

To the Graduate Council:

I am submitting herewith a dissertation written by Gregory Eugene Berg entitled
“Biological Affinity and Sex Determination Using Morphometric and Morphoscopic
Variables of the Human Mandible.” I have examined the final electronic copy of this
dissertation for form and content and recommend that it be accepted in partial fulfillment
of the requirements for the degree of Doctor of Philosophy with a major in Anthropology.

Richard L. Jantz

Major Professor

We have read this dissertation
and recommend its acceptance:

Murray K. Marks

Walter E. Klippel

Edward F. Harris

Accepted for the Council:

Carolyn R. Hodges

Carolyn R. Hodges, Vice Provost
and Dean of the Graduate School

(Original signatures are on file with official student records.)

Biological Affinity and Sex Determination Using Morphometric and
Morphoscopic Variables from the Human Mandible

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Gregory Eugene Berg
May 2008

Copyright © 2008 by Gregory Eugene Berg
All rights reserved.

Dedication

To My Wife Patika, With Love

Acknowledgements

The acknowledgements are the hardest to write, as there are so many people that influenced this work, directly or indirectly, and I hope I do not forget anyone. First and foremost, this dissertation would not have been possible without the guidance of my committee, Drs. Richard Jantz, Murray Marks, Walter Klippel, and Edward Harris. Dr. Jantz, in particular, guided this research, modified my thinking, and challenged me to produce a better dissertation than I would have been originally written. Dr. Marks provided me with an excellent background and appreciation with soft tissue, as well as a great running partner. Dr. Klippel could always make me think, and always asked the questions that I didn't have the answers to. Dr. Harris provided editorial commentary and discussion that helped me produce a better dissertation than in its original form. I am deeply grateful to these individuals, for they have made me a better scientist and, more importantly, a better anthropologist.

I owe quite a bit of thanks to all of those individuals that allowed me access to the various collections I used in this research. Particularly, Dave Hunt at the Smithsonian tolerated my presence for a spell, Shirley Chacon and Fredy Peccerelli generously allowed me access to the samples at the FAFG, my dear friend and mentor, Dr. Diane Hawkey provided me with access numerous times to the collections housed at ASU, Dr. Bruce Anderson helped me a great deal with a small collection of border crossers found in Arizona, and finally Ms. Chom Noul at the Ministry of Culture, Kingdom of Cambodia for access to the remains at the Cheung Ek Killing Field. Dr. Tom Holland of the Joint POW/MIA Accounting Command – Central Identification Laboratory (my boss)

graciously allowed me access to the collections there, as well as encouraging me to take the time necessary to continue (and begin!) this research, writing, and instruction, even though he probably didn't want to loose the person hours necessary to accomplish this task, given the pace of operations at work.

To my editors, the friends who were subjected to the most heinous task of reading chapters of this opus, I am forever in your debt. Ms. Sabrina Ta'ala, the best office mate in the world, I owe you big-time. So if you and your husband ever need gas for your juggernaut, I'll be the one to bring it to you, or if Henry ever needs a bundle of diapers, consider it done. (Dr.) Ms. Denise To provided an uninterrupted stream of encouragement that I hope I have the ability to return in kind, as well as a large supply of chocolate and clementines. She produced the awe-inspiring illustrations found throughout this dissertation (as well as a wicked-good graphic for my surfboard). Dr. Laura Miller read every horrific page that I asked her to, even with short deadlines. For you, I'll try to not often split my infinitives, and I'll get the next hardcover book. I also would like to say thanks to all of my friends at work and school who have been subjected to me ranting on about my dissertation at some point of another – you know who you are, so...Thanks!

That leaves all of my family and friends in the world outside of anthropology. Without them, I would not have dreamed of beginning this work, or even continuing my education. To my parents, thanks for believing in me, and yes Dad, if I hear GID one more time, I might scream (I'll have Mom talk to you about that...). My brother Norm has always been encouraging in this process and actively interested in what I was doing, even when I wasn't. Kevin always had a patient and sympathetic ear to listen to me

complain, as he has had the pain before me. My extended family is the best a person could ever ask for, even if they weren't too keen on the idea of bones sometimes, or me taking away their daughter/sister. The most important person to me in this adventure has been my wife Patika, who has been an amazingly patient. Sweet P, I think my five years are done, thanks for waiting. Simply said, I love you.

Finally, I'd like to say a big thank-you to all of my friends that have been important in my life, and have been there to listen to my stories, successes, and failures. Phill and Vickie have always been a source of great joy and support in my life. Thanks! John and Barb provide(d) many fine get-togethers and camping adventures, the likes of which cannot be equaled, as well as being the folks that coined "Doc" Berg (now for real!). Together with Jeff and Stacey, Joe and Cecily, Nick and Joanne, and a whole host of others, thanks for being there for me. I think we need to get together a bit more often. Your place or ours? And to Penny, who taught me how to dig a burial and provided me with food and clean clothes while writing this, the next round of margaritas are on me!

Abstract

This study determined that morphometric and morphoscopic variables of the human mandible can be used to estimate the partial biological profile of an individual. Specifically, these mandibular variables were used in linear discriminant function analyses designed to estimate the biological affinity or sex of an individual, with or without biological *a priori* knowledge. The study data set is composed of 17 world samples including U.S. White, Black, and Hispanic individuals, prehistoric and proto-historic Native American groups, Southeast and Northeast Asian peoples, a Central American group, and a Nubian group. Eleven metric measurements were utilized: eight are standard measurements; two were designed for this study; and one was modified from its standard definition. Six morphoscopic variables were employed; most were analyzed as defined in the literature, though several involved expanded definitions and scoring categories. Specific definitions and graphics are provided for the measuring and scoring procedures.

These variables were used in three types of analyses – a morphometric analysis, a morphoscopic analysis, and both types together, forming a morphometrosopic analysis. The combination of morphometric and morphoscopic data into one statistical analysis is a relatively novel approach to the analysis of human remains. Four major combinations of samples were used in the study: all groups, groups of individuals that are forensically interesting, groups that are potentially closely associated, and single groups through time.

Results indicated that sex can be estimated using the morphometric data with high accuracy rates, typically 83% to 89%. Morphoscopic data produced sex estimation

accuracy rates between 63% and 81%. Combining the two data sets produced accuracy rates in excess of 90%. Analyses examining the estimation of biological affinity were successful. Morphometric data produced better accuracy rates than morphoscopic data, but the morphometrosopic data sets were the most accurate. Linear discriminant functions using morphometrosopic data produced biological affinity accuracy rates that were frequently four times better than expected by random chance, and were often seven times greater than chance alone. Overall, the study concluded that mandibular morphometric and morphoscopic variables were useful for the estimation of sex and biological affinity in a variety of world populations.

Table of Contents

Chapter 1: Introduction	1
The Mandible	2
Biological Affinity and Its Diagnosis: The Problem	4
Previous Mandibular Studies	9
Racial Mating Trends in the United States	17
Chapter 2: Methods and Materials	21
Population Samples	23
Terry collection	23
William W. Bass Donated collection	25
Memphis collection	26
Central Identification Laboratory collections	26
Pima County Medical Examiner collection	27
Fundacion de Antropologia Forense de Guatemala collection	28
Chinese sample	29
Cambodian sample	29
Prehistoric Hohokam sample	30
Historic Arikara sample	31
Prehistoric Nubian sample	31
Morphoscopic Traits	32
Morphometric Variables	37
Statistical Considerations	41
Missing Data	50
Chapter 3: Morphometric and Morphoscopic Analyses	59
Morphometric Analyses	59
Sexual Dimorphism	60
Biological Affinity	65
All Groups	66
Forensically Interesting Groups	71
Closely Related Groups	75
Groups Through Time	75
Morphoscopic Analyses	81
Sexual Dimorphism	81
Biological Affinity	85
All Groups	86
Forensically Interesting Groups	86
Closely Related Groups	90
Groups Through Time	95
Chapter 4: Morphometrosopic Analysis	99
Sexual Dimorphism	99

Biological Affinity	105
All Groups	105
Forensically Interesting Groups	108
Closely Related Groups	117
Groups Through Time	119
Chapter 5: Discussion	127
Study Results	127
Morphometric Data	127
Morphoscopic Data	129
Morphometrosopic Data	132
Sources of Error	136
Intra- and Inter-observer Error	136
The Big Picture	139
Looking Forward	145
References	149
Appendix 1: Sample Summary Data	160
Vita	174

List of Tables

Table Number	Title	Page
Table 1.	Population characteristics of the United States and population characteristics of those involved in violent crime from across the country.	22
Table 2.	The study sample, by collection and sex.	24
Table 3.	Percentage of missing values by measurement, sample, and sex.	53
Table 4.	Discriminant functions for sex determination in five population samples and their associated leave-one-out accuracy rates.	61
Table 5.	Discriminant function statistics for the five population samples in Table 4.	61
Table 6.	Discriminant functions for sex determination of the pooled population samples, and the associated leave-one-out accuracy rates.	63
Table 7.	Discriminant function statistics for the pooled population samples in Table 6.	63
Table 8.	Discriminant function analysis results for the morphometric samples and cross-validated accuracy rates.	67
Table 9.	Discriminant function analysis results, morphometric data, for a selection of forensically interesting groups and the cross-validated accuracy rates.	72
Table 10.	Discriminant function analysis results, morphometric data, for a selection of closely related groups and the cross-validated accuracy rates for those analyses.	76
Table 11.	Discriminant function analysis results, morphometric data, for a selection of closely related groups in time, and the cross-validated accuracy rates for those analyses.	76
Table 12.	Structure matrix for the 19 th and 20 th century U.S. White and Black males, morphometric data.	82
Table 13.	Structure matrix for the 19 th and 20 th century U.S. White and Black samples (pooled sexes), morphometric data.	82
Table 14.	Independent samples T-test of the mean mandibular morphology scores for the study males and females.	84
Table 15.	Discriminant functions for sex determination using mandibular morphoscopic data for the study population samples and the associated leave-one-out accuracy rates.	84
Table 16.	Discriminant function statistics for the mandibular morphoscopic data.	85
Table 17.	Discriminant function analysis results for the morphoscopic sample and cross-validated accuracy rates.	87

Table 18.	Discriminant function analysis results, morphoscopic data, for a selection of forensically interesting groups and the cross-validated accuracy rates.	91
Table 19.	Discriminant function analysis results, morphoscopic data, for a selection of closely related groups and the cross-validated accuracy rates for those analyses.	94
Table 20.	Discriminant function analysis results, morphoscopic data, for a selection of closely related groups in time, and the cross-validated accuracy rates for those analyses.	96
Table 21.	Discriminant functions for sex determination in five population samples and their associated leave-one-out accuracy rates using the morphometrosopic data.	100
Table 22.	Discriminant function statistics for the five population samples in Table 21.	100
Table 23.	Discriminant functions for sex determination of the pooled population samples, and the associated leave-one-out accuracy rates, using the morphometrosopic data.	101
Table 24.	Discriminant function statistics for the population samples in Table 23.	102
Table 25.	Discriminant function analysis results for the morphometrosopic analyses by group and the cross-validated accuracy rates.	106
Table 26.	Discriminant function analysis results, morphometrosopic data, for a selection of forensically interesting groups and the associated cross-validated accuracy rates.	111
Table 27.	Structure matrix for the U.S. White and Black male samples (time pooled), morphometrosopic data.	115
Table 28.	Structure matrix for the U.S. White and Black female samples (time pooled), morphometrosopic data.	115
Table 29.	Structure matrix for the 20 th century U.S. White and Black male samples, Cambodian males, and Chinese males, morphometric data.	117
Table 30.	Discriminant function analysis results, morphometrosopic data, for a selection of closely related groups and the cross-validated accuracy rates for those analyses.	118
Table 31.	Discriminant function analysis results, morphometrosopic data, for a selection of closely related groups in time, and the cross-validated accuracy rates for those analyses.	120
Table 32.	Structure matrix for the 19 th and 20 th century U.S. White and Black samples (males), morphometrosopic data.	126
Table 33.	Structure matrix for the 19 th and 20 th century U.S. White and Black samples (sexes pooled), morphometrosopic data.	126
Table A1.	Summary statistics for the mandibular morphometric data for the 20 th century U.S. White sample.	161
Table A2.	Summary statistics for the 19 th century U.S. White mandibular morphometric data.	162

Table A3.	Summary statistics for the 20 th century U.S. Black mandibular morphometric data.	163
Table A4.	Summary statistics for the mandibular morphometric data for the 19 th century U.S. Black sample.	164
Table A5.	Summary statistics for the mandibular morphometric data for the male Hispanic sample.	164
Table A6.	Summary statistics for the mandibular morphometric data for the Guatemalan sample.	165
Table A7.	Summary statistics for the mandibular morphometric data for the Cambodian sample.	166
Table A8.	Summary statistics for the mandibular morphometric data for the male Chinese sample.	166
Table A9.	Summary statistics for the mandibular morphometric data for the male Vietnamese sample.	167
Table A10.	Summary statistics for the mandibular morphometric data for the Arikara sample.	167
Table A11.	Table A11. Summary statistics for the mandibular morphometric data for the Hohokam sample.	168
Table A12.	Summary statistics for the mandibular morphometric data for the Nubian sample.	169
Table A13.	Summary statistics for the mandibular morphoscopic data for the 20 th century U.S. White sample.	169
Table A14.	Summary statistics for the mandibular morphoscopic data for the 19 th century U.S. White sample.	170
Table A15.	Summary statistics for the mandibular morphoscopic data for the 20 th century U.S. Black sample.	170
Table A16.	Summary statistics for the mandibular morphoscopic data for the 19 th century U.S. Black sample.	171
Table A17.	Summary statistics for the mandibular morphoscopic data for the male Hispanic sample.	171
Table A18.	Summary statistics for the mandibular morphoscopic data, Guatemalan sample.	171
Table A19.	Summary statistics for the mandibular morphoscopic data, Cambodian sample.	172
Table A20.	Summary statistics for the mandibular morphometric data for the male Chinese sample.	172
Table A21.	Summary statistics for the mandibular morphoscopic data for the male Vietnamese sample.	172
Table A22.	Summary statistics for the mandibular morphoscopic data, Arikara sample.	173
Table A23.	Summary statistics for the mandibular morphoscopic data for the Hohokam sample.	174
Table A24.	Summary statistics for the mandibular morphoscopic data for the Nubian sample.	174

List of Figures

Figure Number	Title	Page
Figure 1.	Illustration depicting the four morphoscopic categories of chin shape.	33
Figure 2.	Illustration of the four morphoscopic categories of the lower border of the mandible.	35
Figure 3.	A graphic illustration depicting the two categories of ascending ramus shape.	36
Figure 4.	An illustration depicting the five categories of gonial angle flare.	38
Figure 5.	Illustration depicting the four categories of posterior ramus edge inversion.	39
Figure 6.	Exemplar of the caliper position used to measure the mandibular breadth at mental foramen.	42
Figure 7.	A photograph showing the measurement location for the mandibular body breadth at the M2/M3 junction.	43
Figure 8.	A photograph depicting the measurement of the maximum breadth of dental arcade width at the third molar.	44
Figure 9.	A scatter plot of the first two canonical functions for all population samples by sex using morphometric data.	68
Figure 10.	A scatter plot of the first two canonical functions for U.S. Whites and Blacks by sex using morphometric data.	69
Figure 11.	A scatter plot of the first two canonical functions for U.S. Whites and Blacks sexes pooled, using morphometric data.	70
Figure 12.	A scatter plot of the first two canonical functions for a forensically diverse group selection (analysis #9, Table 13).	73
Figure 13.	A scatter plot of the first two canonical functions for a second forensically diverse analysis (analysis #12, Table 13).	74
Figure 14.	A scatter plot of the first two canonical functions for a 19 th and 20 th century U.S. White and Black males, morphometric data.	77
Figure 15.	A scatter plot of the first two canonical functions for a 19 th and 20 th century U.S. White and Black samples, morphometric data.	78
Figure 16.	A scatter plot of the first two canonical functions for a 19 th and 20 th century U.S. White and Black males, morphometric data, axes condensed.	79
Figure 17.	A scatter plot of the first two canonical functions for a 19 th and 20 th century U.S. White and Black samples, morphometric data, axes condensed.	80
Figure 18.	A scatter plot of the first two canonical functions for U.S. Whites and Blacks by sex, morphoscopic data.	88
Figure 19.	A scatter plot of the first two canonical functions for a forensically diverse group selection (analysis #9, Table 14).	92

Figure 20.	A scatter plot of the first two canonical functions for a second forensically diverse analysis (analysis #12, Table 14).	93
Figure 21.	A scatter plot of the first two canonical functions for a 19 th and 20 th century U.S. White and Black males, morphoscopic data.	96
Figure 22.	A scatter plot of the first two canonical functions for sexes pooled populations of 19 th and 20 th century U.S. Whites and Blacks, morphoscopic data.	97
Figure 23	A scatter plot of the first two canonical functions for all population samples by sex using the morphometrosopic data.	107
Figure 24.	A scatter plot of the first two canonical functions for U.S. Whites and Blacks by sex using morphometrosopic data.	109
Figure 25.	A scatter plot of the first two canonical functions for U.S. Whites and Blacks sexes pooled, using morphometrosopic data.	110
Figure 26.	A scatter plot of the first two canonical functions for a forensically diverse group selection (analysis #9, Table 24), morphometrosopic data.	112
Figure 27.	A scatter plot of the first two canonical functions for a second forensically diverse analysis (analysis #12, Table 24), morphometrosopic data.	113
Figure 28.	A scatter plot of the first two canonical functions for a 19 th and 20 th century U.S. White and Black males, morphometrosopic data.	121
Figure 29.	A scatter plot of the first two canonical functions for a 19 th and 20 th century U.S. White and Black males, morphometrosopic data, axes condensed.	122
Figure 30.	A scatter plot of the first two canonical functions for a 19 th and 20 th century U.S. White and Black samples, morphometrosopic data.	123
Figure 31.	A scatter plot of the first two canonical functions for a 19 th and 20 th century U.S. White and Black samples, morphometrosopic data, axes condensed.	124

Chapter 1

Introduction

Biological affinity studies or geographic population analyses have long been a focus of anthropology. Archaeologists tend to approach this topic in terms descriptions of prehistoric peoples and their migrations across the landscape through the analysis of the material culture left behind. Linguists may examine population studies through changes in word meaning, pronunciation, and language constructs. Physical anthropologists, and more relevant to this dissertation, forensic anthropologists explore populations in terms of identity, or biological groupings (frequently in terms of ethnicities or populations). As physical anthropologists, determining the biological affinity of a group, or simply classifying a single individual to a population, is a demanded skill – both from colleagues in anthropology and professionals in the medico-legal community.

The goal of this dissertation is to provide an “on the ground anthropologist” a suite of tools by which to estimate biological affinity through the use of a relatively robust bone, the mandible. It is intended also to present a method for determining the biological affinity that is straightforward and easily understood (e.g. simple morphometric and morphoscopic scoring methods), without the need for complex statistical manipulations (they are provided). A byproduct of this study is the evaluation of the mandible in the determination of the sex of an unknown individual. As the mandible is a relatively robust skeletal element, it (or portions of it) can survive circumstances that other elements may not. Not a complete mandible, but rather just portions of it, could be all that is needed for accurate estimates of ancestry or sex. Further, if both morphometric and morphoscopic

features are employed at the same time, smaller and smaller portions of the bone are all that may be needed to determine the biological profile of an individual. This dissertation explores mandibular morphometric data, morphoscopic data, and the combination of both for their potential to diagnose the partial biological profile of an unknown individual, based on data from multiple world populations.

The Mandible

A brief review of mandibular architecture and function is provided, as it is the form, which follows the function that is specifically analyzed in the bulk of this dissertation. The primary functions of the adult mandible are to form the lower floor of the mouth, to provide a vehicle for the growth and development of the lower dentition, and to provide anchor points for the muscles of mastication. It is a complex bone and is the only bone of the cranium to have independent movement other than the ear ossicles (Scheur and Black 2000). The principal portions of the mandible include the body (the horizontal ramus) and the vertical (ascending) rami, the latter are divided into a triangular portion called the coronoid process, a rounded articular eminence called the mandibular condyle. A final feature of the adult mandible is the chin, which is a uniquely human feature (Bass 2005). The mandible articulates with the cranial base, at the temporomandibular joints on the temporal bones, through the mandibular condyles.

The mandible arises through endochondral ossification processes, beginning at approximately the seventh week of intrauterine life; it is the second bone in the body to begin ossification after the clavicle (Baker *et al.* 2005; Gray 1995; Scheur and Black 2000). The mandible begins ossification in two separate centers, one each in a symmetrical half, both of which articulate together at the mandibular symphysis. An

extensive review of this ossification processes can be found in Scheur and Black (2000). By the perinatal period, the mandible consists of the body and ascending ramus. The ascending ramus is complete with the condylar and coronoid processes and is approximately half the length of the body (Scheur and Black 2000). At birth, the tooth crypts are present, as well as tooth germs. The mandibular hemispheres are united at the mental symphysis by a fibrous tissue that fuses at approximately one year (Baker *et al.* 2005; Gray 1995).

After birth, the mandible undergoes more variations in shape and size than any other facial bone in order to maintain proper growth trajectories with the maxilla, cranial base, and the dentition (Enlow and Hans 1996; Scheur and Black 2000). The mandibular condyle plays an important role in this process, due to downward and forward movement from the cranial base, but also the modeling and remodeling of the entire ramus is responsible for these actions (Enlow and Hans 1996). Overall, the modeling and remodeling experienced in the months and years after birth reduce the mandibular angle from approximately 175 degrees to around 130 degrees (Gray 1995; Scheur and Black 2000). The chin rapidly changes, increasing in size and depth to make way for the developing dentition, as does the alveolar process. The body elongates, particularly behind the mental foramen to provide space for the developing distal dentition (Gray 1995). Sexual dimorphism starts to appear in the mandible around puberty, though it is argued that since most growth and development is completed earlier in childhood, sexual dimorphism should be apparent in younger individuals as well. While some studies have argued this point (see Humphrey, 1998; Molleson *et al.* 1998), it is far from readily proven.

The mandible has the anchoring points for the muscles of mastication, but this musculature is also responsible for many other activities. Specifically, the mandibular musculature maintains the airway, is responsible for the gag reflex, provides for infant suckling and swallowing, and allows for speech and facial expressions (Enlow and Hans 1996). The muscles most obviously associated with the mandible are the masseter and temporalis, which attach on the lateral aspect of the ascending ramus and the superior and medial surfaces of the coronoid process. Equally important and often unmentioned muscles associated with mastication, facial movements, speech, are those found on the medial mandibular surface such as the superior pharyngeal constrictor, medial and lateral pterygoids, mylohyoid, digastric, genioglossus and geniohyoid muscles. Without these small, but important muscles, the floor of the mouth, speech, and chewing would not be possible. Each of the muscles attaches to a various ridge, spine, fossa, process, etc. that often play a part in the specific traits and measurements analyzed in this study.

Biological Affinity and Its Diagnosis: The Problem

Frequently, an individual's biological affinity is labeled as that person's "race." Defining the term race has been extremely difficult in anthropology simply because racial identity often is based on a multifaceted construct of characters such as social identity, ethnic identity, and the body's phenotypic configuration. A discourse of the various viewpoints on the term race is beyond the scope of this dissertation; however, suffice it to note that physical anthropology recognizes that there are no pure human "races" (AAPA 1996). A dichotomy exists between what is scientifically recognized and the practical application of physical anthropology in modern forensic situations. Physical and forensic anthropologists frequently are asked to make statements about the race of an unknown

individual by police agencies, medical examiners, and government officials in the pursuit of the identity of an unknown person. Indeed, the U.S. government categorizes persons based on their race in a manner proscribed by the Executive Office of the President of the United States, Office of Management and Budget. Directive 15 published on October 30, 1997, with an effective date of January 1, 2003, states that the federal government recognizes six racial groups (or a minimum of five racial groups and two ethnicities). These are American Indian or Alaska Native, Asian, Black or African American, Hispanic or Latino, Native Hawaiian or Other Pacific Islander, and White; the government specifically states that these labels do not necessarily correlate to biological or genetic underpinnings (Federal Register Notice, 1997).

The idea of race is important to law enforcement and medical professionals (it is part of the foundation for identity in the United States), although the concept of discrete races are not accepted scientifically. Even for the average person in today's society, predefined social, socio-economic, and biological connotations are associated with a given race. It is the dichotomy between the scientific and social concepts that arguably has led to the continued use of the term race and it may be why many recent introductory textbooks to physical and forensic anthropology and scientific publications continue to use the term. Even though the use of the word "race" is commonplace, the terms biological affinity, geographic population, or ancestry are used to describe the biological origins (perceived, estimated, or real) of a given individual or population, rather than race, where possible.

This study presupposes that the determination of the biological affiliation of an individual is an extremely important aspect of an anthropologist's workload, particularly for those in a forensic setting. The ability to determine the biological affinity of unknown

human remains often narrows the possibilities of who that individual was, helping lead to a positive identification. The genetic make-up of any given individual is an amalgamation of their parents, their parents' parents, and so on, who frequently shared a geographical population (particularly before the advent of modern travel conveniences). This geographic background is taken into account when determining aspects of skeletal biology, such as stature (Ross and Konigsberg 1999; Trotter and Gleser 1952) and age (Berg 2004, in press; Katz and Suchey 1989; Prince and Ubelaker 2002; Schaefer 2004). The need for population specific estimation methods for age and stature are increasingly pointed out in the literature (see Hoppa 2000; Komar 2003), which obviously questions how good are estimation techniques for biological affinity and what techniques are available to the anthropologist. Without a strong and accurate assessment of biological affinity, other skeletal determinations can be inaccurately estimated.

Anthropologists' ability to accurately diagnose the biological affinity of an unknown set of human remains is somewhat limited. Physical anthropologists typically utilize craniofacial traits and dental morphology to determine the biological affiliation of a given set of remains (e.g. Brues 1990; Edgar 2005; Gill 1986; Krogman 1962; Rhine 1990; Stewart 1979). Unfortunately, the fragile facial bones and teeth are frequently missing, damaged, or destroyed due to trauma or taphonomy, particularly in cases such as vehicular accidents, skeletonized remains (particularly in outdoor, above ground environments), intentional mutilation, and in archaeological contexts. Metric cranial analyses, including univariate (e.g. Hanihara 2000) and multivariate (Burris and Harris 1998; Byers *et al.* 1997; Holland 1986; Howells 1973; Jantz 1973; Key and Jantz 1990; and Owsley and Jantz 1977) methods are another tool for determining population affinity.

Few studies attempt to analyze large world populations and typically only focus on two to three groups. While often statistically more robust than morphoscopic applications, these types of analyses suffer from the same problems that plague cranial morphoscopic analyses.

Postcranial methods for determining population affinity are particularly lacking. A few studies on the femur currently exist (Baker *et al.* 1990; Gilbert and Gill 1990; Stewart 1979), but are rarely employed in forensic cases, simply due to the limited variety of populations that are represented. A radiographic approach using the femoral intercondylar shelf angle (Craig 1990) to determine White or Black ancestry for an unknown femur has recently been shown to be problematic (Berg *et al.* 2007). A somewhat recent study was published on the utility of determining the sex and population group from the bones of the hand (Smith 1996). In addition to these methods, the computer programs FORDISC 2.0 or 3.0 (Ousley and Jantz 1996; Jantz and Ousley 2005) are frequently used to assess the biological affinity of postcranial elements for U.S. Black and White individuals through the creation of custom discriminant functions for desired measurements.

The problem of determining population affiliation is stated eloquently by White and Folkens (2005:403):

“Even with this element (the cranium), all workers agree that racial estimations are usually more difficult, less precise, and less reliable than estimations of age, sex, or stature. Despite decades of research, much more osteological work on geographic differentiation with *Homo sapiens* remains to be done and is urgently needed.”

Their statement may be interpreted to be a bit extreme (except for the last point), but their early points are often echoed by the choice of content provided by the authors of several recent basic physical anthropology and forensic textbooks. Examination of the table of contents within these texts gives the general impression that biological affinity is something best left to others, or, at the minimum, is a very troubling topic. White and Folkens (2005) devote four pages to the determination of ancestry yet have 22 pages on estimation of age and 13 pages on the estimation of sex. In the introductory *Forensic Anthropology Training Manual* by Burns (1999), the determination of race is discussed on three pages, whereas sex, stature, and age are discussed on a multitude of pages in relation to many of the individual bones and teeth that play a part in their estimation; to be fair, racial analysis of the skull is one of the three aforementioned pages. Pickering and Bachman (1997) detail various osteological analyses in their introductory text as well. While listed nearly first in the order of basic anthropological operations to undertake, their section on race, ethnicity, or cultural affiliation, is one and a half pages long. Discussion of sex is five and a half pages and age also is given a similar amount. Finally, in their chapter on skeletal tissues in the book *Forensic Human Identification*, Scheuer and Black (2007) allocate two paragraphs to the determination of ethnic identity, yet spend three pages on determination of sex and seven pages on age-at-death. In three of four of these texts the largest contributor to the allocated space is tabularized information from Gill (1995) and Rhine (1990) or Krogman (1962) on cranial morphology and racial assessment. The lack of text in these books suggests several rudimentary problems:

- 1) Anthropologists do not have enough techniques with which to estimate biological affinity;
- 2) It is too difficult for the introductory student/practitioner to estimate biological affinity, thus little time will be spent on it;
- 3) The types of metric analyses that are present in the literature are complicated and require specialized tools/data sets and therefore are not very usable to the common “anthropologist on the ground;”
- 4) The techniques present are not valid (in the author’s minds) to warrant detailed mention,
- 5) Perhaps there is some aversion to or unfamiliarity with metric analysis of the human skeleton for biological affiliation;
- 6) The majority of the previously reported cranial metric analyses are specific to small, forensically uninteresting populations;
- 7) And finally, timid anthropologists might shy away from such a contentious issue (i.e. the whole “race” debate), particularly in an introductory setting.

Which of these problems, or a combination thereof, is actually the correct answer is up for debate.

Previous Mandibular Studies

Researchers have used mandibular morphoscopic and morphometric data to classify and describe populations, but analyses of three or more groups (either morphometric or morphoscopic) are rarely available. Early papers on mandibular morphometrics include those by Harrower (1928), Hrdlicka (1940), and Morant (1936). Interest in the mandible waned through the intervening decades, except for Giles (1964) work with discriminant

functions and sex determination. The early 1980s to the 1990s saw increasing interest in the mandible. Kile (1983) used mandibular morphometrics to classify U.S. Whites and Blacks, to include those of unknown biological affinity. Some of the most widely known and cited works include papers by Angel and Kelley (1990) and Rhine (1990), which utilized few populations or solely examined morphoscopic traits. Humphrey *et al.* (1999) found that mandibular morphometric variables were poor discriminators of recent human groups. Berg (2001, 2006) has explored mandibular morphoscopic traits between large groups of individuals, as well as the ability to use discriminant function analysis to achieve population classifications. The results of 3-D geometric morphometric analyses to explore the shape of the mandible in relation to population groupings have recently been published (Buck and Vidarsdottir 2004; Nicholson and Harvati 2006).

Older studies examined different populations using mandibular morphometrics (e.g. Harrower 1928; Hrdlicka 1940; Morant 1936). These studies often used non-standardized measurements, relied heavily on indices, and frequently reported summary data rather than raw data. These studies were undertaken in the infancy of anthropology, when the focus was not so much on identifying an unknown individual as it was in characterizing a population. Comparisons between large numbers of groups were not typical pursuits until the latter part of the century; human biological variation studies incorporating mandibular morphometrics or characteristics then started in earnest (Carlson and Van Gerven 1977; Corruccini 1974; Hauser and De Stefano 1989; Schendel *et al.* 1980). These studies were mostly focused on the cranial vault and face rather than the mandible, though a few traits or measurements were incorporated (e.g. mandibular tori, mylohyoid bridging, rocker jaw).

Kile (1983) examined the metric differences between equal numbers of male and female American White and Black mandibles from the Terry collection (using 25 variables). Nine discriminant functions were determined for the data; all but one was used to separate both sex and biological affinity. The functions were designed to utilize sections of the mandible in most cases, rather than a complete specimen, or areas that were determined to be population specific based on his observations. The last function was developed solely to determine American Whites from U.S. Blacks, regardless of sex. Discrimination ability ranged between 38.5% and 76.9%, depending on the variables used. From the data, Kile determined that functions utilizing the corpus and ramus, or variables that had high individual coefficients produced the best results. This work remains as an unpublished master's thesis.

Two papers appeared in Gill and Rhine (1990) concerning the mandible. Angel and Kelley's (1990) contribution explored biological affinity based on morphoscopic attributes of the posterior edge of the ascending ramus (posterior jaw ramus border inversion), as well as gonial angle eversion (or flare). Both traits were visually scored on a scale of absent, slight, +, or ++. Their sample was derived from multiple collections, though it was drawn predominately from the Terry collection. They found that the posterior edge was a viable population discriminator between American Black and White individuals, and from American Blacks and Native Americans. Some 70% of all of their American White individuals lacked the posterior edge eversion trait, while 95% of their American Black individuals expressed the trait. Gonial angle flare was found not to be as population specific. From the presented information, it also appears that they quantified their categorical data, likely as 1, 2, 3, and 4, to determine population means of the

morphological traits. The means were compared in some fashion (t-test?) to determine if there were significant differences between American Blacks and Whites, likely by sex, and the results are presented as p-values.

Angel and Kelley (1990) also explored some metric differences between the American Black and White populations. Within the metric analysis, six mandibular measurements were analyzed (mandibular angle, minimum ramus breadth, ramus height, bigonial breadth, bicondylar breadth, and mandibular length). Of these, several were found to be significantly different between groups (male/female, Black/White), but their choice of statistic and their comparisons are not detailed. It is likely that the comparisons are between Black and White males and Black and White females. Instead of producing ways of separating the individuals based on results of the metric analyses, the authors primarily used them to explain a probable genetic underpinning for the observed morphology of the ascending ramus.

Rhine (1990) used limited samples and created generalized statements about mandibular morphoscopic traits for four populations thusly labeled: Anglo, Black, Indian, and Hispanic. The Anglos were composed of those of European origin, the Blacks were likely contemporary U.S. Blacks, Hispanics were likely those of southern European ancestry mixed with a number of Indian tribes, and the Indians were both modern and prehistoric southwest Amerindians. The majority of his conclusions and generalizations were based on extremely small sample sizes for the mandibular traits (Anglo = 51, Hispanic = 8, Black = 3, Indian = 3). His generalizations have been taken to heart by the anthropological community, and are often found in lists of racial traits in forensic textbooks and other publications (Burns 1999; Byers 2002; Gill 1995; White and

Folkens 2005). The lack of sufficient sample size, particularly for the Amerindian and Black categories, makes the regurgitation of his data in modern texts particularly disconcerting (even though he warned of a small sample size problem). Complicating the picture, Rhine's morphoscopic data have been changed through time from "Southwestern Mongoloids (American Indian)" to "Asians", at least in one current forensic text (Byers 2002:154, 167).

Humphrey and coworkers (1999) examined a large collection of modern human and great ape mandibles using 13 measurements. Of the measurements, four are considered standard measurements in the forensic literature (e.g. Buikstra and Ubelaker 1994; Moore-Jansen 1994), and nine were specifically designed for the study. Both univariate and multivariate [principal components analysis (PCA), discriminant function analysis] statistical methods were employed to analyze the data toward three goals: 1) interspecific variation, 2) sexual dimorphism, and 3) regional and population variation in modern humans. Population selection targeted the five major geographical regions, and though the sample sizes often reached 30 individuals, some were lower, and no population samples had over 30 males and females. Specifically for their third question, they found high intraspecific diversity with no obvious regional patterning via basic statistical analysis, and a weak regional pattern using PCA. But their conclusion does not seem to be quite so warranted given that discriminant function analysis did assign 78.4% of the mandibles to the correct geographical region, and 73.4% of all mandibles were correctly assigned to a specific population. The conclusion that the mandible is not a "good" discriminator of modern human populations appears to be derived more from comparisons with cranial metrics that achieve a higher classification rate (93% overall

accuracy for the cranial vault), although the cranial metric studies used more variables and only achieved a 20% increase in accuracy. In general, it seems that their conclusion can be summed up as “it is perhaps inevitable that the mandible will be less useful than the cranium for identifying the relationships between human populations given this (its) plasticity” (Humphrey *et al.* 1999:511).

