THE ESTIMATION OF ANCESTRY AND SEX IN UNKNOWN INDIVIDUALS THROUGH A COMPARISON OF METHODS

by

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This thesis was prepared under the direction of the candidate's thesis advisor, Dr. Meredith Ellis, Department of Anthropology, and has been approved by the members of her supervisory committee. It was submitted to the faculty of the Dorothy F. Schmidt College of Arts and Letters and was accepted in partial fulfillment of the requirements for the degree of Master of Arts.

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ABSTRACT

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When unidentified skeletal remains are found, researchers utilize a number of methods to apportion details for a biological profile. While these practices are used and professed through generations of students, they also require a reevaluation of the methods. This project estimates the ancestry and sex of nine unknown skeletal individuals through two different mechanisms. Modified biological profiles were completed through two different methodologies: anthroscopic traits (Buikstra and Ubelaker 1994; White et al. 2012) and geometric morphometrics using 3D-ID (Slice and Ross 2009). The results serve two purposes: (1) to provide ancestry and sex (2) to compare two methodologies through outcomes and repeatability of results. Intra-observer error testing was conducted on both methods. All outputs resulted in low intra-rater reliability, highlighting the repeatability error in one observer's collection methods. These results conclude and encourage the reevaluation and standardization of the procedures and comparison groups used to assess ancestry and sex.

ESTIMATION OF ANCESTRY AND SEX IN AN UNKNOWN POPULATION THROUGH A COMPARISON OF METHODS

LIST OF TABLES

CHAPTER ONE: INTRODUCTION

Humans have used categories of people, places, and things as a way to understand and navigate the world around them. Understanding things in their place, or putting things in a taxonomic hierarchy as Carl Linnaeus did, helps compartmentalize the environment and all the items within it. Specifically, the classification of human beings has been both an area of scientific inquiry, and a justification for prejudice. As anthropologists, it is common practice to understand ancestry and sex when identifying an unknown individual. The biological profile is the method by which this is done, and entails identification and description of sex, age, ancestry, pathology, and stature. These are the methodological criteria biological anthropologists use to make human identifications. For this study, ancestry and sex are the only two aspects of the profile addressed. Ancestry is defined as an expression of an individual's geographic region of origin, and sex is the biological traits that differentiate males from females (Nikita 2017). Two classifications have been determined through a combination and comparison of methods. Anthroscopic traits are used to visually assess the features that detail ancestry and sex, and geometric morphometrics are used to digitally classify each cranium into an ancestry and sex category.

Anthroscopic methods are visual inspections of identification using qualitative and categorical scales. These traits represent variants of the normal skeletal anatomy that cannot be quantified by metric measures; they are visual diagnostics qualified by a range

of physiognomic expressions (Buikstra and Ubelaker 1994; Slice and Ross 2009; White et al. 2012). They are recorded as either present or absent, and use ordinal scales for the degree of expression (Nikita 2017). In fact, "Over 400 traits have been identified in the human skeleton and they exhibit substantial heterogeneity" (Nikita 2017: 183). This methodology is traditionally used as the main approach of osteological analysis for human skeletal remains when determining ancestry, sex, age, and presence of pathologies, especially when examining partial human remains, or recovered remains. The benefits of using visual assessment of skeletal features have shown to be reliable and reproducible; they "can be obtained from fragmented assemblages, they are relatively easy to collect, and they work" (Hefner et al. 2012: 325). Conversely, non-anthroscopic traits, or quantitative traits, are observances on the skeleton that are measured with calipers, rulers, and other measuring equipment. Lengths and widths of features or regions of the skeleton are assessed metrically, and these numerical values are used for formulae and comparisons with other individuals. A downside to metric measuring is the common lack of complete skeletal remains available for analysis. Metric assessment often necessitates whole specimens in order to accurately obtain uniform quantitative information.

Ancestry has been determined by examining the cranium using the anthroscopic traits established in *Standards* (Buikstra and Ubelaker 1994; Rhine 1990) and in *Human Osteology* (White, Black, and Folkens 2012). A three-category ancestry identification system is used by professionals to narrow down the ancestry of unknown skeletal remains, and specifically using the cranium to do so (White et al. 2012). The most important awareness within the field is that ancestry identification is the summation of a *suite of traits* in estimating an individual's likely population identification (Humphries 2011).

The collection of traits is taken into consideration in order to provide the most conservative assessment of ancestry in an individual. Many other biological features like sex, age, and stature can be dependent on the primary establishment of ancestry, and more accurately, subsequent quantitative and qualitative traits vary based on an individual's ancestry (Spradley and Weisensee 2012). For example, American blacks and whites have different metric formulae to determine biological sex; therefore, in certain populations sex is estimated only after ancestry is confirmed (Spradley and Weisensee 2012). For this reason, ancestry is evaluated first.

Sex is also measured through anthroscopic traits. Biological males and females differ in two specific areas: the cranium and pelvis, and anthropometrics in these elements have shown distinguishing features between sexes (Phenice 1969; Howells 1973; Bass 1987; Walker 2008; White, Black, and Folkens 2012; Weisensee and Spradley 2013). As such, these regions are the focus of the anthroscopic assessment of the study. Sex is determined through analysis of both the pelvis and cranium. The pelvis is assessed using the Phenice Method (1969), an established sex estimation method using three characteristics of the human pelvis, and *Standards* (Buikstra and Ubelaker 1994), a compendium of guidelines for recording osteological remains. The cranium utilizes a five-point grade scale also presented in *Human Osteology* (White, Black, and Folkens 2012).

Geometric morphometrics is a suite of mathematical tools used to examine the three-dimensional shape of an object (Slice 2007). 3D-ID is a software program that analyzes crania through a combination of geometric morphometric techniques, and cranial landmarks pinpointed by Cartesian (x,y,z) coordinates. The program creates

digital models of crania, compares it with those in its database, and categorizes the ancestry and sex of each cranium through comparison with crania in the databank. The program also provides posterior probability and typicality of each cranium's matched ancestry and sex, indicating how common and typical the cranium is to the apportioned group.

Research question

This thesis conducts exploratory research to identify nine skeletons with no official documentation associated with the remains. The two mediums used for identification are anthroscopic techniques and geometric morphometric techniques using the software program 3D-ID.

The primary research question addressed is what is the sex and ancestry of each individual? The secondary question investigates how the results from the anthroscopic techniques and geometric morphometric techniques compare. Each question builds on the previous; thus, utilizing the results from the first research question to test the reliability of the techniques used through intra-rater reliability tests. In other words, what are the outcomes? How do the outcomes compare? What does this tell us about the testing methods themselves?

Population

The collection is composed of nine modern adult individuals with complete skeletal remains, including crania and mandibles. Many individuals retain third molars, indicating adulthood, but the individuals lack known origin and life history. Plausibly, the nine individuals were granted to the Department, or purchased from an undetermined company an unknown number of years ago. Context of each individual is limited to an

undergraduate analysis of the ancestries, statures, ages, pathologies, and sexes of each individual (Benitez, Sun, and Ramsey 2014), which was presented as a poster presentation for an undergraduate research symposium. Results from my analysis contribute to the previous results by providing two different techniques to obtain ancestry and biological sex for each case, but this previous project is not central to my research questions. This significant population provides valuable data, and an analysis of methods upon which future studies can expand.

CHAPTER TWO: SEX, ANCESTRY, AND TECHNIQUES

Qualitative methods utilize visual inspections that are not quantified by numeric measurements for estimation of a biological profile (Buikstra and Ubelaker 1994; Ousley and Jantz 2012). This method of skeletal investigation observes bone traits that are not solely unique to certain groups, but occur in all groups with varying frequencies (Ousley and Hefner 2005, 2006; Klales and Kenyhurcz 2015). Qualitative techniques to investigate human remains have been found to be an accurate and reliable means to investigate affiliation and relatedness of populations. The principles overarching this study emphasize that populations displaying the most similarities in morphology are the most closely related geographically and genetically. A corollary to this is the understanding that individuals, especially from the past, are more likely to choose a mate from nearby than farther away, creating pockets of genetic and geographic relatedness (Saunders 1978; Relethford 2004a). This latter point is the crux of the study of biodistance: crania are used to investigate the relatedness of individuals with the understanding that quantitative traits are affected by environmental and developmental factors. Craniometry is a viable tool used when distinguishing gene flow within and between populations. Its reliability and validity has been proven with evidence showing the majority of human diversity is found within individual and within regional populations (Roseman and Weaver 2004). Although the influence of these selective regional pressures is profound in populations, it does not erase patterns of genetic relatedness between populations (Relethford 2004a). Through visual, anthroscopic

assessments, recognizing the trends of familiarity between and among individuals connects individuals to a population, and populations to other populations.

Anthroscopic analyses are principally used to categorize individual crania and pelvises into ancestry categories and sex categories. Ancestry variation is a continuum that is a result of complex factors and evolutionary forces, such as migration, bottlenecks, and population divisions that interrupt gene flow as larger populations are split up (DiGangi and Moore 2013). While cranial shape and morphology are structured by geography, these evolutionary forces have forced noticeable varieties of skeletal and phenotypic traits as seen through the frequency of the traits appearing in certain geographic clusters or populations.

Anthroscopic traits used in biological sex determination are seen in the body structures of men and women. Generally, anthroscopic traits appear as more robust features in males and more gracile features in females, and these differences are seen throughout geographic regions (Buikstra and Ubelaker 1994; White et al. 2012). In the pelvis, males and females display intricate differences, with the appearance of some traits in females, and absent or ill-defined traits in males. For these reasons, anthroscopic traits are used in biological sex studies with a high degree of use and acceptability.

Ancestry

The roots of categorizing humans into discrete groups can be pinpointed to the publication by the famous taxonomer, Carolus Linnaeus, *Systema Naturae* (1759). This is the first recorded text of publicizing the different subgroups of the human species: *Homo sapiens africanus, americanus, asiaticus,* and *europaeus*. Linnaeus created these divisions of humans based on different anatomical and perceived differences in behavior

and social interaction (Dirkmaat and Cabo 2012). While noticing and recording human differences may have originated centuries prior to Linnaeus's publication, the onset of worldwide travel and development of scientific paradigms of thought catapulted the dialogue explaining why and how people looked and acted differently.

In contrast to Linneaus's understanding, German anatomist Johann Blumenbach understood human variation as many varieties emanating from degenerations from a single origin. His description of the origin was that of an original, "perfect", light-skinned form hailing from the Caucasus area. He explained the physical and social differences exhibited by different groups were due to different climates, nutrition, and modes of life. Blumenbach argued because of environmental variations, soft tissue and skeletal changes had manifested, and so he classified the human species into three groups with no hierarchical schemata: Caucasian, Mongolian, Ethiopian, American, and Malayan (Dirkmaat and Cabo 2012; DiGangi and Moore 2013).

These two opposing viewpoints on the beginnings of human beings and human variation set the stage for recurrent debates on the roots of human differences. In the 20th century, Samuel Morton, the 19th century physician, established the polygenist view of human variation and the "American School" of ethnography. The polygenist teachings he professed emphasized the ideas that different human groups stemmed from different originations (i.e. different Adam and Eves) (Larsen 2010; Caspari 2010; Geller and Stojanowsi 2016). The 19th-20th century anthropologists, Ales Hrdlicka and Earnest Hooton, continued these studies advocating that different evolutionary pathways have led to the different "races" seen today (DiGangi and Moore 2013). All of these scientists viewed the "most superior and smartest" of the humans is the white European-Caucasian.

While these biased views of human variation are fervently discredited today, Morton performed metric measurements on human crania, and such quantitative comparisons of human crania were established and used for ongoing studies.

During the turn of the century, Franz Boas performed a craniometric study of immigrants in New York City, This exploration threatened the polygenic view. He measured the skulls of living immigrant children and compared the metrics. He found that the siblings of those who were born in the United States had significantly different cranial lengths and widths than their siblings born overseas in Europe. Boas understood human variation as a reflection of the influence of culture, nutrition, stress, and climate. The reason for these differences was purely environmental (Boas 1912). This study challenged the notion that biological determinism, different races constitute different physical and sociocultural traits that predetermine a hierarchy of human beings, created people that were more developed and important than others. Many of these biological determinist studies were used as a way of classifying and identifying a criminal, or class of criminals, based on cranial measurements and correlated character traits.

Presently, human variation is understood in the way Boas understood it. *Homo sapiens* has no hierarchy of evolution, the environment does, can, and will influence human phenotype and culture, and no variant of human phenotype is of lesser or greater importance. However, measuring crania to identify ancestry is now used in forensic cases with unknown individuals, and in certain studies for biological distance. Through these differences lie a relationship between cranial morphology and social race categories. Identifying someone by "race" has become a socially constructed way of categorizing people frequently used in modern medico-legal terminology (Sauer 1992; Konigsberg et

al. 2009; Ousley et al. 2009). While some ways of identifying people by "race" can correlate to a geographic or ancestral origin, "race" has become a way of glossing over ancestry. It labels people by skin color and associated craniofacial phenotypes, and does not give credence to specific geographic backgrounds. Ultimately, "race" can negate differences in ancestry, heredity, and geography.

