ESTIMATION OF SEX THROUGH METRIC MEASUREMENTS OF THE PETROUS PORTION OF THE TEMPORAL BONE IN CONTEMPORARY POPULATIONS

THESIS

Presented to the Graduate Council of
Texas State University-San Marcos
in Partial Fulfillment
of the Requirements

for the Degree

Master of ARTS

by

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San Marcos, Texas
May 2013

ESTIMATION OF SEX THROUGH METRIC MEASUREMENTS OF THE PETROUS PORTION OF THE TEMPORAL BONE IN CONTEMPORARY POPULATIONS

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ACKNOWLEDGEMENTS

I would first like to thank my parents and big brother for all of their love, unwavering support, and patience during this research. You all have kept me emotionally grounded and constantly inspired to grow with the experiences and opportunities I have been generously provided. To the rest of my family and friends, thank you so much for your support and for believing in me. I am so truly thankful to have each and every one of you in my life.

To my thesis committee members- there are no words for how incredibly grateful I am to each of you for your time, patience, and guidance. First and foremost, thank you Dr. Michelle Hamilton for your guidance, wisdom, and for instilling in me a passion for forensic anthropology and bioarchaeology. You have constantly challenged me to become better with every passing day and have inspired a curiosity that will continue to drive me throughout the rest of my academic career. Thank you a million times to Dr. Corina Kellner for igniting the spark that fueled my interest and love in biological anthropology and for providing me with the opportunity of a lifetime to learn and grow through research. To Dr. Kerrie Lewis Graham and Dr. Katherine Spradley, thank you so much for your guidance and wisdom throughout the entire process of this research.

Finally, I would like to thank the other faculty who assisted me in my endeavors: Thank you Dr. Britt Bousman for answering my ever-persistent questions and Dr. Beth

Erhart for helping me get my ideas for my thesis up and running. To Rosie Bongiovanni who helped give me direction, your time and assistance will forever be appreciated. Next, thank you to The University of Tennessee-Knoxville for allowing me to utilize the William M. Bass skeletal collection for this research. And last but certainly not least, no words can ever convey the gratitude I have to Mr. Grady Early whose generous donations helped to provide for the amazing facilities and equipment I have had the privilege of using these past two years and for assisting in the funding of this project. Without you this research would not have been possible.

This manuscript was submitted on April 15, 2013.

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ABSTRACT

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The current study seeks to determine if metric measurements of the petrous portion of the temporal bone is an appropriate method of sex estimation for contemporary individuals. Skeletal remains utilized in this study were derived from the William M. Bass Donated Skeletal Collection at The University of Tennessee-Knoxville and the Texas State University-San Marcos donated skeletal collection. Methods utilized for this study were derived from Kalmey and Rathbun (1996) who compiled 9 measurements of the petrous portion and applied them to historic individuals. Intraobserver error was calculated via a 10% approach, comprised of remeasuring 10% of the total sample at the end of data collection and comparing them with the original measurements. Intraobserver error resulted in a Pearson's correlation coefficient ranging from 0.994 and 0.999, indicating a high level of repeatability and reliability. General Linear Model MANOVA (GLM MANOVA) procedures suggest that age at metric measurements of the petrous portion and sex are statistically significant for measurements D at p= 0.000 and F at p=0.029. Additional GLM MANOVAs indicate that there is a significant relationship between metric measures and age at death by decade intervals for measurement D, and between metric measures and age at death by 2 decade intervals for measurements HI, D, and F. Results show that a GLM MANOVA for metric measures and ancestry were not statistically significant; however, the sample sizes for American Blacks and Hispanics in this study are too small preventing any reliable inferences regarding ancestry and metric measures to be made. Discriminant function analysis resulted in approximately 60% of females and 66% of males to be correctly classified with a cross-validated classification rate of 63% for sexes pooled. Stepwise discriminant function analysis selected measurements C and D as the best variables to use together to estimate sex. Cross validated classification rates utilizing the sectioning point created via a linear discriminant function with selected variables C and D resulted in correct classifications of 58% females, 72% males, and 66% for sexes pooled. This research shows that the petrous portion can be used as an accurate estimator of sex and can be another method in the arsenal of forensic anthropologists in the absence of other osseous remains.

CHAPTER I

INTRODUCTION

This thesis research focuses on estimating the sex of individuals through metric analysis of the petrous portion of the temporal bone for applications within forensic anthropology. Forensic anthropology is a sub-field of study within biological anthropology concerned with the applications of skeletal biological knowledge and techniques to forensic medicolegal cases. One important endeavor of these forensic anthropological investigations is the identification of individuals who may otherwise go unidentified due to advanced stages of decomposition, skeletonization, commingling or severe osteological fragmentation. In such cases, it is the responsibility of the forensic anthropologist to create a biological profile through osteological study of the remains which includes estimations of sex, age, ancestry, stature, possible trauma, overall health, and any evidence of unique pathological conditions.

The process of creating a biological profile typically begins first with the estimation of the sex of a given individual, as most methods of estimation of other biological information are affected by sex assessment (SWGANTH 2010). This is due in large part to the presence of sexual dimorphism in the human skeleton due to different hormone secretions during puberty which help form anatomical and physiological differences between males and females (White and Folkens 2005). As a general rule, female skeletal elements are characterized by smaller size and more gracile features, whereas male skeletal elements are characterized by larger, more robust elements. Not taking sex into account prior to the estimation of stature, for instance, will confound the process due to different morphological changes in the skeleton between men and women. It is imperative, then, that a multitude of sex estimation techniques be available to a practitioner of forensic anthropology in order to accurately assist in the identification of the deceased.

Current Methods for the Estimation of Sex

Techniques for the estimation of sex generally fall under two categories of methods: morphological trait assessment and metric analysis (SWGANTH 2010). Morphological trait assessment refers to the visual assessment of skeletal characteristics as they are present in osteological remains. Certain traits and features of skeletal elements are known to display marked differences caused by sexual dimorphism in the appearance or absence of certain traits (Norén et al. 2005). Morphological assessment is usually performed on the pelvis and skull, as these two regions of the human skeleton exhibit the most visually observable sexual dimorphism in the body second to secondary sexual characteristics present in fresh human remains (Bruzek 2002; Houghton 1974; Phenice 1969; White and Folkens 2005). These morphological trait assessment methods utilizing the pelvis and skull generally requires extensive training and experience and can result in approximately 80-90% accuracy (White and Folkens 2005).

Metric analysis refers to taking metric measurements of various features and elements on the human skeleton and comparing them to known variation of measurements for males and females. Metric analysis can be performed on any bones present in the human skeletal system and can also be used to estimate other aspects of the biological profile such as stature and ancestry (Auerbach and Ruff 2010; Cardoso 2009; Meadows and Jantz 1992; Pelin and Duyar 2003; Raxter et al. 2006; Simmons et al. 1990; Spradley et al. 2008; Trotter et al. 1958). In terms of estimating sex, metric analysis is typically used on femoral head diameter, mid-shaft diameters of various long bones, pelvis, humeral head, and various cranial measurements (Ali and Maclaughlin 1991; Anderson 1990; Berrizbeitia 1989; Dwight 1905; Giles and Elliot 1963; Kimmerle et al. 2008; Spradley and Jantz 2011; Walker 2008). More recently, research has focused on the possible application of metric analysis in the estimation of sex using other elements of the body, including but not limited to the patella, sternum, sternal rib ends, and talus and calcaneus (Introna et al. 1998; Introna et al. 1996; Bongiovani 2010; Gavit 2009).

Methods for Sex Estimation of Fragmentary Remains

Many techniques in use today for sex estimation are heavily reliant on intact, complete skeletal elements, and those techniques tend to use osseous elements that are easily damaged through taphonomic processes and trauma (Introna et al. 1998; Rogers 2005; Walrath et al. 2004). Despite this, many cases in which forensic anthropologists become involved are those comprised of individuals who have suffered traumatic accidents or are in poor states of preservation (Introna et al. 1998; Mundorff 2011; Rogers 2005). In such cases, traditional methods of sex estimation cannot be used (Hsu et al. 1999; Mundorff 2011). What, then, should be done when individuals are too highly fragmented or destroyed for traditional methods of sex estimation?

DNA analysis is often used to help narrow down possible identification of individuals (Hsu et al. 1999). Analysis of the DNA of an individual can provide a determination of sex with high precision regardless of age (White and Folkens 2005). However, DNA analysis is often a costly, time consuming procedure, taking many months in most modern crime laboratories due to backlog (Crime Lab Report 2008). In cases where there are multiple numbers of individuals and remains to be sent to crime laboratories for analysis, DNA analysis is often not a realistic option and is both cost and time prohibitive. Likewise, reference samples from possible living relatives must be collected in order for a DNA match to be possible. Without DNA samples from the living to compare with the deceased, the individual may not be successfully identified. Additionally, for remains that are too poorly preserved, DNA extraction is not always possible.