Berg (2001) presented a large mandibular non-metric data set with the intent of reexamining the generalizations presented by Rhine (1990). The paper examined seven morphoscopic traits from three distinct populations: Cambodians, U.S. Whites, and Nubians. Only males were included in the assessment, and some data (Native American, and a portion of the U.S. Whites) were taken from the Rhine (1990) and Angel and Kelley (1990) publications for comparison purposes. The scoring of several non-metric traits was modified from the original descriptions (Angel and Kelley 1990; Rhine 1990) after categorical differences were observed. The data showed that it was incorrect to assume that Native American data could be substituted for Asian populations. The rates of various morphoscopic states, such as the lower border of the mandible for American Blacks and chin shape for Asians and American Blacks, were found to be significantly different from those reported by Rhine (1990).

In a follow-up paper, Berg (2006) demonstrated the utility of constructing discriminant functions for determining population affinity based on morphoscopic scores. Research conducted by Ousley and Hefner (2005) showed that cranial non-metric traits (as ordinal data) could reliably be used in linear discriminant functions to determine ancestry. They reported that in-depth statistical analyses did not yield substantial objections concerning the application of the discriminant functions to their ordinal data.

Following this logic, Berg (2006) treated the mandibular non-metric trait scores as ordinal variables and constructed linear discriminant functions for multiple populations. Over 1000 individuals were used in the analysis; functions were constructed not only using two group comparisons, but also three to seven group comparisons. Each analysis was cross-validated (leave-one-out method) for accuracy assessment. The only variable to typically be removed from the analyses was the ascending ramus profile shape. Seven population comparisons yielded a 48% cross-validated accuracy rate, approximately three times better than random expectation. Two group comparisons fared better, some in excess of 90%, while three group comparisons approached 70% accuracy rates. Further, two group comparisons of closely related populations had viable functions, some with 74% cross-validated accuracy rates.

Morphometric analysis of mandibles is an underrepresented technique in forensic anthropology. Analyses of large population groups for mandibular morphometrics are rare. Comparative mandibular data are available for American Blacks, Whites, and Japanese in FORDISC 2.0 (Ousley and Jantz 1996). Mandibular metric data are not present for the other comparative populations. The FORDISC 2.0 database comprises individuals from multiple populations from the continental U.S., to include Terry collection specimens with birth years after 1900, and a selection of 100 Japanese males and females, courtesy of Hanihara and Hajime Ishida. Ten standard mandibular measurements are available for custom-generated discriminant functions, though several measurements are unavailable for the Japanese data. FORDISC 3.0 has similar populations, though a Guatemalan population has been added (Jantz and Ousley 2005).

Buck and Vidarsdottir (2004) discuss the use of three-dimensional geometric morphometrics as a method of determining the racial identity of sub-adult individuals using three-dimensional coordinates obtained for 17 homologous landmarks of the mandible. In their analysis, five populations were considered: African Americans, Native Americans (Arikara), Caucasians, Inuit, and Pacific Islanders (total sample size was 174 individuals). After employing generalized Procrustes analysis to superimpose and scale the coordinate data to centroid size, principal components analyses, Mahalanobis distance analyses, and cross-validated discriminant analyses were conducted. In the first portion of their analysis, they found that the cross-validated linear discriminant functions produced an average 70.1% accuracy rate for the five populations (or three times chance alone). Using only three populations, African Americans, Caucasians, and Native Americans, the cross-validated accuracy rate was 87.6%. To determine if the method could be applied to partial skeletal material, the landmark data were divided into two series, those that dealt with the corpus and those that were related to the ramus. Again using the three groups, they found that the corpus could accurately predict race with 67% accuracy, while the ramus accurately predicted the group membership 73% of the time.

A poster presented at the American Academy of Forensic Sciences Annual Meeting examined mandibular and other measurements of the dental arcade from American Black and White mandibles (Danforth 2005). Eighteen measurements were taken on 183 American Black and White individuals from the Terry Collection. Of the measurements, ten were standard and the remaining eight were defined specifically for the project. Danforth (2005) reported that five measurements (M2-prosthion length, bigonial breadth,

minimum ramus breadth, alveolar length, and ramus height) consistently entered into functions that discriminated between American Blacks and Whites (and between sexes as well). Her functions had accuracy rates of 75.3% for the entire sample, 86.2% for males only, and 93% for females only (female sample sizes were small).

Nicholson and Harvati (2006) discuss the use of three-dimensional geometric morphometrics in relation to mandibular shape using three-dimensional coordinates obtained for 28 landmarks. Their principal aim was directed at modern human origins debates, rather than a forensic application. The sample included 155 mandibles from broad regions of the world, though no sample population contained more than 26 individuals (a European population sample had the greatest number). Sex was unknown in most cases; therefore their study sample was pooled. Their analysis utilized generalized Procrustes analysis, which produced group centroids devoid of size (essential for a “shape” analysis). Additional analyses utilizing principal coordinates analysis, Mahalanobis D^2 statistic, multiple regression analysis, and discriminant analysis were conducted. Ultimately, the authors determined that geographic patterning is present in recent human mandibular shape, though there is considerable overlap. Their classification rates were approximately 84% (by re-substitution), and several climatological patterns were identified. As acknowledged by the authors, the study suffers from small sample sizes within populations and their findings become less clear at the fine-grained geographical scale.

Racial Mating Trends in the United States

A brief discussion on racial mating trends is appropriate here, as it is these patterns that either maintain or create the patterns seen in human skeletal variation. According to

the National Center for Health Statistics, Division of Vital Statistics, interracial marriages are rare. Indeed, the percentage of interracial marriages during the period of 1963-1967 averaged only 1.1% (Hetzel and Cappetta 1971). This percentage may be artificially low as only 35 states tracked the racial category of individuals on marriage registrations. A recent review of the U.S. Census data shows a growth trend in interracial marriages, from 0.4 percent in 1960 to 2.2% in 1992 (U.S. Bureau of the Census 1998). This indicates that the Division of Vital Statistics data are likely a good estimate for its time period as well. Although interracial marriages account for a small fraction of the all marriages in the United States, the amount of racial admixture in U.S. populations is greater (if migration rates are held constant), since admixture is an likely an additive process through time (per generation).

The effect admixture has on skeletal morphology can be a difficult question to answer. The question is compounded by the fact that “race” is frequently self-reported and it is based on the social group an individual ascribes to. Skeletally, an individual may be determined to be “Black” by an anthropologist, but that individual is ascribed to a “White” racial group. More difficult is the “Hispanic” racial group, as these individuals may ascribe to being White, Black, Latino, or Native American. Therefore, measuring the effect of admixture on skeletal traits becomes exceedingly difficult in the absence of genetic data.

Genetic data do shed light on the admixture problem in skeletal biology, in that it can potentially be used to “inform” the anthropologist of the likelihood of finding ancestral traits of one group expressed in an individual of another. But the actual genetic makeup of any one phenotypic trait commonly used by skeletal biologists has not been

determined. Instead, the amount of admixture of various groups has been reported, and it is this data that may be helpful in the future. Parra *et al.* (2001) found that the amount of European admixture in African American populations for several rural populations in South Carolina was approximately 12%, though for a more urban sample from Columbia, the percentage of admixture was higher, at 18%. The urban figures compared well with studies conducted in populations from urban settings such as New York (20%), Baltimore (16%), and Detroit (16%) (Parra *et al.* 1998). African American admixture into European populations is definitively smaller. A study conducted by Shriver *et al.* (2003) showed that a group of European Americans from State College, Pennsylvania had a higher admixture component of Native American genes (3.2%) than African American genes (0.7%).

Two other interesting points are noted: first, the majority of the admixture into African American populations by European Whites is contributed by males, a fact that fits well with American slavery practices (Parra *et al.* 1998). Second, the amount of genetic change in the African American populations is increasing. Relatively closed groups have retained smaller amounts of admixture, ~11%, while populations from more urban and potentially more open mating situations have increased to ~20%. Parra *et al.* (1998) suggest one possible explanation for this change in admixture frequency is from a large migration of African American populations from the south to the north after World War I. Given this hypothesis, a rough estimate of the admixture amount in these populations per generation could be calculated. The estimated generational increase in admixture is about 3% (9% over three generations) for African American populations, if the hypothesis of Parra *et al.* (1998) is correct.

What does this mean to the physical anthropologist? Potentially it means is that we could see more “White” traits expressed skeletally in individuals of “Black” ancestry than is expected in a “pure” ancestral line. Also, traits found more frequently in Native American populations would likely be found in White populations. Further, this pattern would likely grow with time, until a genetic balance is achieved, if that can actually happen. If admixture is an additive process, then physical anthropologists should continue to see a dilution of absolute phenotypic expressions and a change through time toward a moderate or midline phenotypic state.

This brief review illustrates that there is a continued need for detailed study of the mandible, particularly emphasizing populations other than American Blacks and Whites, which are usually from the Terry collection. This dissertation places a particular emphasis on those that are forensically relevant to today’s U.S. population as well as consider a diverse set of world-wide groups. As was noted, several studies using world populations have been conducted, and the ability to discriminate between them is robust, albeit not quite that of cranial metric analyses. While variability in some of the previous results is the norm, the notion that the mandible is a poor discriminator of recent human groups appears unfounded. The results of this study will contribute to this particular argument. Furthermore, a combined analysis of morphometric and morphoscopic data from the mandible may provide better classification rates than have been achieved to date.

Chapter 2

Materials and Methods

The majority of forensic methods for determining biological affinity have focused on the differences between American White and Black populations, largely based on skeletal material from the Robert J. Terry collection. Studies focusing only on these two population samples obviously suffer in their applications considering the diverse population currently living in the United States. Table 1 lists the recent population characteristics for the country. As seen, over 20% of the U.S. population is neither White nor Black. But the census data are only a portion of the “forensic” picture that should be considered. Recent statistics from the U.S. Department of Justice (Rennison 2001) give the specifics for those involved in, or are victims of, violent crime. Current homicide data from Los Angeles County (Leovy *et al.* 2007) also shed light on the forensic picture (Table 1). These data demonstrate that if forensic personnel only considered American White and Black populations, they would substantially underestimate numbers of “other” individuals who find themselves in violent and dangerous situations. While not listed in Table 1, the historic homicide rates for all racial categories averaged across the country are approximately the same (~5 per 100,000), except for Black individuals, who are six times more likely to be murdered than White individuals, and eight times more likely than people of other races (Rennison 2001). The Los Angeles County data show a higher prevalence of homicide rates involving Blacks and Hispanics. In general, since those involved in violent crime arguably have a higher likelihood of becoming a forensic case, developing biological affinity models for only U.S. Whites and Blacks is short-sighted.

Table 1. Population characteristics of the United States and population characteristics of those involved in violent crime from across the country.

Population	Percent¹	Average number of incidents per 1000 individuals²	Homicides rates per 100,000 individuals, Los Angeles County³
White	65.0	60.9	3.2
Black	14.0	83.7	34.0
Hispanic	13.0	59.0	11.2
Asian	4.6	38.0	2.7
American Indian	2.0	173.8	n/a
Other	1.4	n/a	10.1

¹Taken from the 2000 U.S. census.

²These figures reflect the average annual victimizations from 1993-1998, and include both violent crime and serious violent crime; Hispanic figure is an average of all Hispanic ethnicities, as reported by Rennison (2001).

³As reported by the Los Angeles Times for the year 2007, January to August (Leovy *et al.* 2007). Hispanic category was reported as “Latino.”

Population Samples

The need to develop more methods for assessing biological affinity from diverse populations is clear. Bearing this in mind, multiple samples from world populations were gathered for this study. Table 2 lists the study samples broken down by sex and sample size. With a perusal of Table 2, the reader may assume that some of the populations are not forensically relevant; this is not the case since prehistoric Native American remains, trophy skulls, and other unusual cases are presented to forensic investigators as recent forensic cases with certain regularity.

The mandibular data were collected over a period of approximately four years in a variety of world-wide locations, from the Killing Fields of Cambodia to laboratories containing the results of recent mass grave excavations in Guatemala and at the various collections housed at the Smithsonian Institution. Many of the collections are well documented and contain information on age, sex, stature, and ancestry. In other instances, the biological data were determined through osteological analysis. No juveniles are included in the study. The justifications for lumped categories, such as Hispanics, are discussed and each sample is described more fully below.

Terry collection (U.S. White and Black samples)

Mandibular data for U.S. Whites and Blacks were gathered at the Terry collection, housed at the Smithsonian Institution, Washington, D.C. The Terry collection was procured by Dr. Robert Terry in St. Louis, primarily between 1910 and 1941, though Dr. Mildred Trotter continued to add to the collection until near her retirement in 1967. The collection is comprised of primarily U.S. Whites and Blacks, and records documenting the sex, age, race, and cause of death are available. Birth years are primarily between

Table 2. The study sample, by collection and sex.

Samples	Males	Females	Total
U.S. Whites, Terry collection	55	6	61
U.S. Whites, William Bass collection	125	56	181
U.S. Whites, CIL collection	22	0	22
U.S. Blacks, Terry collection	55	55	110
U.S. Blacks, William Bass collection	27	3	30
U.S. Blacks, Memphis collection	15	13	28
Hispanics, William Bass/PCME collections	30	1	31
Guatemalans, FAFG collection	89	14	103
Vietnamese, CIL collection	42	1	43
Chinese, CIL and Hrdlicka collections	65	1	66
Cambodian sample	149	29	178
Prehistoric Hohokam, ASU/Hrdlicka collections	35	14	49
Proto-historic Arikara, UT collection	30	30	60
Prehistoric Nubians, ASU collection	56	55	111
Total:	795	277	1072

1822 and 1943 (the data in this study represent individuals with predominately 19th century birth years). While efforts were made to select for complete, toothed mandibles and documented ages, no other criteria were used in the selection process. A minimum of 55 individuals was collected for both population samples and sexes, with the exception of White females, which are sadly underrepresented since most in the collection were edentulous.

William W. Bass Donated collection (U.S. White, Black, and Hispanic samples)

The William W. Bass Donated collection began in the early 1980's and is composed of individuals who specifically donated their remains to the University of Tennessee, Department of Anthropology. Individuals are allowed to decompose on several acres of land at the Anthropology Research Facility, after which the remains are cleaned, measured, and curated. The size of the collection is slightly over 1000 individuals, nearly all of which have documented sex, age, stature, and cause/manner of death. The birth years range for the collection is from 1892-1987, with the vast majority falling between the years 1915 and 1962 (20th century birth years). In addition to this collection, a few specimens were selected for analysis from the University of Tennessee Anthropology Department's Forensic collection. The majority of the individuals collected for this study had known ages, though a few only had age ranges. Black and Hispanic individuals are poorly represented in the collection, and White females were not as commonly encountered as White males. The Hispanic data were combined with those from the Pima County Medical Examiner collection (see below).

Memphis collection (U.S. Black sample)

This sample stems from a cultural resource management archaeological excavation of an American Black cemetery in Shelby County, Tennessee (Oster *et al.* 2005). The cemetery was in use ca. 1899 to 1933. Given the adult status of these individuals, and the dates of the graveyard, the likely birth years for these individuals are between 1840 and 1900 (19th century birth years). All of the selected mandibles had confident sex assignments from osteological findings and all ages were based on osteological assignment. Additional osteological information on this collection can be found in Meadows-Jantz and Wilson (2005). In the remainder of the study this sample was combined with the Terry collection sample, based on the birth years of both groups.

Central Identification Laboratory (CIL) collections (U.S. Whites, Vietnamese, and Chinese samples)

Samples from three populations were obtained from the CIL at Hickam Airforce Base, Hawaii. The first is a small sample of U.S. war dead predominately from World War II and the Korean War. All of these White male individuals have been identified and have known ages-at-death. The majority were young, between 19 and 28 years at death. The span of birth years is between 1901 and 1936, with the majority between 1917 and 1932. One casualty from the Vietnam War is in the study; he also is the oldest individual, 49 years of age, and was born in 1936. All of these individuals have been repatriated back to their respective families. For all forthcoming statistical evaluations, these individuals were combined with the William W. Bass Donated collection sample (20th century birth years).

The second sample is a large group of Vietnamese males who were aboard a C-130 aircraft that crashed in 1974, during the Vietnam War. All individuals aboard the aircraft were male, and of “fighting age.” All are aged as “adult,” and none appeared to be older than 50 years or younger than approximately 20 years. Based on this assessment, the likely birth years for these individuals is between 1925 and 1955. In addition to the single crash incident, multiple sets of remains, which have been identified as Vietnamese, are housed at the laboratory. All sex and age estimates of these individuals are derived from osteological analysis, and several are aged merely as adult. One female is represented in this latter group. Although nearly impossible to determine, the birth years for these individuals are likely similar to those involved in the C-130 crash, or slightly older.

The final sample is a small group of likely Chinese individuals (n=9) that have been recovered by CIL anthropologists during excavations on the Korean peninsula, usually north of the 53rd parallel. All associated cultural materials were Chinese in origin (e.g. buttons, clothing, and military equipment). The excavation locations are consistent with Chinese military engagements with U.N. troops (e.g. the Chosin Reservoir area). When available, cranial-metric analysis using FORDISC 2.0 (Ousley and Jantz 1996) was conducted and each classified as a Chinese male. While it is possible that one or more of these individuals is actually a Korean, all available evidence indicates a Chinese origin. Therefore, these data were combined with the Hrdlicka Chinese sample (see below).

Pima County Medical Examiner (PCME) collection (Hispanic sample)

The PCME office has a relatively small, rotating collection of unidentified human remains that have been found in the desert between roughly Tucson, Arizona and the

U.S./Mexico border (Bruce Anderson, pers. comm. 2004). Frequently, the remains have been found by hunters/hikers and are in a skeletonized condition. Undoubtedly, these remains represent those individuals that attempted to cross the border into the U.S. and failed to find safety. Roughly once a year, the unidentified remains are buried in a common grave by county officials. While identifying their biological affinity currently is difficult, anthropological analysis typically classifies them as Hispanic; eight individuals have been identified positively as Mexican nationals and the rest are held in a status of unidentified border crossers (Bruce Anderson, pers. comm. 2007). All of the biological data from this sample are from osteological analysis (most individuals are complete/nearly complete skeletons). All but one individual were males. Given their classification, these individuals and those identified as Hispanics from the William Bass collection have been grouped together as Hispanics.

Fundacion de Antropologia Forense de Guatemala (FAFG) collection (Guatemala Maya sample)

The FAFG is an organization in Guatemala dedicated to the recovery and identification of those individuals that were killed during a brutal, multiple-decade civil war. Their collections are rapidly rotating; as individuals or groups of individuals are identified, their remains are returned to the appropriate village for internment. As would be expected from a civil war environment, the majority of the remains are those of males, though females and children are often recovered. All sex and age estimates are from osteological analysis by FAFG anthropologists. Females are under-represented in this sample. The individuals comprising this particular sample were from several villages from the country's interior and can be considered indigenous Indians (Mayan). Broken

or missing mandibular portions due to taphonomy (e.g. crushing, warping, erosion) or trauma (e.g. projectile damage) were frequently encountered, and where possible, still scored and measured.

Chinese sample

The Chinese sample is comprised of two groups, the CIL Chinese collection detailed above, and a sample from a Chinese cemetery in Uyak Bay, Kodiak Island excavated by A. Hrdlicka in 1931 (Hrdlicka 1944). These individuals were “hired” to work in the canneries on Kodiak Island in the late 1800s (Dave Hunt 2007, pers. comm.). These individuals are thought to be labeled the “Canton District Workers” in his later publications (Hrdlicka 1940). The likely birth dates for the Canton District Workers are from the late 1860s to the late 1890s, while the birth date for the CIL Chinese are from the 1900s to 1930s. Sex and age data were based on osteological analysis. The general state of preservation of the remains is fair to good, though damage to the anterior dentition and underlying bone was regularly encountered.

Cambodian sample

From 1975-1979, the Khmer Rouge regime is believed to be directly and indirectly responsible for the deaths of approximately 1.5 million Cambodians (Chandler 1999). One of the most notorious mass graves associated with this period is known as Choeung Ek; it was the execution and burial ground for several thousand individuals near the capital city of Phnom Penh. Approximately half of those buried at Choeung Ek were disinterred between 1979 and 1980 and were eventually placed into a stupa, constructed in 1988. The 30+ meter tall funerary shrine contains multiple tiers, each of which holds stacks of human remains, stored by type, or by similar types, e.g. crania, femora, tibiae.

The crania typically are stored on the bottom six to eight shelves and the mandibles were near the top. The stupa is an open-air facility, though the remains are protected from rain by the surrounding glass and concrete structure. Various taphonomic processes patently are visible on the exterior surfaces of the remains, such as cracking, exfoliation, and sun bleaching. Postmortem breakage due to poor excavation and storage are apparent as well. Missing data were frequently encountered due to the taphonomic problems, though other issues, such as edentulous mandibles were rarely encountered due to the relatively young age at death. Most age estimates were between 20 and 50 years, and were based on dental attrition and general dental health. Sex estimates were made on mandibular size and shape. As inferred from the ages represented and the timing of their probable deaths, the vast majority of birth years are between 1925 and 1955.

Prehistoric Hohokam sample

The Hohokam sample is a prehistoric Native American group from the Central Arizona area (Southwest Indian). Three sites (from the now greater Phoenix area and one site from approximately 50 miles north of Phoenix) are represented in the study sample. The most northern site is considered part of the “Sinagua” tradition, though it still falls within the Hohokam culture area (see Deaver 1997). The collections are housed at two locations, the Maxwell Museum at Arizona State University (ASU) and the Smithsonian Institution. The Smithsonian collection was procured by A. Hrdlicka, while the remainder was from several excavations conducted by ASU. The associated time period for the sites is the Classic Period, from approximately A.D. 1150-1450. As with any archaeological sample, all biological data are osteologically determined. In most cases, a cranium and mandible were co-located (e.g. at the Smithsonian) while in other instances,

the entire set of remains was present (e.g. at ASU). Taphonomic changes to the mandibles were relatively minor, and females are under-represented in the group.

Proto-Historic Arikara sample

This sample is drawn from a single occupation site, the Larson site (39WW2), which is housed at the Department of Anthropology, University of Tennessee. The Larson site was located on the east bank of the Missouri river in Walworth County, South Dakota (see Owsley and Bass 1979). The site is dated to between A.D. 1679 and A.D. 1733 and is associated with the Plain Indians group, the Arikara. The mandibular remains from the site are well preserved; while some missing data were encountered, it was not nearly as great as many other archaeological groups. A sample of 30 males and females was available from this population. All age and sex estimates were derived from osteological analysis, and were recorded for this study from existing information sources.

Prehistoric Nubian sample

The Nubian osteology collection is also housed at the Maxwell Museum, ASU. The skeletal materials were excavated by the Oriental Institute and the University of Chicago during the 1966-1968 UNESCO Project, prior to flooding of the Nile River valley by the completion of the High Aswan Dam. Only those individuals from the Meroitic time period, 100 B.C.-A.D. 350, were included in the data collection. The remains were generally well preserved, including soft tissue in several cases. All individuals included complete skulls, and the majority of the individuals had preserved postcranial elements (e.g. the pelvis). When sex or age assessment from the cranium did not appear to agree with the box labels, postcranial elements were used to verify the sex assignments. Over

50 individuals of each sex were analyzed on two separate occasions as part of the intra-observer error study.

Morphoscopic Traits

This study examines seven morphoscopic traits of the mandible for their reliability in determining the ancestry of an individual. Each trait has been described previously in the literature (Angel and Kelley 1990; Rhine 1990; Marshall and Snow 1956); however, several modifications including additional categories to the previously described traits have been made. To minimize intra- and inter-observer inconsistencies, line drawings of the various morphological states are presented in figures following the definitions and should be used whenever these traits are scored. The morphoscopic traits and their corresponding scoring categories are:

- 1) Chin shape (CS). The chin shape is viewed from above (superiorly) and scored as either *blunt* (smoothly rounded), *pointed* (the chin comes to a distinct point), *square* (the chin has a nearly straight front) or *bilobate* (the chin has a distinct central sulcus). Using a straight-edge is helpful for distinguishing between the traits, and, in particular, diagnosing the square and bilobate forms (Figure 1).
- 2) Lower border of the mandible (LBM). Four categories are recognized for this trait, and it is easiest to score the trait by placing the mandible on a flat surface. If the majority of the lower border of the mandible is flush against the surface,

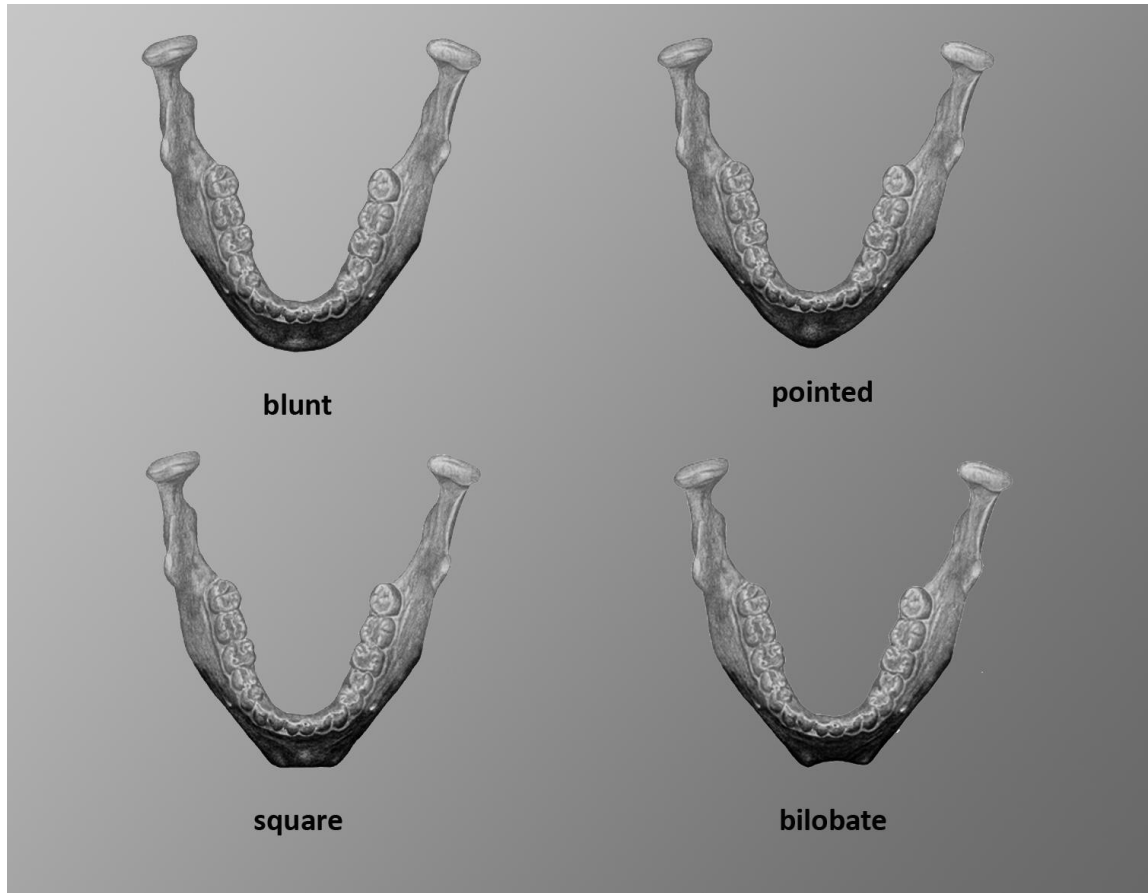


Figure 1. Illustration depicting the four morphoscopic categories of chin shape.

Darkened areas highlight the differences in the categories. The trait is coded as CS.

it is scored as *straight*. If there is a deviation of the border upward, typically in the region of the lower second to third molars, it is scored as *undulating*. If the mandible inclines near the chin (and is somewhat rounded in the gonial region), and it rocks forward when gentle pressure is applied to the anterior dentition, it is scored as a *partial rocker*, and finally, if the mandible is sufficiently rounded on the bottom, such that pressure on the anterior teeth causes it to rock forward and back, it is scored as a *rocker* (Figure 2).

- 3) Ascending ramus shape (ARS). This trait is scored as *pinched* if the ascending ramus noticeably narrows about its midpoint, or *wide* if it is a relatively uniform width (Figure 3).
- 4) Ascending ramus profile (ARP). This trait is scored as a morphometric trait in which each category reflects a measurement from 90 degrees: *straight* = 0-10 degrees, *medium* = 11-20 degrees, *slanted* = > 21 degrees. Given that this trait has a measurement degree associated with it, it is likely best expressed as a metric variable (see Chapter 3).
- 5) Gonial angle flare (GAF). This trait is scored in five stages, the first being *inverted*, where the gonial process slants medially toward the midline; *absent*, when the gonial process is in line with the ramus; *slight* when the gonial process flares outward a short distance (~1-2 mm); *medium*, when the gonial process flares beyond slight to double that distance (~2-4 mm); and *everted*, which is greater than twice the distance of slight (>~4 mm). This trait is best

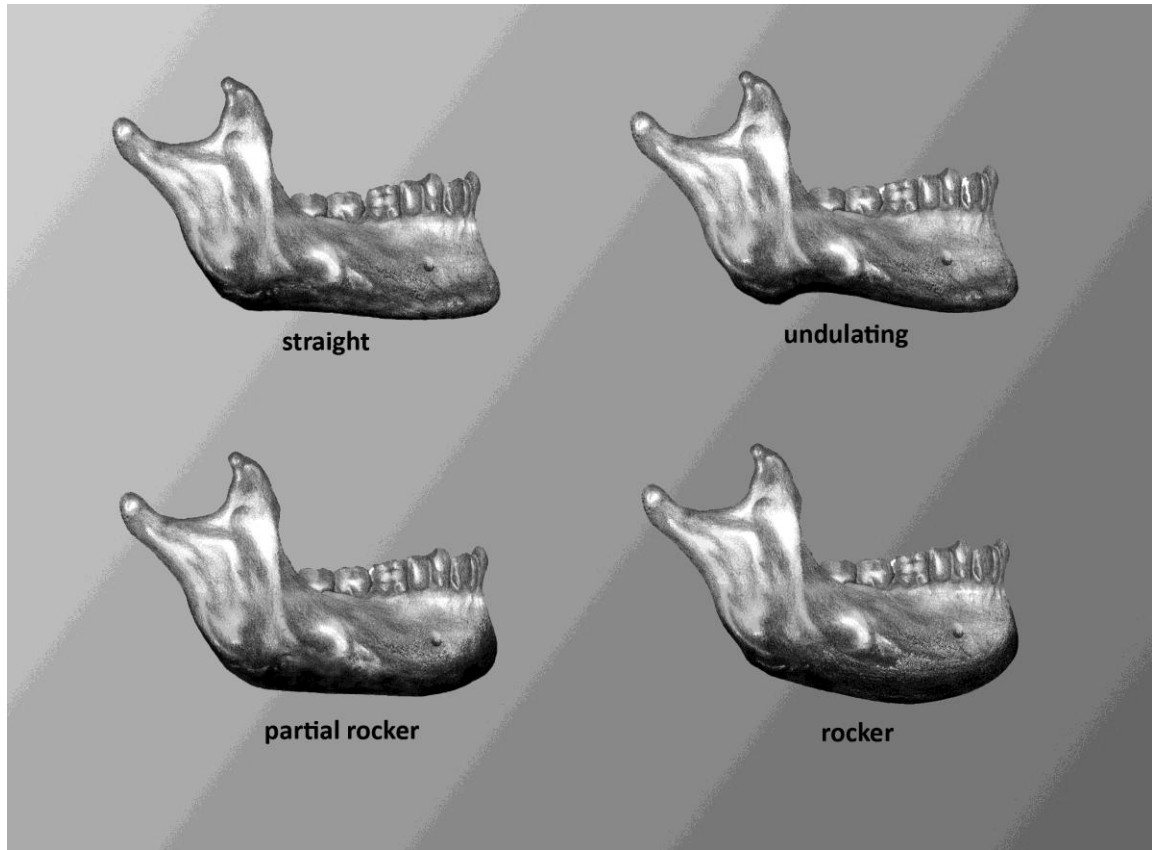


Figure 2. Illustration of the four morphoscopic categories of the lower border of the mandible. Darkened areas highlight the differences in the categories. The trait is coded as LBM.

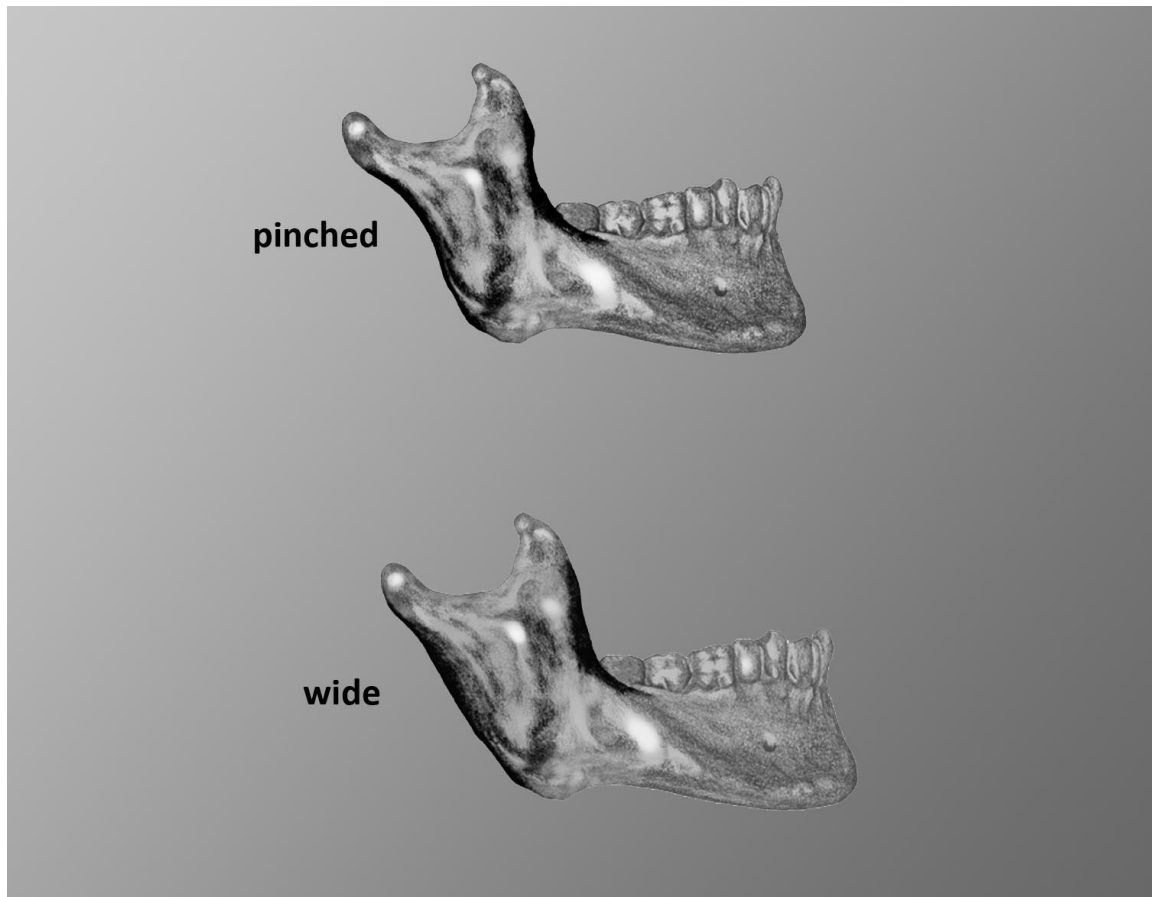


Figure 3. A graphic illustration depicting the two categories of ascending ramus shape. Darkened areas highlight the differences in the categories. The trait is coded as ARS.

scored in relation to the line drawings found in Figure 4, and familiarity with multiple mandibles is recommended prior to scoring the trait.