The question remains though, "If races don't exist, why are forensic anthropologists so good at identifying them?" (Sauer 1992). Races are a division between basic phenotypic differences, but concordance between social race categories and cranial morphology has been reported (Ousley et al. 2009). Clearly because there are differences in skull shape and geographic origins, researchers can actually measure trait frequency in specific populations. These trait frequencies can be measured using both metric and visual methods. This study expounds upon the visual, or anthroscopic, methods. Even though a simplified three-category system of ancestry is not the most descriptive of a population, in modern usage, categories such as, "Asian, European, and African" offer an easily communicated description of unknown human remains across disciplines. In the medico-legal sphere, the biological and social constructs of ancestry have overlapped through time, and have resulted in a consensus of these terms across medico-legal disciplines (Sauer 1992).

Modern Ancestry

When one looks around a room in the modern, globalized era, the array of faces displays many combinations of genetics and geographic origins. An individual's cranium, and the soft-tissue surrounding it, is the most observable source for information about their ancestry and are thusly used as the primary skeletal area for assessing ancestry.

Measuring crania to identify ancestry is now used in forensic cases with unknown individuals, geographic ancestry, and in certain studies for biological distance (Boas 1912; Buikstra and Ubelaker 1994; Relethford 1994; France 1998; Ross et al. 2004; White and Folkens 2005; Gonzalez et al. 2007; Hefner 2009; White, Black, and Folkens 2012; Humphries 2015; Ross et al. 2016). Allocating individuals into groups helps professionals understand the geography, or clines and nests in which we fit. Other anatomical methods, such as the pelvis and ribs, have shown distinguishing characteristics in different known ancestral populations (Iscan et al. 1987), but these assessments have not been deemed reliable and require further testing to prove their repeatability and reliability (Garvin 2012). Therefore, the cranium is the only region that is used for determining ancestry.

Ancestry establishment is one of the first aspects of the biological profile. Other features of the biological profile, including sex, age, and stature, depend on awareness of ancestry for more accurate reporting of these features. Subsequent quantitative and qualitative traits to determine these characteristics vary based on an individual's ancestry. For example, American black and whites have different metric formulae to determine biological sex, so clearly sex should only be estimated after ancestry is established (Spradley and Weisensee 2012).

The traditional categories used for medical examiners and medico-legal forensic specialists are separated into Asian-Native American-Indian, European-White, and African-Black. While it is challenging to pinpoint exactly from where an individual identified under one of the categories comes, globally there are local tendencies of variation (White et al. 2012). The most important caveat to note is that the origins of the

three-category system were borne from the masses of immigrants to the United States. Many individuals identified as "black" came from the slave trade region of Western Africa. Black in the North American medicolegal sense details the particular features from the populations in West Africa. "Black" does not specifically indicate African, but African does denote "Black" (White et al. 2012: 422). Yet a person from Haiti or Zimbabwe will most likely be categorized under the "African-Black" group because of the shared craniofacial features. This classification system also does not account for the immense gene pool and genetic variations seen in Africa today. Quite possibly, an individual with these similar cranial features living in Cuba or Brazil may also be classified into this category. Even though their ethnicity may be Hispanic or Brazilian, the biological ancestry classification could deem them as "African-Black". Although ancestry classification is associated with geographic roots, the three-category ancestry classification cannot always correlate ancestry with geography and self-identified ethnicity. This system is unmistakably problematic and is continually being improved with advancements in mathematics and DNA.

Method: Anthroscopic Ancestry Traits of the Cranium

For anthropometry, and especially craniometry, anthroscopic traits can be preferential to metric analyses in certain studies, and recording the frequency of each trait within a specified population is advantageous to a research design (Buikstra and Ubelaker 1994; Humphries 2011). For example, presence or absence of a postbregmatic depression does not require measuring how deep of an incurvature a skull may exhibit, but noting the number of skulls possessing this trait gives researchers ample information on the population altogether. Therefore, anthroscopic traits are observed on the skulls, and the

combination of the most evident traits conservatively elucidates in which ancestry group each cranium belongs. The traits used to determine ancestry are identified in the table below. The recording form for data collection is located in the Appendix.

Cranium

The human skull is a dynamic region of the body that relays a bevy of information. The malleability of the skull has been shown through a multitude of studies (Boas 1912; Howells 1973; Relethford and Blangero 1990; Relethford 2004, 2009; Humphries 2013). Four substantiated statements have become standard premises for ancestry studies within Anthropology:

1. Variation exists within and between populations
2. Environment (culture and geography) has exerted considerable influence on variation
3. Race is not a useful way, nor a correct way to describe populations
4. Research in human variation holds implications for society and fields such as forensics and medicine (Edgar and Hunley 2009).

There is still much discrepancy over how phenotype is displayed based on environment. Two realms of thought are enduring ongoing study: clinal variation and nested variation. Clinal variation is a gradual change of features in a species over a geographic area; it exists due to complex factors and evolutionary forces that interrupt population's gene flow as large populations are split into smaller ones. Nested variation means that diversity in one population is a subset of the diversity found in another (larger) population (Caspari 2010). Whether one or both of these organizational models are correct, the fact is that

phenotypic changes are apparent, visceral, and reflect the latitude and longitude from which one's ancestors emanate.

The skull can be divided into three regions: the face, base, and vault. These three regions of the human skull are strongly integrated and behave as a composite where changes in one region will produce correlated phenotypic changes in other regions (Martinez- Abadias et al. 2012). With studies demonstrating environmental adaptation of the cranium (Powell and Neves 1999; Relethford 2004; Ross et al. 2004; Von Cramon-Taubadel 2012), the morphology of the human skull truly reflects geographic and cultural influences as strong stimuli on the shape and size of human skull features. Urbanova et al. (2014) state, "The human skull, particularly the midface, has been shown to be the most reliable of the skeletal regions to estimate ancestry."

Table 1. Anthroscopic traits of Cranium. Adapted from: Rhine 1990; Buikstra and Ubelaker 1994; White and Folkens 2005; White, Black, and Folkens 2012.

Trait	Asian, American Indian	White, European	Black, African
Incisor Shape	Shovel-shaped	Blade-form	Blade-form
Incisor Rotation	Present	-	-
Carabelli's Cusp	-	Present	-
Dentition	Not crowded, well-sclerosed; enamel extensions, buccal pits	Small, crowded; Carabelli's cusp	Not crowded; molar crenulations
Palate	Elliptic	Parabolic	Hyperbolic
Zygomatics	Robust, flaring, malar tubercle	Small, retreating	Small, retreating
Zygomatic Tubercle	Present	-	-
Zygomatico-maxillary Suture	Angled	Jagged/ S-shaped	Curved/ S- shaped
Ascending Ramus	Wide and vertical	Intermediate and pinched ramus; slanted vertical ramus	Narrow and oblique, pinched, slanted
Chin	Blunt, median	Square, bilateral, projecting	Blunt, vertical, median, retreating
Mandible	Straight mandibular border; everted gonial angle	Cupping below incisors; undulating; straight gonial angle	Straight gonial angle
Prognathism	Moderate	Limited	Marked alveolar and facial
Palatine Suture	Straight	Jagged, Z-shaped, bulging	Arched, bulging
Cranial Sutures	Complex, with Wormian	Simple	Simple
Postbregmatic Depression	-	-	Postbregmatic Depression

Table 1. Continued

Cranial Vault	Low, sloping; keeled	High	Low with postbregmatic depression
Orbits	Rounded	Sloping/ Aviator	Rectangular
Base Cord	Short	Long	Long
Sagittal Arch	Low and sloping	-	-
Inion Hook	-	Present	-
Wormian Bones	Present; Inca bones present	-	-
Nasal Spine	Small/ medium, "tilted"	Long and large	Small, none
Nasal Sill	Blurred	Deep, very sharp	Guttered lower nasal border
Nasal Profile	Concavo- convex	Straight	-
Nasals	Low and tented, straight sides; angled at midline	Highly arched/ steepled; pinched in below root, break in contour at or near nasomaxillary	Low and flat, rounded contour
Nasal Aperture	Medium	-	Wide
Nasion	-	Depressed	-
Nasal Root	Tented/ intermediate	Steepled/ narrow	Wide
External Auditory Meatus	Elliptic	Round	Rounded
Canine Fossa	-	Canine Fossa present	-
Venous Markings	-	-	Venous markings (vascularization)
Metopic Suture	-	Metopic trace	-

Sex

Nutrition, hormones, sexual selection, body size, muscle mechanics, age, health, geography, genetics, and occupation can all influence the "masculinity" or "femininity" of an individual (Buikstra and Ubelaker 1994; Walker 2008; Garvin 2012). Sex estimation through skeletal analysis is most precise on the adult, post-pubertal skeleton. The cranium and pelvis display the most extreme sexually dimorphic features, and are predominantly used to establish sex. When determining biological sex, males have more pronounced and defined features because of thicker musculature with more massive areas of muscle origin and insertion than do females (France 1998; White et al. 2012). Where females generally have lighter and smaller bones, males have bulky and larger elements. The cranium is used in sex and ancestry identification in both anthroscopic and geometric morphometric techniques, and the pelvis is be used for only anthroscopic sex determination.

Analyses are typically conservative for these observations. Different populations have been found to display different rates of sexually dimorphic traits. This is seen through space and time (Steyn and Iscan 1998; Walker 2008; Hefner 2009). There can also be notable overlap with the sexual dimorphism between males and females. Geography, occupation, genetics, and nutrition, can influence females and individuals with larger body sizes to also exhibit pronounced muscle attachment sites (Cabo et al. 2012). For these reasons, seriation is a necessary practice. Therefore, researchers are to be familiar with the population they are studying as a whole, and score traits based on features relative to the population's observable parameters (Garvin 2012: 245). Because

this study examines unknown individuals who may all come from different populations, assessing sex in relation to population parameters is not possible.

In 1969, T.W. Phenice developed a method with a reported accuracy of 96%. These analyses were based on three traits of the human pelvis: the ventral arc, subpubic concavity, and medial aspect of the ischiopubic ramus (found to be the least reliable area of the three). Phenice examined these three traits on pelves of confirmed sex from the Terry Collection, and had a 96% accuracy rate in sex identification. The Phenice Method has persisted through the discipline and is a primary source of sex identification in *Standards* (Buikstra and Ubelaker 1994). Phenice disclosed the lack of reliability in the medial aspect of the ischiopubic ramus, but also affirms that at times "one to two traits may be ambiguous, but there is 'almost always one of the criteria which is obviously indicative of male or female'" (Phenice 1969: 300; Garvin 2012). Other studies have examined pelvic traits with high accuracy rates to indicate biological sex (Rogers and Saunders 1994; Bruzek 2002), but the Phenice Method persists as the standard.

Method: Anthroscopic Sex Traits of the Pelvis

In modern forensic anthropology and bioarchaeology, the primary region of the body used for sex analysis is the pelvis (White, Black, and Folkens 2012: 412). Biological males and females differ in two important ways: (1) the human pelvis is equipped to withstand bipedal walking to allow for the shifting weight of one leg balance during locomotion. Women differ than men in this regard because women have a different body frame that results in biomechanical differences in force, lever arms, and torques (Dirkmaat and Cabo 2012), and (2) women have the potential for pregnancy and

childbirth (France 1998). In general, women possess wider os coxae, which create a marked bowl shape when this region is articulated.

Only females exhibit a ventral arc and subpubic concavity. On the medial ischiopubic ramus, women exhibit a sharp edge, whereas males have a flat, broad, and blunt medial aspect. There are wider greater sciatic notches in females. The preauricular sulcus is present in females more than males; generally, the auricular surface is more elevated from the female ilium than from the male ilium. All pelvises for this study have all five regions available.

Table 2. Anthroscopic traits of the pelvis adapted from Standards (1994) and White and Folkens (2005).

Pelvic Trait	**Scale Used***	**Males**	**Females**	**Notes**
Ventral Arc Phenice 1969	0, 1-3	Nonexistent in males	Thin in females	A slightly elevated bone which extends from the pubic crest and arcs inferiorly across the ventral surface to the lateral most extension of the subpubic concavity where it lends with the medial border of the ischio-pubic ramus. Orient pubis so rough ventral surface faces you and you are looking down the plane of the pubic symphyseal surface. V.A. is a slightly elevated ridge of bone that sweeps inferiorly and laterally across the ventral surface of the pubis, merging with the medial border of the ischiopubic ramus. The V.A. sets off the inferomedial corner of the pubic bone in ventral view. Wide, evenly arching path in female, and set off the lower medial quadrant of the pubis (White and Folkens 2005:397).
Subpubic Concavity Phenice 1969	0, 1-3	Straight and broad; convexity in males	Concavity seen in females	A well- developed lateral recurve which occurs in the ischio-pubic ramus of the female a short distance below the lower margin of the pubic symphysis. This concavity is absent in the male subpubis. Turn pubis over, orienting it so that its smooth, convex dorsal surface faces you and your sight is along its midline. Observe the medial edge of the ischiopubic ramus in this view. Female ossa coxa display a subpubic concavity here; the edge of the ramus is concave in this view. Males show no evidence of concavity here; male edges are straight or very only slightly concave (White and Folkens 2005:397).