When identification via DNA analysis is not possible or is not a feasible option in a given situation, morphological visual assessment and metric analysis can be performed on fragmentary remains. To the extent that certain osseous elements are still present and preserved, visual morphological assessment can be used. Metric studies tend to focus on regions of skeletal elements that tend to preserve, such as the study of fragmentary skeletal remains by Albanese et al. 2008. This study examined two different methods for two scenarios forensic practitioners often face in the field: the presence of only the proximal femur, and the presence of the proximal femur and a portion of the hip with a damaged os pubis. Both methods tested resulted in approximately 90-97% accuracy in sex estimation without being population specific.

The portions of the human skeleton that tend to survive contexts of high impact or poor preservation are those comprised of the densest bone (Lynnerup et al. 2006; Isçan 2005). One of the densest areas of bone in the cranium and often the only portion of bone well-preserved in highly traumatized or disintegrated human remains is the petrous portion of the temporal bone (Jorkov et al. 2009; Lynnerup et al. 2006). It has been suggested in previous studies that the petrous portion of the temporal bone may yield accurate estimations of sex due to its density and location in the endocranial region of the cranium (Isçan 2005; Todd et al. 2010). The petrous portion of the temporal bone according to White and Folkens (2005) is:

> "… the massive, dense bony part that dominates the endocranial aspect of the temporal. The sharp superior edge of the endocranial petrous surface angles anteromedially, separating the temporal and occipital lobes of the brain and housing the internal ear. The petrous is wedged between the occipital and the sphenoid… The petrous part of the bone houses the delicate organs of hearing and equilibrium…" (White and Folkens 2005: 95).

Due to its location on the endocranial portion of the skull, it is expected that the petrous portion will not be affected morphologically by changes that occur due to cultural activities or environmental stressors in life. Further, previous research demonstrates that the petrous portion does not undergo bone remodeling throughout life after 2 years of age except in the outer periosteal layers (Jorkov et al. 2009; Zehnder et al. 2005). This suggests that the petrous portion is not as susceptible to changes over time as long bones, which undergo bone remodeling every 7-10 years and allows the petrous portion to be used as a proxy in bioarchaeological contexts when tooth enamel is absent (Jorkov et al. 2009; Zehnder et al. 2005). Reliable methods to estimate sex of an individual from the petrous portion that are both widely available to forensic practitioners in the field and are cost effective would be highly beneficial in the endeavor to identify individuals.

Previous Studies Involving the Petrous Portion

Recent research has utilized a variety of methods to estimate sex from the internal acoustic meatus on the petrous portion of the temporal bone. One approach involves the creation of casts of the lateral angle of the internal acoustic meatus utilizing dental casting materials (Graw et al. 2005; Norén et al. 2005). This technique has demonstrated some promise in showing the present sexual dimorphism of this feature; however, this method can be quite costly, time consuming, and requires a large amount of expertise as casts must be created accurately and left to set for an appropriate amount of time in order for a cast to be used for angle measurements. If a cast from this technique is created and a mistake is made in the formation process or is not allowed to set for the appropriate allotment of time, the entire cast must be discarded. In two separate studies, this method has shown approximately 62.5-66.3% accuracy in females and 68.5-73.3% accuracy in males (Graw et al. 2005) and 82.3% accuracy overall for sex estimation (Norén et al. 2005).

Other techniques of sex estimation of the petrous portion have been created and tested that are less costly. These focus on measurements of the diameter of the internal acoustic meatus via the insertion and fit of various standard sizes of Dremel© drill bits (Lynnerup et al. 2006). The accuracy of this method was approximately 70%. This method of sex estimation is both time and cost efficient, and Dremel© bits are widely available; however, this method seems to reflect more regarding shape rather than diameter measurement. As the internal acoustic meatus is more oval in shape in comparison to rounded or angled Dremel© bits, and because the internal acoustic meatus shape is not constant across individuals, this method does not account for the remainder of the meatus that cannot be measured which may provide important information and its inclusion may allow sex to be estimated more accurately. Alternate avenues of sex estimation, then, are still needed.

In 2001, Wahl and Graw utilized a metric method of estimating the sex of individuals from the petrous portion. The authors utilized a collection of cadaver remains (of which the origin and description are not provided), and created a large set of landmarks and measurement combinations. However, the definitions of these landmarks are confusing and utilize a system of arrows and numbers that are difficult for anyone to use without extensive experience. Their method resulted in approximately 67% correct estimation of individuals in their collection which can be a useful method to estimate sex in a situation where the petrous portion is the only remaining osseous element (Wahl and Graw 2001).

If possible, a cost and time prohibitive method for measuring the petrous portion of the temporal bone that is more accurate and precise enough to be used in the field should be developed. The most accurate and applicable metric method was developed by Kalmey and Rathbun (1996) and involves taking metric measurements of 9 landmarks of the petrous portion. It was based on individuals from the historic Terry Collection at the Smithsonian Institution which is comprised of American individuals of European and African ancestry with dates of birth ranging from 1842-1943. Their results revealed sex estimation accuracy rates of 66 to 74% which will be useful in contexts where other osseous remains are not recovered. As their method has not yet been applied to modern forensic populations, my thesis research project attempts to further test this method to achieve greater accuracy.

The present research examines documented skeletal collections of contemporary adult American populations to assess patterns of sexual dimorphism in the petrous portion of the temporal bone. It explores whether or not it is possible to accurately estimate sex of an individual through metric examination of 9 measurements of the petrous portion developed and refined by Kalmey and Rathbun (1996). Two hypotheses are tested, which are:

1) This research will test if there is a significant relationship between metric measurements of the petrous portion of the temporal bone and sex.

2) If a significant relationship between metric measurements and sex is present, this research seeks to provide a classification function for estimating sex for professional anthropologists to utilize in real world forensic and bioarchaeological situations.

The present research utilizes contemporary populations from the William M. Bass Donated Skeletal Collection housed at The University of Tennessee-Knoxville and the Texas State University donated skeletal collection. These collections comprise of individuals with birth years after 1910 and attempts to expand the Kalmey and Rathbun (1996) study by incorporating American White, Black, and Hispanic individuals.

CHAPTER II

MATERIALS AND METHODS

Collections

The skeletal remains utilized in this study were of known sex, age at death, and ancestry. Age at death ranged from 20 years to 91 years, birth years ranged from 1892 to 2012, and population groups included American Whites, Blacks, and Hispanics. Data compilation began in June of 2012 from two skeletal research collections: The William M. Bass Donated Skeletal Collection at The University of Tennessee-Knoxville, and the Texas State University-San Marcos donated skeletal collection. These collections were utilized due to the number of available documented donated skeletal remains featuring cranial autopsies. In addition, these collections are composed of individuals who were born in the last 100 years, which allows this research to represent contemporary individuals of forensic context.

The William M. Bass Donated Skeletal Collection at The University of Tennessee-Knoxville was founded in 1981 and houses several hundred donated individuals. All individuals in the collection have birth years ranging from 1892 to 2011, though the majority of individuals have birth years after 1940. Of the available 228 autopsied crania, 140 individuals were randomly chosen with birth years after 1910 via a random number generator. Biological profile information, which is provided on the front of each donated individual’s box, was not viewed until after data collection was complete in order to avoid observer bias.

Data collection at The University of Tennessee-Knoxville was performed one individual at a time to ensure each cranium was delivered to its correct box after metric measurements were taken. The cranium was removed and placed atop a donut-shaped beanbag to protect the basicranium and features of the skull from breakage. The callote of the cranium, which is the autopsied top portion of the skull, was removed and the exposed endocranium was visually assessed for any damage to the left petrous portion; if the damage was too severe for metric measurements to be taken, the right side was used. However, if both right and left petrous portions were too damaged for measurements to be taken with confidence, the skull was replaced in its collection box and removed from the data collection sample. Likewise, if the crania were falsely noted as autopsied which occurred in 22 instances, they were removed from the study sample.

Each of the 9 metric measurements was taken with a digital Kobalt 6” Metric and SAE Caliper and a General Tools & Instruments 3” Metric and SAE Caliper (available at local hardware stores) accurate to the nearest hundredth and recorded first in a scientific composition notebook and then input into a spreadsheet. Calibration checks were performed for both calipers at the beginning of every data collection day and were checked throughout the data collection process. Photographs were taken of the posterior, superior, and anterior views of the petrous portion of each cranium with corresponding comments on condition and feature presentation recorded into the composition notebook and spreadsheet. The individual was then returned to their collection box. The data collected from the remaining individuals was done in an identical manner. A total of 118 individuals were sampled from UTK (Table 1, Table 2).