- 6) Mandibular torus (MT). The mandibular torus is a bony protuberance of varying size and shape on the lingual surface, below the alveolar margin, typically in the region of the premolars (see Hauser and De Stefano 1989 for additional description). This trait is only scored as *present* or *absent*.
- 7) Posterior ramus edge inversion (PREI). This trait can be difficult to score, though use of the provided line drawings in Appendix 1 alleviates most discrepancies. The trait is observed on the posterior one-third of the ascending ramus. If no discernible flexure toward the midline is present, the mandible is scored as *absent*. If a small, but discernible flexure toward the midline is present, the trait is scored as *slight*. *Medium* is a very noticeable inward deviation, up to twice the distance of the slight category. The mandible is scored as *turned* when it is greater than a double expression of the slight category (Figure 5). While additional line drawings are available in Angel and Kelley (1990), no depiction of the slight category is present.

Morphometric Variables

In addition to the morphoscopic variants described above, eight standard, two newly defined, and one modified measurement were collected for each mandible. The standard measurements have been defined numerous times and the definitions given in Moore-Jansen *et al.* (1994) are followed. The defined standard measurements are:

- 1) Chin height (GNI), defined as the direct distance from infradentale to gnathion.

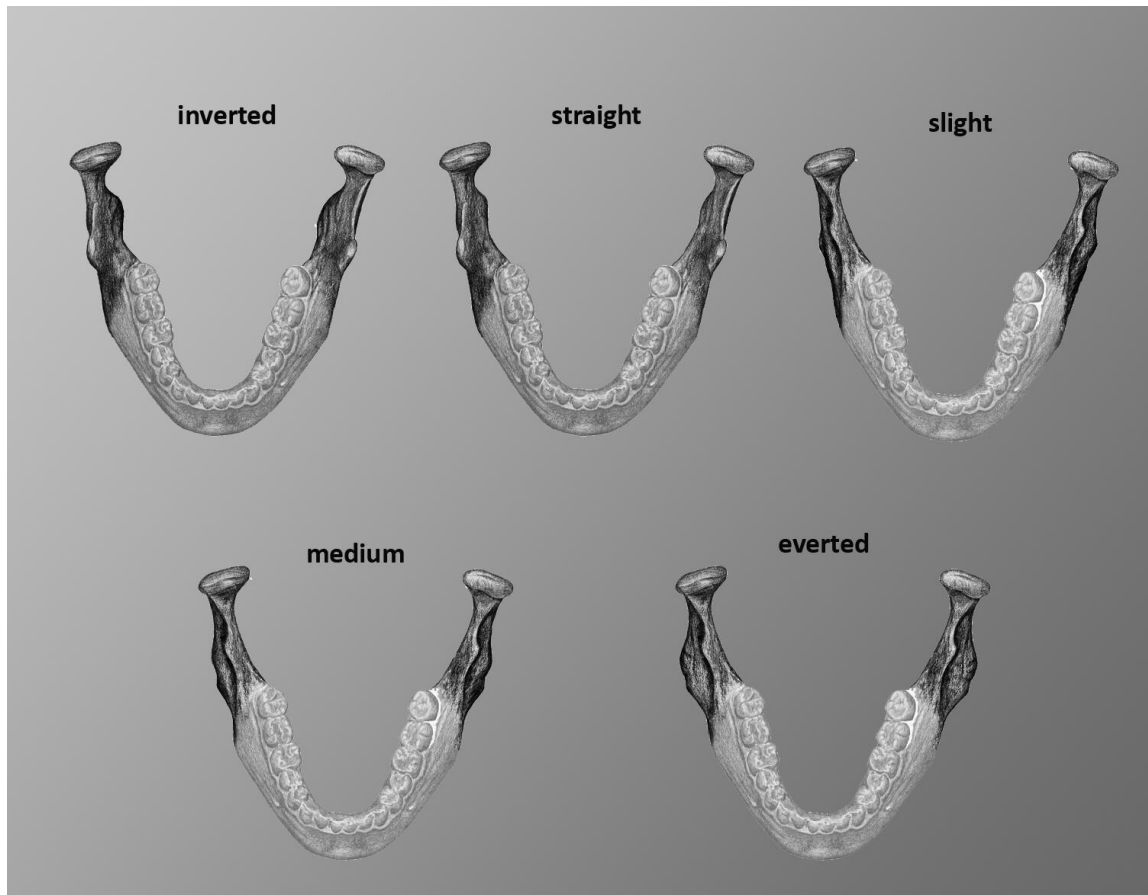


Figure 4. An illustration depicting the five categories of gonial angle flare. Darkened areas highlight the differences in the categories. The trait is coded as GAF.

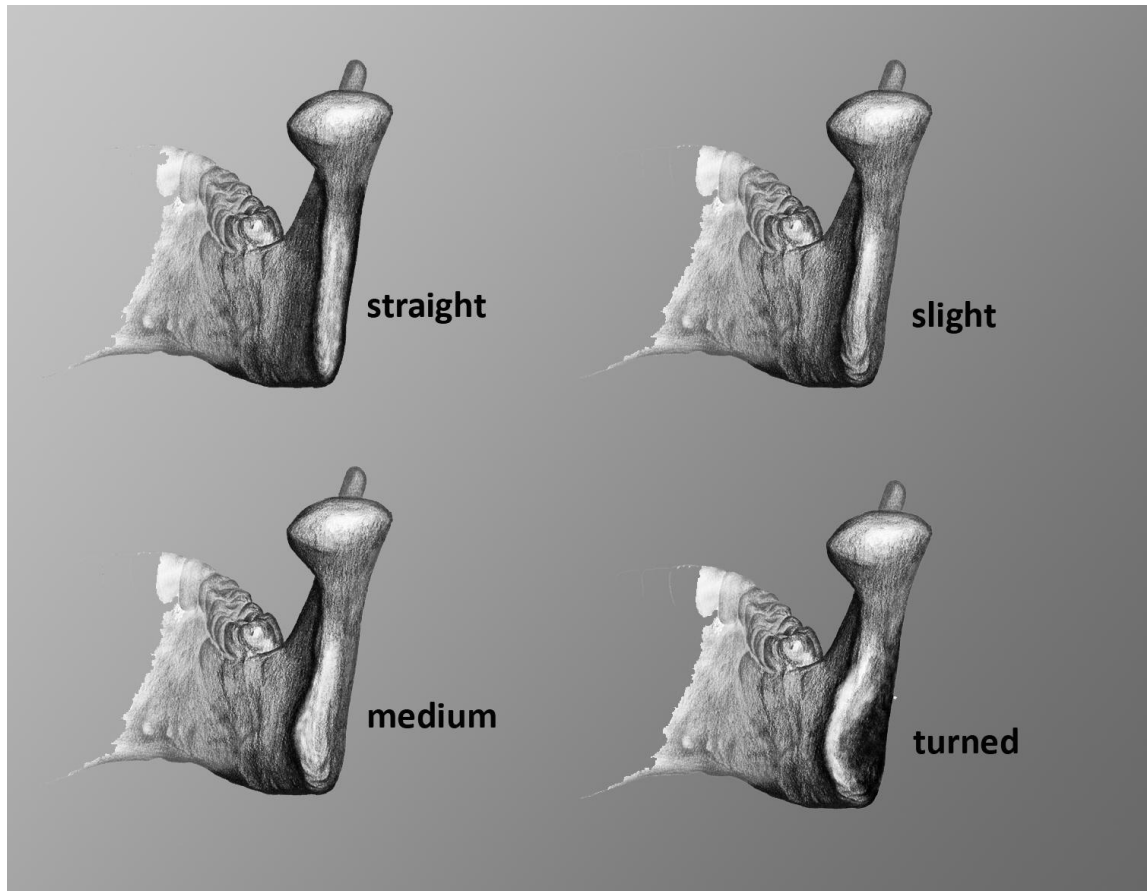


Figure 5. Illustration depicting the four categories of posterior ramus edge inversion. Darkened areas highlight the differences in the categories. The trait is coded as PREI.

- 2) Height of the mandibular body at the mental foramen (HML), defined as the direct distance from the alveolar process to the inferior border of the mandible perpendicular to the base at the level of the mental foramen.
- 3) Bigonial width (GOG), defined as the direct distance between the right and left gonions.
- 4) Bicondylar width (CDL), defined as the direct distance between the most lateral points on the two condyles.
- 5) Minimum ramus breadth (WRB), defined as the least breadth of the mandibular ramus measured perpendicular to the height of the ramus.
- 6) Maximum ramus height (XRH), defined as the direct distance from the highest point on the mandibular condyle to gonion.
- 7) Mandibular length (MLT), defined as the distance from the anterior margin of the chin to a center point on the projected straight line placed along the posterior border of the two mandibular angles.
- 8) Mandibular angle (MAN), defined as the angle formed by the inferior border of the corpus and the posterior border of the ramus.

The following three measurements include two measurements defined specifically for this study and one measurement that was consistently taken in a slightly different orientation to the published measurement definition. Photographs of the measurements are provided in the accompanying figures.

- 9) Mandibular body breadth at mental foramen (TML), defined as the maximum width of the mandibular body taken at the mental foramen. The measurement is

typically taken from a superior to inferior direction and the caliper arm should be parallel to the flat surface on which the mandible is resting (Figure 6).

- 10) Mandibular body breadth at the M2/M3 junction (TML23), defined as the maximum mediolateral breadth of the corpus taken at the level of the articulation between the second and third molars. The sliding caliper arm should be parallel to the surface the mandible is resting on. The measurement location usually corresponds to a medial-lateral thickening of the mandible at that location (Figure 7).
- 11) Dental arcade width at the third molar (XDA), defined as the maximum breadth of the dental arcade at the level of the posterior most points of the third molar sockets on the lingual surface. If necessary, a line should be drawn perpendicular to the ramus body and the tooth crypt to mark the measurement locations. If the third molars are absent, the measurement could be taken at the location of the second molar position, but should be annotated appropriately (Figure 8).

Statistical Considerations

Biodistance studies in physical anthropology have a relatively long history, and have become increasingly prevalent with the advent of modern computing ability. Biological affinity studies are really the attempt to discover the amount of genetic relatedness of any two individuals/groups, assuming that those who have evolved in a common region are likely to share genetic and morphological similarities to a greater degree than those that have not (Underwood 1979). Of course, the group breeding relationships are constrained in terms of time, space, and amount of genetic exchange (or the possibility of genetic



Figure 6. Exemplar of the caliper position used to measure the mandibular breadth at mental foramen. The measurement is abbreviated as TML.



Figure 7. A photograph showing the measurement location for the mandibular body breadth at the M2/M3 junction. The measurement is abbreviated as TML23.



Figure 8. A photograph depicting the measurement of the maximum breadth of dental arcade width at the third molar. The measurement is abbreviated as XDA.

exchange). The amount of genetic variation in any one group is the sum of the genetic variation possible for each of its individuals' genes or genetic coding information. The number of different alleles fluctuates between each successive generation; at the micro-evolutionary level, these changes in allele frequency are expressed in the phenotypic characters present in each individual. For the physical anthropologist, the changes in allele frequency can be measured through skeletal variation, (though at best, this is an extremely difficult task, particularly for ancient populations that do not have known pedigree information).

Physical anthropology biological affinity studies use four primary datasets: continuous or metric features of the cranium (e.g. Hanihara 1996, 2000; Howells 1973; Jantz 1973; Key and Jantz 1990), discontinuous or non-metric features of the cranium or postcranium (e.g. Corruccini 1974; Hauser and De Stefano 1989; Ousley and Hefner 2005), metric and discontinuous features of the dentition (e.g. Burris and Harris 1998; Scott and Turner 1997; Edgar 2005) and metric features of the postcranium (e.g. Ousley and Jantz 1996; Smith 1996; Spradley and Jantz 2003). The bulk of recent studies used multivariate statistical treatment of the data rather than univariate models, since multivariate statistical approaches generally have more power for separating population samples than univariate techniques, which do not allow for the intercorrelation of variables (Key and Jantz 1990).

Barnard (1935) and Fisher (1936) introduced the world to discriminant function analysis. Within discriminant function analysis, linear arrangements of weighted variables that contribute the most information regarding differences between group centroids are produced. By maximizing the between-group variation relative to the

within-group variation, discriminant function analysis maximally separates the groups. The first discriminant function accounts for as much variation between the groups as possible, the second the next most, and so on. Typically, the first two discriminant functions account for the bulk of the variation used to discriminate between three given populations, and can be used to successfully classify an unknown individual.

Discriminant function analysis utilizes continuous data, but can be argued to accept binary data as well. Some statisticians have argued that ordinal variables can be used in linear discriminant functions instead of metric variables, which are essentially extensions of binary data (c.f. Ousley and Hefner 2005). Recently, researchers have applied this type of analysis to cranial non-metric traits and have argued that linear discriminant functions could achieve 90% classification rates between populations from just a few morphological variables, scored as ordinal data (Ousley and Hefner 2005). In-depth statistical analysis of their data did not yield substantial objections concerning the application of the generated discriminant functions.

For the metric variables analysis portion of this study, no significant problems are anticipated by the choices of statistical procedures. However, the morphological data are scored as categorical variables, which cannot necessarily be used in discriminant function analysis. This presents a significant hurdle to the analysis, particularly when *both* morphoscopic and morphometric data are analyzed using linear discriminant function analysis, concurrently.

Of the seven morphological variables, two of them, mandibular torus and ascending ramus shape, are scored as ordinal variables. One variable, ascending ramus profile, while scored as a non-metric trait, is really best captured as a metric variable. Indeed, it

is effectively the same as the metric measurement of the mandibular angle. On this basis, this variable will be removed from the remainder of the study as it is essentially duplicate data. The four additional variables are essentially categorical, but can they be justified as ordinal data?

Ordinal data are a type of data that are effectively one step in magnitude more specific than nominal data. Ordinal data possess a ranked order, according to some criterion. The criterion is not necessarily fixed in equal units; rather, the criterion is placed according to some level of quality, complexity, or other justification (Shennan 1990). For example, if we look in a kitchen cupboard at the flatware present, we could effectively rank order the pieces based on their complexity. Paper plates might be ranked the lowest at a 1, paper plates with decoration ranked as a 2, stoneware ranked as a 3, and fine china ranked as a 4. Each of these ranks indicates a level of *complexity* in manufacture or even perhaps use, greater than the previous, but *how much greater* the complexity is not known. If a justifiable means of rank ordering the mandibular morphology categories can be achieved, the data becomes *ordinal* rather than nominal.

Two of the remaining four morphological variables are implicitly rank-ordered data. The gonial angle flare and posterior ramus edge inversion variables are both defined and scored on the basis of their size, relative to the other size possibilities in the category. While the tool for measuring the size difference (the eyes) lacks clearly definable units, they are regardless still rank ordered on the basis of a justifiable difference.

The chin shape and lower border of the mandible categories may be the hardest to define in terms of ranks. Nevertheless, a justifiable order can be developed for both through biological complexity. For the lower border of the mandible, a level of

biological complexity can be deduced by examining the curvature needed to achieve the categorized shape. Simply put, a straight mandible lacks curvature and an undulating mandible has a single curve, medio-posteriorly located. Two small curves are present on a partial rocker, anteriorly and posteriorly located. Finally, the growth and development of these two smaller curves into a substantial curve produces a rocker jaw. Thus, the addition of curves to a straight mandible, and their growth, development, and placement can be used to rank order the complexity of the morphological shape.

A similar level of biological complexity can be argued for the shape of the chin. If it is accepted that the baseline form of a chin is a smooth, sloping curve, then deviations from this state can be judged in terms of their complexity. If the chin narrows, coming to a point, then a certain level of difference or complexity is achieved. Instead of forming a single point, if the chin then forms a series of points roughly on a straight line, yet another level is deduced. And finally, if the straight line is modified by placing a central sulcus into it (adding curves to the interior of the straightened area), then a final level of complexity is achieved. Thus the shape of the chin can be rank ordered, from one to four, based on the biological complexity needed to form the morphology.

A second point should be made for the rank ordering of these two morphological characters. A “correct” rank order presumes that there will not be discrepancies between two states that are removed from each other by an intervening state, and logically, if there are discrepancies between two separated categories, then the rank order is obviously not correct. In the flatware example given above, no confusion should exist between paper plates and fine china since there is an intermediate category of stoneware. Some confusion could be present between stoneware and fine china, particularly if the

investigator is not skilled at determining the differences in flatware. The ordering of these categories is correct because there is no confusion across variable states. Likewise, the mandibular data should be correctly ordered if there are no logical confusions between variable states separated by at least one state. With the shape of the chin, the only confusion is between a bilobate chin and one that is square, when the sulcus is poorly expressed. The only confusion on diagnosing variable states for the lower border of the mandible occurs when the investigator is differentiating between the undulating and partial rocker shapes. Like the chin, both of these variable states are progressive, and do not have intervening categories, thus showing the rank order of these variables is logically correct.

Based on the presented arguments, all of the mandibular morphological data is utilized as ordinal data. As previously expressed, ordinal data can be used in linear discriminant function analyses. But how ordinal data should be codified is not necessarily known. The morphological data could be scaled between 0 and 1 (binary data). Or it could be scaled as they are scored. Several tests of both methods were conducted, resulting in similar results (not presented here). Therefore, all of the data are kept as ordinal for the remainder of the analysis.

This study involves both univariate and multivariate methods of data analysis; univariate statistics are used to report the data, typically at the single population sample level and across population samples (e.g. summary statistics and t-tests). Linear discriminant function analysis is used to quantify the relationships between groups and to discriminate among them. Several choices exist when computing linear discriminant functions in terms of the type and style of data processing. For this study, step-wise

discriminant function analyses are used, which allow for variables to enter and be removed from an analysis, depending on their significance at any point (minimum F-value to enter = 3.84, minimum F-value to remove = 2.71). This procedure will be employed to the exclusion of other alternative methods. The method in which variables enter into the analysis is by using the Mahalanobis D^2 statistic. Mahalanobis' generalized distance statistic is a function of the metric differences between samples, such that when there is no difference, the $D^2 = 0$, and when there is maximum separation, D^2 can be quite large (see Rao 1952). Classification accuracy rates are computed using a leave-one-out method, and all groups have an equal prior probability, rather than weighted based on the sample sizes. (It is noted though that weighting based on sample size can improve the classification accuracy, a topic that will be explored in a subsequent study.) The inclusion of morphoscopic data in the various linear discriminant functions means that the assumptions of those particular analyses are not necessarily met. Therefore, the significance of the model is not the primary way of evaluating its performance. Rather, the leave-one-out cross validated accuracy rate is used to judge the model performance. All data analysis is conducted using SPSS 10.0 software (Statistic Package for Social Sciences 1999).

Missing Data

Missing data can be a significant problem for multivariate analyses. Missing data can be handled in many ways; for instance, if cases with missing data are placed into a linear discriminant function analysis in SPSS 10.0 (Statistic Package for Social Sciences 1999) or similar statistical package, the program will automatically remove incomplete cases. This effectively limits the discrimination power of the statistic, simply because not all of

the potential cases have been used, and also can violate the study sampling design. Four common ways for dealing with missing data exist: replacement of the data with the grand means of all cases, replacement of the data with a population means, estimating the missing data through multiple linear regression, or using a best guess or an *a priori* value (Leney 1996; Tabachnick and Fidell 1989).

Data replacement through a grand means solution is a relatively neutral technique (Tabachnick and Fidell 1989). This procedure involves estimating the mean of a variable over the entire dataset and replacing the missing values with this mean. This has an advantage over other techniques in that the estimated value adds no variance to the solution and its deviation from the mean is zero, by definition. The disadvantage is that the grand mean replacement would homogenize the entire dataset, effectively bringing each group centroid closer to each other, and minimizing discrimination power. Similarly, using a group mean replacement strategy would effectively homogenize each group, and any outliers in a group dataset would have extraordinary effects over the replaced data. This is particularly problematic if small sample sizes are included in the analyses.

A more satisfactory method for missing data replacement is by using multiple linear regressions to estimate the missing data. Several ways of replacing the data come to mind: using all populations to estimate the missing data, using only related variables to replace the data, and using only the biological population or sample to replace the missing values in each group. The first option would suffer from the same problems as the grand means method outlined above. The second option, while interesting, would not necessarily replace the data in a biologically correct manner. The objective of multiple

linear regression is not only to replace the variance in the data (e.g. the effect of a variable-by-variable method), but also the covariance in the data. Therefore, all possible variables should be used to predict the missing data, on a group by group basis, and in this case, separately between the sexes as well (which was the method used in this study).

The major drawback to using replaced data via multiple linear regressions is that, since the predicted missing values are generated from higher order interactions between the variables, excessive use of the technique will simply replicate the structure of the data present in the complete cases (Leney 1996). Discretion in using this method should be exercised. But what constitutes too much data placement, per sample? It can be argued that missing data replaced in this fashion below 25% of the total group membership should not necessarily interfere with further analyses. Arguably, 50% or more data replacement might realize the objection noted above.

Only the metric data for this study utilized replaced data. In several instances where the sample size did not warrant data replacement (e.g. U.S. 20th century Black females), it was not conducted. The morphologic data had few missing values, with a total of 18 cases and 27 values. The distribution of the non-metric missing data was weighted toward the White (seven cases) and Vietnamese (six cases) samples, both of which are fairly robust. Therefore, these individuals were removed from the subsequent analyses. Table 3 lists the data replacement percentages for the metric variables in the study, exclusive of values less than 10%. Only five variables had greater than 10% data replacement in the study, XDA, GNI, TLM23, HML, and CDL. The average amount of data replacement is relatively low, with the maximum being for XDA at 41.7%. But both XDA and GNI measurements frequently have samples exceeding a 50% replacement

Table 3. Percentage of missing values by measurement, sample, and sex (where appropriate). All values are percents.

Sample	XDA	GNI	TLM 2/3	HML	CDL
Terry White, Males	34.5	34.5		12.7	
Terry Black, Males	36.4				
Terry Black, Females	30.9	10.9			
Donated White, Males	56.8	16.8	21.6		
Donated White, Females	75.0	26.8	37.5	16.1	
Donated Black, Males	63.0	18.5	37.0	14.8	
Memphis Black, Males	31.3	50.0			25.0
Memphis Black, Females	66.7	41.7	16.7	41.7	
CIL White, Males	54.5	13.6			68.3
Hispanics, Males	36.7				20.0
Guatemalan, Males	52.8	14.6			12.4
Guatemalan, Females	71.4	28.6	21.4	21.4	
Vietnamese	46.3	41.5			68.3
Chinese	43.9	25.8			
Cambodian, Males	28.2	59.7			10.1
Cambodian, Females	24.1	72.4			13.8
Hohokam, Males	37.1	20.0			22.9
Hohokam, Females	28.6				14.3
Arikara, Males	20.0				
Arikara, Females	23.3				
Nubian, Males	28.6				
Nubian, Females	27.3				
Average	41.7	28.3	6.1	4.9	11.6

value. Given the concerns noted above, these variables were watched closely in the subsequent analyses for any possible problems stemming from the missing values replacement strategy.

In this study, several sources for the missing data were identified. Most sources of error were tied to taphonomic processes that affected the mandibles or to individual biological idiosyncrasies. Taphonomic change affecting the mandibles included damage due to trauma, poor preservation, excavation, and curation issues. Traumatic damage on the mandibles was identified in samples that stemmed from conflict or inter-personal violence. The Cambodian and the Guatemalan samples had the majority of traumatic taphonomy, as these samples were derived from populations that underwent open warfare or genocide. Typical examples of the taphonomic damage included missing mandibular condyles or rami due to machete damage found in the Cambodian sample (see Berg 2008), or gunshot wounds to the mandibular body (Guatemalan sample). Poor preservation and excavation taphonomic changes were observed in the archaeological samples. Examples included missing condyles (recently broken) due to improper excavation, friable and eroded bone exemplified by natural decomposition processes, broken or shattered bone, and missing alveolar processes (or exceptionally thin bone). Poor curation practices also led to some missing data due to freshly broken bone, particularly in the alveolar areas. The vast majority of the taphonomic changes affected the metric data collection—the morphological data collection could often proceed even though mandibular portions were missing, eroded, or damaged.

Some individuals' biological life histories also produced missing data. This category of missing data refers to all of the biological changes inherent in an individual,

particularly in terms of growth and development or the aging processes. The first identified area of change was found in the growth and development of the dentition, specifically the congenital absence of the third molars (laterally or bilaterally). Congenital absence of the third molars made collection of the XDA measurement impossible in many cases. The second process was that of the loss of teeth and remodeling of the mandibular body and rami. As tooth loss increases toward edentulism, the mandibular body and rami change shape and thickness (see Enlow and Hans 1996). The ascending ramus angle also increases as the skeletal system attempts to keep the remaining teeth in occlusion. Further, the mandibular body remodels, and the mandibular body height decreases as tooth loss increases.

In order to counter the problem of missing data, several practices were undertaken. First, edentulous mandibles were excluded from this analysis. Some mandibles missing the majority of the molars or premolars were still selected for analysis if the mandibular body was judged to be relatively sound, e.g. large remodeling processes were not evident. Ultimately, these criteria eliminated many potential mandibles, thereby lowering the overall study sample sizes. Second, traumatically damaged mandibles or mandibles that were significantly changed due to taphonomic processes were evaluated on a case-by-case basis. Whenever a particular variable was unable to be measured and scored, it was coded as missing data. On particularly damaged mandibles, if the majority of the study variables could be acquired, the mandible was measured and scored, leaving various data cells coded as missing data. If only a few variables could be acquired, the mandible was removed from the study.

As noted, no data replacement was undertaken for missing morphoscopic variables, which ultimately lowered the sample sizes in the morphoscopic and morphometric analyses, but it did not contribute error to these analyses either. For the morphometric data, multiple linear regression analysis was used to estimate and replace the missing data; all estimation was conducted using the entire sample for a given group, e.g. all 20th century White males were used to estimate the missing data for that sample. As noted in Chapter 2, excessive use of the technique will replicate the structure of the data in the complete cases (Leney 1996). Defining excessive use is somewhat difficult, and exploration of the variables with the highest frequency of replaced data was conducted. Two variables, XDA and GNI, had the greatest amounts of replaced data across all samples, though several samples had high percentages of missing data for CDL. The reason for the missing data for XDA likely was due to the high prominence of the congenital absence of the third molars or loss of the teeth at this location. The high percentage of missing data for GNI was associated with taphonomic damage of the alveolar process, stemming from poor preservation to poor curation. The measurement location is fragile, and damage to this location should be expected in any collection. While some missing data were shown for CDL, the majority of it was found in the collections housed at the CIL. The majority of these mandibles were missing the condyles due to perimortem trauma.

Given the fairly large amount of missing data for these variables, the natural question of “did they impact the results of the study in a negative way” is posed. For the study analyses regarding sex estimation (morphometric and combined analyses), 18 models were created (see Chapters 3 and 4). The variable CDL was a contributing factor in less

than half of the overall models, while both XDA and GNI contributed to slightly more than half of the models. This suggests that while these variables are sexually dimorphic for some samples, they are not necessarily as sexually dimorphic as others (group dependant). Further exploration of this was conducted by reanalyzing a sample that contained these variables in the model. The 19th century Black samples were reanalyzed, removing the GNI variable. The resulting classification rate was 86%, a decrease in accuracy of 2% for the overall model. The 20th century White samples were used to examine the effects of CDL and XDA on the overall model performance. For CDL, the model accuracy rate declined 0.5% when it was removed from the analysis. More strikingly, the removal of XDA decreased the model accuracy from 88% to 81%, or 7%. When the 19th and 20th century White samples are pooled, the contribution of XDA drops slightly to 6% of the overall model accuracy and CDL accounted for a decline of 0.3% of the model accuracy. These findings suggest that removal of the GNI and CDL variables will not largely impact the stated accuracy rates, though the removal of XDA can significantly alter the accuracy rates for the models.

For the morphometric and the combined analyses examining biological affinity, CDL did not enter into 44 of the 48 models, indicating that this variable contains little information that is not already present or expressed greater in other variables. Both XDA and GNI entered into significantly more models (XDA entered 75% of all models and GNI entered 65% of all models). The effects of XDA and GNI were explored using the time pooled U.S. White and Black samples. When GNI was removed from the analysis, the accuracy rate declined by 2.3%; when XDA was removed, the accuracy rate did not decline and remained the same. This suggests that when larger numbers of variables

enter into the models that the contribution of XDA and GNI are relatively small, and do not heavily impact the reported accuracy rates.

In the proceeding chapters, each of the data sets are presented singly, and finally both morphoscopic and morphometric data are examined simultaneously. Since there are a large number of possible combinations of the current data, only select analyses are conducted. For each type of data, all groups are considered in one discriminant function analysis. Select others, such as “forensically interesting populations” or “related groups” are also conducted. A time component to several of the populations is present and secular change is explored, where relevant (e.g. 19th and 20th century Whites and Blacks). A final consideration is that of intra-observer error. Several groups were scored or measured at different times during data collection process so intra-observer error could be calculated. At the completion of the study, it is believed that the “anthropologist on the ground” will be presented with several suites of relatively simple tools (functions), morphoscopic, morphometric, and a combination of both, for use in daily casework.

Chapter 3

Morphometric and Morphoscopic Analyses

This chapter deals with the mandibular morphometric and morphoscopic data each separately and is organized into two broad sections. The first section examines the morphometric data and the second section presents the morphoscopic data. These are further subdivided into two major subsections that examine: 1) sexual dimorphism in each sample that contains statistically reliable numbers of males and females and 2) the utility of the data to determine biological affinity. The latter subdivision is additionally divided into four types of analyses: 1) those that examine all groups, 2) groups of particular forensic interest, 3) closely associated groups, and 4) groups through time. While 17 collections are present in the data pool, several of the collections have been collapsed into single groups (see Chapter 2, population definitions). Therefore, a total of 12 population samples, 20th century U.S. Whites, 19th century U.S. Whites, 20th century U.S. Blacks, 19th century U.S. Blacks, Hispanics, Guatemalans, Cambodians, Chinese, Vietnamese, Arikara, Hohokam, and Nubians will be considered in the remainder of the analysis. Summary morphometric and morphoscopic data for the study population samples is presented in Appendix 1, Tables A1-A24.

Morphometric Analyses

As presented in the preceding chapter, 11 measurements were taken from each of the mandibles in the study. This section presents the results of various univariate and multivariate analyses, presented in two major subsections; one examines the question of whether or not there is significant sexual dimorphism in the morphometric data, and the

second explores the question of the usability of the morphometric data to determine the biological affinity of a mandible of unknown origin.

Sexual Dimorphism

While the primary purpose of this dissertation is to explore the value of using mandibular morphometrics and morphology to discriminate between populations, part of the data also allows for an exploration of sexual dimorphism. Of the 12 population samples, five (20th century U.S. Whites, 19th century U.S. Blacks, Cambodians, Arikara, and Nubians) samples have enough males and females to make statements regarding sexual dimorphism. In addition, two pooled groups, U.S. Whites and Blacks, as well as several overarching samples, such as all U.S. Whites and Blacks and all males and females, can be evaluated.

Sexual dimorphism is readily apparent in the data. Appendix 2, Tables A1 through A12, show, as expected, that males tend to be larger than females. When discriminant functions for sex determination for these samples were computed, the leave-one-out cross-validated accuracy rates ranged from the mid to high 80 percents (Table 4). Table 5 lists the Eigenvalues, Wilks' lambda, a Chi-square transformation of Wilks' lambda, and significance for the five functions in Table 4. Between three and five variables entered into in each computation. Each population sample had different components contributing to the functions; the most common measurement was CDL, followed by MLT. The only measurements unused in the functions were the ramus thickness measurements, TML and TML23, suggesting that ramus thickness is not a demonstrably sexually dimorphic feature of the human jaw. Two groups, the

Table 4. Discriminant functions for sex determination in five population samples and their associated leave-one-out accuracy rates.

Group	n	Function¹	Section point²	Accuracy rate
Nubians	56 m 55 f	0.158(HML) + 0.139(GOG) + 0.109(CDL) - 29.637	0.0	87.4%
Cambodians	149 m 29 f	0.239(GOG) + 0.097(CDL) + 0.083(MAN) + 0.076(MLT) - 24.242	-1.4	83.1%
Arikara	30 m 30 f	0.299(GOG) + 0.136(WRB) + 0.101(MAN) - 28.545	0.0	83.3%
19 th century U.S. Blacks	55 m 55 f	0.154(GNI) + 0.082(CDL) + 0.155(MLT) - 22.169	0.0	88.2%
20 th century U.S. Whites	147 m 56 f	0.092(GNI) + 0.064(CDL) + 0.08(XRH) + 0.075(MLT) + 0.127(XDA) - 22.491	-1.1	88.2%

¹Unstandardized coefficients

²A computed value greater than the sectioning point indicates male

Table 5. Discriminant function statistics for the five population samples in Table 4.

Group	Eigenvalue	Wilks' lambda	Chi-square	d.f.	Significance
Nubians	1.265	0.442	87.877	3	<0.0001
Cambodians	0.598	0.626	81.536	4	<0.0001
Arikara	1.202	0.454	44.588	3	<0.0001
19 th century U.S. Blacks	1.245	0.446	86.109	3	<0.0001
20 th century U.S. Whites	1.190	0.457	155.639	5	<0.0001

Cambodians and Arikara, produced accuracy rates less than the other groups. Likely, two reasons account for the lower accuracy rates. First, these are archaeological samples, and the lower rates may indicate that some individuals are sexed incorrectly. Second, the generally small sample size of females in both the Cambodian and the Arikara samples might have affected the outcome. A third reason can be possible; the Wilks' lambda shows a large increase in the Cambodian over the other samples, which are relatively consistent, suggesting less dimorphism in the Cambodian sample. While this may be the case, the fact that the sample is derived from an archaeological population, and the mandibles were sexed based on visual techniques, it is felt that this the decline in accuracy rates are more likely due to several incorrect sex assessments than the Cambodian sample having less sexual dimorphism than the samples in the study.

Pooled groups of individuals can also be used to determine sex from the mandibular morphometrics. Discriminant functions, employing four pooled population samples that represent forensically interesting groups, were calculated (Tables 6 and 7). The first two, all U.S. Whites and Blacks, yielded cross-validated functions in excess of 87% accurate. Lumping all U.S. Whites and Blacks together lowered the function accuracy (85%); finally, all population samples together produced a function that was nearly 83% accurate.

Discriminant functions employing as few as three or as many as seven variables have been presented. As a point of comparison, using the Sex Only Function in FORDISC 2.0 (Ousley and Jantz 1996), three vault measurements yielded accuracy rates of 77%, five vault measurements were 81% accurate, and seven vault measurements were 86% accurate. A comparison of seven facial measurements was 81% accurate for sex

Table 6. Discriminant functions for sex determination of the pooled population samples, and the associated leave-one-out accuracy rates.

Group	n	Function ¹	Section point ²	Accuracy rate
Pooled U.S. Whites	219 m 62 f	0.088(GNI) + 0.063(GOG) + 0.092(XRH) + 0.077(WRB) + 0.129(XDA) - 23.417	-1.4	89.3%
Pooled U.S. Blacks	92 m 71 f	0.075(GNI) + 0.067(CDL) + 0.185(MLT) + 0.072(MAN) + 0.46(TML) - 31.483	-0.4	87.7%
Pooled U.S. Whites and Blacks	298 m 130 f	0.075(GNI) + 0.076(GOG) + 0.15(XRH) + 0.02(MAN) + 0.081(XDA) - 25.633	-0.9	85.3%
All populations	792 m 272 f	0.037(GNI) + 0.065(GOG) + 0.023(CDL) + 0.109(XRH) + 0.085(TML) + 0.063(TML23) + 0.059(XDA) - 22.45	-0.9	82.8%

¹Unstandardized coefficients

²A computed value greater than the sectioning point indicates male

Table 7. Discriminant function statistics for the pooled population samples in Table 6.