*Lower numbers indicate mostly female, higher numbers indicate mostly male

Table 2. Continued

Medial Aspect of the Ischiopubic Ramus Phenice 1969	0, 1-3	Flat, broad, and blunt rami in males	Sharp edge/ crest in females	Ridge found on the ischiopubic ramus immediately below the symphyseal surface. Males have a broad surface here instead of a marked ridge/ elevation. "Heavy reliance should be placed on this criterion only in the absence of the areas of bone where the other two criteria are found" (Phenice 1969:300). Turn pubis 90 degrees, orienting the symphyseal surface so that you are looking directly at it. Observe ischiopubic ramus in region immediately inferior to the symphysis. The medial aspect of the ischiopubic ramus displays a sharp edge in females. In males this surface is fairly flat, blunt, and broad (White and Folkens 2005:397).
Greater Sciatic Notch Buikstra and Ubelaker 1994	0, 1-5	Narrow in males	Broad and open in females	Hold ossa coxa above figure in White and Folkens (2005: 393) so that greater sciatic notch has same orientation as the outlines, aligning the straight anterior portion of the notch that terminates at the ischial spine with the right side of the diagram. Move to determine the closest match. Ignore any exostoses near the preauricular sulcus and inferior posterior iliac spine. Configurations more extreme than 1 or 5 should still be scored as a 1 or a 5 (White and Folkens 2005:393).
Preauricular Sulcus Buikstra and Ubelaker 1994	0, 1-4	Absent in males	Present and pronounced only in females	The preauricular sulcus is present more often in females than in males. A corollary is that the auricular surface is more elevated from the female ilium than from the male ilium, even though sexual dimorphism in the auricular surface itself is insufficient for accurate sexing (White and Folkens 2005:393).

*Lower numbers indicate mostly female, higher numbers indicate mostly male

Method: Anthroscopic Sex Traits of the Cranium

The cranium is the other principal region that has catalogued traits indicating human biological sex. In 1875, the anatomist Paul Broca published scoring illustrations of sex assessment from the skull, and since then many studies have found positive results in morphoscopic techniques to assess sex (Moore 2013). Cranial traits are used effectively thanks to their ease of use and ability to "encapsulate morphological information that is difficult to quantify using standard anthropometric techniques… with the only disadvantage being greater subjectivity (between observers)" (Walker 2008: 49). The cranial trait scoring system produced in *Standards* has been able to be used effectively by observers with "minimal osteological training… these scores as independent variables in sex determination equations is excellent" (Walker 2008: 49).

Universally, men are more robust and are born with more musculature, giving rise to more areas of the body for muscle attachments, and hence, larger and more robust entheseal, or muscle insertion, points. Women tend to show gracile, smooth features in their crania (France 1998). In general, the cranium shows enlarged and more pronounced areas in males than in females; this can be due to hormones, sexual selection, body size, muscle mechanics, age, health and nutrition (Walker 2008; Garvin 2012). These overviews are all population-specific, though. For example, archaeological Native American males and females exhibit less sexual dimorphism than many modern populations (Walker 2008). For the most accurate anthroscopic measuring, seriating the skulls from most gracile to most masculine provides an overview of the entire population (White et al. 2012). Since these crania come from a potentially vast number of unknown populations, seriation is not required.

For the majority of osteological regions indicating biological sex, scaling is based on a spectrum from most gracile, or feminine (female) to most robust, or masculine (male) on a scale of 1-5: 1 is very gracile/ feminine and 5 is very robust/ masculine (Buikstra and Ubelaker 1994; White et al. 2012; Garvin 2012; Garvin et al. 2014). These two regions of the human skeletal system have been tested and retested (Rogers and Saunders 1994; Bruzek 2002; Walrath et al. 2004; Rogers 2005; Williams and Rogers 2006; Kimmerle et al. 2008; Walker 2008; Garvin et al. 2014). With high recovery rates, reliable inter- and intra-observer error rates, and clear features apparent on these body parts, the pelvis and cranium have persisted as the top two regions that indicate the most obvious distinguishers of biological sex.

Sex identification is done on a 1-5 scale (gracile-hyperfeminine to robust-hypermasculine) looking at the nuchal crest on the occipital bone, mastoid process, supraorbital margin, supraorbital ridge, and the mental eminence. All of these areas on each cranium in this population are available for study.

Optimal results are obtained by holding the cranium or mandible at arm's length, a few inches above the appropriate portion of the scale illustrated in Figure 4, (Buikstra and Ubelaker 1994; White and Folkens 2005; White, Black, and Folkens 2012) oriented so that the features can be directly compared with those illustrated. It is advised to move the bone from diagram to diagram until the closest match is obtained, and score each trait independently, ignoring the other features.

Table 3. Anthroscopic Cranial Traits, taken from White, Black, and Folkens 2012.

Cranial Trait	**Scale Used***	**Male**	**Female**	**Notes**
Nuchal Crest	1-5	5= maximal expression, massive nuchal crest that projects a considerable distance from the bone and forms a well-defined bony ledge or "hook"	1= minimal expression, external surface of occipital smooth with no bony projections visible when lateral profile is viewed.	Feel surface of occipital with hand and note any surface rugosity, ignore the contour of the underlying bone. Focus on rugosity attendant to attachment of nuchal musculature.
Mastoid Process	1-5	5= lengths and widths several times that of the external auditory meatus	1= minimal expression, very small and projects only a small distance below inferior margins of ex. auditory meatus and digastric groove	Score by comparing size with that of surrounding structures like the external auditory meatus and zygomatic process of temporal bone. Investigate the volume of mastoid process, and not just length alone.
Supraorbital Margin	1-5	5= thick, rounded margin with a curvature approximating a pencil	1= minimal expression, border should feel extremely sharp, like edge of slightly dulled knife	Hold finger against margin of the orbit at the lateral aspect of the supraorbital foramen. Hold the edge of the orbit between your fingers to determine thickness. Look at diagrams to determine which it seems to match most closely.

*Lower numbers indicate feminine, higher numbers indicate masculine.

Table 3. Continued

Supraorbital Ridge/ Glabella	1-5	5= Maximal expression involves a massive glabellar prominence, forming a rounded, loaf-shaped projection that is frequently associated with well-developed supraorbital ridges.	1= contour of frontal is smooth, with little or no projection at midline.	View cranium laterally. Compare profile of supraorbital region with diagrams
Mental Eminence	1-5	5= massive mental eminence occupies most of the anterior portion of the mandible.	1= minimal expression, little or no projection of mental eminence above surrounding bone	Hold mandible between thumbs and index fingers with thumbs on either side of mental eminence. Move thumbs medially until they delimit borders of mental eminence.

*Lower numbers indicate feminine, higher numbers indicate masculine.

Comparative method

In conjunction with anthroscopic traits, a different method is used to assess sex and ancestry of the individuals, and these results are compared with the previous technique. This new approach is called geometric morphometrics. It utilizes three-dimensional shape analysis to digitally represent an object on a computer software program. The specific geometric morphometric software I intend to use is called 3D-ID, a program created in 2009 that identifies ancestry and sex of crania. Geometric morphometrics in anthropology is increasing in use as a new method to understand allometry, biodistance (Vidarsdottir et al. 2002), human sexual dimorphism (Green and Curnoe 2009), dental morphology, and hominin ontogeny (Gunz and Mitteroecker 2009).

Geometric Morphometrics

Geometric morphometrics is a system of mathematical tools used to examine the three- dimensional geometry of an object, and these methods are used to compare the shape variation of multiple objects (Slice 2005). The foundations of this niche stem from Kendall's (1984) establishment of non-Euclidean, multidimensional shape space where two or more dimensions can be plotted. The technique uses Cartesian coordinate points to generate a digitized shape of a specimen. Shape is defined as the geometric properties of an object that are invariant to location, orientation, and scale; shape plus scale define the form (Slice 2007; Slice and Ross 2009). Comparing coordinates of cranial landmark points quantitatively obtains the homology of crania (Slice 2005, 2007; Mitteroecker and Gunz 2009; Ross et al. 2016). Landmarks are corresponding points that have the "same locations in every other form of the sample and in the average of all the forms" (Mitteroecker and Gunz 2009: 236). In this study, the x, y, and z coordinates are taken for each landmark point during the digitizing phase of this study.

Isolating shape has become the principal way to view three-dimensional objects into a two-dimensional computerized format (Slice et al. 1996). Removing non-shape variables must be mathematically conducted before any comparison of objects can take place. To do this, superimposition techniques, overlaying objects repeatedly in order to find the mean shape, are conducted. The most common superimposition tool used for these practices is a Generalized Procrustes Analysis. Superimposition using Generalized Procrustes Analysis is an iterative procedure that translates and rotates the objects digitally to overlay all landmark coordinates the user inputs (Slice 2007; Mitterocker and Gunz 2009). After superimposition, shape differences can be seen by the variances in

corresponding landmark coordinates (Adams et al., 2004; Rohlf 2005). Once this crucial step is complete, the object's variables become shape variables and are appropriate for statistical analysis and graphical representation (Rohlf 2005). In other words, two skulls of different size can still be compared through the comparison of each skull's landmarks, giving rise to the constant shape of both objects. This allows a convenient method for researchers to examine all properties of a real-life object with the simplicity of the two-dimensional computer program. An important advantage of geometric morphometrics is that all measurements can be seen visually, so any mistakes made by the researcher can be seen and rectified (Gunz et al. 2009).

Therefore, no matter the size factor of the objects in question, coordinate points are manipulated in such a way that it allows researchers to look at each object's shape on a uniform scale. This method is akin to comparing the layouts (or shapes) of a standard house and a child's dollhouse. When size is uniformly scaled down, researchers can look at the blueprints of each house. Because the architectural measurements are drawn on the same-sized paper, the shapes of the houses can be compared with one another without extraneous biases affecting the layouts.

3D-ID

3D-ID is a program created by Drs. Dennis Slice and Ann Ross that assesses ancestry and sex in a skull of unknown affiliation. The software program was created to identify unknown skulls for forensic cases, and is key for forensic facial reconstruction (Ross and Slice 2009). 3D-ID uses a continually agglomerated database of 2300 modern sample crania of known origin and sex from collections all over the world, and clusters them into geographic groups. 3D-ID's main action is to assign the unknown skull to one

of the available classes for which there are sufficient individuals (Slice and Ross 2009; Humphries 2015; King 2015).

The software program provides the Mahalanobis Squared Distance (D^2), sample-adjusted posterior probabilities of membership, and typicality measures for unknown individuals with respect to each available reference group. 3D-ID uses of the suite of geometric morphometric techniques and multivariate procedures to discover the three-dimensional shape of an object. These techniques include Generalized Procrustes Analysis, and discrimination and classification methods, respectively. Using these formulae, it assigns an unknown cranium to those in the databank with the smallest squared Euclidean distance from the centroid mean (Mahalanobis D^2) (Ross et al. 2016). The 3D-ID program manual cautions users to take all statistics into consideration (Slice and Ross 2009: 25).

While 3D-ID houses a relatively small database in comparison to other programs, "The use of geometric morphometrics creates a useful alternative to the one-dimensional measurement methods… that are unable to account for curves and between-point differences" (King 2015: 2). The value of the mathematics used in 3D-ID demonstrates its magnitude for forensic identification. Orientation and placement of an object awaiting measurement can vary based on platform used, observer testing, or equipment variations; thus, "The technology focuses on the isolation of shape variation while factoring out and sequestering a size component that may or may not be considered alone or with shape/ form" (Slice and Ross 2009: 21).

Typicality and Posterior Probability

3D-ID determines cranial belongingness through discriminant function analysis, posterior probability, and typicality probability of the skull in question. Posterior probability is the prospect of membership for the unknown individual, based on the assumption the unknown actually *belongs to* one of the reference groups in the databank. This calculation is based on relative distances to each group where the sum of the distances equals 1. The method discerns the differences in means and determines distances based on standardized variances. The values range from 0-1; the closer the value is to 1, the higher the probability the cranium is part of the group. There is no required cutoff to classify an unknown individual, but Posterior Probabilities above 0.90 are considered strong classifications because they "seem to show similarity to one group as opposed to all other groups" (Ousley and Jantz 2012: 323).

One disclaimer cautions that discriminant function analysis is fashioned to always categorize a mystery skull, even if the skull in question is not from one of the reference groups. The integrity of 3D-ID is to always return a value, but it is necessary to subsume all statistical outputs in the cranial apportionment. The program will always match an unknown skull to one in the database, but it may not be a good classification.

