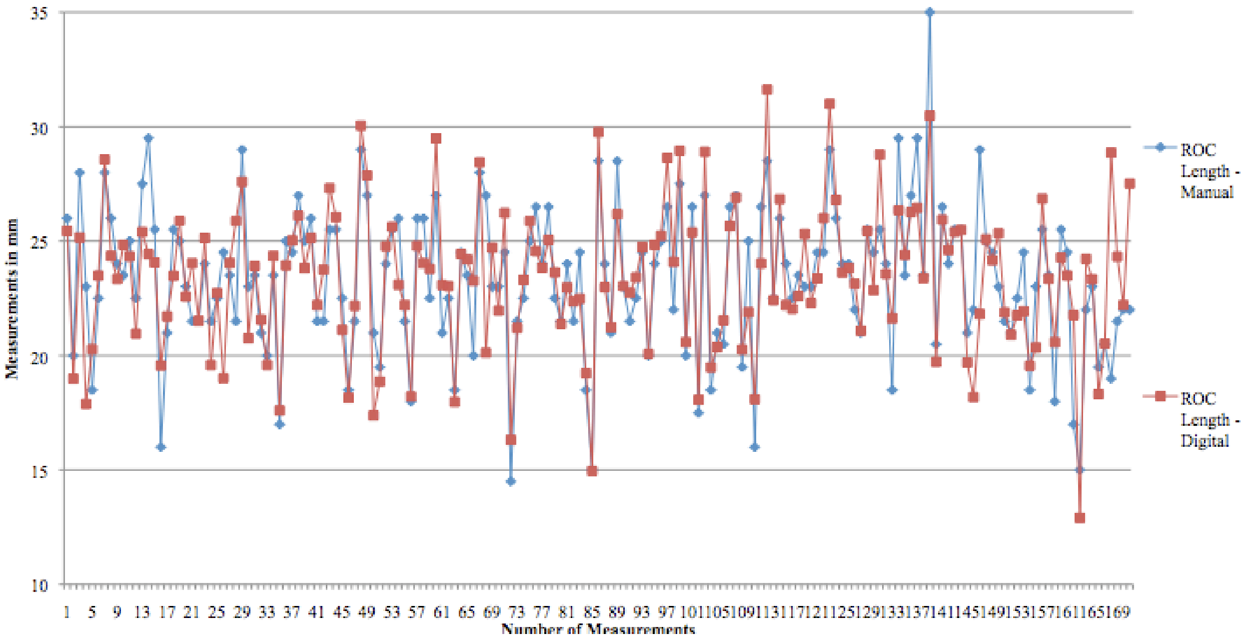

Figure B7. Comparison of Manual and Digital Measurements for the Right Occipital Condyle Length.