Group	Eigenvalue	Wilks' lambda	Chi-square	d.f.	Significance
Pooled U.S. Whites	1.065	0.482	188.166	5	<0.0001
Pooled U.S. Blacks	1.366	0.423	133.927	5	<0.0001
Pooled U.S. Whites and Blacks	1.021	0.495	297.940	5	<0.0001
All populations	0.718	0.582	572.894	7	<0.0001

function only. The mandibular morphometric data perform arguably better than facial measurements and they appear to be equivalent to vault measurements (depending on the number available for an analysis). These data also compare well to early work by Giles (1964) who found that mandibular morphometric data could be used to sex an unknown mandible with approximately 84% accuracy (U.S. Black and White samples only).

It should be noted that for cranial and postcranial metric data, pooling groups for a sex-only function can have the undesirable effect of misclassifying those individuals in populations of smaller size, effectively classifying too many individuals as females. This problem is noticeable in cases where Hispanics, Guatemalans, etc. are present in analyses containing larger-sized individuals, e.g. American Whites and Blacks (R. Jantz, pers. comm. 2008; see also Spradley *et al.* 2008). This concern was explored by examining the misclassification rates for males and females in the pooled race and sex analyses. For the U.S. Whites and Blacks samples, the misclassification rate was overall biased toward the U.S. White sample, at 15.6% [33 males (16.3%) and 8 females (12.9%) misclassified out of 263 individuals]. This is in contrast to the U.S. Black sample, where 11.9% of the cases misclassified [14 males (14.4%) and 6 females (8.8%) out of 168 individuals]. In both instances, males were misclassified more frequently than females. When an all samples analysis is examined, several noteworthy items appear. First, the overall misclassification rate for the function was 17%, only slightly greater than the pooled sexes U.S. Whites and Blacks function. Second, all samples except the Arikara, Guatemalan, and Nubian maintained misclassification rates between 11% and 14%. The Arikara sample was misclassified 20% of the time, and all of the misclassifications were females as males. The Guatemalan sample was misclassified 30% of the time, and all but

two were males classified as females. And finally, the Nubian sample was misclassified 36% of the time and all but one case were males classified as females. These three samples obviously impacted the overall effectiveness of the discriminant function and appear to follow the problem outlined above – those samples containing relatively small individuals are most often misclassified, but the directionality (sex distinction) is somewhat dubious. In two samples, small males were misclassified as females, though in the first sample, there appeared to be few small males and a large quantity of large females. Therefore, perhaps there is more to this problem than meets the eye – the user should be aware of the consequences of using the large composite analysis to sex an unknown mandible. It is clear that mandibular morphometric data can be a useful tool in determining the sex of an individual even if the biological affinity of the specimen is unknown, or if the potential population the unknown individual might belong to can be limited by additional information, given the above caveat.

Biological Affinity

This section examines the value of morphometric data to determine biological affinity of a mandible of known or unknown sex. Four primary categories of analysis, 1) all groups, 2) groups of particular forensic interest, 3) closely associated groups, and 4) groups through time are detailed below. Since there are several hundred combinations of samples possible, only a few analyses of each type will be presented. Also, it should be noted that while several of these analyses are hampered by the lack of data for females (not included in several analyses due to small sample size), overall the discriminant functions perform very well.

All Groups

Several different types of “all groups” analyses can be constructed with the morphometric data. Four analyses are presented, which are all U.S. Whites and Blacks by sex, all U.S. Whites and Blacks with sexes pooled, all possible samples by sex, and all possible groups with the sexes pooled. In each case, 19th and 20th century groups (U.S. Whites and Blacks) are considered as separate samples. Table 8 gives a summary for these analyses, including the group, sample size, number of variables entering the functions, and the accuracy rates.

Classification of all possible groups yielded an accuracy rate of 41.5% (seven times chance alone). The data dispersion is presented in Figure 9. It is evident from Table 8 that when sex is pooled, the cross-validated accuracy rates increase slightly (~4%). But the number of samples drops, thereby creating a situation where the classification rate versus chance declines precipitously. For example, all U.S. Whites and Blacks yield a 61.5% accuracy rate when sex is considered in the analysis, which is approximately 3.6 times chance alone of getting a correct classification (Figure 10). When the sexes are pooled, the resulting accuracy rate is only 2.6 times chance. Graphically, this can be seen also by comparing Figures 10 and 11. Figure 10 is easily interpreted: the first function is a division of the population samples, with negative scores for White individuals and positive scores for Black individuals, while the second function separates males (positive scores) from females (negative scores). Figure 11 instead focuses on population sample (first function, U.S. Whites positive scores, U.S. Blacks negative scores) and time (second function, 20th century more positively loaded, 19th century more negatively

Table 8. Discriminant function analysis results for the morphometric samples and cross-validated accuracy rates.

Groups	n	Variables NOT entering functions	Number of groups	% variance (1st two functions)	Accuracy rate
U.S. Whites and Blacks by sex	423	GOG, WRB	6	87.3%	61.5%
U.S. Whites and Blacks pooled sexes	423	GOG, WRB	4	94.6%	65.2%
All groups, by sex	1032	WRB	17	68.2% (84.6% 3 rd function)	41.4%
All groups, pooled sexes	1060	WRB	12	75.6% (84.2% 3 rd function)	46.0%

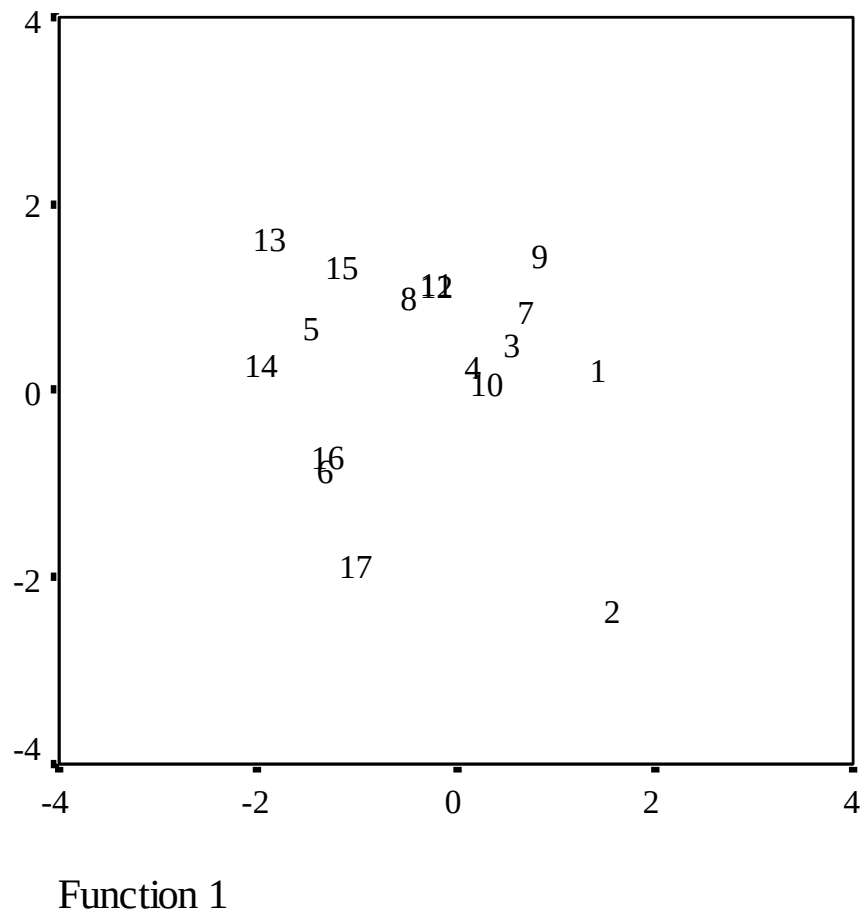
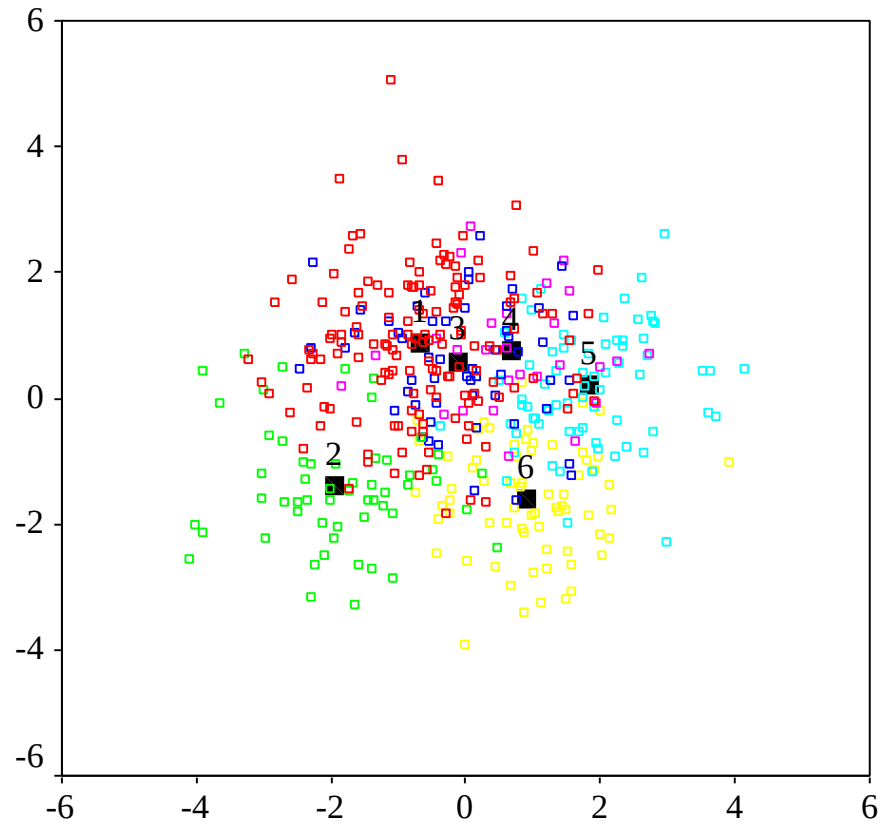
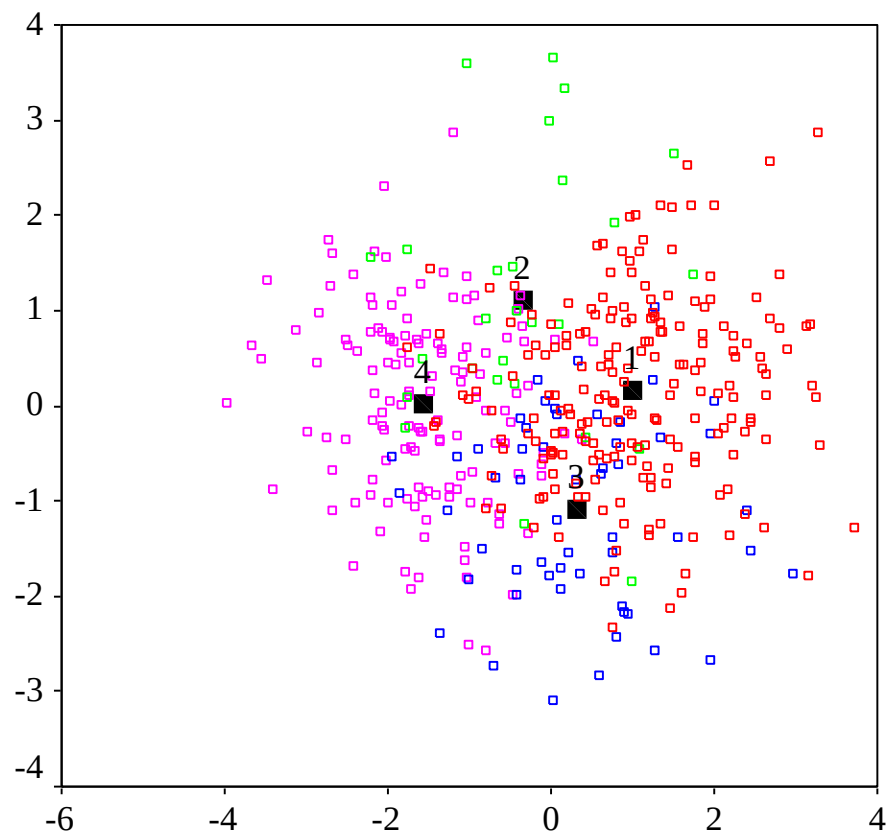


Figure 9. A scatter plot of the first two canonical functions for all population samples by sex using morphometric data. Sample centroids are marked with numerals and are as follows: 1 = 20th century White males, 2 = 20th century White females, 3 = 19th century White males, 4 = 20th century Black males, 5 = 19th century Black males, 6 = 19th century Black females, 7 = Hispanic males, 8 = Guatemalan males, 9 = Cambodian males, 10 = Cambodian females, 11 = Vietnamese males, 12 = Chinese males, 13 = Arikara males, 14 = Arikara females, 15 = Hohokam males, 16 = Nubian males, 17 = Nubian females.



Function 1

Figure 10. A scatter plot of the first two canonical functions for U.S. Whites and Blacks by sex using morphometric data. Sample centroids are marked with black squares and are as follows: 1 = 20th century White males, 2 = 20th century White females, 3 = 19th century White males, 4 = 20th century Black males, 5 = 19th century Black males, 6 = 19th century Black females.



Function 1

Figure 11. A scatter plot of the first two canonical functions for U.S. Whites and Blacks sexes pooled, using morphometric data. Sample centroids are marked with black squares and are as follows: 1 = 20th century Whites, 2 = 20th century Blacks, 3 = 19th century Whites, 4 = 19th century Blacks.

loaded, as compared to their respective samples). The mixing of time into the equation, rather than a sex component, ultimately lowers the classification rate.

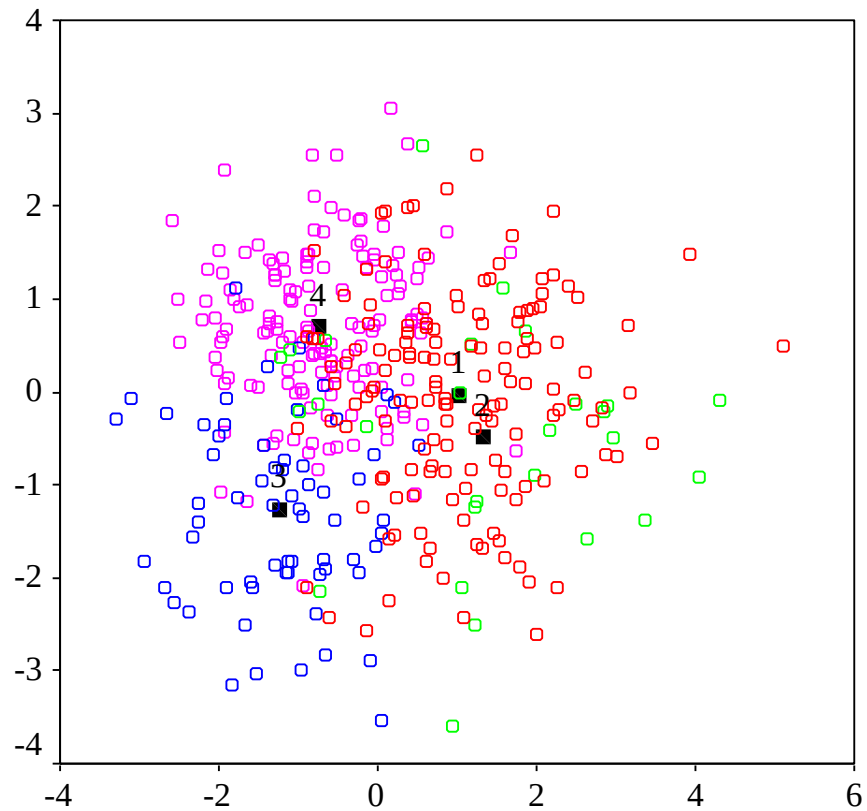
Forensically Interesting Groups

Analyses comparing groups of particular forensic interest can be drawn from the data. For any analysis, the choices made regarding population samples are stipulated by the question needing an answer. For forensic interest in the United States, the typical coverage for a usual case might be U.S. Whites and Blacks, Asians, Hispanics, and Native Americans. The data presented in this dissertation contain these groups, or variants of them, since these populations are by definition, generalizations. In addition to just the group, sex should either be considered or discounted. Twelve different analyses, constructed using both the morphometric and morphoscopic data, covering a range of groups are presented; Table 9 and Figures 12-13 present a selection of the results for the morphometric data.

The accuracy rates are typically between 70% and 90% for analyses containing two samples. When more than two groups are compared, the accuracy rates are relatively robust, between 58% and 75%. The multiple group comparisons still retain accuracy rates between two and three times that of chance for a correct assignment. The graphical data dispersion for these analyses is enlightening, showing the dispersion of the individual points around each group centroid (and hence the misclassification rates for each sample). Examination of Figure 12 shows similar group clustering for an analysis using 20th century U.S. White males, 20th century U.S. Black males, Cambodian males, and Chinese males. The morphometric data classified these groups at a rate about three times that of chance, with the U.S. groups clustering together (positive scores function

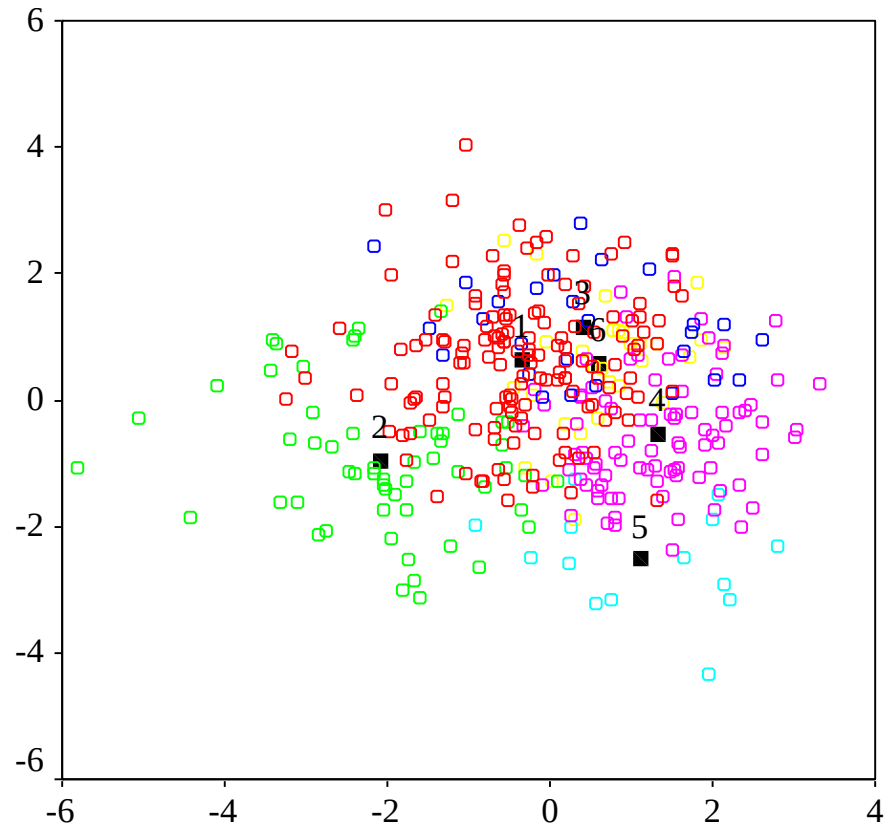
Table 9. Discriminant function analysis results, morphometric data, for a selection of forensically interesting groups and the cross-validated accuracy rates.

Analysis	n	Variables not entering functions	% variance (1st 2 functions)	Accuracy rate
U.S. Whites, males, time pooled	202	HML, GOG,	100%	82.9%
U.S. Blacks, males, time pooled	97	CDL, WRB	(one function only)	
U.S. Whites, females, time pooled	62	HML, CDL, WRB,	100%	88.7%
U.S. Blacks, females, time pooled	68	MAN, TML	(one function only)	
U.S. Whites, sexes and time pooled	264	HML, GOG, CDL,	100%	84.7%
U.S. Blacks, sexes and time pooled	165	WRB	(one function only)	
20 th century U.S. White males	147	HML, GOG, CDL,	100% (one function only)	70.1%
Hispanic males	30	WRB, XRH, MAN, TML23		
20 th century U.S. White males	147	GOG, CDL, WRB,	100%	86.4%
Guatemalan males	89	TML23	(one function only)	
20 th century U.S. Black males	27	GOG, CDL, WRB,	100%	91.4%
Guatemalan males	89	XRH, XDA	(one function only)	
20 th century U.S. Black males	27	GNI, HML, GOG,	100% (one function only)	78.9%
Hispanic males	30	CDL, WRB, XRH, MLT, XDA		
20 th century U.S. White males	147	WRB, CDL	89.0%	60.9%
20 th century U.S. Blacks males	27			
Hispanic males	30			
Cambodian males	149			
Guatemalan males	89			
20 th century U.S. White males	147	CDL, WRB	85.6%	69.3%
20 th century U.S. Blacks males	27			
Chinese males	65			
Cambodian males	147			
20 th century U.S. Whites, pooled sexes	203	CDL, WRB	88.9%	67.4%
20 th century U.S. Blacks, pooled sexes	30			
Cambodians, pooled sexes	178			
Arikara, pooled sexes	60			
Guatemalan, pooled sexes	103			
20 th century U.S. Whites, pooled sexes	203	CDL, WRB	92.7%	75.4%
20 th century U.S. Blacks, pooled sexes	30			
Cambodians, pooled sexes	178			
Arikara, pooled sexes	60			
20 th century U.S. White males	147	GOG, CDL, WRB, TML23	87.0%	58.1%
20 th century U.S. White females	56			
20 th century U.S. Blacks males	27			
Guatemalan males	89			
Guatemalan females	14			
Hispanic males	30			



Function 1

Figure 12. A scatter plot of the first two canonical functions for a forensically diverse group selection (analysis #9, Table 13). Group centroids are marked with black squares and are as follows: 1 = 20th century White males, 2 = 20th century Black males, 3 = Chinese males, 4 = Cambodian males.



Function 1

Figure 13. A scatter plot of the first two canonical functions for a second forensically diverse analysis (analysis #12, Table 13). Sample centroids are marked with a black square and are as follows: 1 = 20th century White males, 2 = 20th century White females, 3 = 20th century Black males, 4 = Guatemalan males, 5 = Guatemalan females, 6 = Hispanic males.

one), nearly equidistant from either the Chinese or Cambodian males. Function two distinguishes the Cambodians from the Chinese (again strong positive scores on function two). Figure 13 exemplifies data patterning for sex and biological affinity. The first function separates U.S. Whites from the other groups. The second function classifies the sex of the individuals, with strong negative scores for females.

Closely Associated Groups

For the purposes of this dissertation, closely associated groups are defined as those that occur in the same broad classification, such as Native American or Asian. Several groups do not necessarily correlate in time, others are correlated in extremely broad geographic regions, and finally, some may be considered essentially “cousins” of one another. Table 10 gives the statistical results of ten comparisons, with the cross-validated accuracy rates. Based on these results, it can be construed that some groups are in fact fairly closely related (resulting accuracy rates are relatively low, e.g. Vietnamese and Chinese samples), and other groups are much more distant (good discrimination accuracy rates, e.g. Arikara and Cambodian samples). Multiple sample analyses still performed relatively well, maintaining accuracy rates better than at least twice that of chance alone.

Groups Through Time

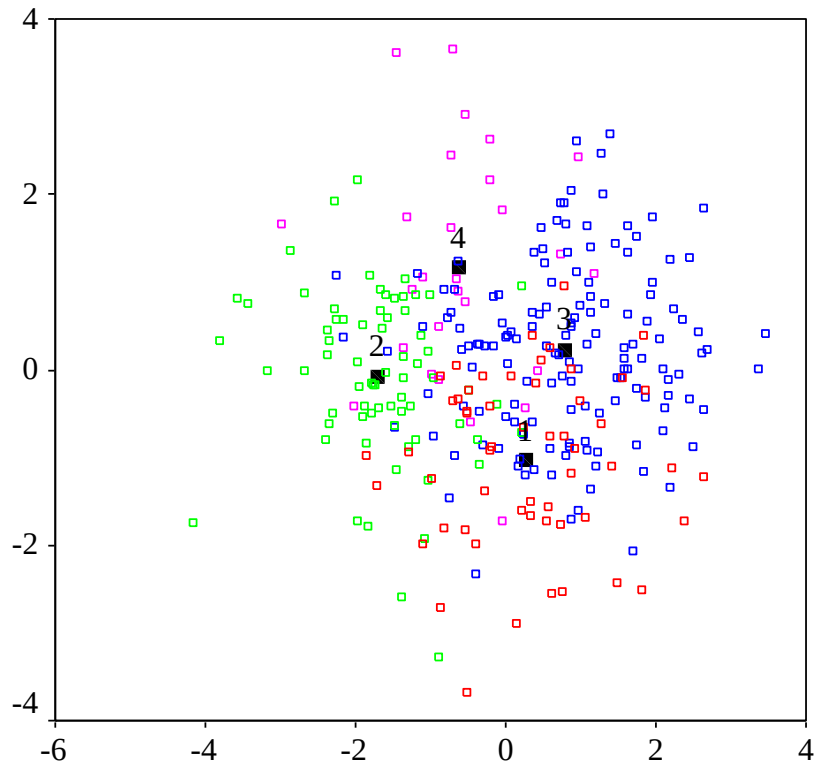
Time components are apparent in the U.S. White and Black samples for the study data. Two analyses pertaining to time are presented in Table 11 and are graphically displayed in Figures 14-15, and Figures 16-17 display the condensed axes plots of the same analyses (the plots depict the group centroid devoid of the individual data points and the plot axes are minimized). The morphometric data are able to effectively separate the groups when either sex is held constant (males only) or when the sexes are pooled.

Table 10. Discriminant function analysis results, morphometric data, for a selection of closely related groups and the cross-validated accuracy rates for those analyses.

Group comparisons	n	Variables entering functions	Accuracy rate
Vietnamese males	41	GNI, MAN, TML, XDA	75.5%
Chinese males	65		
Arikara, pooled sexes	60	GOG, XRH, MAN, XDA	86.2%
Hohokam, pooled sexes	49		
Arikara, pooled sexes	60	HML, GOG, CDL, XRH, MLT, TML, TML23	95.8%
Cambodians, pooled sexes	176		
Arikara males	30	GOG, CDL, MAN, TML23	94.7%
Chinese males	65		
Hispanic males	30	HML, MLT, MAN, TML, XDA	78.2%
Guatemalan males	89		
Nubians, sexes pooled	111	GOG, MAN, XDA, TML23	74.2%
19 th century U.S. Blacks, pooled sexes	165		
Vietnamese males	41	CDL, WRB, TML	69.0%
Chinese males	65		
Cambodian males	149	GNI, WRB, XRH, TML	76.0%
Arikara males	30		
Guatemalan males	89	GNI, WRB, TML	67.5%
Hohokam males	35		
Arikara, pooled sexes	60	GNI, WRB, TML	67.5%
Guatemalan, pooled sexes	103		
Hohokam, pooled sexes	49	GNI, WRB, XRH	66.3%
Arikara males	30		
Guatemalan males	89	GNI, WRB, XRH	66.3%
Hohokam males	35		
Hispanic males	30		

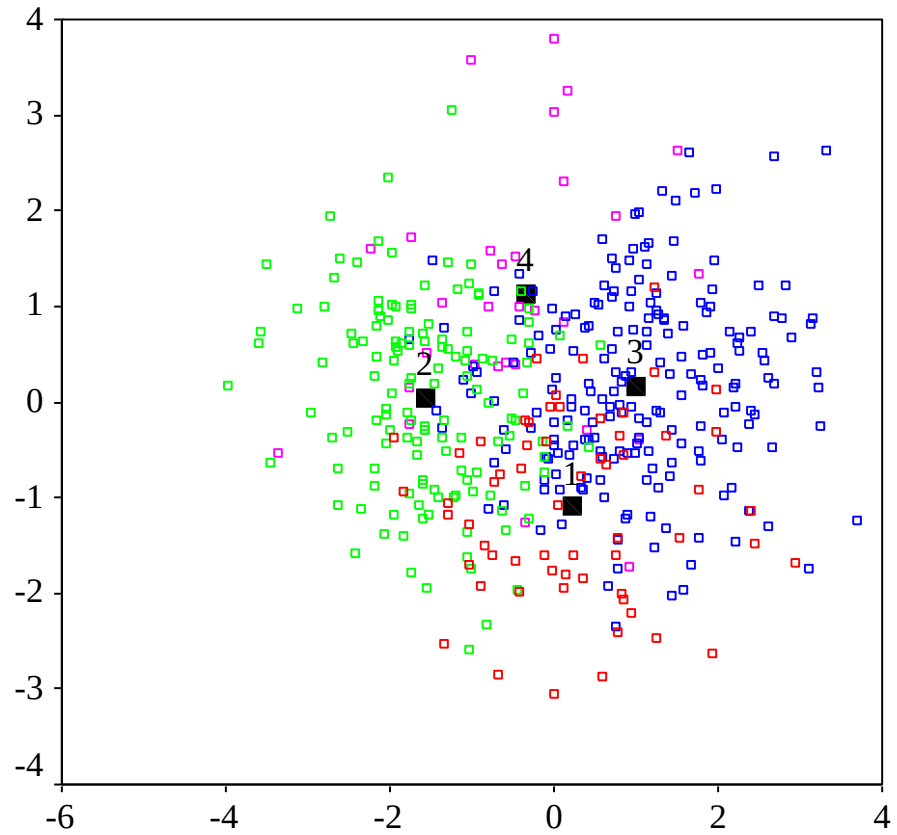
Table 11. Discriminant function analysis results, morphometric data, for a selection of closely related groups in time, and the cross-validated accuracy rates for those analyses.

Group comparisons	n	Variables NOT entering functions	% variance (1st two functions)	Accuracy rate
19 th century U.S. White males	55	CDL, TML, XDA	96.7%	62.1%
19 th century U.S. Black males	71			
20 th century U.S. White males	146			
20 th century U.S. Black males	27	GOG, WRB	94.8%	65.4%
19 th century U.S. Whites, sexes pooled	61			
19 th century U.S. Blacks, sexes pooled	138			
20 th century U.S. Whites, sexes pooled	202			
20 th century U.S. Blacks, sexes pooled	30			



Function 1

Figure 14. A scatter plot of the first two canonical functions for a 19th and 20th century U.S. White and Black males, morphometric data. Group centroids are marked with a black square and are as follows: 1 = 19th century White males, 2 = 19th century Black males, 3 = 20th century White males, 4 = 20th century Black males.



Function 1

Figure 15. A scatter plot of the first two canonical functions for a 19th and 20th century U.S. White and Black samples, morphometric data. Group centroids are marked with a black square and are as follows: 1 = 19th century Whites, sexes pooled, 2 = 19th century Blacks, sexes pooled, 3 = 20th century Whites, sexes pooled, 4 = 20th century Blacks, sexes pooled.

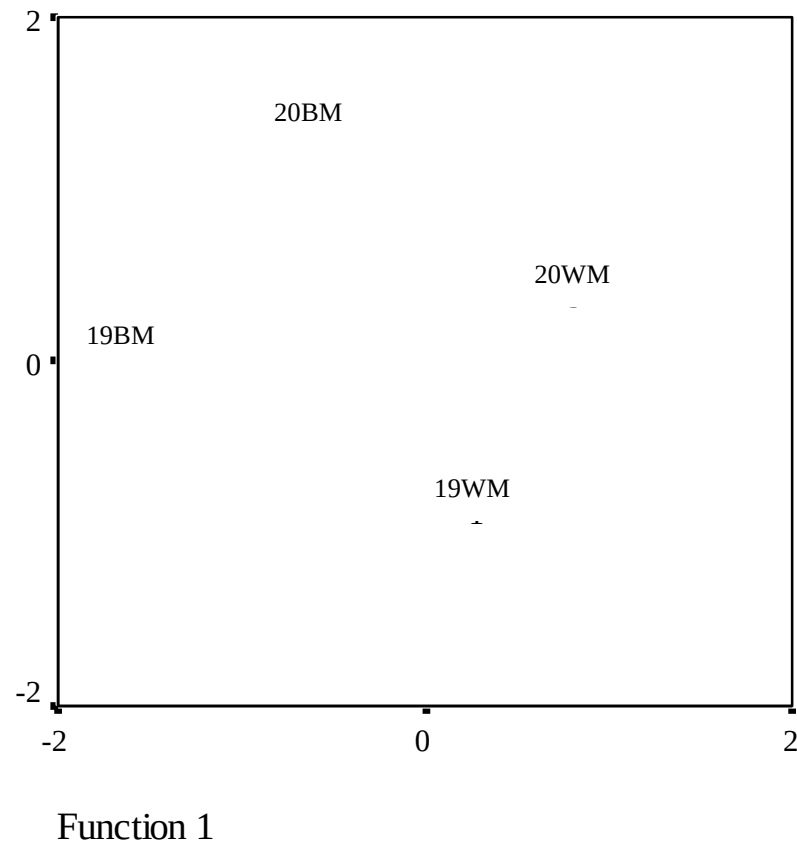
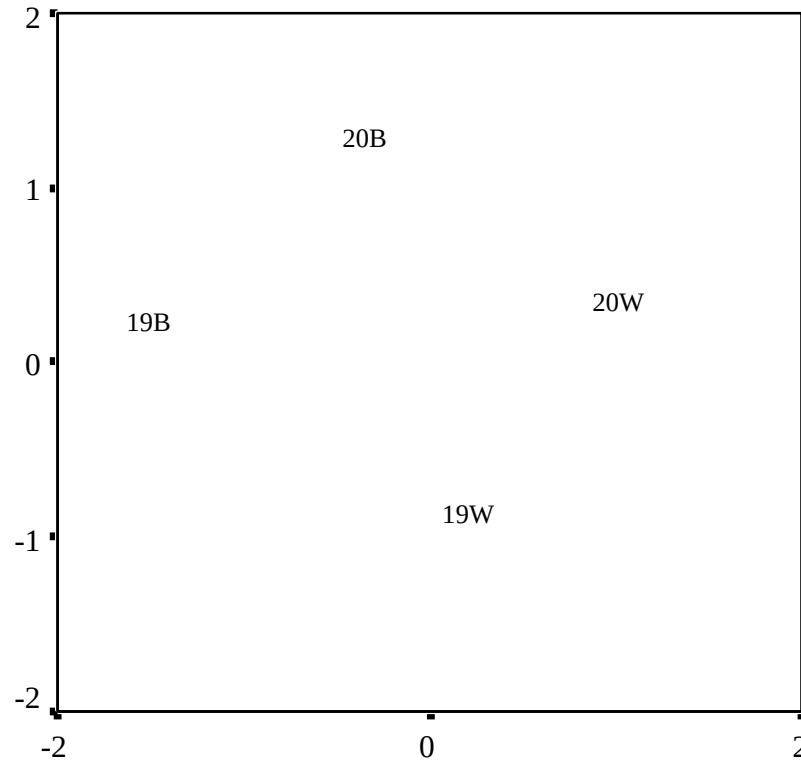


Figure 16. A scatter plot of the first two canonical functions for a 19th and 20th century U.S. White and Black males, morphometric data, axes reduced. Group centroids are marked with a black dot and are as follows: 19WM = 19th century White males, 19BM = 19th century Black males, 20WM = 20th century White males, 20BM = 20th century Black males.



Function 1

Figure 17. A scatter plot of the first two canonical functions for a 19th and 20th century U.S. White and Black samples, morphometric data, axes reduced. Group centroids are marked with a black dot and are as follows: 19W = 19th century Whites, sexes pooled, 19B = 19th century Blacks, sexes pooled, 20W = 20th century Whites, sexes pooled, 20B = 20th century Blacks, sexes pooled.

As can be determined from the figures, the morphometric variables associated with the time component are located primarily on the second function, while group membership is primarily associated with the first component. The matrix structure for these two analyses is presented in Tables 12 and 13. For the morphometric data, strong negative scores for function 2 are found with GOG and XDA (pooled only), and strong positive scores are associated with MLT, GNI, TML23, and WRB (pooled only). For the latter variables, an increase in size is indicated for both groups from the 19th to 20th centuries. A decrease in size is associated with HML for both samples. The pattern is the same with the addition of females into the analysis, given the additional variables of XDA and WRB. Therefore, there a general increase mandibular size through time, though a small decrease in size is associated with the height of the mandibular ramus.