Table 1: Sample Group Information for Study

COLLECTION	TOTAL	MALES	FEMALES	MIN AGE	MAX AGE	MEAN AGE
BASS COLLECTION	118	67	43	20	93	51.56
TSU-SM	9	6	3	32	91	54.89

Table 2: Sample Group Information for The William M. Bass Collection at The University of Tennessee-Knoxville

BASS COLLECTION	MEAN AGE	# WHITE	#BLACK	#HISPANIC
MALES	49.04	55	9	2
FEMALES	55.2	40	2	0

Table 3: Sample Group Information for Texas State University-San Marcos Donated Skeletal Collection.

TSU-SM	MEAN AGE	#WHITE	#BLACK	#HISPANIC
MALES	50.67	6	0	0
FEMALES	63.33	3	0	0

The Texas State University-San Marcos donated skeletal collection was founded in 2007 and currently houses approximately 30 individuals, with 109 body donations total. These individuals have birth years ranging from 1910 to 2012, and are between 36 weeks and 102 years of age. Due to the smaller size of the collection, there is a limited number of autopsied individuals, thus all 9 were sampled. Unlike the collection at UTK, the donation number is the only visible information on each donated individual’s collection box. This allows for data collection to occur while avoiding observer bias. After data collection, the corresponding biological profile information was recorded. Data collection at Texas State University-San Marcos followed the same procedures as those utilized at

UTK (above). A total of 9 individuals were sampled and included in the total sample (Table 1, Table 3).

At the end of data collection at each institution, 10% of the sample was randomly selected and the measurements for that individual retaken in order to calculate the intraobserver error. These measurements were recorded both in the scientific composition notebook and spreadsheet for record keeping and later compared to assess the variability and repeatability for the methods utilized.

Measurements

Metric measurements taken during data collection follow the points and definitions of Kalmey and Rathbun (1996) with one of their measurements taken from Wahl and Graw (2001) and additional requirements added during data collection to ensure standardization (Table 4; Figures 1-5). Each measurement was taken with a Kobalt 6" Metric and SAE Caliper and a General Tools & Instruments 3” Metric and SAE Caliper to the nearest hundredth and were re-zeroed after each measurement and checked for calibration after each individual. These tools were chosen due to their public availability and low cost in an effort to avoid methods that are cost prohibitive for researchers and professionals in the field.

Table 4: List of Measurements with Descriptions and Instructions for each. Original Descriptions are Derived from Kalmey and Rathbun (1996) and Wahl and Graw (2001); Modified Additional Descriptions are Provided on the Right Side by the Author.

MEASUREMENT	DESCRIPTION (KALMEY AND RATHBUN 1996)	ADDITIONAL DESCRIPTION
L	Sigmoid sulcus-petrous apex intersection (SS) to the most medial point on the petrous (med. Pt.)(sliding caliper)	Taken at suture closest to the endocranial wall for SS; if med. Pt is fused to sphenoid, do not insert caliper end inside the suture
C	SS to posterior (lateral) margin of internal acoustic meatus (IAM) (Sliding caliper)	Fit caliper jaw inside IAM for measurement—this becomes difficult with variation in cranial autopsy cuts
E	Posterior margin of IAM to eminentia arcuata (EA). Taken on EA at highest point; if EA is plateau or if it has two peaks at either end then take the measurement in the center (sliding caliper).	
HI	Height of IAM (taken at center of meatus)(vernier dial caliper)	Use inside jaws of calipers
B	Cochlear aqueduct (CA) to EA (sliding caliper)	This measurement may be impeded by extra bony growth around the CA.
D	CA to superior margin at IAM (center of superior IAM) (vernier dial caliper)	
F	CA to posterior (lateral) margin of IAM (from Wahl) (vernier dial calipers)	
G	EA to med pt. (sliding caliper)	if med. Pt is fused to sphenoid, do not insert caliper end inside the suture
W	CA to hiatus of facial canal (sliding caliper)	This measurement may be impeded by extra bony growth around the hiatus of the facial canal or the formation of a bony bridge.

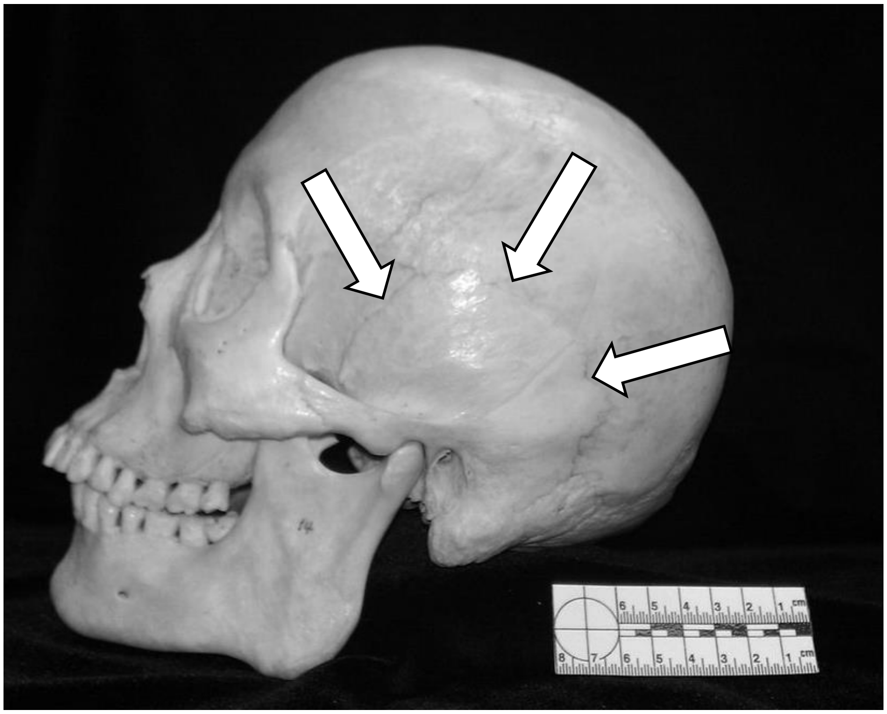

Figure 1: Lateral left ectocranial view of a human skull with arrows pointing to left temporal bone.

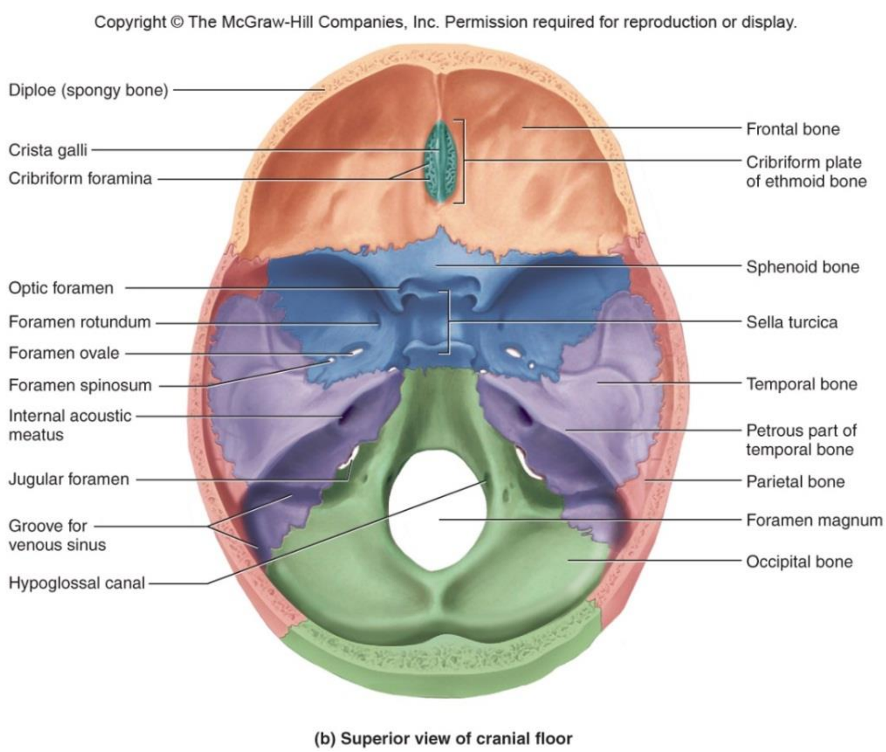

Figure 2: Transverse endocranial view of the human skull with the temporal bones denoted in purple and other identifying features labelled (The McGraw-Hill Companies, Inc.).