Thankfully, indication of group membership can be double checked through the typicality probability assessment. Typicality simply determines the likelihood that the individual in question fits in with the group the unknown placed into, based on the average variability of all the groups in the analysis. The scale is measured from 0.0 to 1.0; the closer the typicality is to 1.0 the farther away from the average the cranium in question is. According to Ousley and Jantz (2012), if the typicality value is above the

0.05 level, the cranium is not a typical cranium in the group and can be disregarded. Typicality probability utilizes absolute distances, rather than relative distances as used in posterior probabilities (DiGangi and Hefner 2013). The typicality results for this project show that none of the crania measured are typical of the reference populations; thus, the classifications of the crania provided by 3D-ID are taken with extreme caution. Nonetheless, I use 3D-ID as a quick identification or classification method for a more detailed comparison with anthroscopic methods.

Table 4. Specimens in the 3D-ID Databank organized by geography and research facility

Ancestry/Origin	**Context**	**N_{Total}**	**N_{Male}**	**N_{Female}**
Asian	Forensic - Caphil	1	1	0
Basque	Spain	1	0	0
African American	Forensic - Caphil Forensic - NC OCME UTK Donated Terry Collection GBI	179	97	82
Cuba	Cuba	21	20	1
Eastern European	Turkey Yugoslavia Albania Yugoslavia Southern Yugoslavia Yugoslavia Bosnian Macedonia	88	51	10

Table 4. Continued

Hispanic	Forensic - NC OCME Forensic - Caphil UTK Donated New Mexico GBI	14	14	0
Hispanic-Guyana	Forensic - Caphil	1	1	0
Mexican-American (Toltecan)	Morton Collection	10	8	2
Mongolian Chinese	Morton Collection	11	9	2
M-A Hispano Indian	Morton Collection	1	1	0
Native African	Morton Collection	27	6	5
Native American		1	1	0
Panama	Forensic Panama	28	6	4
Panama-Afroantille	Forensic Panama	6	3	3
Peru	Peru- Forensic	9	8	1
Puerto Rico	Puerto Rico	5	4	1
Southern European	Lisbon Collection Oloriz - Spain	188	5	3

Table 4. Continued

European American	Terry Collection Forensic - Caphil New Mexico UTK Donated Forensic - NC OCME GBI	305	183	121
Unknown		3	-	-

3D-ID Dataset

The 3D-ID dataset comprises cranial landmark recordings of about 2300 individuals, and is increasing as newly acquired samples are included (Slice and Ross 2009). Dr. Ann Ross has been the sole recorder of data in the database; the crania come from various museums and universities. Altogether there are 19 groups or populations that compose the databank, and these are grouped into 14 geographic clusters, each containing trauma and pathology-free male and female individuals. The unknown cranium a user enters into the program is categorized into the most closely related group based on cranial shape:

Table 5. List of the 14 groups 3D-ID runs unknown data against.

African	Male	Female
African American	Male	Female
African- Brazilian	Male	Female
Brazilian	Male	Female
Circumcaribbean	Male	Female
East Asian	Male	Female
European American	Male	Female
European Central	Male	Female
European Eastern	Male	Female
European Southeastern	Male	Female
European Southwestern	Male	Female
Japanese Brazilian	Male	Female
Mesoamerican	Male	Female
South American	Male	Female

Landmarks

3D-ID operates using 34 landmarks determined from Howells (1973), Bookstein (1996), and Moore-Jansen and Jantz (1994). Foundations of geometric morphometrics are

grounded on landmark Cartesian coordinates. The data digitally reconstructs the shape of the object. Then, the digital images of the shapes are compared.

Meaningful landmarks are homologous and discrete structures found on the same place throughout all specimens. Bookstein's analysis of Type I, II, or III landmarks are defined as follows: Type I landmarks are clear locations based on distinct structures that juxtapose tissues; Type II are the maxima of local curvature along tissue boundaries, such as cusps and invaginations, and commonly indicating biomechanical purpose; and Type III are extremal points that are acquired only in relation to another structure, like the endpoints of maximum length, or breadth, defined with respect to some distant structure (Howells 1973; Bookstein 1991; Humphries 2011; Slice and Ross 2009; McKeown and Schmidt 2013). Type III landmarks were found to be unreliable, since they are reference points that necessitate remote structures to locate the landmark, and are therefore not part of the 34 landmarks (Slice 2005; Ross and Williams 2008; Humphries 2011).

Originally, 75 landmarks were chosen for the preliminary 3D-ID analysis, but due to inter-observer error testing, and testing the types of landmarks (I, II, and III), 34 landmarks remained to give the most accurate and robust measurement of each cranium (Slice 2007; Slice and Ross 2009)..

Landmarks in 3D-ID

Table 6. List of cranial landmark points, their abbreviations, and definitions established in 3D-ID.

Landmark	**Abbreviation**	**Definition**
Left Asterion	astl	Intersection of left parietal, left temporal, and occipital bones. If sutures are indistinct or include Wormian bones, project suture lines until they intersect.
Right Asterion	astr	Intersection of right parietal, right temporal, and occipital bones. If sutures are indistinct or include Wormian bones, project suture lines until they intersect.
Basion	bas	The midline point of the anterior foramen magnum margin where it is intersected by the midsagittal plane. Directly opposite of the opisthion. In some cases, thickening of the margin can make position location difficult to determine.
Bregma	brg	The midline point where the sagittal and coronal sutures intersect. In cases where the intersection is interrupted, such as with fontanelle bones, the suture lines are projected.
Left Dacryon	dacl	Left eye orbit: point on the medial border where the frontal, lacrimal, and maxilla bones meet, also noted as the intersection of the lacromaxillary suture and frontal bone. A small foramen is often present.
Right Dacryon	dacr	Right eye orbit: point on the medial border where the frontal, lacrimal, and maxilla bones meet, also noted as the intersection of the lacromaxillary suture and frontal bone. A small foramen is often present.

Table 6. Continued

1. Left Ectomalare	ecml	Left maxilla: positioned at the most lateral point on the lateral surface of the alveolar crest. Found along the second molar on the maxilla.
2. Right Ectomalare	ecmr	Right maxilla: positioned at the most lateral point on the lateral surface of the alveolar crest. Found along the second molar on the maxilla.
3. Left Ectoconchion	ectl	Left eye orbit: intersection of the most anterior surface of the lateral border and imaginary horizontal line bisecting the orbit.
4. Right Ectoconchion	ectr	Right eye orbit: intersection of the most anterior surface of the lateral border and imaginary horizontal line bisecting the orbit.
5. Left Frontomalare Anterior	fmal	Left side of skull: most anterior projecting point on the frontomalare suture (different from the frontomalare orbitale and temporale).
6. Right Frontomalare Anterior	fmar	Right side of skull: most anterior projecting point on the frontomalare suture (different from the frontomalare orbitale and temporale).
7. Left Frontomalare Temporale	fmtl	Left side of the skull: most lateral point on the frontomalare suture.
8. Right Frontomalare Temporale	fmtr	Right side of the skull: most lateral point on the frontomalare suture.
9. Glabella	glb	Most projecting midline point on the frontal bone above frontonasal suture. In juveniles with forward vaulted foreheads the most projecting point may not be the glabella.
10. Lambda	lam	Point where sagittal and lambdoidal sutures meet. If Wormian bones are present, project the suture lines to their intersection point.

Table 6. Continued

1. Left Mastoideale	mastl	Left mastoid process: point located on the inferior end.
2. Right Mastoideale	mastr	Right mastoid process: point located on the inferior end.
3. Nasion	nas	Midline intersection of the frontonasal suture and midsagittal plane
4. Left Lower Orbital Border	obhi	Lower border of the left eye orbit: Measured as the maximum height from the upper to the lower orbital borders perpendicular to the horizontal axis of the orbit and using the middle of the inferior border as a fixed point.
5. Right Lower Orbital Border	obhir	Lower border of the right eye orbit: Measured as the maximum height from the upper to the lower orbital borders perpendicular to the horizontal axis of the orbit and using the middle of the inferior border as a fixed point.
6. Left Upper Orbital Border	obhs	Upper left eye orbit: Upper border of right eye orbit: Measured as the maximum height from the upper to the lower orbital borders perpendicular to the horizontal axis of the orbit and using the middle of the inferior border as a fixed point.
7. Right Upper Orbital Border	obhsr	Upper right eye orbit: Upper border of right eye orbit: Measured as the maximum height from the upper to the lower orbital borders perpendicular to the horizontal axis of the orbit and using the middle of the inferior border as a fixed point.
8. Opisthion	ops	Midline point of the posterior foramen magnum margin where the midsagittal plane intersects. Opposite of basion.
9. Prosthion- Howells estimated	pr/ proHEST	Most anterior, midline point on the alveolar process of the maxilla between the central incisors.

Table 6. Continued

1. Supspinale	ssp	The deepest point of the profile below anterior nasal spine.
2. Left Nasomaxillary Suture Pinch	wnbl- simotic chord	Narrowest portion of the midline of the face to the left nasomaxillary suture. The minimum distance between wbnl-wnbr forms the semiotic chord.
3. Right Nasomaxillary Suture Pinch	wnbr- simotic chord	Narrowest portion of the midline of the face to the right nasomaxillary suture. The minimum distance between wbnl-wnbr forms the semiotic chord.
4. Left Zygion	zygl	Left zygomatic: most lateral point on the zygomatic arch. Point is determined by measuring bizygomatic breadth.
5. Left Zygomaxillare	zygoml	Left side of skull: intersection of zygomaxillary suture and most medial masseter muscle attachment.
6. Right Zygomaxillare	zygomr	Right side of skull: intersection of zygomaxillary suture and most medial masseter muscle attachment.
7. Left Zygoorbitale	zygool	Left eye orbit: point of intersection between zygomaxillary suture and eye orbit.
8. Right Zygoorbitale	zygoor	Right eye orbit: point of intersection between zygomaxillary suture and orbital border.
9. Right Zygion	zygr	Right zygomatic: most lateral point on the zygomatic arch. (Point is determined by measuring bizygomatic breadth.)

Previous Research

Previous studies have utilized the formidability of geometric morphometrics to assess group belongingness within and between populations. One of these important studies was that of Rebecca King (2015). In her study, she examined the correct

classification of black and white South Africans using FORDISC 3.1 and 3D-ID. Her results show both strengths and weaknesses in each of the computer software programs. Per her results, 3D-ID had 63.1% classification accuracy for the black and white South African populations, and 'typicality' results were approximately the same for both 3D-ID and FORDISC. These results could have been confounded due to the lack of specification of groups she needed to compare in the version of 3D-ID (King 2015). 3D-ID has since then been updated, and users can now specify to which ethnic/ ancestral group and sex they want to compare their data. She concludes and emphasizes that while 3D-ID provided a sub-75% classification accuracy rate, 3D-ID is a useful tool that should be used in congruence with another method or software program and not the sole method of ancestry estimation (King 2015).

In another study, Hefner (2009) used the program *Macromorphoscopics* to determine group affiliation for 321 known females and 426 known males from documented museums. He discovered the extreme versions of qualitative traits to assess ancestry should be used with caution and recommends using these expressions with a statistical framework to provide a barrier of subjectivity in data collectors' biases and errors (Hefner 2009).

There are numerous studies digitally examining craniometrics and anthroscopic traits using the program 3Skull (Ousley 2014). While this program has been used with repeatability, examining other software programs, especially those that obtain a three-dimensional shape of a specimen, should be tested and used and examined continually. Many of these research inquiries examine the reliability and validity of testing methods for this type of project, for repeat testing of the tools exponentially increases the validity

or invalidity of these monumental programs. Utilizing 3D-ID provides a novice way of obtaining awareness of the ancestry and sex of the unknown individuals in this study. Cross-referencing this with standard anthroscopic methods counteracts erroneous error and total reliability on one method.

Procedure

Using anthroscopic traits and geometric morphometrics through 3D-ID, this research endeavor determined ancestry and biological sex of nine currently unknown individuals. Anthroscopic techniques used congruently with the digital method provided two different methods for identification. Intra-observer was conducted on both techniques, further examining the repeatability and reliability of the methods and software.

The first part of data collection involved estimating ancestry and sex data through anthroscopic techniques. Ancestry was obtained first through two consecutive weeks of data collection, and sex was second, also with two consecutive weeks of data collection. One week was intra-observer error round one, and the following week was intra-observer error round two.

Results of anthroscopic testing were determined by identifying the ratio of how many traits out of 32 were sorted in one of the three categories. Only one researcher performed all measuring of data. The difference between each round of intra-observer testing was compared through Intra-Rater Reliability (IRR) Testing. This showed the reliability of the tests using the same exact methods each round of data collection over three rounds of testing. The scores for each of the pelvises and cranial traits for sex and ancestry were recorded on separate tables constructed by the investigator (see Appendix A). Sex was determined by the five cranial traits and the five pelvic traits. Each trait was

given a score based on the scale associated with it. A final score for the overall biological sex determination was determined. This was based on the scale: 1-Hyperfeminine 2-Feminine 3- Ambiguous 4- Masculine 5- Hypermasculine (White, Black, and Folkens 2012).