Morphoscopic Analyses

As discussed in Chapter 2, six variables comprise the morphoscopic data analysis portion of this study. This section presents the results of several univariate and multiple multivariate analyses and parallels the format of the morphometric analyses presented above. It is divided in two major subsections; one examines the question of whether or not there is significant sexual dimorphism in the morphoscopic data, and the second exploring the question of the value of the morphoscopic data to correctly identify the biological affinity of a mandible of unknown origin.

Sexual Dimorphism

It is hypothesized that sexual dimorphism also is a component of mandibular morphology. An independent samples t-test of the entire data set provides a simple test of this association. All but one variable, ARS, show significant differences between the

Table 12. Structure matrix for the 19th and 20th century U.S. White and Black males, morphometric data.

Variable*	Function 1	Function 2	Function 3
WRB	-0.542	0.273	0.401
MLT	-0.533	0.484	-0.007
MAN	0.247	0.215	0.162
XRH	0.224	0.136	-0.012
GNI	-0.382	0.419	0.047
TML23	0.261	0.346	0.316
HML	-0.318	-0.002	0.498
GOG	-0.024	-0.155	-0.284

*Variables not used in the analysis are not reported.

Table 13. Structure matrix for the 19th and 20th century U.S. White and Black samples (pooled sexes), morphometric data.

Variable*	Function 1	Function 1	Function 3
WRB	-0.462	0.316	0.044
MAN	0.253	0.200	-0.169
HML	-0.194	0.043	0.065
MLT	-0.411	0.489	0.380
GNI	-0.235	0.403	0.361
TML23	0.265	0.276	0.094
GOG	0.080	-0.203	0.641
XRH	0.285	0.045	0.511
XDA	-0.211	-0.338	0.417

*Variables not used in the analysis are not reported.

mean scores of males and females (Table 14). While t-tests can be constructed for each sample to test for sexual dimorphism, the goal of producing discriminant functions for daily use is paramount in this study. Therefore, the question of “are the differences between the sexes large enough to produce solid discriminant functions” is further addressed, rather than a comprehensive description of sexual dimorphism in the morphoscopic variables.

As with the mandibular morphometric data, five possible samples are available for within group analyses, and multiple groups are available for pooled analyses. Two of the samples, the Cambodians and the Arikara, do not produce functions because no variable met the significance criteria to enter into a model. The remainder of the samples do produce viable functions, though several functions are only slightly better than chance, particularly for the U.S. White data (Table 15). While some functions are better than chance (e.g. U.S. Blacks), the overall impression of the data is that they are poorly suited for sexual discrimination, based on the presented accuracy rates and that in general, the Eigenvalues are relatively low and the Wilks’ lambda values are very high, indicating that little of the variance in the models is actually due to sexual dimorphism (Table 16). When the misclassification rates for each of the population samples are examined, a muddled picture emerges. Overall, 29% of males were classified as females and 37% of females were classified as males. But within each population sample, wildly different results were obtained. For U.S. Whites (time pooled), 22% of males were classified as females while 52% of females were classified as males. In contrast, U.S. Black samples (time pooled) 31% of males were classified as females while only 3% of females were classified as males. Another example is the Arikara sample; only 13% of males were

Table 14. Independent samples t-test of the mean mandibular morphology scores for the study males and females.

Variable	n	t	d.f.	Sig. (2-tailed)	Mean diff.	Std. Error difference
SC	785 m	4.593	636.3	0.000	0.278	0.061
	275 f					
LBM	786 m	-2.790	434.1	0.006	-0.165	0.059
	275 f					
ARS	788 m	-0.644	1059	0.520	-0.014	0.022
	273 f					
GAF	784 m	6.661	576.8	0.000	0.400	0.060
	274 f					
MT	788 m	-4.142	384.6	0.000	-0.113	0.027
	275 f					
PREI	778 m	-8.079	394.6	0.000	-0.581	0.072
	273 f					

Table 15. Discriminant functions for sex determination using mandibular morphoscopic data for the study population samples and the associated leave-one-out accuracy rates.

Group	n	Function ¹	Section point ²	Accuracy rate
Nubians	55 m 55 f	$0.963(\text{GAF}) - 0.560(\text{PREI}) - 1.742$	0.0	76.4%
19 th century U.S. Blacks	71 m 68 f	$0.372(\text{LBM}) - 0.48(\text{GAF}) + 2.198(\text{MT}) + 0.463(\text{PREI}) - 3.332$	0.4	79.1%
20 th century U.S. Whites	138 m 54 f	$-0.385(\text{SC}) + 0.945(\text{LBM}) - 0.539(\text{GAF}) + 0.742(\text{PREI}) - 0.411$	0.4	63.5%
Pooled U.S. Whites	193 m 60 f	$-0.373(\text{SC}) + 0.662(\text{LBM}) - 0.588(\text{GAF}) + 0.88(\text{PREI}) + 0.252$	0.4	65.2%
Pooled U.S. Blacks	98 m 71 f	$-0.346(\text{SC}) + 0.43(\text{LBM}) - 0.476(\text{GAF}) + 1.903(\text{MT}) + 0.465(\text{PREI}) - 2.463$	0.3	80.5%
Pooled U.S. Whites and Blacks	291 m 131 f	$-0.318(\text{SC}) + 0.529(\text{LBM}) - 0.514(\text{GAF}) + 0.973(\text{MT}) + 0.622(\text{PREI}) - 1.134$	0.5	72.0%
All samples	774 m 272 f	$-0.222(\text{SC}) - 0.55(\text{GAF}) + 1.227(\text{MT}) + 0.822(\text{PREI}) - 0.648$	0.4	68.8%

¹Unstandardized coefficients

²A computed value less than the sectioning point indicates male

Table 16. Discriminant function statistics for the mandibular morphoscopic data.

Group	Eigenvalue	Wilks' lambda	Chi-square	d.f.	Significance
Nubians	0.339	0.747	31.27	2	<0.0001
19 th century U.S. Blacks	0.900	0.526	86.68	4	<0.0001
20 th century U.S. Whites	0.139	0.878	24.41	4	<0.0001
Pooled U.S. Whites	0.130	0.885	30.40	4	<0.0001
Pooled U.S. Blacks	0.781	0.562	94.92	5	<0.0001
Pooled U.S. Whites and Blacks	0.305	0.766	111.11	5	<0.0001
All samples	0.158	0.864	152.43	4	<0.0001

classified as females, but 80% of the females were classified as males. These results suggest that while the overall testable hypothesis that sexual dimorphism is present in mandibular morphology is true, the amount of sexual dimorphism is somewhat low and misclassification is omni-directional; thus, using the discriminant functions constructed from mandibular morphoscopic variables to sex individuals is not highly recommended, except for groups that have reasonably strong classification rates, e.g. U.S. Black samples.

Biological Affinity

This section examines the ability of the morphoscopic data to determine biological affinity of known or unknown sex mandibles. Four primary subdivisions of analysis are presented and include 1) all groups, 2) groups of particular forensic interest, 3) closely associated groups, and 4) groups through time. As with the morphometric data, many combinations of samples can be compared, but only a few analyses of each type will be presented.

All Groups

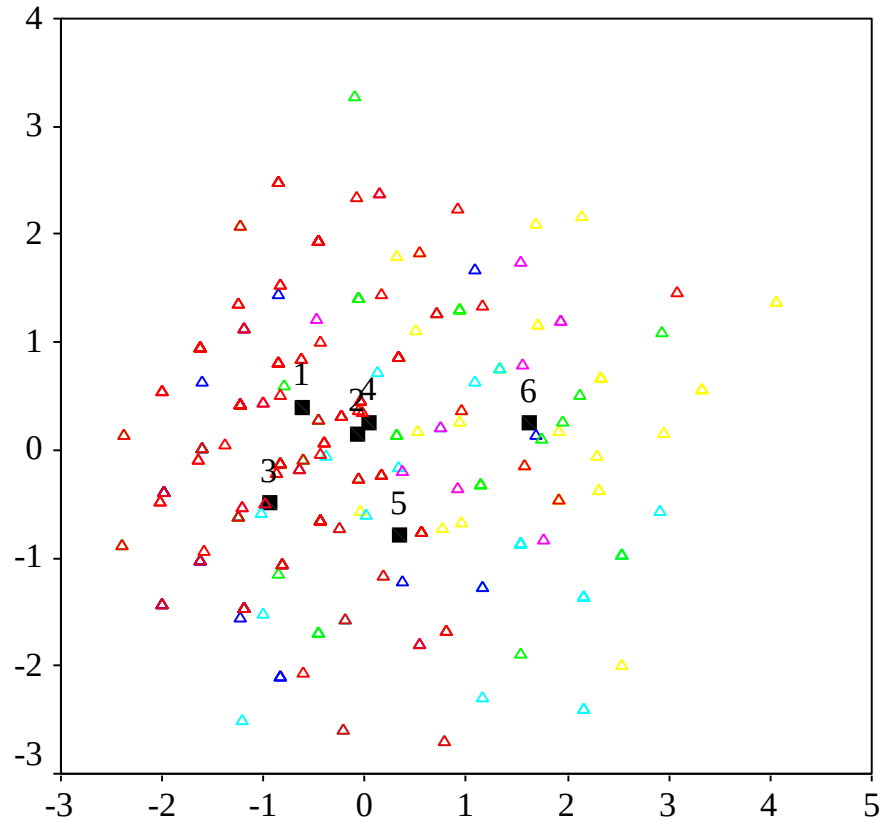
For ease of comparison, the mandibular morphoscopic data are presented using the same group analyses as the morphometric data. Table 17 gives the relevant discriminant function data and Figure 18 shows the data dispersion from the first analysis. In each analysis, while the accuracy rates appear low, they are at twice chance alone for the U.S. Whites and Blacks analyses and three times chance for the larger analyses. Comparing these results with the morphometric data show that the morphoscopic features of the jaw do not perform as well as the morphometric data – typically with about 20% less accuracy when sexes are separate and 15% when the sexes are pooled. Interestingly, when the sexes are pooled, the morphoscopic discriminant function accuracy rates improve dramatically, though since the number of population samples decreases, the functions maintain the same ratio of accuracy to chance. This finding is contrary to the morphometric data, which saw little accuracy rate increases with sexes pooled and a dramatic drop in correct population sample classification versus chance alone. Perhaps this indicates that the morphoscopic data are not as sensitive to sex as they are to population. Finally, it is interesting to note that the primary trait not entered into the first two analyses, LBM, has been argued to be a valid racial trait for White populations (Rhine 1990), and yet it plays no role in discriminating between U.S. Whites and Blacks in these specific analyses.

Forensically Interesting Groups

Groups of particular forensic interest can be drawn from the data, and as stated earlier, the groups of particular interest for this study are U.S. Whites and Blacks, Asians, Hispanics, and Native Americans. The study data are composed of these groups, or

Table 17. Discriminant function analysis results for the morphoscopic sample and cross-validated accuracy rates.

Groups	n	Variables not entering functions	Number of groups	% variance (1st two functions)	Accuracy rate
U.S. Whites and Blacks by sex	413	LBM	6	93.1%	40.7%
U.S. Whites and Blacks pooled sexes	422	LBM, MT	4	98.5%	50.7%
All groups, by sex	1009	None	17	72.4% (86.9% 3 rd function)	20.5%
All groups, pooled sexes	1046	GAF	12	69.4% (89.0% 3 rd function)	29.9%



Function 1

Figure 18. A scatter plot of the first two canonical functions for U.S. Whites and Blacks by sex, morphoscopic data. Sample centroids are marked with black squares and are as follows: 1 = 20th century White males, 2 = 20th century White females, 3 = 19th century White males, 4 = 20th century Black males, 5 = 19th century Black males, 6 = 19th century Black females.

variants of them, since groups such as Native Americans are by definition, generalizations. For each type of analysis, the sexes are either considered separately or pooled. As with the morphometric data, 12 different analyses are constructed using morphoscopic data and the results are presented in Table 18 and Figures 19-20.

For the morphoscopic data, the correct classification rates for two samples were between 58% and 82% accurate. When more than two groups are compared, the accuracy rates are between 44% and 62%, which still maintains accuracy rates between two and three times that of chance for a correct assignment. When these results are compared to the morphometric results presented above, it is clear that the morphoscopic variables perform worse, although they still produce viable functions. On average, the morphoscopic functions' accuracy rates are about 8% less accurate than the morphometric functions, though they noticeably declined more when Hispanic and Guatemalan groups are included in the comparisons. In multiple group analyses, the morphoscopic variables are approximately 12% less accurate, and again the comparisons using Hispanic and Guatemalan groups are noticeably worse.

A specific point can be made by examining both the morphoscopic and morphometric data together, which is that both types of data are functioning in the same fashion in the discriminant models. For example, in analysis #9 (Tables 9 and 18), it is clear that both the morphometric and morphoscopic data classified these groups at a rate three times chance, and the dispersion of the data is similar in both instances (compare Figures 12 and 19). In both analyses, the U.S. groups cluster together (positive scores function one, morphometric data and negative scores for function one, morphoscopic data), and are nearly equidistant from the Chinese or Cambodian males. Function two separates the

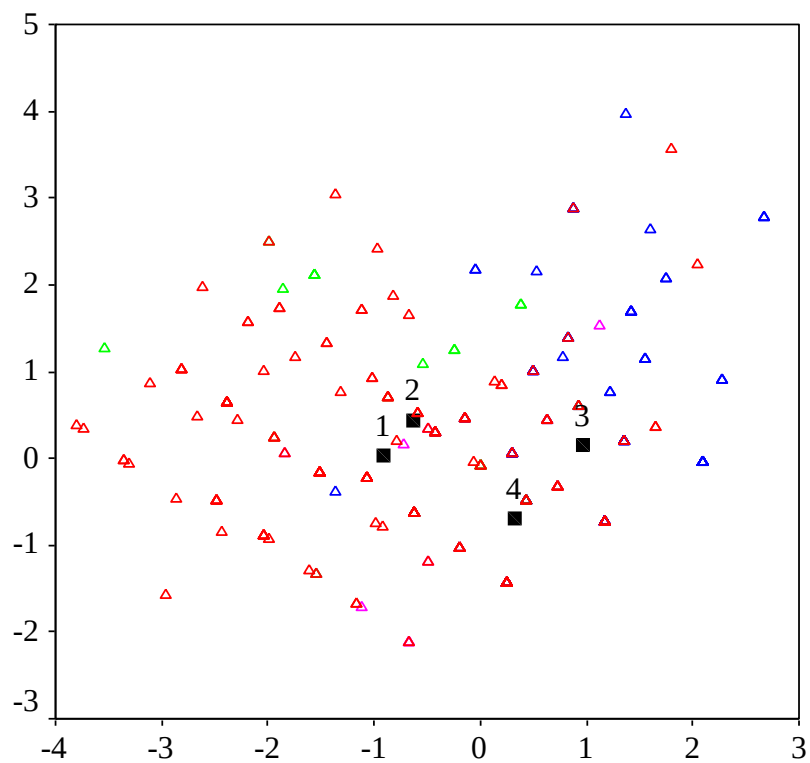
Cambodians from the Chinese (again strong positive or negative scores for these groups on function two). Again, compare Figures 13 and 20 (analysis #12, Tables 9 and 18). These graphs show the same data patterning for both data types. The first function separates U.S. Whites from the other groups (morphometric data) and U.S. Whites and Blacks (morphoscopic data). In both instances, the second function classifies the sex of the individuals with strong negative scores for females (morphometric data) and strong positive scores for females (morphoscopic data). Therefore, it is apparent that the morphoscopic data are performing within the discriminant functions in a similar fashion as the morphometric data, even if the assumptions of discriminant function analysis are being violated.

Closely Associated Groups

As discussed in the morphometric section, closely associated groups are defined as those that occur in the same broad geographic classification or correlate in time, and finally, some may be considered essentially “cousins” of each other. Table 19 shows the statistical results of ten comparisons, with the cross-validated accuracy rates. Analyses utilizing the morphoscopic data uniformly did much poorer than the morphometric analyses, rarely achieving 75% correct classification rates for two population samples. Only one analysis, pooled sexes for Nubians and 19th century Blacks performed better than the morphometric data, a 2.9% increase in the accuracy rate. On average, morphoscopic analyses were 14% worse, with a range of 2.9% better to 25.9% worse than the morphometric data. Many of the morphoscopic analyses, particularly those based on more than two groups, produced results only slightly better than chance. These results imply that morphology is a better discriminator of very diverse or broad groups

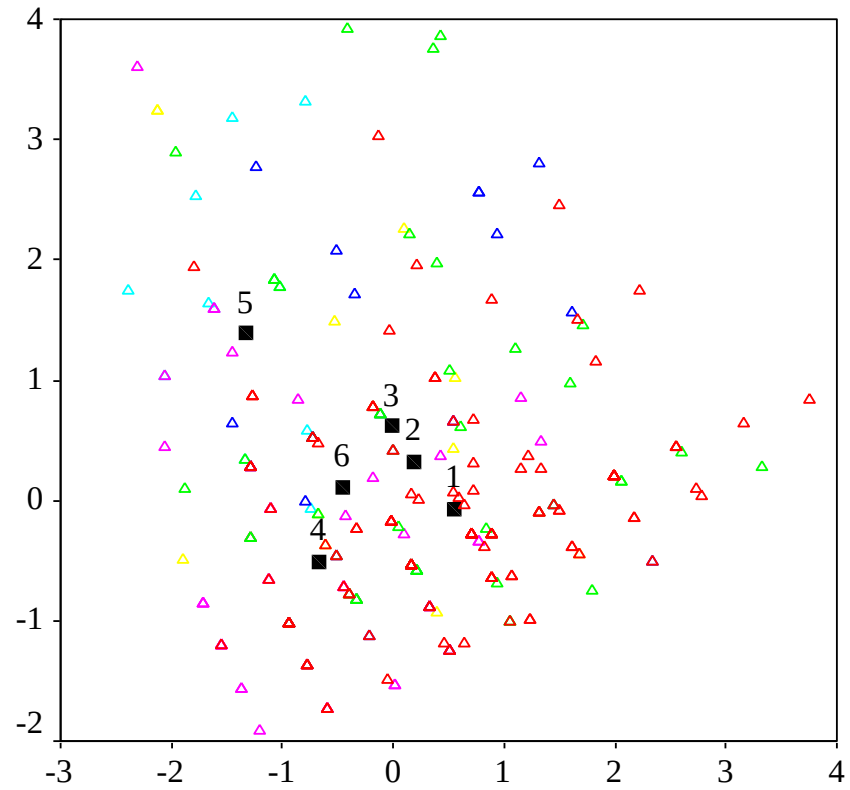
Table 18. Discriminant function analysis results, morphoscopic data, for a selection of forensically interesting groups and the cross-validated accuracy rates.

Analysis	n	Variables not entering functions	% variance (1st two functions)	Accuracy rate
U.S. Whites, males only, time pooled	193	LBM, ARS,	100%	75.9%
U.S. Blacks, males only, time pooled	98	GAF	(one function only)	
U.S. Whites, females only, time pooled	69	LBM, ARS,	100%	82.4%
U.S. Blacks, females only, time pooled	71	GAF	(one function only)	
U.S. Whites, sexes and time pooled	253	LBM, ARS,	100%	77.5%
U.S. Blacks, sexes and time pooled	169	GAF, MT	(one function only)	
20 th century U.S. White males	138	LBM, ARS,	100%	68.6%
Hispanic males	26	PREI	(one function only)	
20 th century U.S. White males	138	ARS, GAF,	100%	74.6%
Guatemalan males	88	PREI	(one function only)	
20 th century U.S. Black males	27	SC, LBM,	100%	66.0%
Hispanic males	26	ARS, MT, PREI	(one function only)	
20 th century U.S. Black males	27	LBM, ARS,	100%	76.5%
Guatemalan males	88	GAF	(one function only)	
20 th century U.S. White males	138			55.6%
20 th century U.S. Blacks males	27			
Hispanic males	26	ARS	93.0%	
Cambodian males	149			
Guatemalan males	88			62.3%
20 th century U.S. White males	138			
20 th century U.S. Blacks males	27	GAF	95.5%	
Chinese males	65			
Cambodian males	149			50.9%
20 th century U.S. Whites, pooled sexes	192			
20 th century U.S. Blacks, pooled sexes	30			
Cambodians, pooled sexes	178	GAF	93.1%	
Arikara, pooled sexes	59			59.3%
Guatemalan, pooled sexes	102			
20 th century U.S. Whites, pooled sexes	192			
20 th century U.S. Blacks, pooled sexes	30	GAF	92.0%	
Cambodians, pooled sexes	178			44.7%
Arikara, pooled sexes	59			
20 th century U.S. White males	138			
20 th century U.S. White females	54			
20 th century U.S. Blacks males	27	ARS	86.7%	
Guatemalan males	88			
Guatemalan females	14			
Hispanic males	26			



Function 1

Figure 19. A scatter plot of the first two canonical functions for a forensically diverse group selection (analysis #9, Table 16). Group centroids are marked with black squares and are as follows: 1 = 20th century White males, 2 = 20th century Black males, 3 = Chinese males, 4 = Cambodian males.



Function 1

Figure 20. A scatter plot of the first two canonical functions for a second forensically diverse analysis (analysis #12, Table 16). Sample centroids are marked with a black square and are as follows: 1 = 20th century White males, 2 = 20th century White females, 3 = 20th century Black males, 4 = Guatemalan males, 5 = Guatemalan females, 6 = Hispanic males.

Table 19. Discriminant function analysis results, morphoscopic data, for a selection of closely related groups and the cross-validated accuracy rates for those analyses.

Group comparisons	n	Variables entering functions	Accuracy rate
Vietnamese males	35	SC	67.0%
Chinese males	65		
Arikara, pooled sexes	59	ARS, MT, LBM	68.8%
Hohokam, pooled sexes	49		
Arikara, pooled sexes	59	LBM, PREI, ARS	72.3%
Cambodians, pooled sexes	178		
Arikara males	30	PREI, ARS	62.1%
Chinese males	65		
Hispanic males	26	MT, GAF,	72.2%
Guatemalan males	88		
Nubians, sexes pooled	110	MT, LBM, SC	77.1%
19 th century U.S. Blacks	139		
pooled sexes			
Vietnamese males	35	ARS, LBM	58.1%
Chinese males	65		
Cambodian males	149	LBM, MT, GAF	55.2%
Arikara males	30		
Guatemalan males	89	ARS, LBM, MT	58.5%
Hohokam males	26		
Arikara, pooled sexes	60	ARS, MT, LBM	51.6%
Guatemalan, pooled sexes	103		
Hohokam, pooled sexes	49	ARS, MT, LBM	51.6%
Arikara males	30		
Guatemalan males	88	ARS, MT, LBM	51.6%
Hohokam males	35		
Hispanic males	26		

rather than geographically neighboring or related groups.

Groups Through Time

The only groups that have a time component associated with them are the U.S. White and Black population samples. Two analyses pertaining to time are presented in Table 20 and are graphically displayed in Figures 21-22. The morphoscopic data are able to effectively separate the groups when either sex is held constant (males only) or when the sexes are pooled, as are the morphometric data. As with the forensically interesting populations, the morphoscopic data underperform the morphometric data, by approximately 15%, though the classification rates are minimally twice that expected by chance alone.

From the figures, it is apparent that the morphoscopic variables primarily associated with a time component are found on the second function, while group membership is associated with the first component. For the 20th century males, the morphoscopic data indicate positive increases in the ARS, MT, and PREI variables; 19th century males are associated with a decrease in the SC variable. This indicates that the ascending ramus is increasing in width, mandibular tori are becoming more frequent, and that there is more inversion along the posterior edge of the ascending ramus. The chin is tending to become more of a complex shape through time as well. When males and females are pooled, ARS, SC, and PREI are positively loaded and GAF negatively loaded. Again, the ascending ramus is becoming wider, the chin shape is becoming more complex, more inversion is appearing along the posterior edge of the ramus, and gonial angle flare is slightly increasing. When these data are combined with the findings from the morphometric data, it is clear that not only is there a general increase in the size of the

Table 20. Discriminant function analysis results, morphoscopic data, for a selection of closely related groups in time, and the cross-validated accuracy rates for those analyses.

Group comparisons	n	Variables NOT entering functions	% variance (1 st two functions)	Accuracy rate
19 th century U.S. White males	55	LBM, GAF	99.5%	50.5%
19 th century U.S. Black males	71			
20 th century U.S. White males	138			
20 th century U.S. Black males	27			
19 th century U.S. Whites, sexes pooled	61	LBM, MT	98.5%	50.7%
19 th century U.S. Blacks, sexes pooled	139			
20 th century U.S. Whites, sexes pooled	192			
20 th century U.S. Blacks , sexes pooled	30			

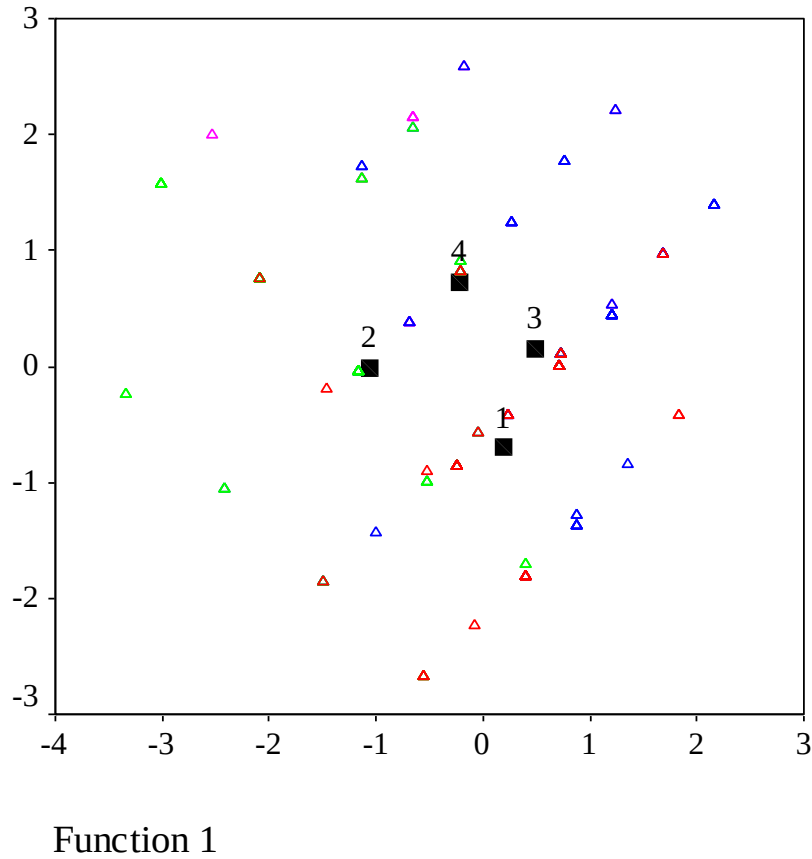
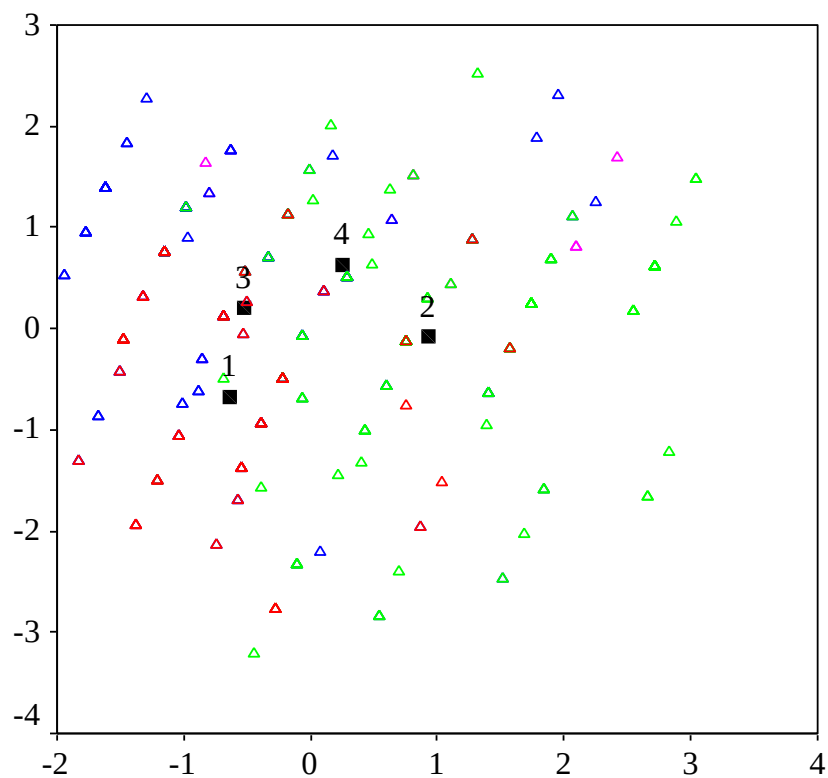


Figure 21. A scatter plot of the first two canonical functions for a 19th and 20th century U.S. White and Black males, morphoscopic data. Group centroids are marked with a black square and are as follows: 1 = 19th century White males, 2 = 19th century Black males, 3 = 20th century White males, 4 = 20th century Black males.



Function 1

Figure 22. A scatter plot of the first two canonical functions for sexes pooled populations of 19th and 20th century U.S. Whites and Blacks, morphoscopic data. Group centroids are marked with a black square and are as follows: 1 = 19th century Whites, 2 = 19th century Blacks, 3 = 20th century Whites, 4 = 20th century Blacks.

mandible, but there also is a change in its shape through time.

In summary, the results presented here demonstrate that mandibular morphometrics and morphology can be used to segregate different groups and distinguish between the sexes. The complex pairings or groupings of populations, or even closely related groups typically produced results with accuracy rates at least twice that of chance, frequently three to five times that of chance alone. The morphometric data substantially outperformed the morphoscopic data in these analyses, but the morphoscopic data showed similar patterns of change or groupings as were found in the morphometric data. This indicates that the morphoscopic data are performing similar to the morphometric data in the discriminant functions (even if they violate several assumptions). The next chapter focuses on what occurs when both data sets are combined into single discriminant function analysis.

Chapter 4

Morphometroscopic Analysis

The preceding chapter was composed of analyses that focused on the morphological and metric data evaluated independently. This chapter combines the metric and morphological data into one data set and assesses the performance of the generated *morphometroscopic* models. The term *morphometroscopic* is used to describe the data set representing the combined metric and morphological variables and is derived from the Greek roots for the words shape (morpho), measure (metro) and scopic (look at). As before, both sexual dimorphism and population affinity are examined through discriminant function analysis. The analytical framework set out in Chapter 3 is followed here, for ease of comparison between the results for each analysis.

Sexual Dimorphism

In this section, the morphometroscopic data are used to explore sexual dimorphism. For consistency, each analysis featured in Chapter 3 is undertaken in this section again. Computed discriminant functions for single groups include the 20th century U.S. White, 19th century U.S. Black, Cambodian, Arikara, and Nubian samples and the pooled groups samples are the U.S. Whites and Blacks singly, as well as all U.S. Whites and Blacks and all males and females.

Discriminant functions for sex determination for the single samples were calculated using the morphometroscopic data and the analyses' leave-one-out cross-validated accuracy rates ranged from the mid 80 to low 90 percentages (Table 21). Table 22 lists the Eigenvalues, Wilks' lambda, a Chi-square transformation of Wilks' lambda, and

Table 21. Discriminant functions for sex determination in five population samples and their associated leave-one-out accuracy rates using the morphometrosopic data.

Group	n	Function¹	Section point²	Accuracy rate
Nubians	55 m 55 f	0.136(HML) + 0.114(GOG) + 0.104(CDL) + 0.470(SC) + 0.068(MLT) – 32.345	0.0	89.1%
Cambodians	149 m 29 f	0.097(GOG) + 0.239(TML) + 0.083(XRH) + 0.076(MLT) -24.242	-1.4	83.1%
Arikara	30 m 29 f	0.127(CDL) + 0.116(MLT) + 0.371(TML) – 0.523(SC) – 29.057	0.0	85.0%
19 th century U.S. Blacks	70 m 68 f	0.112(GNI) + 0.102(XRH) + 0.075(MLT) + 0.094(XDA) + 0.415(GAF) – 0.366(LBM) – 1.538(MT) – 0.437(PREI) -18.176	0.0	92.8%
20 th century U.S. Whites	137 m 54 f	0.071(GNI) + 0.069(GOG) + 0.073(XRH) + 0.082(WRB) + 0.122(XDA) – 0.491(LBM) – 20.947	-1.1	89.9%

¹Unstandardized coefficients.

²A computed value greater than the sectioning point indicates male.

Table 22. Discriminant function statistics for the five population samples in Table 19.

Group	Eigenvalue	Wilks' lambda	Chi-square	d.f.	Significance
Nubians	1.488	0.402	96.176	5	<0.0001
Cambodians	0.598	0.626	81.536	4	<0.0001
Arikara	1.348	0.420	46.951	4	<0.0001
19 th century U.S. Blacks	2.292	0.304	157.271	8	<0.0001
20 th century U.S. Whites	1.353	0.425	159.129	6	<0.0001

significance for the five models in Table 19. The total number of variables entering in the models ranged between four and eight; one morphological variable typically entered into each function, though none entered into the model for the Cambodian sample and four were used for the 19th century U.S. Black model. This compares well with the results from Chapter 3, in that a sex function was not possible for the morphoscopic variables for the Cambodian sample (here, no morphoscopic variables entered into the morphometrosopic function) and multiple morphoscopic variables entered into U.S. Black models in Chapter 3, similar to these results as well. The results for the pooled samples are given in Tables 23 and 24 and the cross-validated accuracy rates were from 85-93%. On average, more variables entered into these functions than for the single samples (range 6-11). The number of morphoscopic variables also was higher on average, ranging between one and three per analysis. Overall, the morphometric variables were used in the models at an approximate 3:1 ratio over morphoscopic variables.

Morphometric variables entering into the morphometrosopic analyses often were similar to those that appeared in the morphometric only models (Chapter 3, Tables 4-8), though differences were frequently encountered. The mandibular length (MLT) was the most frequent variable entering the functions in these analyses, followed by GOG, CDL, and TML. In the previous analyses, MLT was the second most common variable, following CDL. The presence of mandibular thickness measurement (TML) in the current analyses contrasts with its previous absence, indicating that TML does contain a reasonably strong sexually dimorphic component. The positive scores on the morphometric variables, in conjunction with a negative constant, show that males are

Table 23. Discriminant functions for sex determination of the pooled population samples, and the associated leave-one-out accuracy rates, using the morphometrosopic data.

Group	n	Function ¹	Section point ²	Accuracy rate
Pooled U.S. Whites	192 m 60 f	0.075(GNI) + 0.065(GOG) + 0.094(XRH) + 0.066(WRB) + 0.123(XDA) – 0.362(LBM) – 22.004	-1.3	90.0%
Pooled U.S. Blacks	97 m 68 f	0.173(XRH) + 0.048(GOG) + 0.062(MAN) + 0.090(MLT) + 0.051(XDA) – 1.388(MT) – 0.542(LBM) – 0.236(PREI) – 28.881	-0.5	93.3%
Pooled U.S. Whites and Blacks	289 m 128 f	0.060(GNI) + 0.146(XRH) + 0.059(GOG) + 0.082(XDA) + 0.104(TML) + 0.023(MAN) – 0.553(LBM) – 0.702(MT) – 23.186	-1.0	89.4%
All samples	774 m 269 f	0.114(XRH) + 0.051(GOG) + 0.108(TML) + 0.026(CDL) + 0.030(MAN) + 0.062(TML23) + 0.114(XDA) + 0.057(WRB) – 0.790(MT) – 0.304(LBM) – 0.147(PREI) – 24.391	-1.0	85.1%

¹Unstandardized coefficients.

²A computed value greater than the sectioning point indicates male.