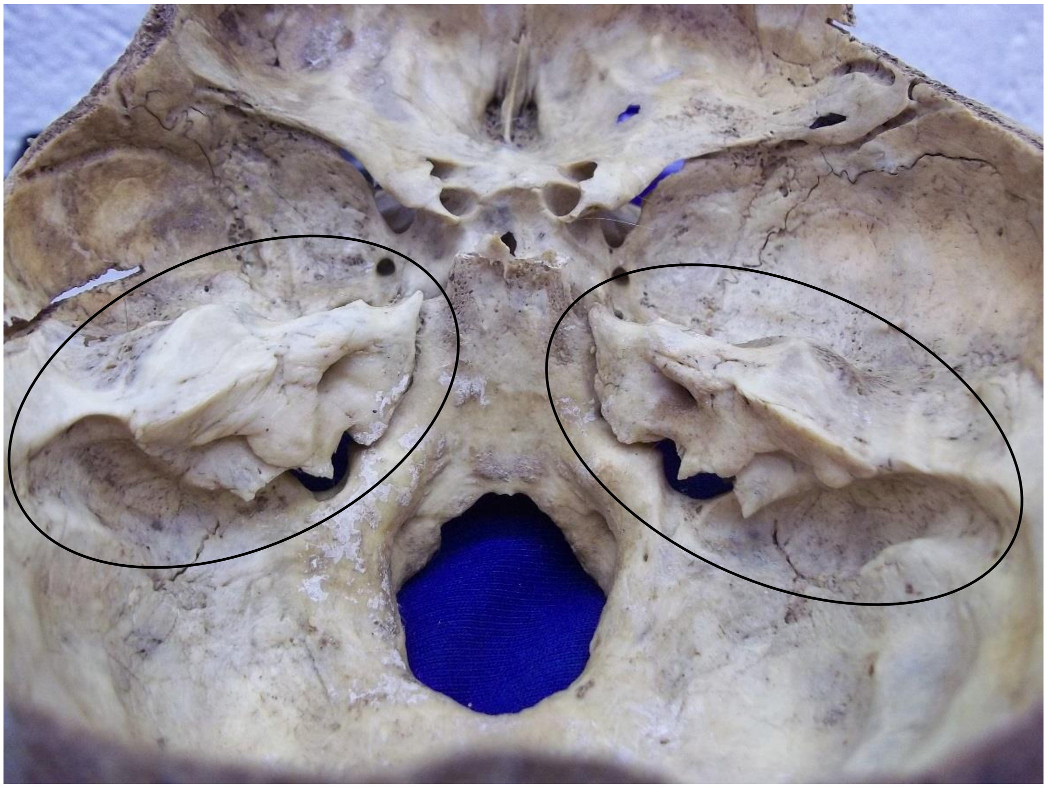

Figure 3: Posterior view of the endocranium of a human skull with both petrous portions demarcated with black circles.

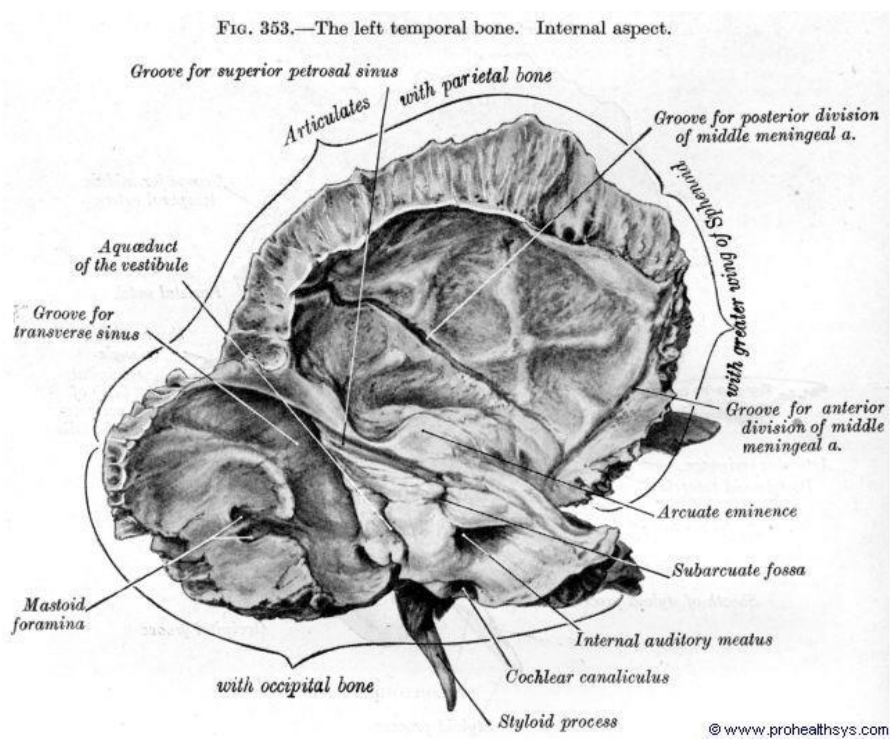

Figure 4: Diagram of a left temporal bone (Gray's Anatomy taken from www.prohealthsys.com).

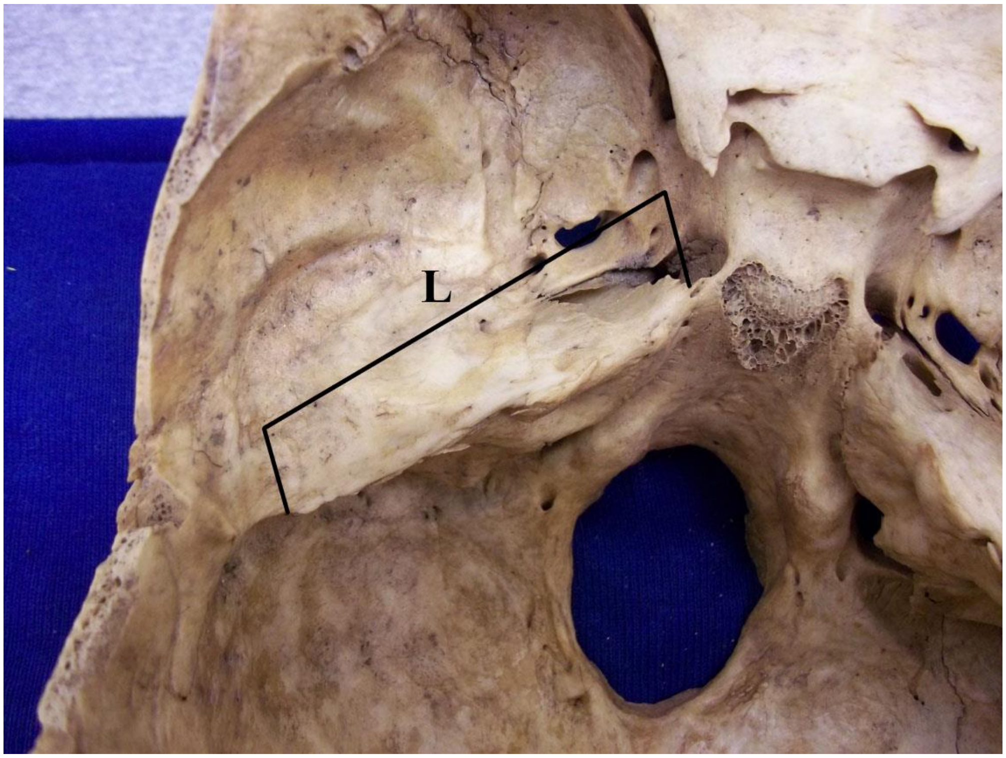

Figure 5: Superior view of the left petrous portion with measurement L.