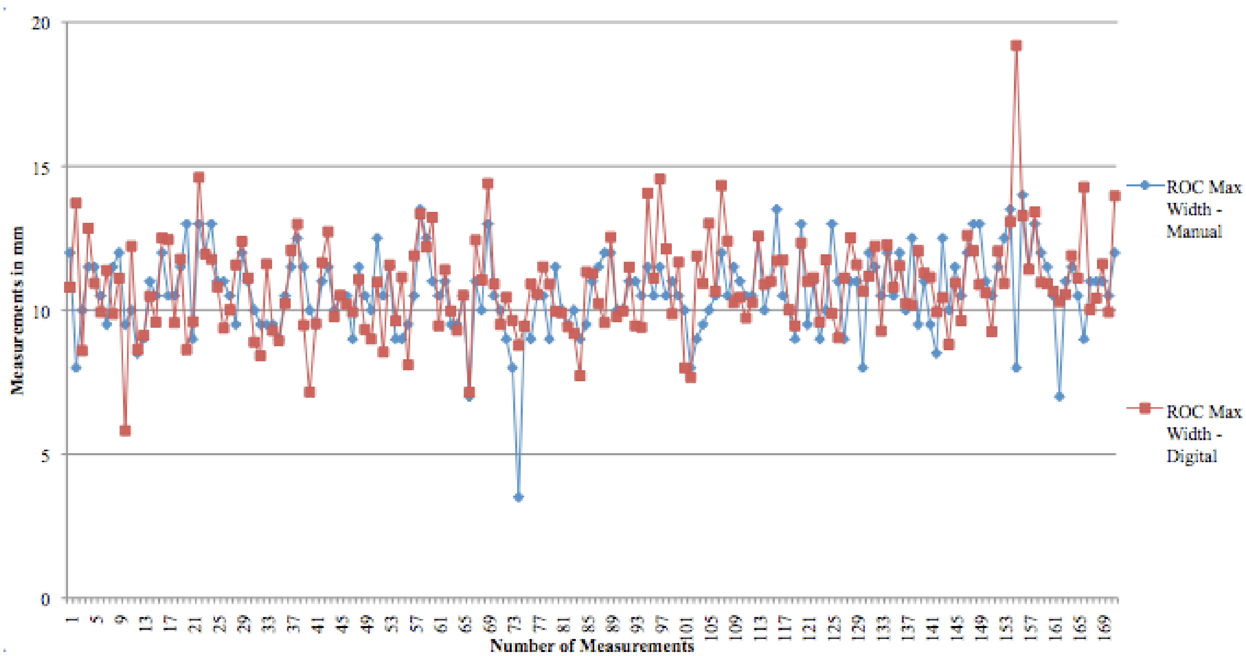

Figure B8. Comparison of Manual and Digital Measurements for the Right Occipital Condyle Maximum Width.

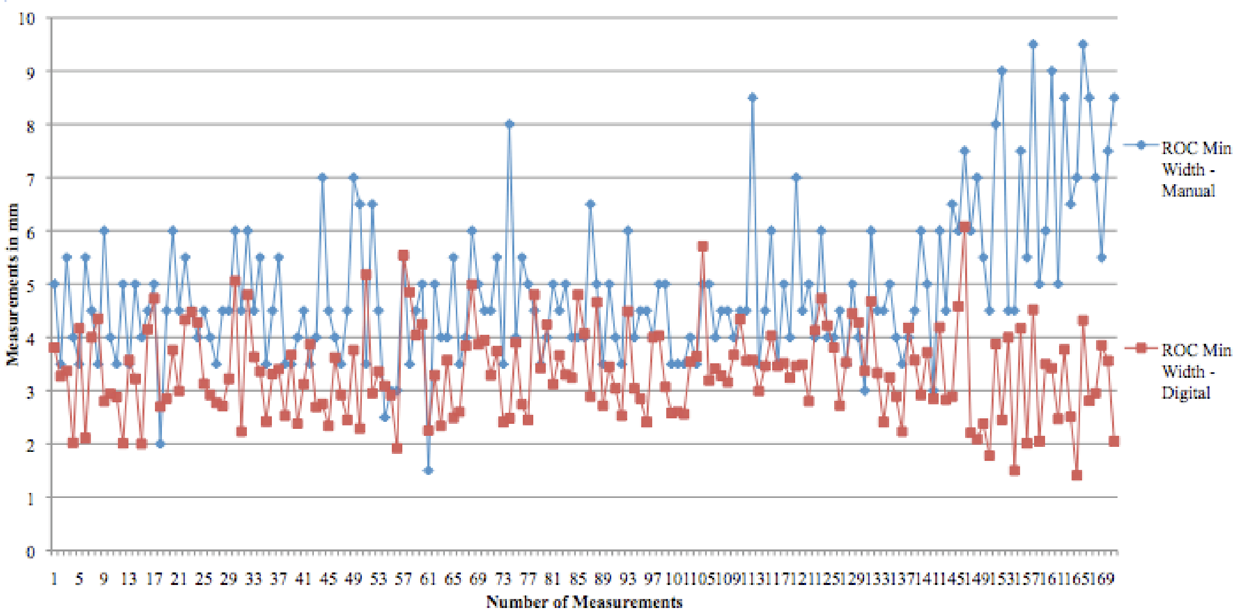

Figure B9. Comparison of Manual and Digital Measurements for the Right Occipital Condyle Minimum Width.