Upon completion of the anthroscopic phase, the 3D-ID intra-observer error-testing phase came next. The landmark coordinates were obtained using the MicroScribe MX digitizer equipment and the MUS Software package that comes with the digitizer equipment. The MUS Software transcribed each cranial landmark's (x,y,z) coordinate points onto Excel spreadsheets. Each cranium was recorded on its own spreadsheet with the list of the 34 cranial landmarks as per the 3D-ID website (www.3d-id.org). This version of the MicroScribe came with a foot pedal used to click and capture the coordinate point at the region on the skull where the tip of the MicroScribe stylus is pointed.

Next, the data was uploaded to the 3D-ID software via Excel sheets. The output of each round of 3D-ID analysis indicated how the geometric morphometric procedure allocated each unknown skull into sex and ancestry categories based on the program's databank. The 3D-ID software has filter options where the data points can be compared with one or both sexes, and the researcher's choice of fourteen ancestry groups. This study included all sexes and groups; all options available were utilized for analysis. The software also allows researchers to include or exclude the size component of the unknown skull into the analysis through the check box called "Include Size." This aspect takes into consideration the size of each cranium along with the shape of the craniofacial region as determined by the coordinate points; it directs that "size be restored to the

coordinates and included in the classification process" (Slice and Ross 2009). Size was included for one part of the analysis, and size was excluded for another part. Three rounds of intra-observer testing were completed with size included in the processing of the data points, and with size not included in the processing of data points. This entire process was done for each of the nine skulls, and repeated after one week to obtain intra-observer error data. A third round of intra-observer testing was performed three weeks after the initial phase began. Intra-Rater Reliability testing was also completed to test the usability and repeatability of this MicroScribe MX equipment and the 3D-ID software.

To also examine the reliability of the 3D-ID software, three cranial casts with known sex and ancestry were also measured with the MicroScribe and 3D-ID program. These plastic casts were purchased from the company Bone Clones. The measurement of these three casts was performed three times, with IRR testing, and inclusion of size and omission of size also completed on them.

CHAPTER THREE: RESULTS

Anthroscopic Results

The anthroscopic testing method was divided into two sessions acquiring ancestry data, and two sessions acquiring sex data. Each session was done over the course of one week with two weeks in between the ancestry data collection and the sex data collection periods. This ensured enough time in between the data collection periods to prevent any inadvertent user bias when calculating the anthroscopic scores.

Ancestry

The results of the anthroscopic ancestry portion were determined through use of Decision Tables. A Decision Table is a method where qualitative characteristics are organized into the overarching categories that they describe (Byers 2016). For this study, the 32 categories used to describe each ancestry category (Asian/ Native American; White/European; African/ Black) were used as the Decision Table. After the skeletal traits were determined, I counted how many traits exhibited those of each ancestry category. The ancestry category with the highest number of traits associated with it was established as the ancestry for that individual. When two categories had equal number of traits under it, the individual was classified as both ancestries.

At times, a trait was not present and led to the omission of one ancestry category. This opened up the possibility of two categories being likelihoods for the ancestry. For example, if an unknown did not exhibit incisor rotation, the Asian category was omitted,

but the White/European *and* Black/ African categories were then potential ancestries for that individual for that trait. For the final analysis of anthroscopic ancestry traits, only the traits that corresponded to one ancestry category were counted in the final ancestry decision-making. This meant that some traits that fit under two categories were removed from the final quantity in the Decision Table. While this may give a skew to the results, it was the one way to ensure the most direct determination of ancestry through anthroscopic means, and compensate for two or more ancestry possibilities per trait.

Table 7. Decision Tables for Anthroscopic Ancestry Traits Individuals A-1 through A-17.

	A1		A2		A11		A12		A13		A14		A15		A16		A17	
Number of Cranial Traits per Ancestry Category																		
Asian/ Native American	15	11	16	17	11	15	10	10	11	14	12	16	9	8	10	15	15	16
White/ European	7	7	3	0	11	8	12	8	4	5	7	6	5	3	15	7	8	6
Black/ African American	4	5	1	3	1	3	2	3	10	6	3	1	7	12	0	0	1	2
Overall Ancestry Score	Asian	Asian	Asian	Asian	Asian & European	Asian	European	Asian	Asian, African	Asian	Asian	Asian	Asian, African	African	European	Asian	Asian	Asian
Final Anthroscopic Ancestry	Asian		Asian/ Native American		Asian & Euro		European		Asian, some African		Asian/ Native American		Asian, some African		European		Asian	

Round 1 of testing resulted in a 4/9 categorized as having Asian ancestry, 2/9 as having mostly Asian, but a mix of some African traits, and 1/9 that had even traits of Asian and European Ancestry. Round 2 of testing showed 8/9 individuals were estimated as Asian ancestry and one was African ancestry. A-15 was the one with African ancestry, and this result coincided with the results from Round 1 with A-15 having an Asian/ African mix of traits. Overall, only 4/9 ancestry estimations proved the same for both rounds of testing, giving the anthroscopic ancestry testing an overall 4/9 or 44% intra-observer error rate. 4/9 is not a value to disregard, but it is not a strong intra-observer rating either. The general categories could be an overarching benefit to high intra-observer error testing. These are general categories, but can narrow down possible ancestries, especially in (medicolegal) cases where general phenotypic traits suffice.

Sex

Sex was determined by visually and tactilely examining the crania and pelvises of each individual. Each feature on the skull was given a score based on the standards established previously. These scores were culminated and given a final score according to the scale: 1-Hyperfeminine 2- Feminine 3- Ambiguous 4- Masculine 5- Hypermasculine (White, Black, and Folkens 2012).

Table 8. Scores for Anthroscopic Sex Traits Individuals A-1 through A-17.

	A1		A2		A11		A12		A13		A14		A15		A16		A17	
	Data Collection Rounds																	
Cranial Traits																		
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Nuchal crest	1	4	3	1	1	2	3	3	5	5	3	4	3	4	1	3	4	3
Mastoid Process	2	2	2	2	3	3	2	2	5	5	2	3	4	5	2	4	4	4
Supraorbital Margin	2	1/2	2	3	1	2	2	3	4	5	1	2	5	5	2	3/4	4	4
Supraorbital Ridge	1	2	3	2	3	3	1	1	5	5	2	1	4	4	2	3	2	2
Mental Eminence	4	4	4	3	4	3	3	3/4	5	5	4	2	3	4	3	3	5	4
Pelvic Traits																		
Ventral Arc	1	1	1	1	3	3	1	2	3	3	2	1	3	3	1	1/2	2	2

Table 8. Continued

Subpubic Concavity	1	1	1	1	3	3	1	3	3	3	1	1	3	3	3	2	1	2		
Medial Ischiopubic Ramus	1	1	1	1	3	3	1	2/3	3	3	2	1	3	3	2	3	3	2		
Greater Sciatic Notch	4	4	2	2	2	4	4	3	3	3	5	5	5	5	5	5	4	2		
Preauricular Sulcus	1	1	3	2	3	4	4	2	3	3	3	3	3	2	2	4	2	4		
Final Score	1	1	1	2	4	4	2	3	5	5	3	3	5	5	4	5	3	3		
Overall Score for Individual	1		2		4		3		5		3		5		4		3			
Description	Hyperfeminine		Feminine		Masculine		Ambiguous		Hypermasculine		Ambiguous		Hypermasculine		Masculine		Ambiguous			

A-1: This individual can confidently be estimated to be a Hyperfeminine female. The pelvic traits were the most extreme exhibition of gracile female traits. Both rounds gave a score of 1. A-2: This individual is a female, with one round indicating a 1 Hyperfeminine, and the other round indicting 2 Feminine characteristics. A-11: This individual displayed more masculine features than feminine, and this can be seen in the pelvis more so than the cranium. Overall this individual can be considered leaning toward a score of 4 Masculine. A-12: A-12 displayed more feminine characteristics in the cranium than it did in the pelvis, though this testing data is a good indicator of possible user unfamiliarity with the traits or technique. This is seen in Round 1 in the first three traits of the pelvis. This individual can be considered 3 Ambiguous overall. A-13: This individual displayed the most hypermasculine traits in the cranium and pelvis, and both rounds agree. This individual is a 5 Hypermasculine Male. A-14: This individual had traits that indicated both female and male characteristics; therefore, both rounds of testing indicate this is a 3 Ambiguous sex. A-15: A-15 is a clear hypermasculine individual, with both rounds of testing agreeing with a score of 5. A-16: This individual was scores with scores of 4 and 5, and can be classified as a Male. A-17: The final individual had ambiguous traits, and is classified as a 3 Ambiguous. Both rounds of testing agreed upon this score.

Anthroscopic sex results showed only 5/9, 56%, of the results produced the same score for rounds 1 and 2 of intra-observer error testing. A 56% agreement rate is moderate. Deliberating on the final score for each round of testing was a more subjective experience than originally expected. Cranial traits were scored on the same value system (1-5), but pelvic traits were on different a different scoring scale (1-3, 1-5, and 1-4). A score of 2 for the Phenice Method was indicative of ambiguous sex, whereas a score of 2

for a cranial trait indicated a feminine characteristic. This urged me to selectively focus on the overall robusticity and gracility of each trait independently as they combined to form the puzzle that was the sex of the individual. Taking all scores based on their own scales into account, I was able to estimate the final sex score per individual.

3D-ID Analysis

After obtaining the (x,y,z) coordinate points on three separate data collection days, the points were input to the 3D-ID software program. The program used the points to determine in which geographic group the skull best fit. Based on the distance from the calculated centroid, posterior probability, and typicality probability, the skull was classified into one group. The data from all three rounds of intra-observer testing underwent analyses that both included size and did not include size. To help give perspective to how strong the cranium matches to one of the groups in the database, the geographic and sex group with the highest posterior probability is also provided. The 3D-ID Manual cautions that as the Mahalanobis D^2 statistic may not be a clear-cut statement of group membership, posterior and typicality probabilities are also used in the analysis of membership. The geographic and sex group membership is indicated and the group membership with the highest posterior probability is also provided to measure the "relative closeness of the unknown to each group" (Slice and Ross 2009). If no secondary posterior probability is provided, the posterior probability associated with the smallest D^2 distance was the highest.

Control Crania

Three crania with known ancestry and sex from the company, Bone Clones, were analyzed in 3D-ID and used as control crania to see how the program allotted each. This

portion of the project investigated the reliability of the 3D-ID program by creating a control test. The results are reported below with size included and omitted in the analyses. These results show that the program overall sorted the skulls into inaccurate geographic/ ancestry categories. While the size inclusion did not affect the results greatly, it did produce some variation in the output.

Table 9. Forensic Bone Clones Crania 3D-ID Analysis - Asian Male.

	Intra-Round	Including Size	Not Including Size
Ancestry	1	European American	European American
	2	European	European
	3	African American	African American
IRR		0/3	0/3
Sex	1	Male	Male
	2	Male	Male
	3	Male	Male
IRR:		3/3	3/3

Table 10. Forensic Bone Clones Crania 3D-ID Analysis – African Male.

	Intra-Round	Including Size	Not Including Size
Ancestry	1	Mesoamerican	Mesoamerican
	2	European	European American
	3	Mesoamerican	Mesoamerican
IRR		2/3	2/3
Sex	1	Female	Female
	2	Male	Male
	3	Female	Female
IRR:		2/3	2/3

Table 11. Forensic Bone Clones Crania 3D-ID Analysis - European Female.

	Intra-Round	Including Size	Not Including Size
Ancestry	1	European American	European American
	2	European American	European American
	3	European American	European American
		3/3	3/3
Sex	1	Female	Male
	2	Male	Male
	3	Male	Male
IRR:		2/3	3/3

Table 12. Including Size.

Intra-1:

Individual	**Geographic Group (Ancestry)**	**Sex**	**D^2**	**Probability**	**Typicality**
Asian Male	European American	Male	5766.8647	0.0000 *1.0000 Circumcaribbean Female	0.0000
African Male	Mesoamerican	Female	423.2574	0.9876	0.0000
European Female	European American	Female	462.0957	0.0000 *0.9156 Circumcaribbean Female	0.0000

Table 12. Continued

Intra-2:

Individual	**Geographic Group (Ancestry)**	**Sex**	**D^2**	**Probability**	**Typicality**
Asian Male	European	Male	24161.6053	…..	0.0000
African Male	European American	Male	595.7988	0.0000 *1.0000 Circumcaribbean Female	0.0000
European Female	European American	Male	428.5622	0.0000 *0.7107 Circumcaribbean Female	0.0000

Table 12. Continued

Intra-3:

Individual	**Geographic Group (Ancestry)**	**Sex**	**D^2**	**Probability**	**Typicality**
Asian Male	African American	Male	501.8272	0.0000 *0.5714 Mesoamerican Female	0.0000
African Male	Mesoamerican	Female	360.8645	0.9882	0.0000
European Female	European American	Male	451.3035	0.0000 *0.9984 Mesoamerican Female	0.0000

Table 13. Not Including Size.