Table 24. Discriminant function statistics for the population samples in Table 21.

Group	Eigenvalue	Wilks' lambda	Chi-square	d.f.	Significance
Pooled U.S. Whites	1.153	0.464	189.447	6	<0.0001
Pooled U.S. Blacks	2.275	0.305	188.629	8	<0.0001
Pooled U.S. Whites and Blacks	1.295	0.436	340.794	8	<0.0001
All samples	0.854	0.539	639.029	11	<0.0001

larger than females, as is expected.

For the single population samples, the two most common morphoscopic variables entering into the functions were SC and LBM, though GAF, MT, and PREI did enter into one function. For the pooled samples, the predominant morphoscopic variable was LBM, followed by MT and PREI. In each case, positive or negative scores associated with these variables were easily interpreted. For example, a positive score for SC indicates that square and bilobate chin shapes are most frequently associated with males, and the scores on PREI, GAF, and MT indicate that the size and expression of these traits are larger in males than females. Males appear to be more strongly predisposed than females to a partial or complete rocker jaw form, particularly among the 20th century U.S. Whites and 19th century U.S. Blacks, as well as pooled samples using these groups.

An examination of the misclassification rates shows that, for the largest analysis, both males and females are misclassified at nearly the same rate (15.3% of males and 15.2% of females). Nearly the same situation is found for the time pooled U.S. White and Black samples, with 12.3% of males misclassified and 11.7% of females misclassified. As discussed in the previous chapter, a sex bias for misclassification is possible with these data and does still exist – 55% of the Nubian males were classified as females (all females classified correctly – 27% total misclassification rate), 43% of the Arikara females were classified as males (all males correctly classified – 21.6% total misclassification rate), though only 11% of the Guatemalan males were misclassified as females (12.6% total misclassification rate). On the surface, it appears that the addition of the morphoscopic variables to morphometric variables has exacerbated this problem, but it actually has reduced the overall misclassification rate within two of three of these

samples. The Nubian sample has a net increase of 9% accuracy, the Guatemalan sample has a net increase of 17%, but the Arikara has a net decrease of 1% (one case).

The morphometrosopic data allowed for the most sexually dimorphic variables of either type to be expressed (as noted by their presence in the resulting analyses), thereby eliminating those variables that contained less information. For the single population samples, the average increase in accuracy was 1.9%, with a range of 0.0-4.6%. For the pooled population samples, the average increase was 3.6%, with a range of 1.7-5.6%. The largest increases in accuracy were found in models containing a U.S. Black sample. Not surprisingly, U.S. Black samples also had the highest accuracy rates in the morphoscopic only analyses, as well high accuracy rates in the morphometric only analyses. The U.S. Black samples also had the largest number of variables entering the discriminant functions in the morphometric, morphoscopic, or morphometrosopic analyses. This suggests that there is a greater amount of sexual dimorphism for U.S. Blacks within these variables as compared to the other study groups.

Joining the two types of data (morphoscopic and morphometric) has produced cross-validated accuracy rates stronger than if these data are used separately. In some instances, the increase in accuracy is arguably small, but nonetheless, the morphometrosopic results are better than their component parts. Furthermore, as variables ebb and flow from the analyses, only the best-suited variables are present in the final model, thereby maximizing the overall accuracy from a pool of maximized data. The largest accuracy increases were found in analyses of the U.S. Black samples, or in comparisons utilizing these data. Further, a morphometrosopic approach has lessened the impact of the sex bias (by population sample) found in the composite analyses, and

therefore arguably has improved the overall classification confidence, though the user should still be aware of this particular problem. Overall, these functions are a valuable tool for any anthropologist undertaking this type of analysis, given the listed caveat.

Biological Affinity

This section examines the utility of the morphometrosopic data to determine biological affinity of mandibles of known or unknown sex. As with the sexual dimorphism section above, the data presented follow the format outlined in Chapter 3. Sample sizes are slightly different from the previous analyses due to minor amounts of missing data. Four primary categories of analyses, 1) all groups, 2) groups of particular forensic interest, 3) closely associated groups, and 4) groups through time are detailed below.

All Groups

Multiple “all groups” analyses can be constructed. Four are presented here: all U.S. Whites and Blacks by sex, all U.S. Whites and Blacks with pooled sexes, all possible samples by sex, and all possible groups with the sexes pooled. In each case, 19th and 20th century groups (U.S. Whites and Blacks) are considered as separate samples and frequently the 20th century U.S. Black females and 19th century U.S. White females are not included due to small sample size. Table 25 gives a summary for these analyses, including the group, the sample size, the variables not entering the functions, and the accuracy rates.

The morphometrosopic data produced better cross-validated accuracy rates than either variable type used alone. As was seen in the sexual dimorphism section, the morphometrosopic data allowed variables that contained more information regarding

Table 25. Discriminant function analysis results for the morphometrosopic analyses by group and the cross-validated accuracy rates.

Groups	n	Variables not entering functions	Number of groups	% variance (1st two functions)	Accuracy rate
U.S. Whites and Blacks by sex	432	TML, CDL, SC, ARS, GAF	6	84.9%	64.6%
U.S. Whites and Blacks pooled sexes	432	TML, CDL, LBM, GAF, MT	4	94.8%	66.4%
All groups, by sex	103 1	CDL, GAF	17	59.0% (76.9% 3 rd function)	49.8%
All groups, pooled sexes	105 8	CDL, GAF	12	69.1% (79.9% 3 rd function)	53.0%

biological affinity to be expressed, while eliminating those containing less information. For analyses using solely the U.S. White and Black population samples, accuracy increased by 2.2% over analyses using morphometric data only and 19.8% over analyses using morphoscopic data only. For all samples, the average increase was 7.2% greater than the morphometric data and 26.2% more than the morphoscopic data. These net increases in accuracy increased the probability of getting a correct classification versus chance alone by at least a factor of two. Therefore, the morphometrosopic model increases accuracy slightly in some cases (2.2%, lowest), and moderately in other cases (7.4% highest).

Similar to the findings using morphometric and morphoscopic data separately, the morphometrosopic models graphically show the same data dispersion in the population samples (Figure 23). Classification of all possible groups by sex yielded an accuracy rate of 49.8%, or greater than eight times chance alone. It is evident from the Table 25 that

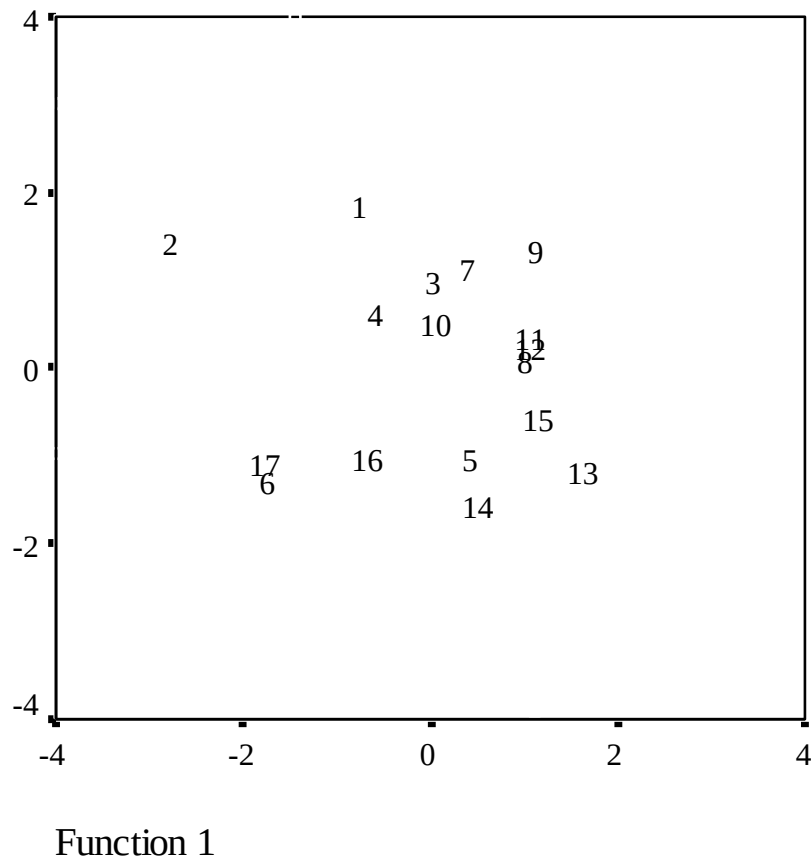


Figure 23. A scatter plot of the first two canonical functions for all population samples by sex using the morphometric data. Sample centroids are marked with numerals and are as follows: 1 = 20th century White males, 2 = 20th century White females, 3 = 19th century White males, 4 = 20th century Black males, 5 = 19th century Black males, 6 = 19th century Black females, 7 = Hispanic males, 8 = Guatemalan males, 9 = Cambodian males, 10 = Cambodian females, 11 = Vietnamese males, 12 = Chinese males, 13 = Arikara males, 14 = Arikara females, 15 = Hohokam males, 16 = Nubian males, 17 = Nubian females.

when sex is pooled, the cross-validated accuracy rates increase slightly (~3%), but the number of samples drops. Thus, while producing higher classification rates, a correct classification is less likely when compared to chance alone. For the U.S. Whites and Blacks, the accuracy rates are 64.6% when sex is considered in the analysis, which is approximately 4 times chance alone of producing a correct classification. When the sexes are pooled, the resulting accuracy rate declines to only 3 times chance.

Examining the plots of the first two functions can shed some light on this finding (Figures 24-25). In Figure 24, the first function is dividing the samples along population lines with negative scores for White individuals and positive scores for Black individuals, while the second function separates males (positive scores) from females (negative scores). As is seen in Figure 25, with the sexes pooled, the first function focuses on population sample (first function, U.S. Whites positive scores, U.S. Blacks negative scores) and time secondly (second function, 20th century more positively loaded, 19th century more negatively loaded, as compared to their respective samples). As was determined in the metric data section (Chapter 3), the addition of a time component into the analysis, instead of sex, lowers the classification rate.

Forensically Interesting Groups

As in Chapter 3, the construction of models using samples of particular forensic interest is next presented. The samples are drawn from groups representing Asian, Hispanic, Native American, and U.S. Whites and Black populations. Analyses covering known sex or pooled sexes are presented. Twelve analyses, using the morphometrosopic data, are presented in Table 26, and scatter plots of two analyses are presented in Figures 26-27.

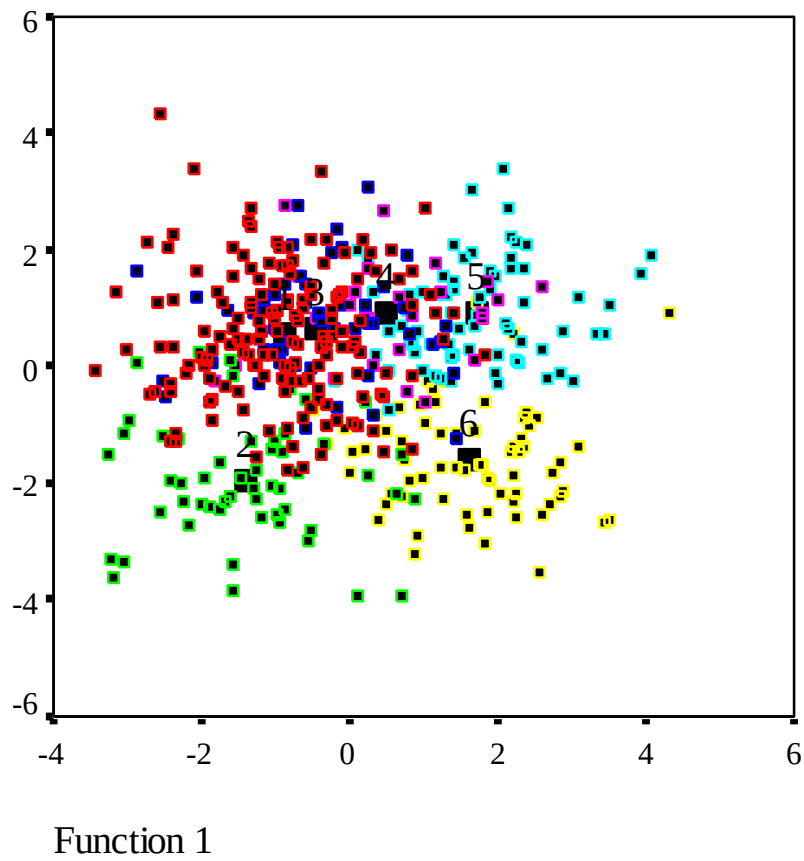


Figure 24. A scatter plot of the first two canonical functions for U.S. Whites and Blacks by sex using morphometric data. Sample centroids are marked with black squares and are as follows: 1 = 20th century White males, 2 = 20th century White females, 3 = 19th century White males, 4 = 20th century Black males, 5 = 19th century Black males, 6 = 19th century Black females.

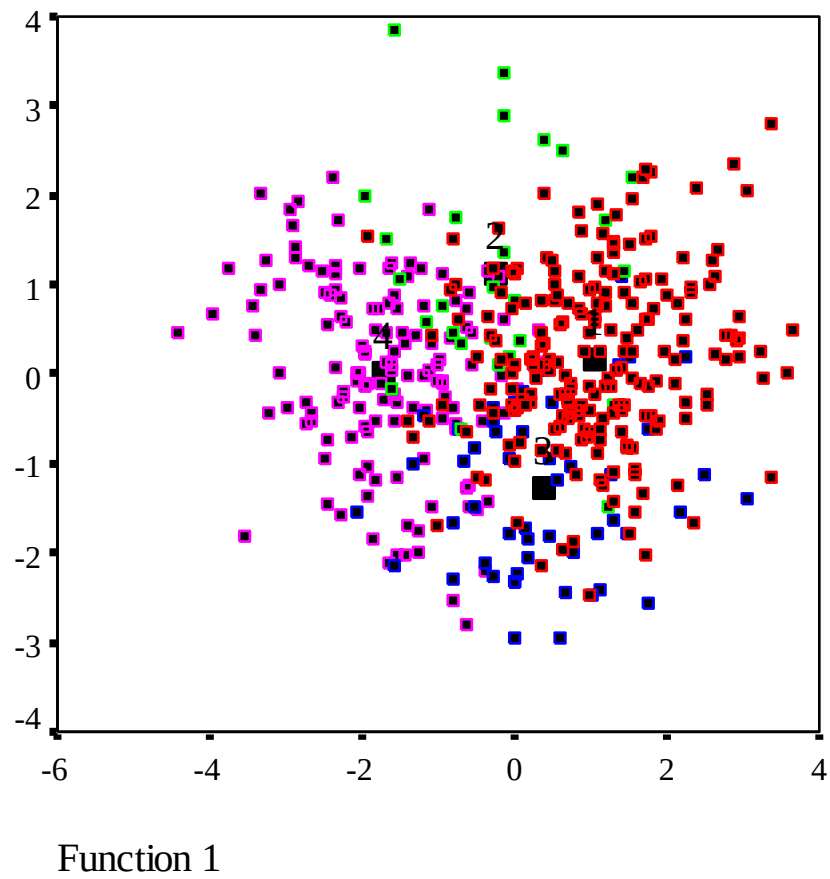


Figure 25. A scatter plot of the first two canonical functions for U.S. Whites and Blacks sexes pooled, using morphometric data. Sample centroids are marked with black squares and are as follows: 1 = 20th century Whites, 2 = 20th century Blacks, 3 = 19th century Whites, 4 = 19th century Blacks.

Table 26. Discriminant function analysis results, morphometric data, for a selection of forensically interesting groups and the associated cross-validated accuracy rates.

Analysis	n	Variables not entering functions	% variance (1st 2 functions)	Accuracy rate
U.S. Whites, males, time pooled	196	HML, TML, GOG,	100% (one function only)	87.1%
U.S. Blacks, males, time pooled	98	CDL, MAN, LBM, ARS, GAF		
U.S. Whites, females, time pooled	60	HML, TML, GOG,	100% (one function only)	88.3%
U.S. Blacks, females, time pooled	68	CDL, XRH, MLT, MAN, LBM, ARS, GAF		
U.S. Whites, sexes and time pooled	264	HML, GOG, CDL,	100% (one function only)	87.3%
U.S. Blacks, sexes and time pooled	165	MAN, ARS, GAF, MT		
20 th century U.S. White males	158	HML, TML, GOG,	100% (one function only)	71.7%
Hispanic males	28	CDL, WRB, XRH, MLT, TML23, LBM, ARS, PREI		
20 th century U.S. White males	147	CDL, TML23, SC,	100% (one function only)	90.1%
Guatemalan males	89	LBM, ARS, GAF, PREI		
20 th century U.S. Black males	27	GOG, CDL, WRB,	100% (one function only)	94.8%
Guatemalan males	88	XRH, XDA		
20 th century U.S. Black males	27	MLT, GAF*	100% (one function only)	80.0%
Hispanic males	30			
20 th century U.S. White males	158	GOG, CDL, SC, ARS, GAF	90.6%	66.2%
20 th century U.S. Blacks males	27			
Hispanic males	28			
Cambodian males	149			
Guatemalan males	88			
20 th century U.S. White males	158	GOG, CDL, GAF, PREI	91.9%	79.7%
20 th century U.S. Blacks males	27			
Chinese males	65			
Cambodian males	149			
20 th century U.S. Whites, pooled sexes	212	GOG, CDL, GAF, ARS	88.3%	74.4%
20 th century U.S. Blacks, pooled sexes	27			
Cambodians, pooled sexes	178			
Arikara, pooled sexes	59			
Guatemalan, pooled sexes	102			
20 th century U.S. Whites, pooled sexes	212	GOG, CDL, GAF, ARS	93.9%	75.4%
20 th century U.S. Blacks, pooled sexes	27			
Cambodians, pooled sexes	178			
Arikara, pooled sexes	59			
20 th century U.S. White males	147	TML, GOG, CDL, TML23, SC, LBM, ARS, GAF	82.9%	60.2%
20 th century U.S. White females	56			
20 th century U.S. Blacks males	27			
Guatemalan males	89			
Guatemalan females	14			
Hispanic males	30			

*When denoted, these are the only variables that ENTERED the analysis.

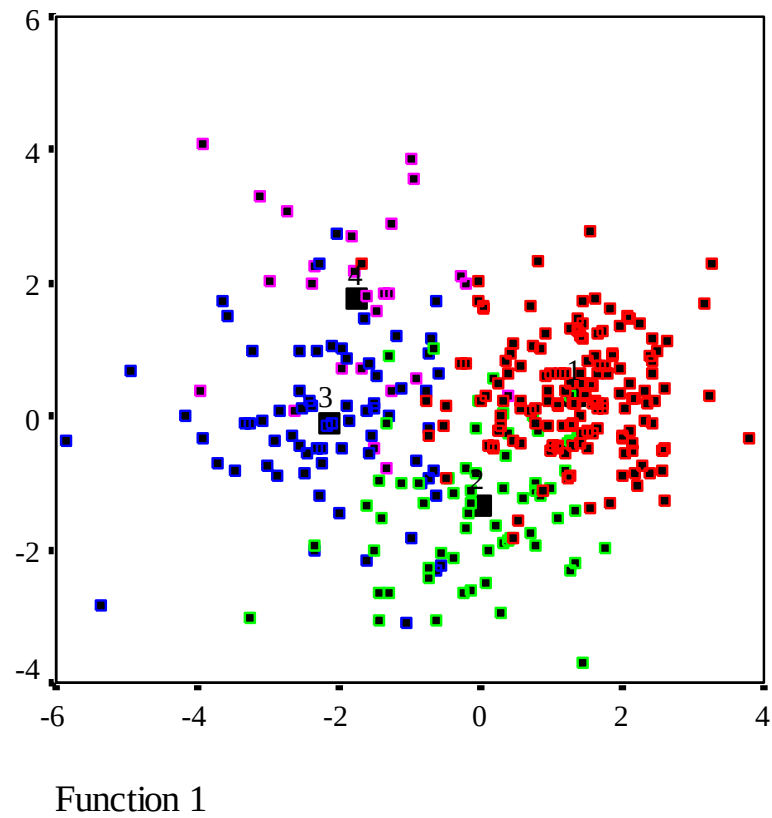


Figure 26. A scatter plot of the first two canonical functions for a forensically diverse group selection (analysis #9, Table 26), morphometric data. Group centroids are marked with black squares and are as follows: 1 = Cambodian males, 2 = Chinese males, 3 = 20th century White males, 4 = 20th century Black males.

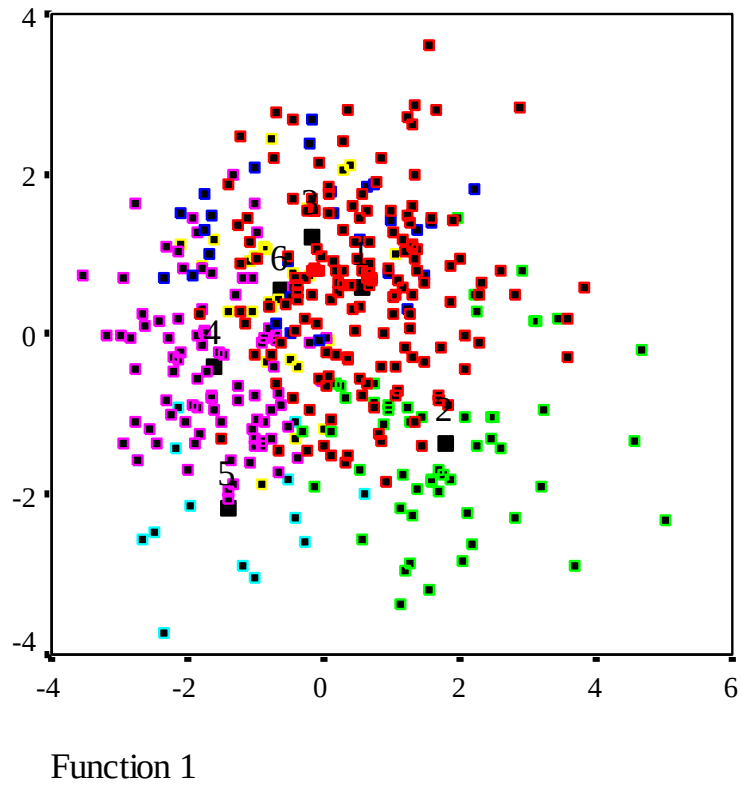


Figure 27. A scatter plot of the first two canonical functions for a second forensically diverse analysis (analysis #12, Table 26), morphometric data. Sample centroids are marked with a black square and are as follows: 1 = 20th century White males, 2 = 20th century White females, 3 = 20th century Black males, 4 = Guatemalan males, 5 = Guatemalan females, 6 = Hispanic males.

Using the morphometrosopic data sets, the accuracy rates nearly always increase, and are typically between the upper 80 to lower 90 percents for two population sample analyses. Only in models when admixed populations, e.g. Hispanics, are included do the accuracy rates negatively deviate from this range. In analyses focusing on three groups or more, the accuracy rates drop to between 60 and 75 percent. Still, these multiple group comparisons are at least three times that of chance alone for a correct assignment of the biological affinity for an unknown mandible. The morphometrosopic data increased the accuracy rates an average of 4% over the metric analyses alone (range of 0.4% to 7.4%) and only in one analysis did the performance decrease (-0.4%). A mean increase of 14% in accuracy was found for the morphometrosopic data compared with morphoscopic variables, with a range of 3.1% to 23.5%.

The morphometrosopic data sets produced superior models to either the morphometric or morphoscopic analyses. While the average increase in accuracy over morphometric analyses might not be viewed as meaningful, the addition of morphoscopic variables produced better models depending on the population samples used. Those analyses in which the Guatemalan sample was present did better, as did analyses with more than four population samples. Typically, the more samples in the analysis, the larger the increase in accuracy was observed. One of the primary threads to the improved accuracy is the inclusion of U.S. Black samples, which suggests that there is a strong mandibular morphoscopic variable tied to Black ancestry.

Indeed, if the structure matrix for the first two analyses in Table 26 is investigated further (Tables 27 and 28), it is clear that functions separating the U.S. White and Black samples are heavily influenced by two morphoscopic variables – PREI for the U.S. Black

Table 27. Structure matrix for the U.S. White and Black male samples (time pooled), morphometrosopic data.

Variable	Function 1
MLT	0.566
WRB	0.531
PREI	0.471
GNI	0.409
SC	-0.258
XRH	-0.181
TLM23	-0.169
XDA	0.078

*Variables not used in the analysis are not shown.

Table 28. Structure matrix for the U.S. White and Black female samples (time pooled), morphometrosopic data.

Variable	Function 1
WRB	0.543
XDA	0.485
PREI	0.412
SC	-0.346
GNI	0.281
MT	0.274
TLM23	-0.095

*Variables not used in the analysis are not shown.

individuals and SC for the U.S. White individuals. For the U.S. Black samples, they are more frequently inverted through the ascending ramus but show a broader chin than do the U.S. White samples. The U.S. White samples are much more disposed toward a bilobate chin form with smaller amounts of inversion on the ascending ramus. The inclusion of the PREI variable throughout the structure matrices in this study show that this particular variable is aligned with U.S. Black samples, while the SC variable, particularly the presence of a bilobate chin form, is likewise aligned to U.S. White samples.

Continuing on, interpretations from the graphical dispersion of morphometrosopic data for several analyses essentially codify the findings of the separate morphometric and morphoscopic data analyses. For instance, as was shown in Chapter 3, Figures 5-6, clear group clustering was apparent for an analysis using 20th century U.S. White males, 20th century U.S. Black males, Cambodian males, and Chinese males. The morphometrosopic data sets duplicate these findings into one data dispersion (Figure 26). The U.S. groups cluster together (strong negative scores, function one), nearly equidistant from either the Chinese or Cambodian males (positive scores, function one). From the structure matrix (Table 29), it is apparent that the U.S. samples are separating from the Asian samples on the bases of larger chin heights (GNI) and longer mandibles (MLT). Function two separates the Cambodians from the Chinese (strong positive or negative scores on function two), as well as the U.S. samples. For this particular function, mandibular length and ramus heights are the factors, with longer and shorter mandibles for the Cambodian and Black males compared to the other groups. Similarly, Figure 27 illustrates a nearly exact copy of the data dispersion shown in

Table 29. Structure matrix for the 20th century U.S. White and Black male samples, Cambodian males, and Chinese males, morphometric data

Variable	Function 1	Function 2	Function 3
LBM	0.425	0.185	-0.286
GNI	-0.399	-0.155	0.312
TLM23	0.331	0.090	0.152
WRB	-0.164	-0.135	-0.164
MLT	-0.429	0.492	-0.434
HML	-0.329	-0.350	0.043
ARS	0.201	0.251	0.207
XDA	0.211	0.061	-0.419
MT	-0.153	0.174	0.378
XRH	0.024	0.046	0.223
MAN	-0.021	0.099	0.196

*Variables not used in this analysis are not shown.

Figures 13 and 20, Chapter 3 (morphometric and morphoscopic data sets, singly). As before, the first function separates U.S. Whites from the other groups (positive scores, function one, morphometrosopic data set) and function two appears to separate the population samples by sex (strong negative values, function two, morphometrosopic data set). These examples show that the morphometrosopic data models mesh the morphometric and morphoscopic data together in a logical and expected way.

Closely Related Groups

The results for the closely associated groups using the morphometrosopic data sets are presented next. Table 30 shows the statistical results of the ten comparisons, with the analyses associated cross-validated accuracy rates. As was seen for the forensically interesting groups, a general increase in accuracy rates was found. Of the ten models, seven increased in accuracy over morphometric variables alone (average increase 1.8%, range -0.6% to 7.3%), and all 10 increased over models using the morphoscopic variables

Table 30. Discriminant function analysis results, morphometric data, for a selection of closely related groups and the cross-validated accuracy rates for those analyses.

Group comparisons	n	Variables entering functions	% variance (1st two functions)	Accuracy rate
Vietnamese males	35	GNI, MAN, MLT,	100%	76.4%
Chinese males	65	XDA	(one function only)	
Arikara, pooled sexes	59	WRB, TML, MT,	100%	89.9%
Hohokam, pooled sexes	49	LBM, ARS, HML, MAN CDL	(one function only)	
Arikara, pooled sexes	60	HML, GOG, XRH, MLT, TML,	100%	95.4%
Cambodians, pooled sexes	176	TML23, WRB, MAN, PREI, LBM	(one function only)	
Arikara males	30	GOG, MLT, TML,	100%	95.8%
Chinese males	65	TML23, PREI	(one function only)	
Hispanic males	28	XRH, MAN TML,	100%	77.6%
Guatemalan males	88	GAF, PREI, GOG, XDA	(one function only)	
Nubians, sexes pooled	110	MT, MLT, XDA,	100%	81.5%
19 th century U.S. Blacks, pooled sexes	138	SC, LBM, TML23	(one function only)	
Vietnamese males	35	HML, XRH, GNI,	100%	73.9%
Chinese males	65	WRB, MLT, LBM,		
Cambodian males	149	XDA, ARS, TML23		
Arikara males	30	XRH, XDA, HML,	100%	76.6%
Guatemalan males	88	TML23, TML,		
Hohokam males	35	GOG, MT, ARS, MLT		
Arikara, pooled sexes	60	XRH, TML23,	100%	68.4%
Guatemalan, pooled sexes	103	HML, MT, ARS,		
Hohokam, pooled sexes	49	MLT, GOG, TML, XDA, WRB		
Arikara males	30	XRH, TML23,	88.3%	65.8%
Guatemalan males	88	HML, MT, MAN,		
Hohokam males	35	XDA, GOG, MLT,		
Hispanic males	28	TML		

alone (average increase 15.8%, range 4.4% to 33.7%). All analyses that involve more than two samples maintained accuracy rates better than twice that of chance alone. Based on these results, it is fairly obvious that models using morphometrosopic data are vastly superior to morphoscopic data only, but only somewhat better than morphometric data only. Again, interesting to note, the largest increase in accuracy over morphometric only models occurred in an analysis that contained a U.S. Black sample.

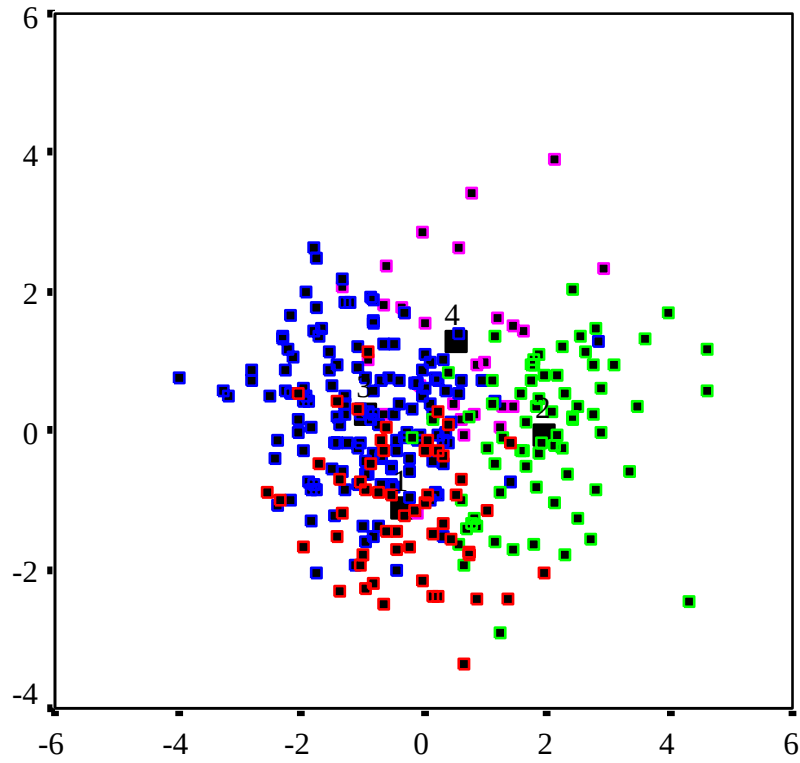
Groups Through Time

Time components are present in the morphometric and morphoscopic models (Chapter 3), and they are equally visible in the morphometrosopic data models. Table 31 presents the morphometrosopic data for analyses focusing on U.S. White and Black samples, several of which are graphed in Figures 28-31. The morphometrosopic data models effectively separate the samples when either sex is held constant (such as males only) or when the sexes are pooled. In each analysis, the accuracy rate is three times greater than chance alone. The males only model is actually slightly less effective than morphometric data only (-0.5%), though it is better than morphoscopic data alone (11.1% increase). For pooled sexes, the morphometrosopic data sets perform better, with increases in accuracy at 0.8% over the morphometric model and 15.5% better over the morphoscopic only model. These models only produce accuracy rates in the mid 60 percents; this might be due to the low sample sizes for the 20th century U.S. Black males and females, as well as the 19th century White females. The accuracy rates may increase if larger samples can be obtained.

Examination of the figures shows that the time component of the analysis is primarily associated with the second function, while group membership is primarily associated with

Table 31. Discriminant function analysis results, morphometrosopic data, for a selection of closely related groups in time, and the cross-validated accuracy rates for those analyses.

Group comparisons	n	Variables NOT entering functions	% variance (1st 2 functions)	Accuracy rate
19 th century U.S. White males	55	TML, CDL, XDA, LBM, GAF, MT	96.3%	61.6%
19 th century U.S. Black males	70			
20 th century U.S. White males	158			
20 th century U.S. Black males	27			
19 th century U.S. Whites, sexes pooled	61	TML, CDL, LBM, GAF, MT	94.9%	66.2%
19 th century U.S. Blacks, sexes pooled	138			
20 th century U.S. Whites, sexes pooled	212			
20 th century U.S. Blacks , sexes pooled	27			



Function 1

Figure 28. A scatter plot of the first two canonical functions for a 19th and 20th century U.S. White and Black males, morphometric data. Group centroids are marked with a black square and are as follows: 1 = 19th century White males, 2 = 19th century Black males, 3 = 20th century White males, 4 = 20th century Black males.

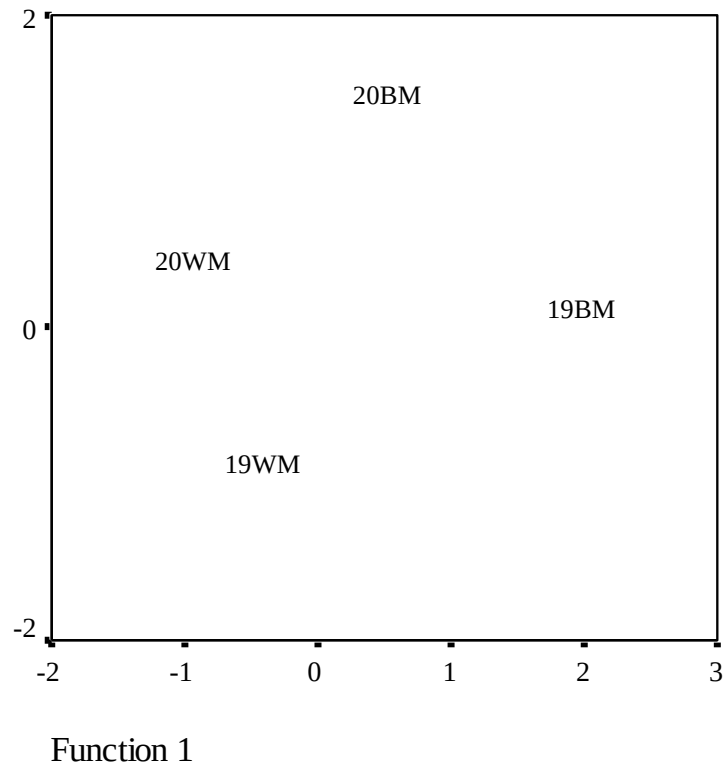


Figure 29. A scatter plot of the first two canonical functions for a 19th and 20th century U.S. White and Black males, morphometric data, axes condensed. Group centroids are marked with a black dot and are as follows: 19WM = 19th century White males, 19BM = 19th century Black males, 20WM = 20th century White males, 20BM = 20th century Black males.