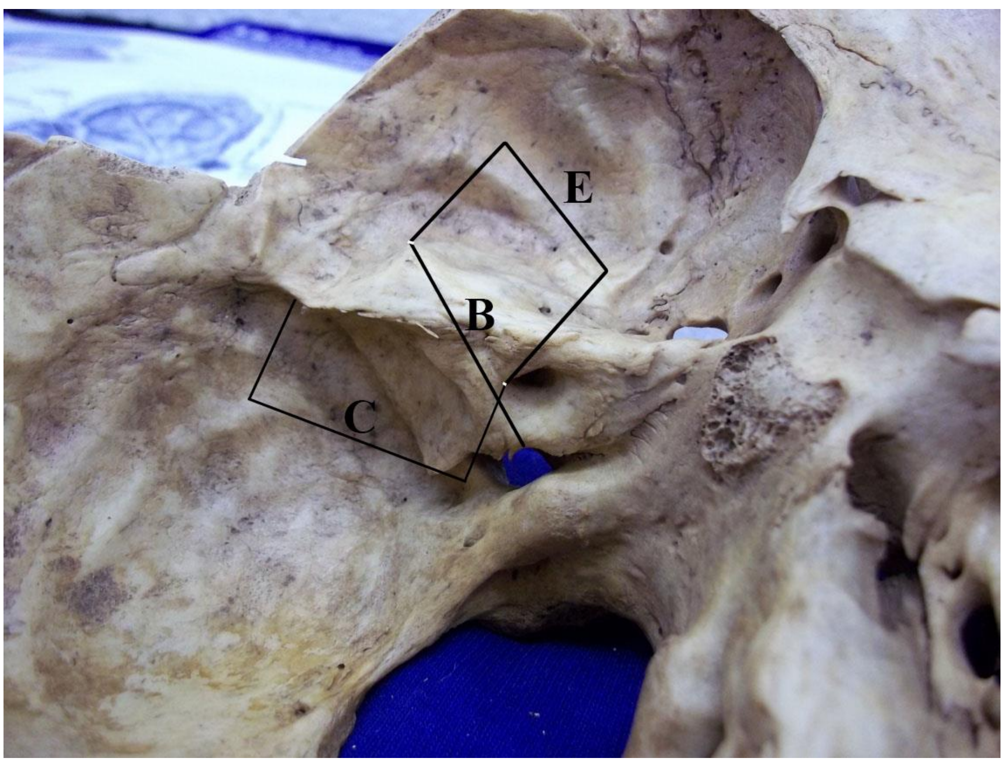

Figure 6: Posterior medial view of the left petrous portion with measurements C, B, and E.

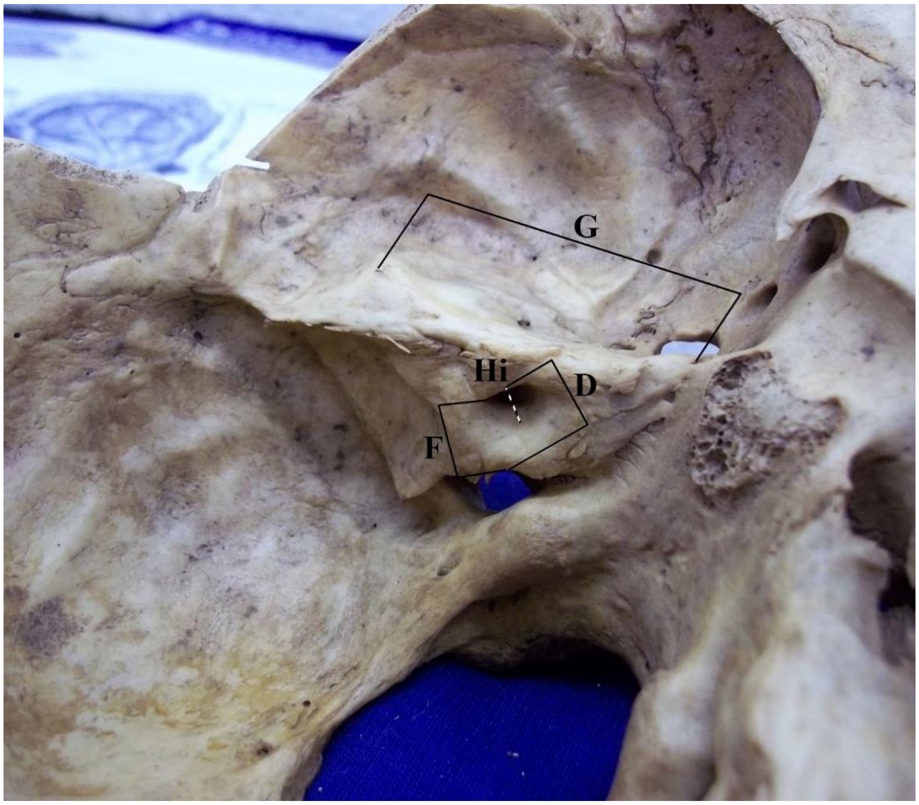

Figure 7: Posterior medial view of the left petrous portion with measurements G, HI, D, and F.

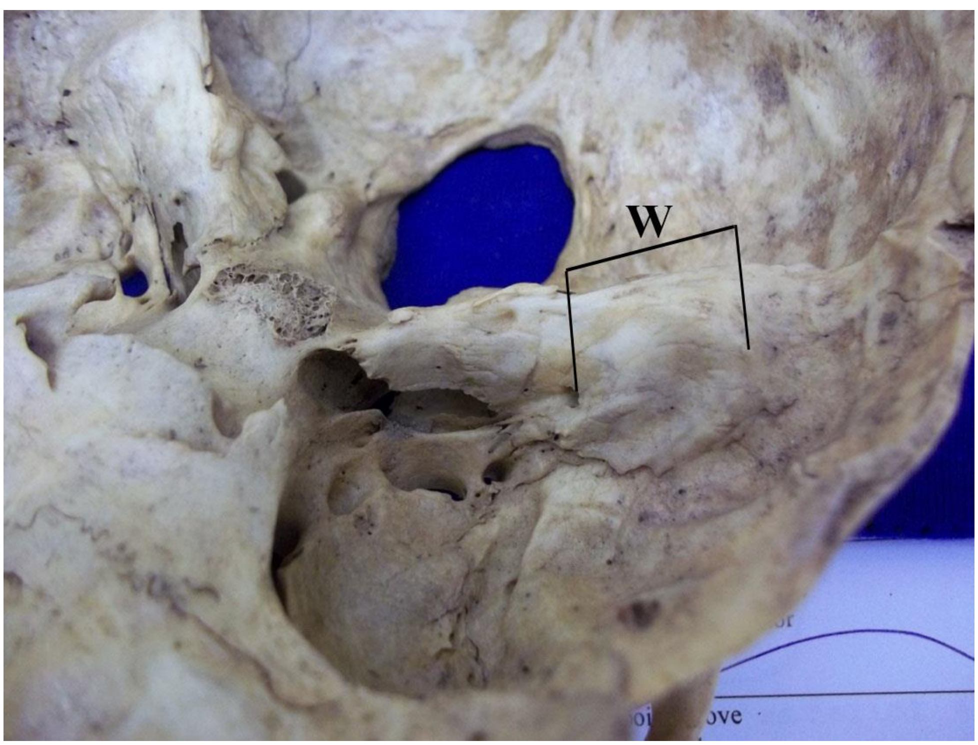

Figure 8: Anterior view of the left petrous portion with measurement W.

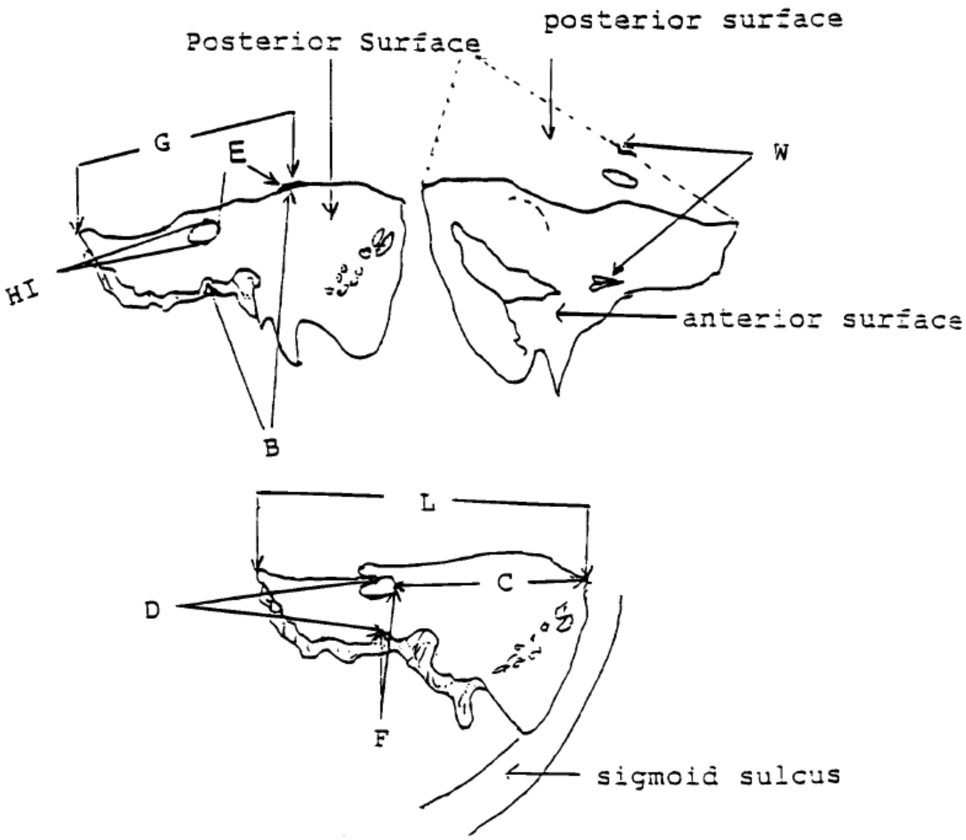

FIG. 1—*Illustration of measurements, viewing right petrous section.*

Figure 9: Original diagrams of measurements from Kalmey and Rathbun 1996.