Intra-1

Individual	**Geographic Group (Ancestry)**	**Sex**	**D^2**	**Probability**	**Typicality**
Asian Male	European American	Male	4434.2090	0.0000 *1.0000 Circumcaribbean Female	0.0000
African Male	Mesoamerican	Female	339.4289	0.9877	0.0000
European Female	European American	Male	402.7586	0.0000 *0.7015 African Female	0.0000

Table 13. Continued

Intra-2:

Individual	**Geographic Group (Ancestry)**	**Sex**	**D^2**	**Probability**	**Typicality**
Asian Male	European	Male	20532.9231	0.0000 *1.0000 Circumcaribbean Female	0.0000
African Male	European American	Male	466.4881	0.0000 *0.9974 Circumcaribbean Female	0.0000
European Female	European American	Male	356.1885	0.0008 *0.9464 Mesoamerican Female	0.0000

Table 13. Continued

Intra-3:

Individual	**Geographic Group (Ancestry)**	**Sex**	**D^2**	**Probability**	**Typicality**
Asian Male	African American	Male	402.3221	0.0017 *0.5561 Mesoamerican Female	0.0000
African Male	Mesoamerican	Female	293.1331	0.9870	0.0000
European Female	European American	Male	392.2009	0.0000 *0.9992 Mesoamerican Female	0.0000

The repeatability of the program and the intra-rater reliability (IRR) show the software output as unreliable for the Asian and African male crania. The geographic placements they were categorized into did not correspond to their identified ancestry. Sex categorization was fairly reliable for the Asian and European crania. The Asian male had 100% intra-rater reliability for sex, but the African cranium had clear discrepancies in sex estimation. The European female skull cast showed the highest IRR reliability in ancestry and sex, and, in fact, the ancestry category was the most accurate and consistent.

The ancestry including size and not including size Intra-Rater Reliability (IRR) was only 33%, as only the European cranium produced the same results for all three rounds of testing. For sex, IRR was 66%; the Asian and European results were the same for all three rounds of testing. The results, although they varied in 3D-ID statistical

output, overall were the same for the inclusion and exclusion of the size factor. The size of the cranium did not influence the categorization of the cranium, and therefore the intra-rater reliability was exactly the same. This is ultimately to be expected because shape analysis through geometric morphometrics omits size and only focuses on shape data.

For the ancestry, the results for Asian male varied in each round of data collection, though the results were the same for size inclusion and exclusion. The variation in each round of data collection could be explained by user measurement, but the results produced for any round of the Asian male did not indicate Asian, or even Mesoamerican or South American. Any of these results would have given some precedence to an Asian ancestry, but the results indicated European and African American ancestry. The plastic material of the cast and the possible skew it created on the cranium could have driven these misleading ancestry results.

The African male cranial results were completely skewed, as the program placed it in Mesoamerican female and European male categories, respectively. Explanation for this may be again due to user error, and/or skull casting alteration. The results though range from gracile to masculine, but not as comparably masculine as an African male skull structure can indicate (Spradley and Weisensee 2012). This does raise awareness about the output of the 3D-ID program, but the program cautions users to consider all statistics provided in the analysis of an unknown cranium (Slice and Ross 2009). With all statistics processed, the posterior probability value still showed that Mesoamerican female was the group it was most likely to be placed into. This is concerning, but reasons

for this requires explicit testing in a more controlled environment where the user error and the cast error can be tested independently.

The European female results were the most accurate overall. The placement into the European and European American ancestry groups assigned this cranial cast into appropriate categories. The sex did indicate a mostly male output, but this could be due to the possibility of a slight cast disfiguration. With these results, there is a possibility the program could allot individuals with European ancestries more correctly than other geographic groups, but this also needs another body of testing. Overall, the results were interesting and motivating; therefore, analysis of the nine unknown skulls used in this study was performed.

3D-ID Results of Unknown Crania

The nine unknown crania were input to the 3D-ID program to acquire ancestry and sex categories. Provided below are the Geographic Group (Ancestry), Sex, Mahalanobis D^2, posterior probability, and typicality probability allocated to each individual. Results are separated into three rounds of intra-observer error testing, and including the size and excluding the size. Also provided is the posterior probability with the highest value, independent of the D^2 value, indicated by an asterisk. This was included to show which group, other than the one categorized by the program, the unknown cranium was most likely to fit within. Some of these posterior probabilities were completely different than the one originally designated, and others were along the lines of ancestral and geographic similarity. This is a significant disclaimer illustrating the holistic interpretation the program warrants.

The output for each round of data collection is indicated below:

Table 14. Intra 1 3D-ID Including Size Round 1.

Individual	**Geographic Group (Ancestry)**	**Sex**	**D^2**	**Probability**	**Typicality**
A-1	South American	Female	36459.5079	…… *….	0.0000
A-2	African American	Male	358.5561	0.0000 *1.0000 African Female	0.0000
A-11	African American	Male	369.5358	0.0000 *0.9546 African Female	0.0000
A-12	European American	Male	382.6076	0.0001 *0.9840 African Female	0.0000
A-13	European American	Male	313.7079	0.9961	0.0000
A-14	African American	Male	344.6553	0.0002 *0.9994 African Female	0.0000
A-15	Mesoamerican	Female	855.3401	0.0000 *1.0000 Circumcaribbean Female	0.0000
A-16	Mesoamerican	Female	454.2925	1.0000	0.0000
A-17	European American	Male	471.7271	0.0000 *0.5447 African Female	0.0000

Table 15. Intra 2 3D-ID Including Size Round 2.

Individual	**Geographic Group (Ancestry)**	**Sex**	**D^2**	**Probability**	**Typicality**
A-1	African	Female	303.7087	0.09973	0.0000
A-2	African	Female	327.0539	1.0000	0.0000
A-11	African	Female	395.9788	0.9999	0.0000
A-12	European American	Male	384.2986	0.0001 *0.5029 Circumcaribbean Female	0.0000
A-13	European American	Male	424.1158	0.0066 *0.8097 Mesoamerican Female	0.0000
A-14	African American	Male	318.0755	0.0003 *0.9968 African Female	0.0000
A-15	East-Asian	Male	359.4408	0.0927 *0.8035 African Female	0.0000
A-16	European American	Male	5076.2546	0.0000 *1.0000 Circumcaribbean Female	0.0000
A-17	European American	Male	371.9846	0.0041 *0.5439 Mesoamerican Female	0.0000

Table 16. Intra 3 3D-ID Including Size Round 3.

Individual	**Geographic Group (Ancestry)**	**Sex**	**D^2**	**Probability**	**Typicality**
A-1	Mesoamerican	Female	314.5843	0.6743	0.0000
A-2	African	Female	325.1434	1.0000	0.0000
A-11	European American	Male	432.3584	0.0000 *0.7010 Mesoamerican Female	0.0000
A-12	European American	Male	408.3023	0.0010 *0.8437 Mesoamerican Female	0.0000
A-13	European American	Male	450.4973	0.0013 *0.9476 African Female	0.0000
A-14	European American	Male	339.7852	0.0052 *0.9929 African Female	0.0000
A-15	Mesoamerican	Female	361.4387	0.7481 *Highest P value (second is 0.2501 African Female)	0.0000
A-16	European American	Male	466.1245	0.0053 *0.9946 Mesoamerican Female	0.0000
A-17	Mesoamerican	Female	378.1230	0.6912	0.0000

Table 17. Intra 1 Does not include size Round 1.

Individual	Geographic Group (Ancestry)	Sex	D^2	Probability	Typicality
A-1	South American	Female	32092.0970	0.0000 *1.0000 Circumcaribbean Female	0.0000
A-2	African	Female	358.2184	0.9999 *Highest	0.0000
A-11	African American	Male	329.6222	0.0001 *0.6881 African Female	0.0000
A-12	European American	Male	334.6682	0.0001 *0.9891 African Female	0.0000
A-13	European American	Male	255.7989	0.9924 *Highest	0.0000
A-14	African American	Male	278.9020	0.0007 *0.9963 African Female	0.0000
A-15	Mesoamerican	Female	620.3089	0.0000 *1.0000 Circumcaribbean Female	0.0000
A-16	European American	Male	390.7245	0.0053 *0.9991 Mesoamerican Female	0.0000
A-17	African American	Male	347.6922	0.0000 *0.4571 African Female	0.0000

Table 18. Intra 2 Does not include size Round 2.

Individual	**Geographic Group (Ancestry)**	**Sex**	**D^2**	**Probability**	**Typicality**
A-1	African American	Male	260.2605	0.0007 *0.9699 African Female	0.0000
A-2	African	Female	314.8811	1.0000	0.0000
A-11	African	Female	351.3240	0.9981 *0.0019 Mesoamerican Female	0.0000
A-12	European American	Male	354.3969	0.0010 *0.6848 African Female	0.0000
A-13	European American	Male	336.1619	0.0366 *0.6145 Mesoamerican Female	0.0000
A-14	African American	Male	269.9978	0.0010 *0.9978 African Female	0.0000
A-15	African American	Male	287.1795	0.0090 *0.3505 African Female	0.0000
A-16	European American	Male	3987.1107	0.0000 *1.0000 Circumcaribbean Female	0.0000
A-17	European American	Male	347.0305	0.0018 *0.6424 Mesoamerican Female	0.0000

Table 19. Intra 3 Does not include size Round 3.

Individual	Geographic Group (Ancestry)	Sex	D^2	Probability	Typicality
A-1	Mesoamerican	Female	272.8994	0.8842 *0.0749 African Female	0.0000
A-2	African	Female	332.7166	1.0000	0.0000
A-11	European American	Male	371.2520	0.0001 *0.0961 African Female	0.0000
A-12	European American	Male	385.4694	0.0004 *0.6755 Mesoamerican Female	0.0000
A-13	European American	Male	369.1808	0.0043 *0.9819 African Female	0.0000
A-14	European American	Male	285.5576	0.0369 *0.9585 African Female	0.0000
A-15	African American	Male	293.0106	0.0006 *0.7183 Mesoamerican Female	0.0000
A-16	European American	Male	404.5712	0.0060 *0.79928 Mesoamerican Female	0.0000
A-17	European American	Male	346.7159	0.0001 *0.8987 Mesoamerican Female	0.0000

Overall, these results generally uphold with each round of user testing, although many of the posterior probability values compel a further look into the placement category. Individuals A-12 and A-13 had the most repeatable results, with European American male being the recurring result for every round of testing. A-14, and A-17 show parallel classification results for intra-observer testing rounds. Other outputs not exactly the same still exemplify results that are comparable. For example, A-15 for round 1 came up as a Mesoamerican female, and round 2 came up as an East-Asian male. East-

Asian male skeletons demonstrate gracile and smooth features, which are similar to the Mesoamerican female skeletal features. For all rounds of error testing, A-2 indicated exhibiting the most common skull features as that of the African female. The posterior probability was the highest for African female, and this was the group it was categorized into each round of testing. A-16 is Mesoamerican female, indicating A-16 has the most common facial skeleton as that of the Mesoamerican females in the 3D-ID database. Interestingly, A-16 for round 1 of error testing proved the best posterior probability with a 1.0000 for how probable this skull fits in with the Mesoamerican female group in the 3D-ID database. This is the most interesting result because the result for A-16 Round 2 was European American male with 0.0000 for Posterior and Typicality Probabilities. This could be because of user error, or Mesoamerican females and European American males both share some similar facial features.

Comparative Results

When comparing the output from both the anthroscopic approach and 3D-ID, the results show some substantiation, as the two techniques gave a few analogous results. The tests did show some very apparent discrepancies, however. A number of individuals had very different results. These can be seen in the table below. Sex is on the scale of 1-5 (White, Black, and Folkens 2012):

Table 20. A-1 Results.

	Intra-Round	Including Size	Not Including Size	Anthroscopic
Ancestry	1	South American	South American	Asian
	2	African	African American	Asian
	3	Mesoamerican	Mesoamerican	
IRR:		0/3	0/3	2/2
Sex	1	Female	Female	Female (1)
	2	Female	Female	Female (1)
	3	Female	Female	
IRR:		3/3	3/3	2/2

1-Hyperfeminine 2- Feminine 3- Ambiguous 4- Masculine 5- Hypermasculine

A-1 can confidently be identified as a female; in fact, the anthroscopic analysis clearly displayed gracile and hyperfeminine characteristics. The ancestry may exactly be from a group not provided by the databank, but the mix of Asian, Central American, and African features compels the researcher to conservatively estimate the ancestry to be from geographic regions with Asian and African influences.

Table 21. A-2 Results.