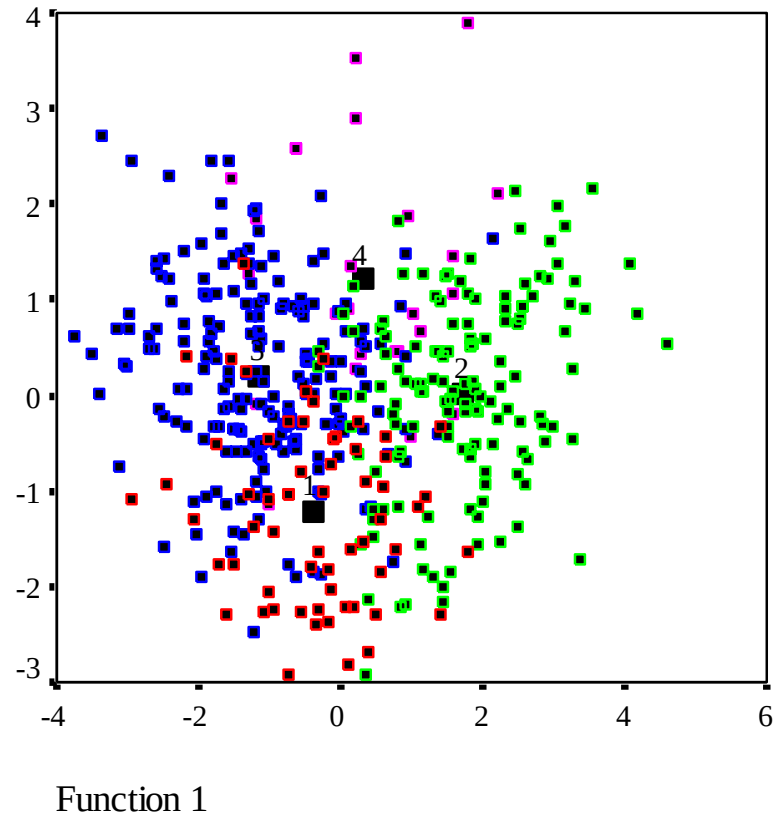
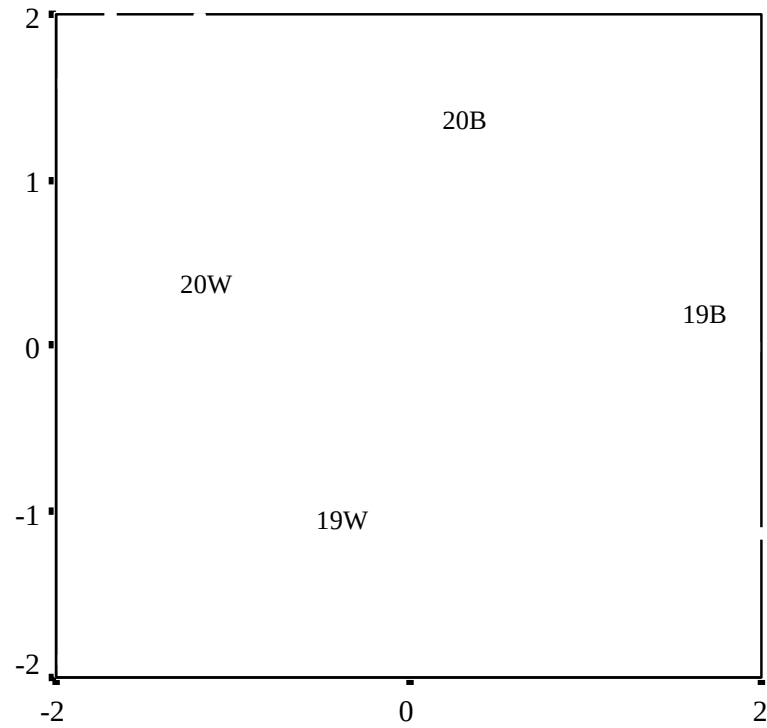


Figure 30. A scatter plot of the first two canonical functions for a 19th and 20th century U.S. White and Black samples, morphometric data. Group centroids are marked with a black square and are as follows: 1 = 19th century Whites, sexes pooled, 2 = 19th century Blacks, sexes pooled, 3 = 20th century Whites, sexes pooled, 4 = 20th century Blacks, sexes pooled.



Function 1

Figure 31. A scatter plot of the first two canonical functions for a 19th and 20th century U.S. White and Black samples, morphometric data, axes condensed. Group centroids are marked with a black dot and are as follows: 19W = 19th century Whites, sexes pooled, 19B = 19th century Blacks, sexes pooled, 20W = 20th century Whites, sexes pooled, 20B = 20th century Blacks, sexes pooled.

the first function, as was the case with the morphometric and morphoscopic data models presented in Chapter 3 (Tables 32 and 33). In these analyses, strong positive scores are associated with MLT, ARS, and GNI and lesser so with PREI (pooled sexes) and TML23 (males only). Moderate negative scores are associated with XDA (pooled sexes) and XDA, GOG, GAF (males only). Examination of the mean measures associated with these variables (Appendix 1) indicates that nearly all mean variable scores are increasing (or, in the case of GNI for 20th century Black males, staying nearly the same) – thus the mandible is getting longer and taller in the chin area, wider for the ramus, and more complex or everted for the ascending ramus. Meanwhile, the width of the palate is decreasing slightly, as seen in the mean measurements for XDA, and the width of the gonial region also is decreasing, as evidenced by lower mean values of GOG and GAF for the 20th century samples.

The results presented in this chapter show that the combination of morphometric and morphoscopic data, a morphometrosopic data set, can be used to determine population affinity as well as distinguish between the sexes. Only four of the 28 analyses in this chapter showed a decrease in the accuracy rates when the morphometrosopic data sets were used as compared with the morphometric data alone. In each case, the drop in accuracy was less than 1%. In every analysis, the morphometrosopic data were superior to the morphoscopic data only models. Generally, the morphometrosopic models improved over morphometric data sets by approximately 3% and they were over 17% more accurate than the morphoscopic models. The greatest increases over the morphometric models were in analyses that contained U.S. Black samples, indicating that there is a morphoscopic variable strongly tied to the biological affinity of these samples.

Table 32. Structure matrix for the 19th and 20th century U.S. White and Black samples (males), morphometrosopic data.

Variable	Function 1	Function 2	Function 3
WRB	0.477	0.266	0.282
MLT	0.463	0.459	-0.090
PREI	0.410	0.294	0.133
SC	-0.289	0.157	-0.107
MAN	-0.217	0.188	0.201
XRH	-0.197	0.117	0.034
ARS	-0.045	0.394	-0.002
GNI	0.331	0.392	-0.015
HML	0.281	0.009	0.413
TLM23	-0.223	0.301	0.325
GOG	0.024	-0.143	-0.283

*Variables not used in this analysis are not shown.

Table 33. Structure matrix for the 19th and 20th century U.S. White and Black samples (sexes pooled), morphometrosopic data.

Variable	Function 1	Function 2	Function 3
PREI	0.449	0.316	-0.279
WRB	0.419	0.262	0.103
SC	-0.335	0.127	0.250
MAN	-0.223	0.195	-0.185
HML	0.173	0.029	0.082
ARS	-0.007	0.395	-0.021
TLM23	-0.232	0.260	0.074
GOG	-0.079	-0.186	0.603
XRH	-0.257	0.051	0.458
MLT	0.373	0.418	0.426
XDA	0.183	-0.319	0.416
GNI	0.213	0.346	0.385

*Variables not used in this analysis are not shown.

Chapter 5

Discussion

The primary goal of this study was to test the hypothesis that mandibular metrics and morphology can be used to accurately determine population affinity. Several researchers have argued that the mandible is a poor skeletal element with which to determine the biological affinity of an unknown specimen; thus a more concise determination of the efficacy of mandibular metrics and morphology to the stated problem is needed. As noted in Chapters 1 and 2, the world is not composed of just Black and White populations, particularly in forensic situations. Therefore, a more holistic approach was undertaken and a diverse world-wide selection of samples was applied to this topic. In this study, three major analytical approaches to the question were used – a morphometric, a morphoscopic, and a combination of both metrics and morphology – a morphometrosopic technique. A byproduct of this research was finding that the sex of an unknown mandible also can be determined using the same three methods. This final chapter is divided into several sections: first, the results are discussed, second, potential sources of error are examined, third, a “big-picture” outlook is addressed for these data, and finally, some forward looking thoughts are presented.

Study Results

Morphometric Data

The next portion of the study focused on the ability of the continuous variables to adequately determine the sex and the biological affinity of a mandible. Throughout Chapter 3, the morphometric data largely performed as expected in analyses focused on

sex determination. Indeed, the morphometric variables discriminated between males and females with accuracy rates equal to or better than those rates published by Giles (1964). Furthermore, the mandibular morphometric data performed well when compared to cranial morphometric variables, slightly outperforming facial measurements and performing equivocally with up to seven vault measurements. This demonstrates that mandibular morphometric data should not, out of hand, be considered as inferior to cranial metric data, and that the mandibular morphometric data have a value-added capacity in sex determination of the human skeleton. In addition to these results, it needs to be noted that a sex bias in misclassification rates for the morphometric data are present, similar to that experienced by cranial metric data, when smaller sized individuals are present in the analyses (e.g. Spradley *et al.* 2008). The misclassification rates are highest in the Nubian, Arikara, and Guatemalan population samples, but do not appear to be as problematic for the U.S. White and Black and the remaining samples. When an analysis of all samples exclusive of the Nubians, Arikara, and Guatemalan samples (time pooled U.S. Whites and Blacks) is conducted, the misclassification rates are nearly equal at 15% males classified as females and 16% females classified as males. Within the population samples, it appears that most misclassification rates are between 10 and 15%, regardless of sex, though nearly half of the Cambodian sample females classified as males. The consumer of this data should be aware of the issue when using the larger discriminant functions to sex an unknown mandible.

The morphometric variables were used to differentiate between the various population samples to determine the biological affinity of a specimen. For the total comparison (17 samples), the morphometric variables accuracy rate was 41.4%, or about

7.1 times more accurate than chance alone. This is very good; for a point of comparison, a 17 group analysis using cranial vault measurements in FORDISC 3.0 (Jantz and Ousley 2005) was conducted, and it yielded an accuracy rate of 56.7% (nine times chance). When facial measurements were employed, the accuracy rates declined somewhat to 42.4% (seven times chance). It is apparent that the mandibular morphometric data are slightly underperforming the accuracy rates achieved by cranial vault morphometric analyses, though they are nearly equivalent to facial measurements, for population samples of similar size.

In two group comparisons, the morphometric data performed very well, with accuracy rates ranging from 70% to 96%, depending on the samples and whether the sexes were pooled. Indeed, in analyses of closely associated groups, e.g. Arikara and Hohokam or Vietnamese and Chinese, the accuracy rates were approximately 80% on average. In larger comparisons (3-6 groups), the accuracy rates declined, but the chance of a correct classification still remained above three times chance, on average. These results hold mostly true regardless of the type of analysis undertaken, e.g. closely related groups, and groups through time. The findings presented throughout Chapter 3 show that discriminant functions based on mandibular morphometrics can be used as a good tool for assessing the biological affinity of an unknown individual.

Morphoscopic Data

At the outset of this study, a concern of using the morphoscopic (ordinal) data in a statistical procedure designed for continuous data was that these data violated the assumptions of the modeling procedure. Therefore, how the ordinal data performed in these analyses needed to be evaluated. The model performance using ordinal data should

not be judged in terms of the model significance (F-values) due to the stated violated assumptions. Rather, the appropriate measure of a model's performance was its cross-validated accuracy rate, or how often and how well the model could accurately predict the sex or biological affinity of an unknown mandible using a leave-one-out analysis. The performance results were stated in Chapters 3 and 4, and deserve reviewing here.

For models judging the sex of an unknown mandible, the accuracy rates were greater than chance for most samples (range 63.5% to 80.5%), although in several comparisons, the morphological variables could not distinguish between the sexes (Cambodian and Arikara samples). In general, the ordinal data were hampered by small sample sizes, and the overall accuracy rates were not nearly as high as models utilizing metric data. Overall, while sex determination can be accomplished with the morphoscopic data, this procedure should probably only be undertaken in cases that have a relatively high accuracy rate (e.g. U. S. Black groups).

When the ordinal data were used to construct models evaluating the biological affinity of an unknown individual, the accuracy rates increased. In analyses focusing on large groups, with the sexes analyzed separately, the accuracy rates were at least double that of chance alone, but with the sexes pooled, the accuracy rates increased to three times chance alone. The same pattern was observed in analyses focusing on forensically interesting groups, closely related groups, and groups through time. Two group comparisons often yielded accuracy rates in the mid 60 percents to the low 80 percents, and larger comparisons were two to three times chance alone. These analyses show that the ordinal data can be used to categorize the biological ancestry an unknown mandible with a moderately good degree of accuracy.

Concerning the analyses focused on closely related groups, the morphoscopic models had accuracy rates that were 14% worse than the metric analyses, with a range of 2.9% better to 25.9% worse. Most models, particularly those evaluating more than two groups, produced results only slightly better than chance. These findings directly contrast with the higher accuracy rates achieved with the morphological data in analyses of more widely separated groups (in time or space); this implies that the mandibular morphology is a better discriminator of very diverse or broad groups rather than geographically neighboring or related groups.

Another method to determine the morphoscopic variables models' viability is the data distributions for the discriminant functions. For this evaluation, the ordinal data were compared against the morphometric data distributions to determine if models were differentiating the samples using similar criteria, or if the morphoscopic and morphometric data were in fact measuring different components of human variation. The generated scatter plots of the first two canonical components of both data sets were examined visually for the same sample analyses. In each instance presented in Chapter 3, the sample distributions and sample centroids were arranged in similar fashions, and in each instance, the same groups clustered together or were nearly equally separate from each other. Further, each canonical function was measuring the same underlying biological variation, e.g. sex, population, or time. These findings indicate that the ordinal variables have the same substantive ramifications as do the continuous variables. A byproduct of this analysis is that it is shown now that the morphometric and morphoscopic data can be effectively combined into a single, morphometrosopic analysis.

Morphometroscopic Data

While Chapter 3 of this dissertation concentrated on the use of morphoscopic and morphometric variables independently to determine the sex and biological affinity of an unknown mandible, Chapter 4 focused on the combination of these variables in morphometroscopic models. Because analysis of the ordinal data determined that it could effectively discriminate between the population samples in the same fashion as the continuous variables, troublesome issues were not foreseen by joining the data sets together. Rather the question of the accuracy of the morphometroscopic models was the primary focus of Chapter 4, principally contrasting the mandibular data sets independently.

Three common themes were apparent in the models throughout Chapter 4. First, while the generated discriminant functions typically contained both morphometric and morphoscopic variables, the variable ratio was approximately 3:1 in favor of morphometric variables for the sex determination functions; on a percentage basis, more morphometric variables entered into functions for biological affinity than did morphoscopic variables. Second, in very few morphometroscopic models did the accuracy rate decline over the best performing model of either morphometric or morphoscopic origin. In the study models, when the accuracy rates declined, it was always less than one percent. This finding shows that morphometroscopic models are superior to those using only one type of variable independently. Third, when analyses using U.S. Black population samples were undertaken, there was a dramatic accuracy increase over analyses that utilized morphometric variables only. Conversely, the accuracy increase was not as dramatic over the morphoscopic variables only analyses, as

compared to analyses that did not contain U.S. Black samples. This finding indicates that there is a morphoscopic variable tied to the biological ancestry of U.S. Black samples. To a lesser extent, this finding was also found in analyses utilizing the prehistoric Nubian sample. When the structure matrices are examined, the PREI variable was the highest contributing morphoscopic variable in the analyses for U.S. Black samples. This finding fits well with the earlier work by Angel and Kelley (1990), who indicated that posterior ramus edge inversion is a particularly racially sensitive trait.

In the sex determination functions, the morphometrosopic models produced accuracy rates nearly always in excess of 85%, and oftentimes reaching into the low 90 percents. The lowest accuracy rate in this study was for the Cambodian sample, at 83.1%, which is likely due to the low number of females in that sample. It is likely that the inclusion of the Cambodian sample in the “all samples” analysis generated that function’s somewhat low accuracy rate (85.1%). When misclassification rates are examined, the expected sex bias was present in the data, particularly for the more gracile or smaller population samples. But the inclusion of the morphoscopic variables actually helped reduce the bias, and for the “all populations” analysis, the Nubian and Guatemalan samples decreased their misclassification rates, while the Arikara sample stayed approximately the same (as compared to a morphometric function only).

Examination of the variables entering into the functions essentially showed the expected trend – males are larger than females in both size and expression of traits. Males are inclined towards a more square or bilobate chin shape, particularly in the U.S. White samples. Another interesting note is that the 20th century U.S. White and 19th century U.S. Black males appear to be more predisposed to a partial or complete rocker

jaw shape as compared to the females. This is contrary to the incidence rates of the rocker jaw noted by Snow (1974) and Schendel *et al.* (1980), where the females are clearly more predisposed to this mandibular form than males, albeit these studies only focused on Polynesian populations.

Turning to biological affinity, examination of the morphometrosopic models' accuracy rates for the "all groups analyses" shows marked improvements over morphoscopic data only analyses and moderate improvement in accuracy over the morphometric only models. For the all groups by sex analysis, the morphometrosopic model (49.8% accuracy) improved 7% over the morphometric only model and a striking 29.3% over the morphoscopic model. When compared with the same FORDISC 3.0 analysis presented above, the morphometrosopic model was *more* accurate than the facial variables and nearly as accurate as the vault variables. When a different FORDISC 3.0 analysis of 15 craniofacial measurements was conducted using 17 populations, its accuracy rate varied between 66% and 71%; this demonstrates that though the mandibular morphometrosopic approach does not perform as well as an equivalent analysis using the craniofacial skeleton, it still produces results superior to a mandibular morphoscopic or morphometric only approach, and is likely equal or superior to limited craniofacial analyses. Thus this method would prove particularly helpful when only partial or incomplete crania are present for analysis.

When the morphometrosopic approach is used in analyses focusing on forensically interesting groups and closely related groups, it nearly always outperforms a morphometric only analysis, and consistently outperformed the morphoscopic analyses. In only a select few analyses did the morphometrosopic approach fail to achieve the

same accuracy rates as the morphometric models did – in these instances, the inclusion of admixed populations (e.g. Hispanics) was the norm. The largest increases over morphometric only models occurred when U.S. Black samples were part of the analysis. As noted before, this is likely due to the addition of morphoscopic variables that are very sensitive among those populations.

The morphometrosopic data were employed in several analyses to discriminate between samples that were closely related in time, e.g. U.S. 19th and 20th century White and Black males and the same samples with sexes pooled. In these two particular analyses, the samples very effectively separated along time components, as well as biological affinity components (see Figures 18 and 19, Chapter 4). The accuracy rates for the four sample comparisons are in the 60 percents; the odds of a correct assignment of an unknown mandible were at least three times chance alone. The percent correct represents a substantial increase over the morphoscopic data when used independent of the morphometric data and equal or minor increase in accuracy over models using the morphometric data only.

From the presented study results, it is clear that the morphometrosopic data typically are superior to either morphometric or morphoscopic data used independently. That said, both the morphometric and morphoscopic data sets can be used separately, if the data are not available (or collected), for any given mandible. Specific portions of the mandible were not tested for their given discriminating power, e.g. the horizontal ramus only, the ascending ramus only (but see below for two examples). If data for partial and incomplete mandibles are collected, the data could still be used to classify the unknown mandible. This type of analysis will be possible when custom discriminant functions are

generated, a planned extension of this research that should be available to investigators in the future (also see below).

It is patently obvious that as the number of samples increase for any analysis (sex determination or biological affinity), so do the number of variables entering into the models. While some variables, e.g. GOG, CDL, GAF, ARS for biological affinity and many morphoscopic variables for sex determination, do not frequently enter into certain models, not a single variable was excluded consistently throughout the study. This indicates that all study variables are important to a model, in a given instance. Each variable may contain important biological information regarding the ancestry of human populations or for the sex determination of an unknown individual. Ultimately, future skeletal analyses should collect the data for all of these variables as part of routine casework.

Sources of Error

Any study should recognize potential sources of error and take actions to reduce the errors. Two main areas for error have been identified in this dissertation and methods to reduce or to evaluate the potential error are discussed. The recognized sources of error are from missing data (see Chapter 2 for the discussion of missing data) and intra- and inter-observer error.

Intra and Inter-observer Error

Throughout the data collection process, both the morphometric and morphoscopic data were gathered twice in order to evaluate intra-observer error. Twenty-four individuals from the Nubian skeletal sample were measured twice using eight measurements (GNI, HML, CDL, GOG, WRB, XRH, MAN, and MLT). The second set

of measurements was collected approximately two years after the first set. Paired samples t-tests were used to evaluate whether or not there were significant amounts of measurement error between the two data sets. One measurement, MLT, was significantly different between the two measuring episodes ($p = .003$). It was consistently measured larger the first time over the second. Several possibilities exist for the discrepancy in the measurements. First, due to a relatively small sample size, significance testing is heavily influenced by even minor discrepancies. The median difference in all values for this measurement was -0.333 mm, which was, in fact, the largest discrepancy of any of the measurements. But merely changing two measurement values by one mm each produces a non-significant result for the paired-samples t-tests. Second, two different mandibulometers were used, and error may have occurred due to the different types of equipment. Third, this could be a real source of error. A fourth source could be recording errors. A larger sample size may be warranted for future exploration, though typically, deviation of around 3% between observers is expected for most skeletal measurements (Adams and Byrd 2002).

For the morphoscopic data, the CIL Vietnamese sample was scored on two different occasions, approximately one year apart. Again, 24 mandibles were re-scored, using all six study variables. Wilcoxon signed ranks tests and Pearson's R correlations were conducted on these data. The resulting Pearson's R correlations all were greater than 0.97 except for CS, which was 0.87, indicating strong concordance in the two data sets. No significant difference was found between the data using Wilcoxon signed ranks tests. The overall dispersion of the data does indicate some slight discrepancies – both the GAF and PREI variables had three differences between scoring sessions. In each case, the

differences were one category different, and for GAF, were unidirectional (GAF was consistently scored larger the second time). While no significant difference was detected using this sample, additional testing on a larger sample may be warranted.

Data for a structured inter-observer analysis were not collected for this study. While differences between investigators can pose a challenge to scientific data, the data collection procedures used in this study do not depart heavily from standard procedures used in daily case work or data collection and should not depart significantly from the published inter-observer error rates for skeletal elements (e.g. Adams and Byrd 2002; Jantz *et al.* 1995). For the morphometric data, two new measurements XDA and TML23, were devised for this study. The measurement locations are clearly defined and photographs are given in Appendix 1 for correct measuring procedures. Given the simplicity of these measurements and the detailed definitions, it is not expected that much inter-observer error would be encountered. The morphoscopic data may prove to be slightly more difficult to score consistently between investigators. Physical anthropologists are used to scoring the morphoscopic features of various human bones, and generally speaking, do quite well between themselves (c.f. Berg in press; Iscan and Loth 1986a, 1986b; Kimmerle *et al.*, in press; Sutherland and Suchey 1991). For the specific morphoscopic features used here, most are well-known to the anthropology community and distributions of their prevalence in various samples have been documented (Angel and Kelley 1990; Rhine 1990; Hauser and De Stefano 1989).

Overall, little intra-observer error was found in this study, though the sample size was small. Some detected error could be due to small sample sizes, recording errors, or equipment differences. Other error, while not significant, could lead to erroneous

conclusions, on a case by case basis. Inter-observer error was not specifically tested, though given the precautions taken in this study, its effects should be mitigated or reduced with the judicious and deliberate application of the supplied definitions and exemplars. Additional testing of the data collection procedures, particularly for inter-observer error testing, may be warranted.

The Big Picture

Human variation is rich and diverse, and the need for forensic classification models to mirror human diversity is paramount. Many applied forensic anthropology techniques and methods are restricted in the scope of the variation characterized, often due to the limited accessibility of collections, money, and time. This study has attempted to incorporate a more diverse world population sample than is typically found in the older literature, or in current forensic anthropological undertakings. Twelve world groups composed of seventeen samples are represented in this study, from Asia to the Americas, and from prehistory to modern times. While the sample sizes are arguably low for certain groups, the overall study sample is robust and well-balanced. Due to this diversity in the research design, the study results have meaningful ramifications for forensic anthropology.

Perhaps one of the most important points to be made, which has been consistently alluded to throughout this study, is that single collections of human remains are not suitable for creating methods to identify unknown individuals from. Indeed, a more holistic and broad-based approach is needed. It is not acceptable to force the phenotypic characters of modern humans into models based on humans hundreds of years old (e.g. using the Terry collection to characterize current U.S. White and Black individuals).

This study among others has shown significant changes in these groups, such that they can be separated out from each other using appropriate models. Instead, these data should be gathered but labeled appropriately for hypothesis testing, and other collections should be used for modern U.S. samples (e.g. the William Bass collection), modern Asians (e.g. Killing Fields collections, assorted Medical Examiner collections), and modern Hispanics (e.g. Medical Examiner collections).

Prior to this study, only certain morphoscopic traits of the mandible could be used easily to make statements regarding biological affinity (Angel and Kelley 1990; Rhine 1990), frequently regarding those of U.S. White or Black descent. Likewise, mandibular morphometrics were readily available only for U.S. White or Black populations through FORDISC 2.0 (Ousley and Jantz 1996). Methods examining the sexual dimorphism of the mandible were likewise narrow (e.g. Bass 2005; Buikstra and Ubelaker 1994; Ousley and Jantz 1996). The methods using morphology of the mandible did not include error or accuracy rates, though cross-validated error rates were available in FORDISC 2.0 (Ousley and Jantz 1996). In the latest release of FORDISC 3.0 (Jantz and Ousley 2005), morphometric analysis of the mandible does include two additional populations, Guatemalans and Japanese, though the number of metric variables is limited. A sex-only function is not possible with the program now, due to the stated problems with the sex bias found for more gracile or smaller populations.

This research provides additional data and especially formulae to evaluate the sex and ancestry of an unknown individual though the use of morphometric, morphoscopic, or morphometrosopic data acquired from the mandible. This study has imparted immediate access to formulae that can ascertain the sex of an unknown individual

without knowing the ancestry, or if *a priori* information is available, the method can be specialized to just a few groups. Any determination of sex made by an “anthropologist on the ground” has the added surety of established accuracy rates, as well as potential error rates. The user must be aware of the sex bias in the data though (and cases where it is small), and interpretation of the data is left in the users hands. More importantly, the study has demonstrated that all three methods can be used to deduce the ancestry of an unknown mandible. A morphometrosopic approach typically works the best; a morphometric approach frequently succeeds with greater accuracy than a morphoscopic approach, though a morphoscopic analysis does surprisingly well, particularly when U.S. Black samples are included. Indeed, with accuracy rates greater than 90% for some two population sample comparisons or eight times chance for the largest analyses, the results of this study run contrary to the opinions expressed by Humphrey and co-workers (1999). While Humphrey *et al.* (1999) believe that mandibular plasticity renders this element impractical for identifying relationships among human populations, it is perhaps this same plasticity that imparts a useful quality for forensic and ancestral determination applications.

The determination of ancestral phenotypic expressions of genetic traits in the human skeletal system is a daunting task. As it becomes more acceptable for individuals to pair and procreate with members of different background, the overall human phenotype will become more centrist and less polarized toward particular expressions. Conversely, if social mating patterns were to shift toward a closed group pattern, phenotypes should become more polarized. In today’s increasingly multicultural environment, admixture is present, and appears to be increasing (see Chapter 1). Three possible outcomes of this

genetic mixing are foreseen: one, the skeletal expressions of admixture should, in theory, decrease the overall efficacy of discriminant formulae among groups as the admixture percentage climbs; two, discriminant models that contain relatively “pure” samples should have better accuracy rates than models containing admixed populations, particularly if the admixed sample contains genetic components from the comparative group; and three, samples from the same population but from different eras (e.g. 18th, 19th, or 20th century samples from U.S. Whites or Blacks) may differentiate statistically (secular change and admixture).

The first scenario may be relatively difficult to empirically test with these data, as the amount of admixture in U.S. populations is not necessarily all that great, yet. Second, the number of clearly documented admixed individuals is very low in skeletal collections throughout the U.S. One possible evaluation method for this scenario would be to determine the accuracy rates for discriminant functions comparing 19th century White and Black samples versus 20th century samples, with the assumption that genetic admixture is increasing within the samples through time. For 19th century individuals, the accuracy rate is 79.2%, and the analysis contained approximately equal sample sizes (U.S. White = 55, U.S. Black = 70). The accuracy rate declined 2.4% for the 20th century analysis to 76.8%, but the sample size is relatively low in the U.S. Black sample (n = 27) compared to the U.S. White sample (n = 163). While the hypothesis of declining accuracy rates does appear to hold true in this example, it might just be a function of the small sample size of 20th century U.S. Black individuals. A larger sample size and several types of samples through time are necessary to determine if this hypothesis will hold.

Evidence for the second scenario, that is analyses containing more “pure” samples having higher accuracy rates than admixed samples, is present in the data. For example, the accuracy rate for the function examining Arikara and Cambodian samples was 95.4% accurate (relatively “pure” samples) while an analysis of the 20th century U.S. White male and Hispanic male samples only produced an accuracy rate of 71.7% (“pure” and admixed samples, respectively). This shows that difficulties are likely to be encountered when admixed populations are used in comparisons; on the other hand, the accuracy rate will depend on the samples compared and whether or not the “admixed” sample contains genetic components of the comparative sample. For example, a relatively admixed sample, the 20th century U.S. Black male sample was compared with the Guatemalan male sample and the ensuing accuracy rate was excellent (94.8%), even though both samples contain admixture, but they do not likely contain “shared” genetic components (i.e. the Guatemalan samples potentially contain very few African genes, but likely do contain high genetic components from multiple Native American groups and minor amounts of European influence). But when the same U.S. population was compared with Hispanic males, the accuracy rate dropped precipitously (80.0%). Since the Hispanic sample is heavily influenced by Native American, European, and African genes and the U.S. Black sample is likely influenced by European genes, the ensuing accuracy rate of the comparison is expected – much lower than comparisons of samples lacking significantly shared genetic components.

The third possibility also was documented in this study, secular change. In Chapters 3 and 4, U.S. White and Black male samples do separate from each other ancestrally, and along time components. Changes in the shape and size of the mandible are apparent from

the data. Both the U.S. White and Black 20th century samples are gaining size in the chin, width of the ramus, bicondylar width, and in the mandibular angle as compared with their 19th century counterparts. The mandible is also becoming more complex in shape, with more mandibular tori, larger expressions of posterior ramus edge inversion, a more complex chin, and the ascending rami are increasing to a uniform width. Both of these groups are following a similar trajectory in the noted secular changes.

Forces identified as playing a role in secular change for height and length of limb bones include nutrition and disease load (Jantz and Jantz 1999; Price *et al.* 1987). Hosts of other factors such as income distribution, temperature, a genetically determined ceiling, birth weight, and genetic variation rather than plasticity also have been correlated to secular changes in stature and cranio-metric variation (Alberman *et al.* 1991; Jantz and Jantz 1999; Price *et al.* 1987; Wescott and Jantz 2005). Wescott and Jantz (2005) have argued that a parallel course of secular change seen in American Whites and Blacks cranial measurements, combined with their failure to converge on a common type, is evidence of genetic variation rather than plasticity in the cranium. Jantz and Jantz (1999) have argued that secular changes in stature are likely not the simple formula of height = intake-demand, and that factors influencing early childhood development play a role in secular change. Other regions of the body such as the cranium also have shown secular change; nutritional status has been suggested as a possible causal agent of these changes. Environmentally-determined constraints, such as brain growth, biochemical or developmental constraints have been proposed as causal agents as well (Cameron *et al.* 1990). The positive secular trend seen in the current data may be due to any of these factors, or as hinted at earlier, may be in part due to admixture.

Interestingly, in the comparisons that assess primarily for a time component, the centroid for the 20th century U.S. Black sample is moving toward the U.S. White centroids (19th or 20th century) along function 1 (see Figures 16-17, 29 and 31). When compared against each other, the distance moved on function 1 for 20th century birth years is over double that for U.S. Black than U.S. White samples. The 20th century U.S. Black centroid moved a distance of +1.533 units from the 19th century U. S. Black centroid, while a distance of +0.682 units was moved along function 1 for the 20th century U. S. White sample. The 20th century U.S. Black sample's centroid is -0.644 units from the 19th century U.S. White centroid. The movement of the U.S. Black sample toward the U.S. White sample centroids suggests that not only are factors such as health and nutrition playing a role in the phenotypic expressions present in U.S. Black samples, but also that genetic admixture may be closing the gap between them. Given that 20th century U.S. Black samples contain nearly a 20% admixture of U.S. White genetic data (Parra *et al.* 1998, 2001) and that 20th century U.S. White samples have little admixture (Shriver *et al.* 2003), it is conceivable that the mandibular morphometric, morphometric, and morphoscopic scatter plots are graphically detailing the effect of admixture on the 20th century U.S. Black samples.

Looking Forward

This study has opened the door to many other topics that can and should be addressed in upcoming research. While this study focused on 17 world samples, additional samples should be added to the database to better characterize unknown individuals. Specifically, the low sample sizes in the U.S. 20th century Black males and females, as well as the 19th century White females need attention. Other population samples can use additional data

collection. This study would also greatly benefit from a test of the scoring and measuring methods between and among investigators. In order to be effectively used in a court of law, error rates need to be firmly understood (see *Daubert v. Merrell Dow Pharmaceuticals* No. 92-102 509 US 579, 1993). This can be accomplished through the measuring of several samples by multiple investigators. While the study did produce error rates for the author, additional error rates should be determined for members of the physical anthropology community.

Another avenue for exploration is found in the contribution of individual variables to the discriminant functions and the frequency in which certain variables are present in the models. The statistical contribution of each variable to a given function or series of functions could shed light on overarching questions of human variation. Given the sheer number of functions possible with these data, this research avenue was determined to be outside the scope of this study.

In this study, the statistical package was allowed to choose which variables entered into the functions based on the amount of information they contained for the question at hand. No specific attempt was made to limit the functions to specific portions of the mandible, such as the ramus or corpus, within the main study parameters. Ultimately, the accuracy rate of any one given function will be a result of the data for a particular set of variables; since incomplete data sets are the norm in forensic and physical anthropology, a need for “custom” discriminant functions is apparent. Two short examples can be put forward here, one using the chin area only, the second using an ascending ramus only. For the chin area, five variables are used to determine the sex or biological affinity of the unknown individual – GNI, TML, HML, MT, and CS. A custom discriminant function

for “sex only” with 12 samples has an accuracy rate of 73% (all variables entering), and a 30% accuracy rate for biological affinity (about 4 times chance alone). If the morphoscopic variables are not included, the accuracy rate for sex drops to 70% and biological affinity drops to 22%. For the ascending ramus example, six variables are obtained – TLM23, XRH, WRB, GAF, ARS, PREI. Again, a custom discriminant function produced an accuracy rate of 81% for “sex only” function (all but ARS were present in the function) and a 27% accuracy rate for biological affinity (3.2 times chance alone). (Both analyses accuracy rates drop approximately 3% and 5% respectively if the morphoscopic variables are not included.)

The tool to accomplish the goal of having the ability to produce custom discriminant functions for whichever variables are present could be found in the form of an updated version of FORDISC, or a new computer program that is web-accessible. The data from this project will be made available to the authors of FORDISC, so that a separate module can be created. Since this process may take several years to complete, these data are made freely available by contacting the author.

This study has ultimately shown that both mandibular morphometric and morphoscopic data, particularly when used in a morphometrosopic analysis, can effectively classify the sex of an unknown mandible (used appropriately) and the biological affinity of a mandible of known and unknown sex. The formulae for some sexual dimorphism discriminant functions are presented in this dissertation; comprehensive models for biological affinity were not made available, due to their length and complexity. Overall, this dissertation has achieved its goal – to provide another tool

in the forensic anthropologist's kit for the determination of the biological affinity and sex of an unknown individual.