Statistical Methods

Statistical methods applied in this study followed the protocol established by Bongiovanni's analysis of the sternum, which included similar questions, materials, and hypotheses (Bongiovanni 2010). These statistical methods were chosen due to the similarities in metric analysis and similar goals involving the estimation of sex from metric measurements. These methods include descriptive statistics of petrous portion measurements (frequencies, means, standard variations, and variances), generalized linear model MANOVA procedures for the 9 measurements in the study, discriminant function analysis and a stepwise discriminant function analysis. All statistical analyses were performed with the program Statistical Package for the Social Sciences (SPSS) on February 14th, 2013.

The Generalized Linear Model MANOVA (GLM MANOVA) procedure was performed to assess if a statistically significant relationship existed between each variable utilized in this study and sex. This procedure also discerned which individual variables provide the best measures for the estimation of sex. Measures that provide significant results at the 0.05 level were considered statistically significant and acceptable in proceedings of court as evidence according to Daubert rulings (Grivas et al. 2008). Additional GLM MANOVA procedures were performed in order to discern any other relationships between metric measurements and age, ancestry, and sex. Significant results at the 0.05 level for these analyses gave insight into other factors that affect morphology and measurements that can confound estimations of sex from the petrous portion.

A discriminant function analysis was performed to determine which measurements are the best estimators of sex and provide classification rates for males, females, and pooled sex.

A stepwise discriminant function analysis was then performed to discern if a combination of measurements provide a better estimator of sex. This was followed by linear discriminant function analysis to develop an equation for the estimation of sex using those metric measurements selected in the stepwise discriminant function.

The linear discriminant function equation was derived following the stepwise discriminant function analysis from the output through the subtraction of the group means of selected measurements of males and females. The resulting equation will provide a quick and easy way to estimate the sex of an individual, as those who fall above the discriminant value would result in a male sex designation and those who fall below the discriminant value would result in a female sex designation. Individuals who fall on the discriminant value will be assigned an ambiguous sex designation. Creating a linear discriminant function equation with these measurements will be important for contexts in which forensic remains of individuals are not complete and only a few of the measurements may be taken. Discriminant function analysis and sectioning points resulting from analysis must provide cross-validated rates of classification and be statistically significant at the 0.05 level to be considered significant in this study and to be used as evidence in court proceedings as a result of the Daubert rulings (Grivas et al. 2008).

CHAPTER III

RESULTS

Statistical analysis performed on the data collected from osteological collections at The University of Tennessee-Knoxville and Texas State University-San Marcos were performed via Microsoft Excel to compute intraobserver error and descriptive statistics for each measurement. The statistical software package SPSS was used for the remaining statistical analyses.

Descriptive Statistics

Descriptive statistics for each of the 9 measurements from The University of Tennessee-Knoxville are available in Table 5, and from Texas State University-San Marcos in Table 6. Table 7 features descriptive statistics from pooled data from both skeletal collections.

Intraobserver Error

Intraobserver error was performed for this study utilizing a 10% approach. This means that at the end of the data collection process at each institution, 10% of the total sample at each institution was measured an additional time. On the measurements that were retaken as part of this procedure and the original measurements, a Pearson's correlation coefficient analysis was performed. This analysis provided a near perfect positive linear relationship for each pair of measurements taken for the individuals sampled twice for error estimations.

Table 5: Descriptive Statistics of Individuals from UTK

VARIABLE	N	MIN	MAX	MEAN	STDDEV
L	109	41.85	60.14	50.539	3.867
C	102	18.11	39.53	27.527	3.700
E	107	12.01	28.15	18.236	3.234
HI	110	2.01	6.6	3.886	0.766
B	108	2.22	31.16	24.045	3.774
D	107	6.86	12.27	9.703	1.118
F	100	4.81	10.5	7.418	1.112
G	103	28.81	48.41	37.499	4.073
W	104	10.19	21.76	17.208	1.821

Table 6: Descriptive Statistics of Individuals from TSU-SM

VARIABLE	N	MIN	MAX	MEAN	STDDEV
L	9	44.5	56.4	51.16	3.937
C	9	23.37	34.03	27.918	3.321
E	9	13.9	27.56	18.421	4.208
HI	9	2.66	5.68	4.124	1.084
B	9	19.07	32.23	24.582	3.627
D	9	6.85	11.64	9.794	1.376
F	9	5.94	9.16	7.81	0.996
G	9	32.26	45.26	37.377	4.348
W	7	12.03	18.07	15.899	1.946

Table 7: Descriptive Statistics of Pooled Data

VARIABLE	N	MIN	MAX	MEAN	STDDEV
L	118	41.85	60.14	50.587	3.859
C	111	18.11	39.53	27.559	3.658
E	116	12.01	28.15	18.251	3.297
HI	119	2.01	6.6	3.904	0.791
B	117	2.22	32.23	24.086	3.750
D	116	6.85	12.27	9.710	1.134
F	109	4.81	10.5	7.451	1.104
G	112	28.81	48.41	37.489	4.075
W	111	10.19	21.76	17.125	1.848

For the individuals sampled from The William M. Bass Donated Skeletal Collection at The University of Tennessee-Knoxville, r ranged from 0.995 to 0.999. From data collected from individuals in the Donated Skeletal Collection at Texas State University- San Marcos, r measured approximately 0.999. With the collections pooled together, the r values ranged from 0.995 to 0.999. These consistently strong r values indicate the high level of repeatability and overall reliability of this method.

General Linear Model MANOVA

The General Linear Model MANOVA (GLM MANOVA) procedure was performed in SPSS on all measurements with sexes pooled to discern significant differences between males and females, between ancestry groups including White, Black, and Hispanic, and between different ages at death. Additionally, GLM MANOVAs were also performed to discern if various combinations of sex, ancestry, and different categories of age at death were acting upon estimations of sex as confounding variables.

Results of the GLM MANOVA indicate significant differences in sex between males and females for 2 different measurements. Measurement D (superior margin of the internal acoustic meatus to the cochlear aqueduct) demonstrates significance differences between males and females at p= 0.000 and measurement F (cochlear aqueduct to posterior margin of the internal acoustic meatus) demonstrates significant differences between males and females at p= 0.029.

Additional GLM MANOVA procedures were performed to discern if significant relationships existed between measurements of the petrous portion and age at death, sex, ethnicity and multiple combinations of age at death, sex, and ancestry. The results of these procedures provided interesting insights into the relationship of endocranial morphology and biological variants. Results demonstrate no statistically significant differences between metric measurements and ancestry, but reveals significant relationships between metric measurements of the petrous portion and age at death parsed by decade intervals for measurement D at p=0.024. Results for GLM MANOVA performed between metric measurements and age at death parsed by 2 decade intervals resulted in statistically significant differences between age and metric measurements for HI at p=0.004, D at p=0.003, and F at p=0.02.

To discern if age at death, sex, and ethnicity were acting as dependent variables rather than independent non-complementary variables, GLM MANOVAs were also performed for all possible combinations of sex, age at death by decade intervals, age at death by 2 decade intervals, and ancestry. These combinations can be found in Table 8, Table 9, and Table 10.

Table 8: Relationships Between Metric Measurements Paired with Variables

COMBINATION	SIGNIFICANT?	MEASURES
MEASURES, SEX	SIGNIFICANT	D: 0.000 F: 0.029
MEASURES, AGE (1 DECADE)	SIGNIFICANT	D: 0.024
MEASURES, AGE (2 DECADES)	SIGNIFICANT	HI: 0.004 D: 0.003 F: 0.02
MEASURES, ANCESTRY	NOT SIGNIFICANT	N/A

Table 9: Combinations of Paired Variables with Metric Measurements

COMBINATION	SIGNIFICANT?	MEASURES
MEASURES, SEX, AGE (1 DECADE)	SIGNIFICANT	D: 0.018
MEASURES, SEX, AGE (2 DECADES)	SIGNIFICANT	HI: 0.010 B: 0.037 D: 0.001 F: 0.031 G: 0.048
MEASURES, SEX, ANCESTRY	SIGNIFICANT	D: 0.006
MEASURES, AGE (1 DECADE), ANCESTRY	NOT SIGNIFICANT	N/A
MEASURES, AGE (2 DECADES), ANCESTRY	SIGNIFICANT	HI: 0.023 B: 0.028 D: 0.037

Table 10: Combinations of Three Variables with Metric Measurements

COMBINATION	SIGNIFICANT?	MEASURES
MEASURES, SEX, AGE (1 DECADE), ANCESTRY	NO SIGNIFICANCE	N/A
MEASURES, SEX, AGE (2 DECADES), ANCESTRY	SIGNIFICANT	H: 0.028 B: 0.029 D: 0.008 F: 0.059

Discriminant Function Analysis

The discriminant function procedure yielded a total sample size of 97 individuals included in the analysis, comprised of 42 females and 55 males. The natural log of the determinant of the covariance matrix yielded 10.285, signifying that the data are not over fitted. Cross-validation for classifications utilizing discriminant functions of the used measurements yield a classification rate of 25 out of 42, or 60% of females correctly classed, and 36 out of 55, or 66% of males correctly classed. The total correct cross-validated classification rate is 63%.