	Intra-Round	Including Size	Not Including Size	Anthroscopic
Ancestry	1	African American	African	Asian
	2	African	African	Asian
	3	African	African	
IRR:		2/3	3/3	2/2
Sex	1	Male	Female	Female (1)
	2	Female	Female	Female (2)
	3	Female	Female	
IRR:		2/3	3/3	0/2

1-Hyperfeminine 2- Feminine 3- Ambiguous 4- Masculine 5- Hypermasculine

A-2 is also categorized as a female, with more robust African phenotypic characteristics. The phenotype still indicated a gracile and feminine face, but African features are more robust than that of Asian. This individual is estimated to be of an African female group.

Table 22. A-11 Results.

	Intra-Round	Including Size	Not Including Size	Anthroscopic
Ancestry	1	African American	African American	Asian and European
	2	African	African	Asian
	3	European American	European American	
IRR:		0/3	0/3	1/2
Sex	1	Male	Male	Male (4)
	2	Female	Female	Male (4)
	3	Male	Male	
IRR:		2/3	2/3	2/2

1-Hyperfeminine 2- Feminine 3- Ambiguous 4- Masculine 5- Hypermasculine

A-11 is estimated to be a Male. The ancestry revolves around African characteristics, with some indication of Asian, or gracile Mesoamerican and European features. Overall the geographic roots come from African and European origins.

Table 23. A-12 Results.

	Intra-Round	Including Size	Not Including Size	Anthroscopic
Ancestry	1	European American	European American	European
	2	European American	European American	Asian
	3	European American	European American	
IRR:		3/3	3/3	0/2
Sex	1	Male	Male	Female (2)
	2	Male	Male	Ambiguous (3)
	3	Male	Male	
IRR:		3/3	3/3	0/2

1-Hyperfeminine 2- Feminine 3- Ambiguous 4- Masculine 5- Hypermasculine

A-12 had some conflicting results in the sex area. 3D-ID categorized this individual as a male, but anthroscopic analysis characterized this individual as a female and ambiguous. It is likely this is a male with some anthroscopic traits that appear more feminine. Nevertheless, this individual is very likely to be of European origins with Ambiguous sex.

Table 24. A-13 Results.

	Intra-Round	Including Size	Not Including Size	Anthroscopic
Ancestry	1	European American	European American	Asian (Slight African)
	2	European American	European American	Asian
	3	European American	European American	
IRR:		3/3	3/3	1/2
Sex	1	Male	Male	Male (5)
	2	Male	Male	Male (5)
	3	Male	Male	
IRR:		3/3	3/3	2/2

1-Hyperfeminine 2- Feminine 3- Ambiguous 4- Masculine 5- Hypermasculine

A-13 is confidently a male with European ancestry. Anthroscopic analysis indicated that of Asian ancestry, but these could be anomalous European characteristics.

Table 25. A-14 Results.

	Intra-Round	Including Size	Not Including Size	Anthroscopic
Ancestry	1	African American	African American	Asian
	2	African American	African American	Asian
	3	European American	European American	
IRR:		2/3	2/3	2/2
Sex	1	Male	Male	Ambiguous (3)
	2	Male	Male	Ambiguous (3)
	3	Male	Male	
IRR:		3/3	3/3	2/2

A-14 is estimated to be a male. Anthroscopic analysis indicated ambiguity in the sex, but all 3D-ID results made clear this was a male. Posterior probability values indicated this cranium was most like the African female group. African female crania display more robust craniofacial features; therefore, it is likely this is indeed a male individual with features indicating African ancestry.

Table 26. A-15 Results.

	Intra-Round	Including Size	Not Including Size	Anthroscopic
Ancestry	1	Mesoamerican	Mesoamerican	Asian (slightly African)
	2	East-Asian	African American	African
	3	Mesoamerican	African American	
IRR:		2/3	2/3	0/2
Sex	1	Female	Female	Male (5)
	2	Male	Male	Male (5)
	3	Female	Male	
IRR:		2/3	2/3	2/2

A-15 showed discrepancies in sex categorization. Where 3D-ID had a mix of sex results, the anthroscopic features indicated this individual displayed hypermasculine features in the cranium and pelvis. This is quite surprising because the craniofacial features showed remarkable masculinization and robusticity of the face. The motley of ancestry results revolved around more robust ancestry categories, with exception of East-Asian male. This individual can be categorized as a male with a mix of Asian and African ancestral roots.

Table 27. A-16 Results.

	Intra-Round	Including Size	Not Including Size	Anthroscopic
Ancestry	1	Mesoamerican	European American	European
	2	European American	European American	Asian
	3	European American	European American	
IRR:		2/3	3/3	0/2
Sex	1	Female	Male	Male (4)
	2	Male	Male	Male (5)
	3	Male	Male	
IRR:		2/3	3/3	0/2

A-16 is estimated with high confidence to be a male with European and Asian ancestry mix. Mesoamerican females' phenotype is a combination of African and Asian facial characteristics, so the result of Mesoamerican female is comparable to a European American male's facial characteristics.

Table 28. A-17 Results.

	Intra-Round	Including Size	Not Including Size	Anthroscopic
Ancestry	1	European American	African American	Asian
	2	European American	European American	Asian
	3	Mesoamerican	European American	
IRR:		2/3	2/3	2/2
Sex	1	Male	Male	Ambiguous (3)
	2	Male	Male	Ambiguous (3)
	3	Female	Male	
IRR:		2/3	3/3	2/2

A-17 resulted in Ambiguous (3) anthroscopic sex estimation, but 3D-ID placed this individual into a male category. This individual has a high likelihood of European and Asian ancestry. For the first intra-observer error testing, the including size gave European American male, and not including size gave African American male. Why the size factor created this disparity involves further investigation. The third round of testing also showed disagreement, Mesoamerican female versus European American male. The majority of testing produced European American male results, allowing the analysis of all the factors to conclude this individual exhibits European American male phenotype, with some influence of Asian (male) facial characteristics.

The final table of results is indicated below:

Table 29. Final Results Table of Combined Techniques.

Individual	3D-ID	Anthroscopic
A-1	South American Female African American Female Mesoamerican Female	Asian Female Asian Female
A-2	African Female African Female African Female	Asian Female Asian Female
A-11	African American Male African Female European American Male	Asian, European Female Asian Female
A-12	European American Male European American Male European American Male	European Female Asian Ambiguous
A-13	European American Male European American Male European American Male	Asian (slight African) Male Asian Male
A-14	African American Male African American Male European American Male	Asian Ambiguous Asian Ambiguous
A-15	Mesoamerican Female African American Male African American Male	Asian (slight African) Male African Male

Table 29. Continued

A-16	European American Male European American Male European American Male	European Male Asian Male
A-17	African American Male European American Male European American Male	Asian Ambiguous Asian Ambiguous

CHAPTER FOUR: DISCUSSION

Introduction and Overview

The results from all phases of testing, anthroscopic ancestry, anthroscopic sex, 3D-ID Forensic Bone Clones, and 3D-ID unknown, all resulted in more questions than answers. The results from the anthroscopic testing showed high intra-observer error rates, and that these techniques can be repeated by the same researcher with very few consistent results. Overall, the testing repeatability was low, and the estimation results were questionable. The general categories for ancestry created for anthroscopic testing showed the broadness and vagueness the traits signify. The anthroscopic sex results were more consistent than ancestry results. This is understandable because sex estimation is less prone to regional changes, admixture, and natural selection pressures than ancestry morphology.

3D-ID results concluded in an amassment of variation. Intra-observer error was less consistent in most of the unknown individuals. The ancestry and sex estimations for the Forensic Bone Clones skulls with known ancestry and sex came up with inaccurate categories for the Asian and African males, but the European female was categorized into the appropriate ancestry group, though the sex category was inaccurate for some rounds of error testing. Nevertheless, the nine skulls analyzed had interesting results, a high rate of intra-observer testing error, and questions about the database of crania used within 3D-ID.

Anthroscopic Technique and Results Discussion

Anthroscopic techniques are useful in many instances where the trained human eye can assess as much pertinent information about an unknown's skeletal remains as possible without equipment or a controlled laboratory environment. Anthroscopic techniques are also beneficial when an appropriate reference sample is unavailable (Langley et al. 2017). Intra-rater reliability for this portion of the testing was moderate. The moderate reliability in data collection and final determination of ancestry and sex could be due to a small sample size, or lack of training in these techniques for the observer. Developing a skill in anthroscopic techniques through repetitive practice under the guidance of a trained and experienced professional may improve these results in future studies (Ross and Williams 2008; Walker 2008; Smith and Boaks 2014). Having another researcher perform the same tests and comparing inter-observer error would also provide relevant testing results that could tell more information about the researcher's testing abilities, or the technique itself.

Ancestry

Categorizing unknown individuals into ancestry groups was shown to be a more nebulous outcome than originally predicted. With worldwide globalization, modern populations are intermixing with previously unassociated populations in various regions. This creates a much more fluid and admixed gene pool where phenotypes display mixes of traits that may have not been previously observed, or housed in the famous large collections around the world. Ancestry in the three-category classification system is useful for unidentified persons in medicolegal cases when remains can be narrowed down to help with victim identification. Beyond this practical use, categorizing a person into an

ancestry category, as we do with the three-category system, can be misleading and impractical for research purposes requiring more in depth ancestry estimations. The traits published by Rhine (1990) have been decreed as a self-fulfilling representation to describe socially reified racial categories. There are no racial archetypes to describe peoples of different geographic region, but this was Rhine's work to determine the traits best suited to describe different races in order to place a label onto a skeleton (Smay and Armelagos 2000).

Sex

The visual assessment of sex can be a strong asset in forensic cases where the visual eye is the only measuring tool available. As a researcher with neophyte experience, having visual aids in reference books was a helpful asset in the deliberation of the trait scores on crania and pelvises. Applying anthroscopic traits was a relatively easy but subjective experience. The five traits used for sex analysis would have been very difficult to measure with a metric tool because of the subtle ranges in size, shape, and angle of the feature. For example, some ventral arcs were clearly sharp with an exact edge, and others that are classified with the same score, showed a very slight but noticeable difference in the sharpness of the ventral edge. In general, the pelvis indicated more definite female to male, and gracile to robust features than did the cranium. This is to be expected because of the high sexual dimorphism apparent in the human pelvis. Visual examination of biological sex traits on the skeleton captures the subtle dimorphic shape variations that are usually difficult to near impossible to measure (Walker 2008). Cranial variations may just be a property of adaptive changes, but the pelvis is not as susceptible to modifications, and can be considered a more reliable source for sex.

This method and technique does not come without downsides though. The components of training techniques, and the reference material used to educate the researcher are inadvertently subjective. Where one researcher can see a ventral arc on a pelvis as sharp enough to be a definite female, another researcher may, through previous experience with ventral arcs or interpretation of the reference images and guides, estimate the arc to be a 2, or an ambiguous trait. Walker (2008) denotes the impact of misinterpreting regional idiosyncrasies, chronological changes, and environmental variations in biological sex traits. Because these individuals were unknown, the most conservative method I could enable was to refer to three known and accepted reference guides (*Standards, The Phenice Method,* and *Human Osteology*) to gather the most comprehensive understanding of the visual traits to look for. The pictures in the texts served as my standard reference guides. While an individual could have displayed a trait I considered that of a female, this could very well have been a manifestation of a regional variation of a male trait. Unfortunately, with this primary assessment of the individuals, taking geographic region into consideration to determine biological sex was inaccessible.

Intra-Rater Reliability Results

Intra-rater reliability for sex and ancestry was markedly consistent. This encourages the use of anthroscopic techniques to assess sex and ancestry in unknown individuals, but the researcher should also be cautioned to the small number of options to choose from within these techniques. Having three categories from which to categorize each individual could promote the consistency of results. This is also true for the sex anthroscopic techniques. The limited value system is a great benefit, for it simplifies the technique for the masses. Even still, the limited number could influence high reliability

during retesting. Nevertheless, the consistency in scoring is an overall positive attribute to the identification of the individuals and the usability of the techniques. Overall, the consistency in the testing for the anthroscopic method portion of the study were a 44% consistency in the two rounds of ancestry tests, and a 56% IRR in the two rounds of sex tests. When combined, intra-observer reliability was a mere 33% reliability. This is quite low for repeatability measures, and gives an important perspective on one observer's error rate for measuring the same set of data at different intervals. These statistics show the rate of consistent results, and does not add to the estimation of ancestry and sex for each individual.

3D-ID Technique and Results Discussion

The results from the 3D-ID output show that the administration of ancestry is a characteristically inconsistent practice and/ or user repeatability is in question. The 3D-ID manual guides each user to the appropriate landmarks with clear pictures of each landmark indicated on large pictures of crania, which makes it clear and easy for users to properly use the program. The size factor did manipulate the results, but not to extremes; therefore, 3D-ID and geometric morphometrics did a good job of analyzing shape without size influencing the overall results. Because the 3D-ID database is still expanding, it is impossible and irresponsible to say that these are the most appropriate ancestry categories to which each individual belongs. The database does not include crania from many Asian groups, such as central Asia, India, China, Southeast Asia, or Japan. As reported in King (2015), ancestry estimation results were low, and this may have been due to a limited population databank. It may be possible one or all individuals are not from the ancestry groups provided by the program. In fact, when typicality is low,

and posterior probability is high, this indicates either a measurement error, or that the individual in question does not come from a group included in the analysis (Ousley and Jantz 2012: 323). Future study with a larger population databank from more geographic regions will give insight into the best ancestry estimation for each individual.