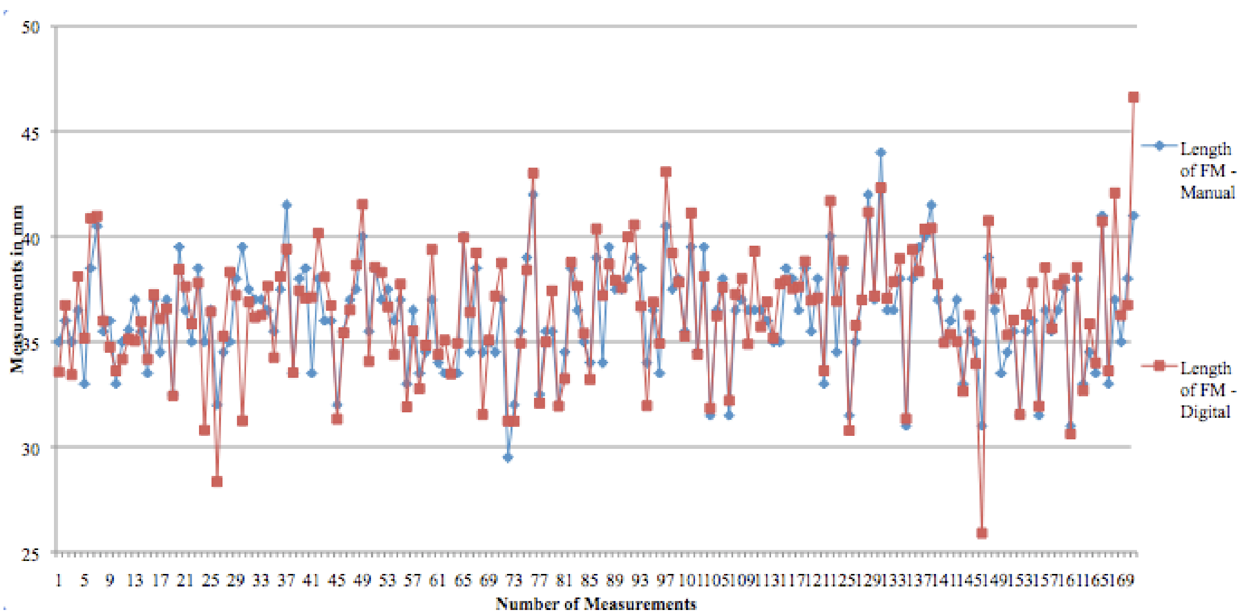

Figure B10. Comparison of Manual and Digital Measurements for the Length of the Foramen Magnum.