Stepwise Discriminant Function Analysis

The discriminant function procedure with stepwise variable selection was performed to discern if a combination of variables together would provide a better estimation of sex. Variables selected included D and C. This analysis utilized 42 females and 55 males for a total of 97 individuals. The natural log of the determinant of the covariance matrix yielded a value of 2.718, signifying that the data have not been over-fitted. Cross-validation for classifications utilizing linear discriminant functions of the stepwise selected measurements yielded correct classification of 26 out of 45 females (58%), and 47 out of 65 males (72%) with a total classification rate at 66%.

A linear discriminant function was created from the results of the variables chosen via the stepwise discriminant function analysis above. The stepwise DFA procedure chose significant variables included in the study that provided a statistical significance of p=0.05. Variables chosen from this procedure were D and C and yielded approximately 66% correct classifications of sex when used together as stated above. When the equation was applied to the entire sample group used in this study, including those that were not included in the statistical analysis due to missing measurements, resulted in approximately 72.8% correct sex classifications. For each individual, the measurements for C and D are taken and input into the equation, then the variables and the constant for this equation are added together (Table 11). Ending values less than 0 are considered female, while ending values greater than 0 are considered male. Values at 0 are considered to be ambiguous

Table 11: Linear Discriminant Function Equation for Sex Estimation

VARS	**METRIC 1**	**METRIC 2**	**CONSTANT**
C, D	-0.146 (C)	0.799(D)	-3.423

CHAPTER IV

DISCUSSION

The goals of this research determined if methods utilizing metric measurements of the petrous portion of the temporal bone are appropriate to estimate sex of individuals. This study utilized the established measurements of Kalmey and Rathbun (1996) based on historical individuals and tested if the metric measurements were significant in the estimation of sex of contemporary American individuals. Measurements are considered significant at the $p = 0.05$ level, which is the required statistical level of significance to be admitted as scientific evidence in a court of law based on Daubert rulings (Grivas et al. 2008).

As much forensic work for mass fatality and traumatic accident identification is done in the field and many techniques in use today such as those that involve DNA analysis are too costly for large case amounts, using and testing more cost-effective materials is imperative. The purpose of this research tested a set of established measurements based on historical individuals housed within the Terry Collection at the Smithsonian Institution and applied them to contemporary individuals so as to provide an additional method of sex estimation to the arsenal of forensic anthropologists. Previous research demonstrated that aspects of the biological profile such as long bone length, which can be used as a proxy for stature, vary throughout time due to secular change (Jantz and Jantz 1999). Secular change is shown to be affected by both environmental factors, such as improved nutrition and health status (Jantz and Jantz 1999). By examining contemporary individuals in the current study and comparing results to the previous study which utilized historical collections, an inference can be made regarding possible change over time of the morphology of structures of the endocranium such as the petrous portion. Additionally, as the petrous portion is one of the densest regions of bone in the human body and preserves well in cases of traumatic accidents and poor preservation environments, this method could be an important tool in medicolegal investigations where methods such as DNA analysis and other methods of sex estimation cannot be utilized due to cost or due to poor quality of remains.

The results of this study show that metric measurement of the petrous portion can estimate sex in modern populations and is statistically significant at the 0.05 level. Correct classifications of sex reached upwards of 73% in this study. Intraobserver error measured through a Pearson's correlation coefficient provides between 0.995 and 0.999, indicating an extremely high positive correlation and thus high repeatability. Although the results are not as high as other methods of sex estimation, such as visual morphological trait assessment of the pelvis and skull and metric measurements of various long bone features and cranial measurements utilizing complete osteological elements or a combination of elements (Dwight 1905; Giles and Elliot 1963; Spradley and Jantz 2011; Walker 2008; White and Folkens 2005), the results show significant association between metric measures and sex that are greater than chance (50%). As this method is based on measurements of only the petrous portion of the temporal bone without relying on any other related structures or features of the skull, this method has the potential to provide forensic professionals with another method of estimating sex of individuals with highly fragmentary remains where other osseous elements are not present or well preserved.

The PROC GLM MANOVA procedure in SPSS was performed on all measurements to discern the presence of significant differences between males and females, between ancestral groups including White, Black, and Hispanic, and to see if relationships between sex, ancestry, and age at death affected sex estimation. The procedure yielded no significant differences for any individual variable with relation to ancestry or ancestry and sex paired together; however, due to the small number of Black and Hispanic individuals that were available for inclusion in this study it cannot be said that ancestry does not affect measurements of sex in the petrous portion. More research with a higher number of individuals from other ancestral groups should be included before considering sex estimation using the petrous portion to be unrelated to an individual's ancestry.

This GLM MANOVA procedure, however, revealed other statistically significant relationships between metric measurements used in this study and various other variables. First, age at death of individuals included in this study were parsed into decade intervals in 8 categories: 20-29, 30-39, 40-49, 50-59, 60-69, 70-79, 80-89, and 90-99. When compared only with metric measures, age at death in decade intervals was only significant for measurement D (cochlear aqueduct to superior margin at the internal acoustic meatus) at $p=0.024$. When analyzed with both metric measures and sex, age at death in decade intervals was also only significant for measurement D at $p=0.018$. Age at death in decade intervals was not significant, however, when compared with ancestry or when compared with sex and ancestry. Due to the small sample size present when age at death was parsed into these eight categories and due to only one variable being significant, age at death by single decade intervals may not be the best way to parse and examine age at death and measures used.

Broader decade categories for age at death were then examined in order to see if more individuals in each category would result in significant results. Age at death was parsed into four categories by 2 decade intervals, beginning with 20-39, 40-59, 60-79, and finally ages 80-99 comprising the final group. The PROC GLM MANOVA reveal a much more statistically meaningful relationship between age at death by 2 decade intervals and the measurements in this study, with significant measurements including HI (height of the internal acoustic meatus) at $p= 0.004$, D at $p= 0.003$, and F (cochlear aqueduct to posterior lateral margin of the internal acoustic meatus) at $p=0.02$. When compared with measurements and sex together, age at death by 2 decade intervals is significant for 5 different measures, including HI, B (cochlear aqueduct to arcuate eminence), D, F, and G (arcuate eminence to medial point). When paired with metric measures and ancestry, and with metrics, sex and ancestry, measures HI, B, and D were all significant. HI, D, F all comprise measurements that include the internal acoustic meatus with B and G including the arcuate eminence. The location of these significant measures along the outer periosteal layers of the petrous portion as well as their general location in the endocranium suggests that measurements including these 2 features may be the most susceptible to age related changes in morphology of the petrous portion.

Finally, the results of the primary focus of this study, which was to determine if there exists a significant relationship between metric measures and sex, resulted in significant differences in sex between males and females for measurements D and F at the 0.05 level. The statistically significant relationship between these two measurements and sex suggest that sexual dimorphism is present among males and females in the petrous portion of the temporal bone. Cross-validation for classifications utilizing linear discriminant functions through the discriminant function analysis yield a classification rate of 25 out of 42 of females (60%) correctly classed and 36 out of 55 of males (66%) correctly classed and a total classification rate of 63% cross-validated. Though these are not high classification rates, they are higher than chance.

The discriminant function procedure with stepwise variable selection was performed to discern if a combination of variables together would provide a better estimation of sex. The stepwise procedure chose the variables that were the better estimators of sex which included measurements C (sigmoid sulcus to posterior lateral margin of the internal acoustic meatus) and D. Classifications utilizing these two measurements together to estimate sex as a linear discriminant function yielded correct classification of 26 out of 45 females (58%), and 47 out of 65 males (72%). Utilizing the stepwise selected variables together as an estimator of sex resulted in lower classification rates for females, higher classification for males, and a higher total cross-validated correct classification rates rising to 66%. The stepwise discriminant function analysis gave a slightly higher classification rate for males and females than did the discriminant function analysis without stepwise variable selection.