Significantly, in 1962 when Giles and Rhine created the formula to deduce race from unknown skeleton, the accuracy of the categorization when applied to a different sample set of skeleton was a mere 18.2 and 14.3% accuracy. Not surprisingly, when the formula was applied to the *same set* of skeleton that the formula was created from gave 85-90% accuracy (Smay and Armelagos 2000). Even applying the same formula on the *same* sample from which the formula came, there was still a margin of error. If a formula is derived from a certain population, and said formula applied *to the same population,* results lower than at least 85% would point to user repeatability error, or a flaw in the design of the procedures. With such alarming differences in Giles and Rhine's testing results, procedures for determining ancestry are seemingly more and more compromised, rendering the ancestry category unserviceable to the biological profile.

Reference Populations

There is a quandary about the comparative databases used in research. The populations used in the 3D-ID database are limited to the Terry, Morton, and C.A. Pound collections, among other small reference groups. Many of these populations are from individuals who died pre-1950 (Terry Collection, Morton Collection). These groups have their own limitations with the Terry group being comprised of solely black and white individuals, and the Morton Collection containing a multitude of individuals with unknown profiles (Renschler and Monge 2008; Geller and Stojanowski 2016). If

researchers continue to use these somewhat antiquated skulls as reference populations, results can show inaccuracy, or a skew in biological profile estimation for modern populations (Smith and Boaks 2014). Other studies emphasize the need to utilize the predictive models only for appropriate target populations that the model was formulated around (Langley et al. 2017). Studies have also observed the changes in cranial morphology when compared to earlier birth cohorts (Godde 2015; Langley et al. 2017). Having clear descriptions of traits, and using a population-appropriate reference sample are two of the most important factors influencing the outcome of modern studies.

Based on the posterior and typicality probabilities, all of the crania I analyzed fall outside the range of probability limits that the program contains for each geographic group. The crania are therefore not typical of the reference populations, and therefore, all are estimated to belong to other ancestry groups outside of the reference populations. The 3D-ID website notes the ongoing accumulation of data to expand population parameters for future studies. I recommend adding groups from different regions in Africa, Southeast Asia, West-Central Asia, and the Eskimo, Inuit, and Native American groups of North America.

European Crania

The European cranium in the Bone Clones series was categorized the most accurately. This brings up the question if the dataset was more apt to categorize European crania more readily and more meticulously than other ancestry groups. The 3D-ID reference manual had no indication that European crania had an advantage over other geographic groups, though five out of 14 of the reference populations were of a European descent group. This may have been an influence on the output of European results. This

interesting result may be a de facto occurrence of the ample amount of European crania available for data collection and reference populations. If this is the case, the collaborators creating the 3D-ID database may have had former experience with European crania in practice and throughout their research experience, giving these crania an inadvertent and unintentional accuracy and proficiency over other crania from geographic groups.

Table 30. 3D-ID Reference Populations.

1. African	Male	Female
2. African American	Male	Female
3. African- Brazilian	Male	Female
4. Brazilian	Male	Female
5. Circumcaribbean	Male	Female
6. East Asian	Male	Female
7. European American	**Male**	**Female**
8. European Central	**Male**	**Female**
9. European Eastern	**Male**	**Female**
10. European Southeastern	**Male**	**Female**
11. European Southwestern	**Male**	**Female**
12. Japanese Brazilian	Male	Female
13. Mesoamerican	Male	Female
14. South American	Male	Female

Intra-Observer Error and Intra-Rater Reliability

Only one researcher performed all the testing, so an intra-rater reliability assessment was conducted to test the dependability of the testing performed. Although the 3D-ID program was quite user-friendly, with clear descriptions of landmarks displayed on large well-defined photographs, user error could be the most significant culprit in the intra-rater discrepancies. The overall consistency in the output of the tests

were as follows: for Ancestry, including size resulted in a 22% reliability, and not including size resulted in 33% reliability; for Sex, including size produced a 44% consistency, and not including size produced a 67%. These statistics show the rate of consistent results, and does not add to the estimation of ancestry and sex for each individual. When ancestry and sex were combined, the intra-observer reliability was 22% when including size, and 44% when not including size. These are still low, but add another dimension of repeatability standards using the data produced by the methods.

Intra-rater reliability proved that user measurement was only effective on individuals A-12 and A-13, as these individuals were estimated to be of the European and Male categories. Each round of data collection was done with no difference in placement of area required, equipment, technology used, or techniques practiced. Possibly, the way the tip of the MicroScribe stylus was held produced a slight variation in coordinate points. Placement of skull should not extremely influence the results since this program calculates the shape components, not the size (although size was used as a secondary analysis to see if size was a factor in the categorization of data). Having another researcher perform inter-observer error controls would give more insight and credence to user error as the main reason to such a low intra-rater reliability score.

Researcher experience may play a large part in the anthroscopic analysis. The subjectivity of many of the traits based on user experience, their approach to analysis, and their reference tools can be the biggest impact to their conclusions. In the study by Adams and Byrd (2002) and referenced in Smith and Boaks (2014), observers can interpret even agreed upon standard landmarks differently and generate variances in measurement technique and recorded physical measurements, regardless of practitioner

experience (Smith and Boaks 2014). *Standards*, a principal reference guide for this discipline, contains pictures and descriptions that can be nebulous for researchers. This text is also already 20 years old, and may illustrate outdated or ill-defined terminology that can be interpreted differently by a number of people; both trained and untrained (Smith and Boaks 2014). Another important concern is the explicit definitions of the traits used in the study. As Langley and colleagues note, features that perform the highest observer errors come with clear definitions, scoring procedures, and illustrations. The variable features can be difficult to score, which can influence method accuracy and reliability rendering them unacceptable for forensic studies (Lewis and Garvin 2016; Langley et al. 2017).

Intra-observer error was the only retesting this study used, and showed that anthroscopic traits are in the eye of the beholder. There was only one researcher and so these results are automatically skewed to the sole researcher's previous experience with human remains, previous coursework on human osteology, and understanding of pictures and scales displayed in reference material. Even the accumulated experience of working with the nine skeletons created a growing bias since these nine exhibited only the traits that pertained to them. The ongoing interaction with this material inevitably gave the researcher more and more practice with these traits, and this may have been a contributing bias to rounds 2 and 3 of intra-testing.

User error with the MicroScribe MX may have been another major culprit in the inconsistency of intra-observer error and intra-rater reliability. The researcher had a full year of practice with this same MicroScribe equipment, which may or may not have been sufficient practice with this tool. Perhaps tools use or the placement of the skull on the

clay pillar varied just enough so that the landmark coordinates were different and the resulting category was different, or the acquisition of each landmark may have been variable. In a study by Slice et al. (2004), Type I landmarks, like nasion and bregma used in this study, are the most reproducible, and the variation in measurement of landmarks was a function of the interaction between landmark, skull, and observer (Slice et al. 2004). This could be a leading factor in the fluctuation of 3D-ID results in this study.

The disparities of 3D-ID results for the same individual may be a result of the 3D-ID database itself. The accuracy of categorizing the Forensic Bone Clones European cranium into the appropriate category led me to believe that the program may be more apt to accurately classify the unknown skull into the European ancestry category. There is no mention of European groups having more leverage over others in the 3D-ID Manual (Slice and Ross 2009). In King's study (2015), it was also noted that 3D-ID categorized white South Africans (generally of European ancestry) more often correctly than black South Africans.

Future Research

Future studies need a push in standardization of reference materials, updated databases, globally representative databases, and transferring accurate information through reliable teaching methods. Having multiple observers trained with the same procedures for a duration of time that could consider them "expert" in their task would be the best way to try and standardize the data acquisition part of this study. If this procedure were to happen, the accuracy and validity of the MicroScribe tool equipment, the 3D-ID database, and outcome would be measured with more control.

The most obvious factor is our reference populations we use in the field of Anthropology. Many of the individuals housed in our esteemed museums and university centers are from ancestral groups that are only representative of that region from that time period. In the United States, for example, the Hamann-Todd museum houses one of the largest collections of 18th-19th century blacks and whites. This is a very rich, but not ethnically diverse collection of modern humans. Researchers gathered the skeletal materials from the years 1912 and 1938, making this collection limited to that time period in that geographic region. The two groups of racially segregated individuals practiced extremely diverse lifestyles, had very different nutrition, occupations, habits, emotional stressors, and physical demands.

Conclusion

With the combination of techniques, ancestry and sex of each individual can be estimated, although not without caveats. From here many more studies can be designed to further investigate the teaching collection. Deeper study into the population's geographic area, history, diet, and nutrition may be undertaken, furthering the capacity for learning novel methodologies and practices for the many future incoming students. Comparing anthroscopic methods with a digital method opens a conversation about the current methodologies used in the professional field. Ultimately we can ask, "What good are nine unknown individuals, if we do not have accurate references to help us classify them?" In universities and research facilities, having a collection of unknown skeletal materials limits the abilities of teaching and research. If these individuals do not have known or estimated biological profiles, information is limited to trying to figure out a way to categorize each individual.

The project begets the question, “Why categorize people in the first place?” With a motley population like this, is it even necessary to categorize each person? Do finding categories in which to place each skeleton provide an answer? This is an exploratory analysis that serves as a launching point for many more studies to come. The most accurate conclusion that can come from this project is the modern population is a remarkable mix of people and places, and researchers must acknowledge and improve the standardization in our chosen field. The future of the field is rapidly evolving.

APPENDIX

Data Recording Worksheets for Anthrosopic Methods

Sex

	Score		**Score**
Cranium (Standards 1994)		**Pelvis (Phenice 1969; Standards 1994)**	
Nuchal Crest		Ventral Arc	
Mastoid Process		Subpubic Concavity	
Supraorbital Margin		Medial Aspect of the Ischiopubic Ramus	
Supraorbital Ridge (Glabella)		Greater Sciatic Notch	
Mental Eminence		Preauricular Sulcus	

Appendix. Continued

Ancestry

Cranial Trait				**Score**
(Standards 1994; Rhine 1990; White et al. 2012)				
	Asian, American Indian	**White, European**	**Black, African**	
Incisors	Shovel-shaped	Blade-form	Blade-form	
Incisor Rotation	Present	-	-	
Carabelli's Cusp	-	Present	-	
Dentition	Not crowded, well-sclerosed; enamel extensions, buccal pits	Small, crowded; Carabelli's cusp	Not crowded; molar crenulations	
Palate	Elliptic	Parabolic	Hyperbolic	
Zygomatics	Robust, flaring, malar tubercle	Small, retreating	Small, retreating	
Zygomatic Tubercle	Present	-	-	

Appendix. Continued

Zygomaticomaxillary Suture	Angled	Jagged/ S-shaped	Curved/ S- shaped	
Ascending Ramus	Wide and vertical	Intermediate and pinched ramus; slanted vertical ramus	Narrow and oblique, pinched, slanted	
Chin	Blunt, median	Square, bilateral, projecting	Blunt, vertical, median, retreating	
Mandible	Straight mandibular border; everted gonial angle	Cupping below incisors; undulating; straight gonial angle	Straight gonial angle	
Prognathism	Moderate	Limited	Marked alveolar and facial	
Palatine Suture	Straight	Jagged, Z-shaped, bulging	Arched, bulging	
Cranial Sutures	Complex, with Wormian	Simple	Simple	
Postbregmatic Depression	-	-	Postbregmatic Depression	

Appendix. Continued

Cranial Vault	Low, sloping; keeled	High	Low with postbregmatic depression	
Orbits	Rounded	Sloping/ Aviator	Rectangular	
Base Cord	Short	Long	Long	
Sagittal Arch	Low and sloping	-	-	
Inion Hook	-	Present	-	
Wormian Bones	Present; Inca bones present	-	-	
Nasal Spine	Small/ medium, "tilted"	Long and large	Small, none	
Nasal Sill	Blurred	Deep, very sharp	Guttered lower nasal border	
Nasal Profile	Concavo- convex	Straight	-	
Nasals	Low and tented, straight sides; angled at midline	Highly arched/ steepled; pinched in below root, break in contour at or near nasomaxillary	Low and flat, rounded contour	

Appendix. Continued

Nasal Aperture	Medium	-	Wide	
Nasion	-	Depressed	-	
Nasal Root	Tented/ intermediate	Steepled/ narrow	Wide	
External Auditory Meatus	Elliptic	Round	Rounded	
Canine Fossa	-	Canine Fossa present	-	
Venous Markings	-	-	Venous markings (vascularization)	
Metopic Suture	-	Metopic trace	-	

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