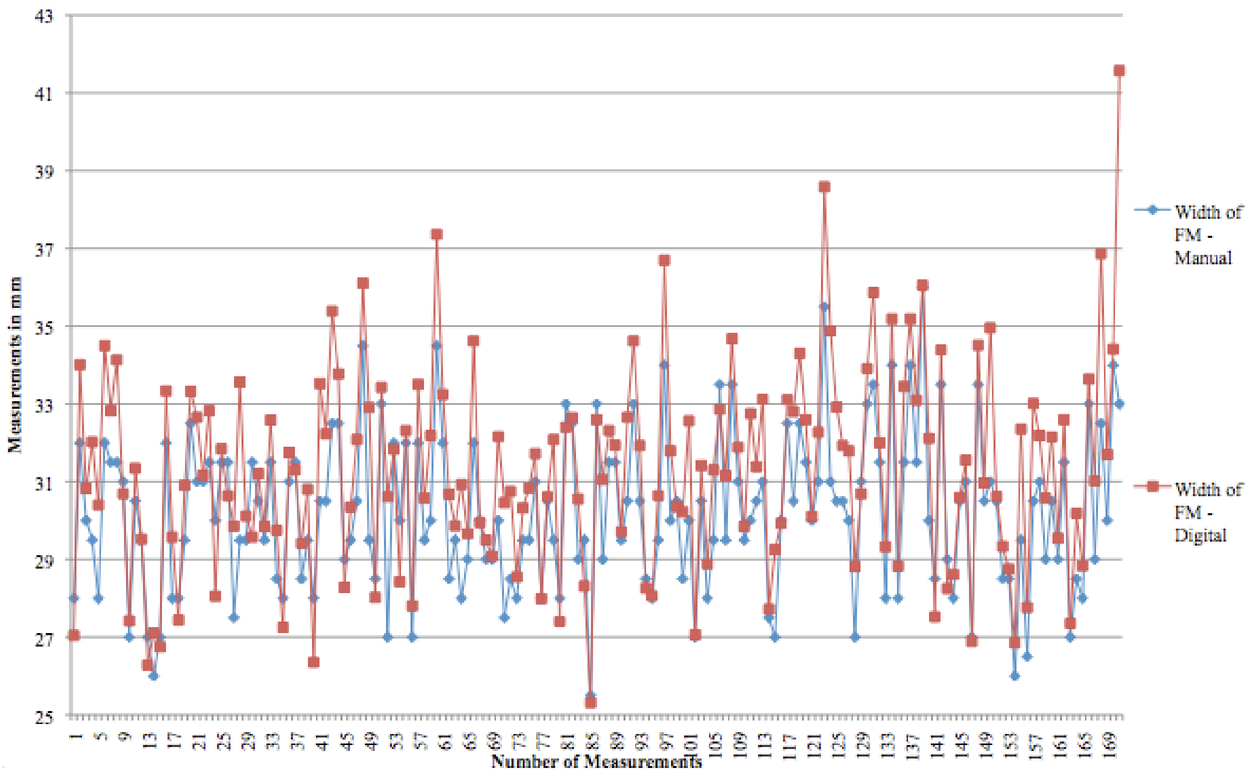

Figure B11. Comparison of Manual and Digital Measurements for the Width of the Foramen Magnum.

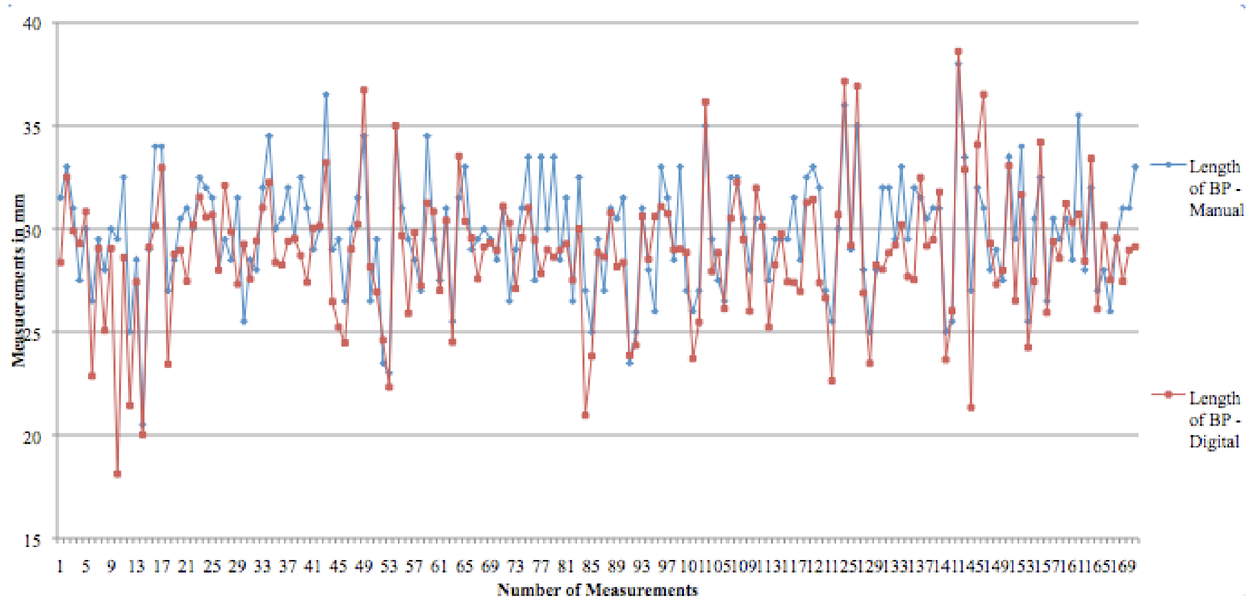

Figure B12. Comparison of Manual and Digital Measurements for the Length of the Basilar Process.

VITA

Stephanie Marie Crider was born in September, 1983, in Orange, California. She was graduated from the University of California at Santa Cruz in June, 2005, with a Bachelor of Arts in anthropology. In August, 2008, Stephanie entered graduate school in the Geography and Anthropology Department at Louisiana State University. Stephanie has presented posters at the American Academy of Forensic Sciences annual meetings in 2006 and 2009 and presented a paper at the American Anthropological Associations annual meeting in 2007. She currently holds student memberships with the American Academy of Forensic Sciences, American Anthropological Association, and the International Association for Identification. Stephanie plans to continue her education in anthropology, earn a Ph.D., and teach at a university.