It is clear, however, from these results that the petrous portions of females are most often misclassified when compared to males, especially at the results of the stepwise discriminant function analysis. This could be caused by several factors including an underrepresentation of females in the sample or the possibility that there could be an age related bias present in the sample. Age-related effects have been known to affect the morphology or structure of bony elements of the female skeleton, such as masculinization of the cranial features with increasing age in females; however, more research is needed to fully understand this process (Rogers 2005). As the average age at death of females in this study is ~55 years with a median of 54 years, and the male average age at death at ~49 years with a median also at 49 years, the older age of women in this sample compared to men could indeed be pulling the estimations of sex upwards toward higher end values that classify the individual as male when utilizing the discriminant function equation which could reflect masculinization processes of the endocranium in females.

Overall, Kalmey and Rathbun's (1996) methods for metric measurements of the petrous portion yielded between 66-74% accuracy in correctly estimating the sex of individuals of historic significance housed in the Terry Collection at the Smithsonian Institution. This percentage represents the range of correct classifications for males and females in the previous study. The results of this current study show that similar accuracy percentages from 58-73% can be achieved utilizing the same metric measurements of the petrous portion on contemporary individuals. Regardless of historical or contemporary provenience, measurements of the petrous portion in this research or previous research have not exceeded 74%. This research, however, represents the first time the petrous has been measured with these numbers on modern individuals. This method still affords forensic practitioners another accurate method to estimate sex in situations that demonstrate an absence of other bones or presence of other fragmentary osseous elements.

CHAPTER V

CONCLUSION

This research focused on applying the metric methods of Kalmey and Rathbun (1996) based on the historic Terry Collection housed at the Smithsonian Institution to modern individuals from two donated skeletal collections. The purpose of this research focused on two questions: Can metric measurements of the petrous portion be used to estimate the sex of an individual in a forensic medicolegal context? If so, how accurate is this method?

This research began during the summer of 2012 and sampled individuals from the William M. Bass Donated Skeletal Collection at The University of Tennessee-Knoxville and the donated skeletal collection at Texas State University-San Marcos. A total of 118 individuals with cranial autopsies were randomly sampled and tested. Included in the study are individuals of White, Black, and Hispanic ancestry. Age at death for individuals included in the sample ranged from 20 years to 91 years.

Results showed a significant relationship between metric measurements utilized in this study compiled by Kalmey and Rathbun (1996) and estimation of sex. Variables D and F were found through the GLM MANOVA procedure to have the highest significant relationship out of all 9 variables. Discriminant Function

Analysis resulted in a cross-validated classification rate of 59.5% of females correctly classed and 65.5% of males correctly classified. Stepwise Discriminant Function Analysis selected variables D and C as the greatest predictors of sex and resulted in a linear equation to determine a sectioning point:

$$-0.146\ (C) + 0.799\ (D) - 3.423$$

Ending values that are positive classify as male while negative values classify as female.

This linear discriminant function equation resulted in the correct classification of 57.8% of females, 72.3% of males, and 66.4% total correct classifications of sex cross validated. When applied to the entire sample group used in this study, using this equation resulted in approximately 72.8% correct sex classifications.

In addition to exploring the relationship of sex and the metric measurements utilized in this study, GLM MANOVA procedures were also performed for all combinations of ancestry, age by decade intervals, age by 2 decade intervals, and sex. Ancestry showed no significant relationship with any combination of variables except when combined with age at death by two decades and age at death by two decades and sex, but sample sizes of other ancestral groups must be increased in future studies for further inferences to be made. Age at death parsed by decade intervals with 8 categories was only significant at measurement D.

Age at death parsed by 2 decade intervals with 4 broad categories, however, showed a significant relationship between metric measurements, sex, ancestry, and when compared with sex and ancestry together. Parsing by 2 decade intervals allowed sample sizes for each category to be larger and more representative of the sample collected. The resulting significance of every combination utilizing age parsed into categories of 2 decade intervals has very important implications. This suggests there may be a relationship between the morphology of the petrous portion of the temporal bone and increasing age. As the mean total age at death for females in this study was approximately 56 years and the mean age for males was 49, a bias toward older females may be present in this sample. Along those same lines, these results may suggest that a form of masculinization of the endocranium with increasing age may be present. More research should be conducted to further explore the relationship of age with the morphology and appearance of the petrous portion to better understand possible age related changes that could affect identification processes.

Limitations

One major assumption that should be addressed is that the individuals in this study sample are representative of the population. This sample, though as broad as possible with the applied limitations of sampling only autopsied crania, cannot hope to be representative of the entire population of the United States. With an increase in the number of foreign immigrants into the United States, more ancestral groups aside from Whites and the small group of Blacks and Hispanics here must be included to provide a more inclusive technique and ensure that ancestry, indeed, does not play a part in the morphological differences in the petrous portion. Further research utilizing more sub-populations can help to affirm or refute the possibility that metric analysis of the petrous portion is a non-population specific technique that can be applied on any ancestral group in the United States.

Factors noted above that could also affect the measurements include an underrepresentation of females in the sample, an age-related bias in the sample with females at age 55 and males at age 49. As shown, however, for the small sample available for use in this study there is no statistically significant relationship between ancestry and the metric measurements taken in this study or a combination of sex and ethnicity except when compared with age at death in broader 20 year intervals. A more equal ratio of males and females in the sample may, however, improve the percentages of correct classifications.

Other factors not discussed above can also include the sampling process. Though all samples were randomly selected based on the presence of cranial autopsies, not all individuals could be sampled due to the quality or dimensions of the cranial autopsies performed. Additionally, the sample was reduced due to misdocumentation of cranial autopsies performed on several individuals. In terms of those individuals with cranial autopsies, craniotomy procedures resulting with higher endocranial walls were much more difficult to measure than individuals with skewed cranial autopsies or larger callotes. Indeed, many times a measurement was not possible due to the interior dimensions of an individual’s autopsy. Further, it is unclear if there is asymmetry present among the right and left petrous portions of individuals. Future research should address this possibility.

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Advantages

This method utilizes an element of the human body that does not have direct association with the outside environment or individual musculature. As such, occupation and musculoskeletal markers or MSMs are not likely to show and have not in previous studies shown any effect on the morphology of the petrous portion of the temporal bone. Through the study of contemporary individuals, the results of the current study does not vary remarkably from the previous study by Kalmey and Rathbun (1996) utilizing historical individuals. This suggests that secular change over time, which can be affected by genetics and environmental factors such as improved nutrition and health status, is most likely not present in the petrous portion of the temporal bone. This suggest that features of the endocranium such as the petrous portion, in addition to not being susceptible to occupational MSMs and other environmental agents, may not be affected through over time by secular change.

Applications and Future Research

Forensic practitioners can utilize this methods through the use of digital sliding metric calipers that are widely available at most hardware and home improvement stores. Practitioners should view the original definitions provided by Kalmey and Rathbun (1996) as well as the additional notes provided by the author of this research project (Table 4). Together, measurements C and D are the two best estimators of sex when used in the equation above for the sectioning point.

The results of sex estimation utilizing these methods mirrors the results of Kalmey and Rathbun (1996), resulting in between 65-74% accurate classification rates of males and females utilizing the stepwise discriminant function results and sectioning point equation. This method provides a method of sex estimation that can be used as an estimator of sex in the absence of other osseous elements. This can be particularly useful in real world applications in cases of high impact accidents and mass fatalities, such as plane crashes, commingling, and other situations of poor preservation or high fragmentation of osteological remains of individuals where the chance of finding intact skeletal remains may be slim. Since the petrous portion is one of the densest elements of bone (Isçan 2005) and is often the only element present in such cases, this method will provide another technique useful in aiding the identification of individuals when other, more diagnostic elements may not be present or are too damaged to be used with integrity. Additionally, as there appears to be no secular change in the measurements of the petrous portion through time for historical and contemporary individuals, this method may also be applicable in bioarchaeological contexts where soils and other taphonomic factors result in poor preservation. Further research should explore this possibility.

Future studies involving the petrous portion should investigate the possible presence of asymmetry between the right and left petrous portions. Larger sample sizes of Blacks, Hispanics, and the inclusion of other ancestral populations found in the United States should also be included to either accept or refute the possibility that this method of sex estimation may not be ancestry dependent. The constraints of this study will limit the use of known collections to include only those individuals that have cranial autopsies performed before skeletal donation at death or cranial fragmentation that would allow access to the petrous portions. Despite this limitation, such collections, though small in sample size, do exist. Additionally, research should also be conducted to test bioarchaeological collections that have the petrous portions and pelves of individuals available to further test the presence or absence of secular change in the endocranium through the passage of time. Finally, researchers should investigate further into the relationship between age and morphology of the petrous portion, especially with the possibility of masculinization of the female endocranium with increasing age.

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