References

AAPA (American Association of Physical Anthropologists)

1996 AAPA Statement on Biological Aspects of Race. *American Journal of Physical Anthropology* 101:569-570.

Adams, B. J. and J. E. Byrd

2002 Interobserver variation of selected postcranial skeletal measurements. *Journal of Forensic Sciences* 47:1193-1202.

Alberman, E., Filakti, H., Williams, S., Evans, S. J. W., and I. Emanuel

1991 Early influences on the secular change in the adult height between the parents and children of the 1958 birth cohort. *Annals of Human Biology* 18:127-136.

Angel, J. L. and J. O. Kelley

1990 Inversion of the posterior edge of the jaw ramus: New race trait. In *Skeletal Attribution of Race: Methods for Forensic Anthropology*, edited by G. W. Gill and S. Rhine, pp. 33-40. Maxwell Museum Anthropological Papers No. 4, Albuquerque, NM.

Baker, B. J., T. L. Dupras, and M. W. Tocheri

2005 *The Osteology of Infants and Children*. Texas A&M University Press, College Station, TX.

Baker, S. J., G. W. Gill, and D. A. Kieffer

1990 Race and sex determination from the intercondylar notch of the distal femur. In *Skeletal Attribution of Race: Methods for Forensic Anthropology*, edited by G. W. Gill and S. Rhine, pp. 91-96. Maxwell Museum Anthropological Papers No. 4, Albuquerque, NM.

Barnard, M.M.

1935 The secular variation of skull character in four series of Egyptian skulls. *Annals Eugenics* 6:352-371.

Bass, W.

2005 *Human Osteology. A Laboratory and Field Manual*. Special publication No. 2 of the Missouri Archaeological Society, 5th Edition, Columbia, MO.

Berg, G. E.

2008 Case Report 6.1: Probable Machete Trauma from the Cambodian Killing Fields. In *Identification of Traumatic Skeletal Injuries Resulting from Human Rights Abuses and Armed Conflicts*, edited by E. H. Kimmerle and J. P. Baraybar, pp. XX-XX. Taylor & Francis Group, LLC, New York, NY.

2008 Pubic bone age estimation in adult women. *Journal of Forensic Sciences*, in press.

- 2006 Discriminant Function Analysis as Applied to Mandibular Morphology to Assess Population Affinity. Paper presented at the 58th Annual Meeting of the American Academy of Forensic Sciences, Seattle, Washington.
- 2001 Four Chins and a Funeral or Racial Affinity as Determined by Mandibular Morphology. Paper presented at the 53rd Annual Meeting of the American Academy of Forensic Sciences, Seattle, Washington.
- Berg, G. E. and E. Kimmerle
- 2004 Aging the elderly: A New Look at an Old Method. Paper presented at the 57th Annual Meeting of the American Academy of Forensic Sciences, Dallas, Texas.
- Berg, G. E., S. Ta'ala, E. Kontanis, and S. Leney
- 2007 Measuring the Intercondylar Shelf Angle Using Radiographs: Intra- and Inter-Observer Error Tests of Reliability. *Journal of Forensic Sciences* 52:1020-1024.
- Brues, A.
- 1990 The once and future diagnosis of race. In *Skeletal Attribution of Race: Methods for Forensic Anthropology*, edited by G. W. Gill and S. Rhine, pp. 1-9. Maxwell Museum Anthropological Papers No. 4, Albuquerque, NM.
- Buck, T. J. and U. S. Vidarsdottir
- 2004 A Proposed Method for the Identification of Race in Sub-adult skeletons: A Geometric Morphometric Analysis of Mandibular Morphology. *Journal of Forensic Sciences* 49:1159-1164.
- Buikstra, J. E. and D. H. Ubelaker (editors)
- 1994 *Standards for Data Collection from Human Skeletal Remains*. Arkansas Archeological Survey Research Series No. 44, Fayetteville, AR.
- Burns, K. R.
- 1999 *Forensic Anthropology Training Manual*. Prentice Hall, Upper Saddle River, New NJ.
- Burris, B. G. and E. F. Harris
- 1998 Identification of race and sex from palate dimensions. *Journal of Forensic Sciences* 43:959-963.
- Byers, S. N.
- 2002 *Introduction to Forensic Anthropology*. Allyn and Bacon, Boston, MA.
- Byers, S. N., S. E. Churchill, and B. Curran
- 1997 Identification of Euro-Americans, Afro-Americans, and Amerindians from palatal dimensions. *Journal of Forensic Sciences* 42:3-9.

- Cameron, N., Tobias, P. V., Fraser, W. J., and M. Nagdee
 1990 Search for secular trends in calvarial diameters, cranial base height, indices, and capacity in South African Negro crania. *American Journal of Human Biology* 2:53-61.
- Carlson, D. S. and D. P. Van Gerven
 1977 Masticatory function and post-Pleistocene evolution in Nubia. *American Journal of Physical Anthropology* 46:495-506.
- Chandler D.
 1999 *Voices from S-21: Terror and History in Pol Pot's Secret Prison*. The University of California Press, Berkeley, CA.
- Corruccini, R. S.
 1974 An examination of the meaning of cranial discrete traits for human skeletal biological studies. *American Journal of Physical Anthropology* 40:425-446.
- Craig, E. A.
 1995 Intercondylar shelf angle: A new method to determine race from the distal femur. *Journal of Forensic Sciences* 40:777-782.
- Danforth, M.
 2005 An evaluation of racial differences in the human mandible using discriminant function analysis. Paper presented at the 57th Annual Meeting of the American Academy of Forensic Sciences, New Orleans, Louisiana.
- Deaver, W. L.
 1997 Chronological Issues of the LVAP. In *Vanishing River: Landscapes and Lives of the Lower Verde Valley* edited by Stephanie M. Whittlesey, Richard Ciolek-Torrello, and Jeffrey H. Altschul. SRI Press, Tucson, AZ.
- Edgar, H. J.
 2005 Prediction of race using characteristics of dental morphology. *Journal of Forensic Sciences* 50:269-273.
- Enlow, D. H. and M. G. Hans
 1996 *Essentials of Facial Growth*. W. B. Saunders Co., Philadelphia, PA.
- Federal Registry Notice
 1997 Revisions to the Standards for the Classification of Federal Data on Race and Ethnicity. Office of Management and Budget, Executive Office of the President of the United States, accessed at <http://www.whitehouse.gov/omb/fedreg/1997standards.html>.

- Fisher, R. A.
1936 The use of multiple measurements in taxonomic problems. *Annals of Eugenics* 7:179-188.
- Gilbert, R. and G. W. Gill
1990 A metric technique for identifying American Indian femora. In *Skeletal Attribution of Race: Methods for Forensic Anthropology*, edited by G. W. Gill and S. Rhine, pp. 97-99. Maxwell Museum Anthropological Papers No. 4, Albuquerque, NM.
- Giles, E.
1964 Sex determination by discriminant function analysis of the mandible. *American Journal of Physical Anthropology* 22:129-136.
- Gill, G. W.
1995 Challenge on the frontier: Discerning American Indians from Whites osteologically. *Journal of Forensic Sciences* 40:783-788.

1986 Craniofacial criteria in forensic race identification. In *Forensic Osteology: Advances in the Identification of Human Remains*, edited by K. J. Reichs, pp. 143-159. Charles C Thomas, Springfield, IL.
- Gill, G. W. and S. Rhine (editors)
1990 *Skeletal Attribution of Race: Methods for Forensic Anthropology*. Maxwell Museum Anthropological Papers No. 4, Albuquerque, NM.
- Gray, H.
1995 *Gray's Anatomy*. 15th Edition. Barnes and Noble Books, New York, NY.
- Hanihara, T.
1996 Comparison of craniofacial features of major human groups. *American Journal of Physical Anthropology* 99:389-412.

2000 Frontal and facial flatness of major human population. *American Journal of Physical Anthropology* 111:105-134.
- Harrower, G.
1928 A biometric study of one hundred and ten Asiatic mandibles. *Biometrika* 20:279-293.
- Hauser, G. and G. F. De Stefano (editors)
1989 *Epigenetic Variants of the Human Skull*. E. Schweizerbart'sche Verlagsbuchhandlung, Schweizerbart, Stuttgart, Germany.

Hetzel, A. M. and M. Cappetta

1971 *Marriages: Trends and Characteristics, United States*. U.S. Department of Health, Education, and Welfare, Health Services and Mental Health Administration, National Center for Health Statistics, Series 21, Number 21, Rockville, MD.

Holland, T. D.

1986 Race determination of fragmentary crania by analysis of the cranial base. *Journal of Forensic Sciences* 31:719-725.

Hoppa R.

2000 Population variation in osteological aging criteria: An example from the pubic symphysis. *American Journal of Physical Anthropology* 111:185-191.

Howells, W. W.

1973 *Cranial Variation in Man: A Study by Multivariate Analysis of Patterns of Difference Among Recent Human Populations*. Papers of the Peabody Museum of Archaeology and Ethnology, Harvard University, Cambridge, MA.

Hrdlicka, A.

1940 Lower Jaw: The gonial angle and bigonial breadth. *American Journal of Physical Anthropology* 27(2):281-308.

1944 *The Anthropology of Kodiak Island*. Wister Institute, Philadelphia, PA.

Humphrey, L. T.

1998 Growth patterns in the modern human skeleton. *American Journal of Physical Anthropology* 105: 57-72.

Humphrey, L.T., Dean M. C., and C. B. Stringer

1999 Morphological variation in great ape and modern human mandibles. *Journal of Anatomy* 195:491-513.

Iskan, M.Y. and S. R. Loth

1986a Determination of age from the sternal rib in White males: A test of the phase method. *Journal of Forensic Sciences* 31:122-132.

1986b Determination of age from the sternal rib in White females: A test of the phase method. *Journal of Forensic Sciences* 31:990-999.

Jantz, L. M. and R. L. Jantz

1999 Secular change in long bone length and proportion in the United States, 1800-1970. *American Journal of Physical Anthropology* 110:57-67.

- Jantz, R. L.
1973 Microevolutionary change in Arikara crania: A multivariate analysis. *American Journal of Physical Anthropology* 38:15-26.
- Jantz, R. L., Hunt, D. R., and L. Meadows
1995 The measure and mismeasure of the tibia: Implications for stature estimation. *Journal of Forensic Sciences* 40:758-761.
- Jantz, R. L., and S. D. Ousley
2005 *FORDISC 3.0*. University of Tennessee, Knoxville, TN.
- Katz, D. and J. Suchey
1989 Race differences in pubic symphyseal aging patterns in the male. *American Journal of Physical Anthropology* 80:167-72.
- Key, P. J. and R. L. Jantz
1990 Statistical assessment of population variability: A methodological approach. *American Journal of Physical Anthropology* 82:53-59.
- Kile, D. P.
1983 *Multivariate Discriminant Function Analyses of the Mandible in American Caucasoid and American Negroid Populations*. Unpublished Masters Thesis, Department of Anthropology, University of Tennessee, Knoxville, TN.
- Komar, D.
2003 Lessons from Srebrenica: the contributions and limitations of Physical Anthropology in identifying victims of war crimes. *Journal of Forensic Sciences* 48:713-716.
- Krogman, M. W.
1962 *The Human Skeleton in Forensic Medicine*. Second Edition. Charles C. Thomas, Springfield, IL.
- Leney, M.
1996 *Morphology and Microevolution in Pleistocene Carnivores*. Unpublished Ph.D. dissertation, Department of Biological Anthropology, University of Cambridge, U.K.
- Leovy, J., D. Smith, and S. Poindexter
2007 Murder stalks minorities. In *The Los Angeles Times, California, Los Angeles Edition*, Sunday August 17, 2007.
- Marshall, D. S. and C. E. Snow
1956 An evaluation of Polynesian craniology. *American Journal of Physical Anthropology* 14:405-427.

Meadows-Jantz, L. and R. J. Wilson

- 2005 Osteological analysis of burial from Providence Baptist Church (40SY619). In Oster, W.J., G.G. Weaver, J.P. Richardson, and J.M. Wyatt (eds.), *Archaeological and Osteological Investigations of the Providence Baptist Church Cemetery (40SY619) Memphis-Shelby County Airport, Memphis, Shelby County, Tennessee*. Weaver and Associates LLC, Memphis, TN.

Molleson, T., Cruse, K., and S. Mays

- 1998 Some sexually dimorphic features of the human juvenile skull and their value in sex determination in immature juvenile remains. *Journal of Archaeological Science* 25: 719-728.

Moore-Jansen, P. M, S. D. Ousley, and R. L. Jantz

- 1994 *Data Collection Procedures for Forensic Skeletal Material*. Report of Investigations No. 48, Department of Anthropology, University of Tennessee, Knoxville, TN.

Morant, G. M.

- 1936 A biometric study of the human mandible. *Biometrika* 28:84-122.

Nicholson, E. and K. Harvati

- 2006 Quantitative analysis of human mandibular shape using three-dimensional geometric morphometrics. *American Journal of Physical Anthropology* 131:368-383.

Oster, W. J., G. G. Weaver, J. P. Richardson, and J. M. Wyatt

- 2005 *Archaeological and Osteological Investigations of the Providence Baptist Church Cemetery (40SY619) Memphis-Shelby County Airport, Memphis, Shelby County, Tennessee*. Weaver and Associates LLC, Memphis, TN.

Ousley, S. D. and J. T. Hefner

- 2005 Morphoscopic traits and the statistical determination of ancestry. Paper presented at the 57th Annual Meeting of the American Academy of Forensic Sciences, New Orleans, Louisiana.

Ousley, S. D. and R. L. Jantz

- 1996 *FORDISC 2.0*. University of Tennessee, Knoxville, TN.

Owsley, D. W. and W. W. Bass

- 1979 A demographic analysis of skeletons from the Larson Site (39WW2) Walworth County, South Dakota: Vital statistics. *American Journal of Physical Anthropology* 51:145-154.

Owsley, D. W. and R. L. Jantz

1977 Intracemetery morphological variation in Arikara crania from the Sully site (39SL4), Sully County, South Dakota. *Plains Anthropologist* 38:139-147.

Parra E. J., Marcini A., Akey J., Martinson J., Batzer M. A., Cooper R., Allison D. B., Deka R., Ferrell R. E., and Shriver M. D.

1998 Estimating African American admixture proportions by use of population-specific alleles. *American Journal of Human Genetics* 63:1839-1851.

Parra E. J., Kittles, R. A., Argyropoulos, G., Pfaff, C. L., Hiester, K., Bonilla, C., Sylvester, N., Parrish-Gause, D., Garvey, W. T., Jin, L., McKeigue, P. M., Kamboh, M. I., Ferrell, R. E., Pollitzer, W. S., and Shriver M. D.

2001 Ancestral proportions and admixture dynamics in geographically defined African Americans living in South Carolina. *American Journal of Physical Anthropology* 114:18-29.

Pickering, R. B. and D. C. Bachman

1997 *The Use of Forensic Anthropology*. CRC Press, Boca Raton.

Price, B., Cameron, N., and P. V. Tobias

1987 A further search for a secular trend of adult body size in South African Blacks: Evidence from the femur and tibia. *Human Biology* 59:467-475.

Prince, D. A. and D. H. Ubelaker

2002 Application of Lamendin's adult dental aging technique to a diverse skeletal sample. *Journal of Forensic Sciences* 47:107-116.

Rao, C. R.

1952 *Advanced Statistical Methods in Biometric Research*. John Willey and Sons, New York, NY.

Rennison, C.

2001 Violent victimization and race, 1993-1998. Bureau of Justice Statistics Special Report # NCJ 176354.

Rhine, S. S.

1990 Non-metric skull racing. In *Skeletal Attribution of Race: Methods for Forensic Anthropology*, edited by G. W. Gill and S. Rhine, pp. 9-20. Maxwell Museum Anthropological Papers No. 4, Albuquerque, NM.

Ross, A. J. and L. W. Konigsberg

1999 New formulae for estimating stature in the Balkans. *Journal of Forensic Sciences* 47:165-167.

Schafer, M. C.

2004 Epiphyseal closure rates in the Srebrenica youth. Paper presented at the 56th Annual Meeting of the American Academy of Forensic Sciences, Dallas, Texas.

Schendel, S. A, G. Walker, and A. Kamisugi

1980 Hawaiian craniofacial morphometrics: Average Mokapuan skull, artificial cranial deformation, and the "Rocker" mandible. *American Journal of Physical Anthropology* 52:491-500.

Scheuer, L. and S. Black

2007 Osteology. In *Forensic Human Identification, an Introduction*, edited by Tim Thompson and Sue Black, pp. 199-220, CRC Press, New York, NY.

Scheuer, L. and S. Black

2000 *Developmental Juvenile Osteology*. Academic Press, New York, NY.

Scott, R. G. and C. Turner II

1997 *The Anthropology of Modern Human Teeth: Dental Morphology and Its Variation in Recent Human Populations*. Cambridge University Press, Cambridge, U.K.

Shriver, M. D., Parra E. J., Dios, S., Bonilla, C., Norton, H., Pfaff, C., Jones, C., Massac, A., Cameron, N., Baron, A., Jackson, T., Argyropoulos, G., Jin, L., Hoggart, C. J., McKeigue, P. M., and R. A. Kittles

2003 Skin pigmentation, biogeographical ancestry and admixture mapping. *Human Genetics* 112:387-399.

Shennan, S.

1990 *Quantifying Archaeology*. Edinburgh University Press, Edinburgh, U.K.

Smith, S. L.

1996 Attribution of hand bone to sex and population groups. *Journal of Forensic Sciences* 41:469-477.

Snow, C.E.

1974 *Early Hawaiians*. University Press of Kentucky, Lexington, KY.

Spradley, K., Jantz, R. L., Robinson, A., and R. Peccerelli

2008 Demographic change and forensic identification: Problems in metric identification of Hispanic skeletons. *Journal of Forensic Sciences* 53:21-28.

Spradley, K. and R. L. Jantz

2003 Skull vs. postcranial elements in sex determination. Poster presented at the 57th Annual Meeting of the American Academy of Forensic Sciences, Chicago, Illinois.

Statistic Package for Social Sciences

1999 *SPSS Base 10.0 User's Guide*. SPSS Inc., Chicago, IL.

Stewart, T. D.

1979 *Essentials of Forensic Anthropology*. Charles C Thomas, Springfield, IL.

Sutherland L.D. and J. M. Suchey

1991 Use of the ventral arc in pubic sex determination. *Journal of Forensic Sciences* 36:501-511.

Tabachnick, B. G. and L. S. Fidell

1989 *Using Multivariate Statistics*. 2nd Edition. HarperCollinsPublishers, Inc., New York, NY.

Thompson, T. and S. Black

2007 *Forensic Human Identification: An Introduction*. CRC Press, Boca Raton.

Trotter, M. and G. C. Gleser

1952 Estimation of stature from long bones of American whites and negroes. *American Journal of Physical Anthropology* 10:463-514.

Underwood, J. H.

1979 *Human Variation and Human Microevolution*. Prentice-Hall, NJ.

U.S. Bureau of the Census

1998 Tables 1 through 4, Internet release date 06/10/98, accessed at <http://www.census.gov/population/socdemo/race/interractab1.txt>.

Wescott, D. J. and R. L. Jantz

2005 Assessing craniofacial secular change in American Blacks and Whites using geometric morphometry. In *Modern Morphometrics in Physical Anthropology*, edited by D. Slice, pp. 231-245, Kluwer Academic/Plenum Publishers, New York, NY.

White, T. D. and P. A. Folkens

2005 *The Human Bone Manual*. Academic Press, New York, NY.

Appendix 1

Sample Summary Data

The summary morphometric and morphoscopic data, including the number of individuals, means, and standard deviations are given for each population sample, males and females (where applicable), in Tables A1 through A24. All data were calculated using only those measurements that were present and not with the replaced missing data.

Table A1. Summary statistics for the mandibular morphometric data for the 20th century U.S. White sample.

Measurement	sex	n	Mean	S.D.
GNI	M	123	33.57	3.15
	F	41	30.34	3.32
HML	M	138	31.14	2.70
	F	47	28.32	3.09
TML	M	144	15.82	2.31
	F	50	14.52	2.07
GOG	M	145	98.41	5.94
	F	56	90.59	4.73
CDL	M	121	117.50	6.26
	F	50	110.44	5.20
WRB	M	142	30.91	3.15
	F	52	28.21	2.35
XRH	M	134	64.81	5.07
	F	52	57.48	4.94
MLT	M	146	76.51	5.24
	F	56	71.86	4.05
MAN	M	139	128.13	7.57
	F	53	130.02	6.56
XDA	M	46	50.35	5.76
	F	14	44.07	4.57
TML23	M	119	19.89	2.32
	F	35	18.34	1.92

Table A2. Summary statistics for the 19th century U.S. White mandibular morphometric data.

Measurement	sex	n	Mean	S.D.
GNI	M	36	32.81	3.65
	F	4	29.00	3.16
HML	M	48	31.22	2.49
	F	5	27.60	2.51
TML	M	55	14.64	1.74
	F	6	12.50	1.22
GOG	M	55	100.21	7.05
	F	6	93.50	6.83
CDL	M	55	116.58	5.41
	F	6	110.17	9.06
WRB	M	55	30.27	2.75
	F	6	28.33	3.08
XRH	M	55	63.35	4.89
	F	6	55.00	2.61
MLT	M	55	74.85	5.02
	F	6	72.33	3.98
MAN	M	55	124.75	7.17
	F	6	125.17	6.88
XDA	M	36	52.81	3.01
	F	4	53.50	3.70
TML23	M	53	18.64	1.78
	F	6	16.50	1.22

Table A3. Summary statistics for the 20th century U.S. Black mandibular morphometric data.

Measurement	sex	n	Mean	S.D.
GNI	M	28	36.46	3.67
	F	10	33.30	3.37
HML	M	35	31.97	2.62
	F	11	29.91	3.02
TML	M	39	15.03	1.84
	F	16	13.25	1.48
GOG	M	39	98.33	6.83
	F	16	89.63	6.25
CDL	M	37	118.46	7.10
	F	14	111.86	7.63
WRB	M	40	34.48	3.46
	F	16	31.81	1.91
XRH	M	39	63.49	4.39
	F	15	53.93	5.15
MLT	M	40	82.95	4.16
	F	16	76.38	3.14
MAN	M	40	124.10	7.83
	F	15	125.67	6.13
XDA	M	20	52.35	4.68
	F	5	48.60	3.43
TML23	M	28	19.07	1.96
	F	12	17.00	1.86

Table A4. Summary statistics for the mandibular morphometric data for the 19th century U.S. Black sample.

Measurement	sex	n	Mean	S.D.
GNI	M	53	36.60	2.94
	F	49	33.06	2.93
HML	M	55	33.42	2.60
	F	52	30.37	2.43
TML	M	55	14.76	1.66
	F	55	13.67	1.91
GOG	M	55	99.09	6.73
	F	55	90.49	5.07
CDL	M	55	117.64	5.33
	F	55	111.92	4.79
WRB	M	55	34.40	2.91
	F	55	32.80	3.49
XRH	M	55	61.55	3.85
	F	55	55.49	3.67
MLT	M	55	81.93	4.61
	F	55	78.51	4.48
MAN	M	55	123.87	6.78
	F	55	124.53	6.50
XDA	M	35	52.23	4.52
	F	38	50.66	3.02
TML23	M	53	18.43	1.77
	F	54	17.43	1.77

Table A5. Summary statistics for the mandibular morphometric data for the male Hispanic sample.

Measurement	n	Mean	S.D.
GNI	29	34.90	3.17
HML	30	31.60	2.79
TML	30	15.43	2.18
GOG	27	97.82	6.48
CDL	24	118.71	6.87
WRB	28	32.54	2.60
XRH	26	64.96	4.61
MLT	29	78.59	4.83
MAN	28	123.14	6.56
XDA	20	51.85	4.57
TML23	29	20.00	2.20

Table A6. Summary statistics for the mandibular morphometric data for the Guatemalan sample.

Measurement	sex	n	Mean	S.D.
GNI	M	76	35.18	3.14
	F	10	31.60	3.50
HML	M	89	32.12	2.61
	F	11	28.73	2.24
TML	M	89	15.01	1.58
	F	14	12.64	1.28
GOG	M	83	97.41	6.53
	F	14	91.50	5.91
CDL	M	78	117.35	6.32
	F	13	110.92	7.80
WRB	M	88	33.30	2.67
	F	14	28.14	1.35
XRH	M	87	61.97	4.31
	F	13	53.85	2.44
MLT	M	89	76.48	4.59
	F	14	69.07	3.22
MAN	M	89	121.14	6.23
	F	14	125.14	6.96
XDA	M	47	52.79	3.03
	F	4	56.25	2.87
TML23	M	87	19.53	1.62
	F	11	17.09	1.70

Table A7. Summary statistics for the mandibular morphometric data for the Cambodian sample.

Measurement	sex	N	Mean	S.D.
GNI	M	60	32.38	3.09
	F	8	30.50	2.93
HML	M	137	30.09	2.42
	F	26	27.69	1.89
TML	M	149	16.39	1.68
	F	29	14.14	1.51
GOG	M	137	99.58	5.42
	F	27	92.78	3.99
CDL	M	133	119.07	5.76
	F	25	112.88	5.47
WRB	M	149	32.93	2.56
	F	28	31.25	2.32
XRH	M	147	62.66	4.26
	F	26	57.15	4.22
MLT	M	149	75.99	4.25
	F	28	71.32	3.34
MAN	M	148	123.41	5.90
	F	27	124.85	5.22
XDA	M	107	55.00	3.61
	F	22	53.41	3.80
TML23	M	148	20.69	1.80
	F	28	18.68	1.52

Table A8. Summary statistics for the mandibular morphometric data for the male Chinese sample.

Measurement	n	Mean	S.D.
GNI	49	35.36	2.75
HML	60	32.73	2.66
TML	65	15.50	1.86
GOG	65	98.74	6.19
CDL	59	118.83	5.75
WRB	66	33.82	2.64
XRH	64	62.73	4.59
MLT	60	73.78	4.49
MAN	59	123.76	5.59
XDA	37	52.14	3.39
TML23	59	19.80	1.89

Table A9. Summary statistics for the mandibular morphometric data for the male Vietnamese sample.

Measurement	n	Mean	S.D.
GNI	17	33.41	3.18
HML	27	31.44	2.49
TML	29	15.52	1.48
GOG	15	98.33	4.19
CDL	7	115.57	9.48
WRB	29	34.14	3.36
XRH	22	60.68	331
MLT	24	76.38	5.29
MAN	22	124.91	8.16
XDA	15	54.07	2.96
TML23	29	19.48	1.40

Table A10. Summary statistics for the mandibular morphometric data for the Arikara sample.

Measurement	sex	n	Mean	S.D.
GNI	M	29	36.00	2.27
	F	27	34.26	2.38
HML	M	29	35.59	2.63
	F	29	32.72	2.70
TML	M	30	14.80	1.71
	F	30	13.30	1.21
GOG	M	29	101.38	6.82
	F	28	94.29	4.07
CDL	M	29	122.45	4.71
	F	28	114.36	4.25
WRB	M	30	36.77	2.22
	F	29	34.76	2.42
XRH	M	30	66.37	5.34
	F	30	58.80	4.33
MLT	M	30	85.40	5.40
	F	30	79.07	3.96
MAN	M	30	116.30	6.00
	F	30	121.00	5.27
XDA	M	24	53.67	2.26
	F	23	52.17	2.89
TML23	M	29	18.83	1.36
	F	30	17.87	1.61

Table A11. Summary statistics for the mandibular morphometric data for the Hohokam sample.

Measurement	sex	n	Mean	S.D.
GNI	M	28	35.21	2.41
	F	13	32.00	2.80
HML	M	33	32.67	2.52
	F	14	30.00	2.63
TML	M	35	15.54	1.88
	F	14	12.71	1.32
GOG	M	34	100.97	6.64
	F	14	91.79	3.49
CDL	M	27	118.56	5.75
	F	12	113.50	4.25
WRB	M	34	32.41	2.90
	F	13	30.15	2.44
XRH	M	31	60.10	5.25
	F	13	54.46	3.86
MLT	M	33	76.7	3.55
	F	13	74.38	3.97
MAN	M	33	123.24	6.08
	F	13	124.46	3.86
XDA	M	22	55.95	3.39
	F	10	52.10	2.42
TML23	M	33	18.58	1.54
	F	14	16.64	1.22

Table A12. Summary statistics for the mandibular morphometric data for the Nubian sample.

Measurement	sex	N	Mean	S.D.
GNI	M	55	33.98	3.22
	F	51	31.80	2.71
HML	M	56	14.27	1.50
	F	54	13.19	1.23
TML	M	56	31.88	2.35
	F	53	29.77	2.51
GOG	M	55	95.43	5.44
	F	55	86.89	3.70
CDL	M	55	114.00	4.61
	F	53	107.53	4.47
WRB	M	56	33.12	2.08
	F	55	31.42	2.81
XRH	M	56	57.68	4.16
	F	54	54.54	4.35
MLT	M	56	77.93	3.72
	F	55	73.55	4.74
MAN	M	56	126.36	6.34
	F	55	126.84	6.68
XDA	M	40	49.53	2.88
	F	40	48.10	3.65
TML23	M	56	17.25	1.49
	F	54	16.19	1.53

Table A13. Summary statistics for the mandibular morphoscopic data for the 20th century U.S. White sample.

Measurement	sex	N	Mean	S.D.
SC	M	143	2.55	1.19
	F	56	2.11	0.93
LBM	M	143	2.11	0.50
	F	56	2.38	0.70
ARS	M	143	1.87	0.34
	F	54	1.87	0.34
GAF	M	143	3.34	0.90
	F	56	3.02	0.82
MT	M	143	1.34	0.48
	F	56	1.27	0.45
PREI	M	138	1.31	0.58
	F	54	1.61	0.94

Table A14. Summary statistics for the mandibular morphoscopic data for the 19th century U.S. White sample.

Measurement	sex	n	Mean	S.D.
SC	M	55	2.16	1.03
	F	6	1.50	0.55
LBM	M	55	2.02	0.68
	F	6	1.83	0.98
ARS	M	55	1.65	0.48
	F	6	1.67	0.52
GAF	M	55	3.78	0.98
	F	6	3.33	0.52
MT	M	55	1.15	0.36
	F	6	1.17	0.41
PREI	M	55	1.16	0.46
	F	6	1.50	0.84

Table A15. Summary statistics for the mandibular morphoscopic data for the 20th century U.S. Black sample.

Measurement	sex	n	Mean	S.D.
SC	M	27	2.33	0.83
	F	3	1.67	0.58
LBM	M	27	2.00	0.39
	F	3	1.33	0.58
ARS	M	27	2.0	0.00
	F	3	2.0	0.00
GAF	M	27	3.26	0.81
	F	3	3.00	1.00
MT	M	27	1.26	0.45
	F	3	1.33	0.58
PREI	M	27	1.93	0.87
	F	3	4.00	0.00

Table A16. Summary statistics for the mandibular morphoscopic data for the 19th century U.S. Black sample.

Measurement	sex	n	Mean	S.D.
SC	M	71	1.56	0.95
	F	68	1.28	0.59
LBM	M	71	1.97	0.61
	F	68	2.28	0.81
ARS	M	71	1.77	0.42
	F	68	1.90	0.31
GAF	M	71	3.49	0.94
	F	68	2.85	0.74
MT	M	71	1.07	0.26
	F	68	1.63	0.49
PREI	M	71	2.15	1.08
	F	68	2.65	0.86

Table A17. Summary statistics for the mandibular morphoscopic data for the male Hispanic sample.

Measurement	n	Mean	S.D.
SC	28	2.00	0.98
LBM	28	2.04	0.51
ARS	28	1.96	0.19
GAF	26	2.58	1.06
MT	28	1.14	0.36
PREI	26	1.50	0.91

Table A18. Summary statistics for the mandibular morphoscopic data, Guatemalan sample.

Measurement	sex	n	Mean	S.D.
SC	M	89	1.71	1.01
	F	14	1.64	0.74
LBM	M	89	1.92	0.66
	F	14	1.79	0.80
ARS	M	89	1.92	0.27
	F	14	2.00	0.00
GAF	M	89	3.26	1.05
	F	14	2.86	0.77
MT	M	89	1.00	0.00
	F	14	1.00	0.00
PREI	M	88	1.33	0.62
	F	14	2.71	0.99

Table A19. Summary statistics for the mandibular morphoscopic data, Cambodian sample.

Measurement	sex	n	Mean	S.D.
SC	M	149	1.66	1.00
	F	29	1.31	0.66
LBM	M	149	2.95	0.69
	F	29	2.83	0.76
ARS	M	149	2.00	0.00
	F	29	2.00	0.00
GAF	M	149	3.07	0.95
	F	29	2.79	1.01
MT	M	149	1.01	0.08
	F	29	1.00	0.00
PREI	M	149	1.69	0.91
	F	29	1.86	1.06

Table A20. Summary statistics for the mandibular morphometric data for the male Chinese sample.

Measurement	n	Mean	S.D.
SC	65	1.23	0.63
LBM	65	2.22	0.78
ARS	65	1.86	0.35
GAF	65	3.14	1.00
MT	65	1.05	0.21
PREI	65	1.63	0.84

Table A21. Summary statistics for the mandibular morphoscopic data for the male Vietnamese sample.

Measurement	n	Mean	S.D.
SC	38	1.66	1.02
LBM	39	2.28	0.83
ARS	41	1.98	0.16
GAF	39	3.08	0.87
MT	41	1.02	0.16
PREI	39	1.41	0.72

Table A22. Summary statistics for the mandibular morphoscopic data, Arikara sample.

Measurement	sex	n	Mean	S.D.
SC	M	30	1.53	0.82
	F	30	1.53	0.73
LBM	M	30	2.40	0.72
	F	30	2.30	0.75
ARS	M	30	2.00	0.00
	F	30	1.93	0.25
GAF	M	30	3.37	1.00
	F	29	2.97	0.68
MT	M	30	1.00	0.00
	F	30	1.00	0.00
PREI	M	30	1.23	0.50
	F	30	1.33	0.61

Table A23. Summary statistics for the mandibular morphoscopic data for the Hohokam sample.

Measurement	sex	n	Mean	S.D.
SC	M	35	1.60	0.91
	F	14	1.07	0.27
LBM	M	35	1.86	0.65
	F	14	2.21	0.70
ARS	M	35	1.77	0.43
	F	14	1.64	0.50
GAF	M	35	3.51	1.09
	F	14	3.14	0.77
MT	M	35	1.14	0.36
	F	14	1.00	0.00
PREI	M	35	1.49	0.74
	F	14	1.71	0.99

Table A24. Summary statistics for the mandibular morphoscopic data for the Nubian sample.

Measurement	sex	n	Mean	S.D.
SC	M	55	2.16	0.54
	F	55	1.82	0.75
LBM	M	55	2.47	1.03
	F	55	2.87	0.98
ARS	M	55	1.89	0.31
	F	55	1.95	0.23
GAF	M	55	3.51	0.94
	F	55	2.69	0.84
MT	M	55	1.00	0.00
	F	55	1.00	0.00
PREI	M	55	1.89	1.07
	F	55	2.54	1.10

Vita

Gregory E. Berg was born in Omaha, Nebraska in September of 1970. He was raised primarily in Arizona, where he earned a Bachelor of Arts degree in anthropology from the University of Arizona in 1993 and a Master of Arts degree in the Bioarchaeology program from Arizona State University in 1999. He enrolled at the University of Tennessee for a Ph.D. degree in 2002. Currently, Greg is a forensic anthropologist at the JPAC-Central Identification Laboratory in Hawaii where he works on the recovery and identification of missing U.S. service personnel. In sum, Greg has over fifteen years of field experience in archaeology and physical anthropology and has presented or published numerous articles and papers in the *Journal of Forensic Sciences*, *Journal of Archaeological Science*, and at various annual meetings. His recent research has concentrated on trauma analysis, aging techniques, human identification and eyewear, and intra- and inter-observer error studies, which have been particularly focused on aging and population determination methods used in human identification. After completing the requirement for this terminal degree, Greg aspires to continue his education through educating undergraduate and graduate students in a fine university, somewhere!