An Evaluation of Metric Methods of Race Differentiation in the Human Pelvic Girdle for the Application of Expert Witness Testimony

Laura Natalie Yurka
University of Southern Mississippi

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AN EVALUATION OF METRIC METHODS OF RACE DIFFERENTIATION
IN THE HUMAN PELVIC GIRDLE FOR THE APPLICATION
OF EXPERT WITNESS TESTIMONY

by

Laura Natalie Yurka

A Thesis
Submitted to the Graduate School
of The University of Southern Mississippi
in Partial Fulfillment of the Requirements
for the Degree of Master of Arts

Approved:

Dr. Marie Danforth________________________
Committee Chair

Dr. Ed Jackson________________________

Dr. Amy Young________________________

Dr. Karen Coats________________________
Dean of the Graduate School

December 2014
AN EVALUATION OF METRIC METHODS OF RACE DIFFERENTIATION
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Research has shown that measurements from the pelvic bones and femur can be utilized for race estimation when the skull is absent or damaged. The literature reported levels up to 95% accuracy when utilizing discriminant function analysis to simultaneously classify race and sex. This research examined the previously reported methods of race estimation within the evidence standards for forensic science as well as current statistical standards. New metric measurements from the pelvis and femur were also proposed and tested to assess their utility as race indicators. Finally, this research addressed concerns that skeletal collections like the Robert J. Terry Skeletal Collection are no longer representative of populations within the United States.

None of the methods sufficiently separated unknown skeletal remains by race. When the methods were modified to conform to current statistical standards, the overall accuracy fell considerably. The reproductions of DiBennardo’s and Taylor’s, and İşcan’s discriminant function analyses yielded accuracy rates of 85.8% and 60.4%, respectively, for the original grouped cases and 80.7% and 58.9%, respectively, for cross-validated grouped cases, which were substantially lower than those reported in the literature and did not adequately meet the standards for admissible evidence. Descriptive statistics showed that more variations exist within African American and Caucasian American
populations in the United States than among them.

The implications of this research demonstrate a need for stricter adherence to current standards, more rigorous validation of morphometric methods utilized for forensic anthropology casework, and investigation into alternative ways of thinking about and utilizing human variation.
ACKNOWLEDGMENTS

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## TABLE OF CONTENTS

ABSTRACT ........................................................................................................................................ ii

ACKNOWLEDGMENTS .................................................................................................................. iii

LIST OF TABLES .............................................................................................................................. vi

LIST OF ILLUSTRATIONS ............................................................................................................... viii

LIST OF EQUATIONS ..................................................................................................................... x

LIST OF ABBREVIATIONS .............................................................................................................. xi

CHAPTER

I. INTRODUCTION ......................................................................................................................... 1

   Research Goals
   Hypotheses
   Significance of Study

II. LITERATURE REVIEW .............................................................................................................. 5

   Evidence Standards in Forensic Science
   Race Determination

III. MATERIALS AND METHODS .............................................................................................. 31

   Skeletal Collections
   Sample Selection
   Materials
   Methods

IV. RESULTS .................................................................................................................................... 48

   General Analysis
   Peleg et al. (2007) Measurements
   İşcan (1983) Measurements and Discriminant Function Analysis
   DiBennardo and Taylor (1983) Discriminant Function Analysis
   Davivongs (1963) Measurements and Indices
   New Variables
   Comparison of Skeletal Collections
   Intra- and Inter-Observer Error
V. DISCUSSION AND CONCLUSIONS .........................................................106

Best-Practices Guidelines
Guidelines for Expert Witness Testimony
Empirical Findings
Implications of This Research
Limitations
Conclusions

APPENDIXES ..........................................................................................133

REFERENCES ..........................................................................................136
LIST OF TABLES

Table

1. Means, Standard Deviations, and Effect Sizes of Pelvic Elements from Prior Research .................................................................50
3. Descriptive Statistics of Sacral Angle ........................................................................................................52
4. Analysis of Variance for Sacral Angle ......................................................................................................53
5. Means, Standard Deviations, F, t² Comparisons Between İşcan (1983) and Yurka ..................................................................................................................55
6. Original Classification Rates Reported by İşcan (1983) ........................................................................57
7. Classification Results When Sexes are Treated Separately ..........................................................................58
8. Classification Table for the Reproduction of İşcan’s Methods ...........................................................................59
9. Classification Table for the Reproduction of İşcan’s Methods Without Age At Death ..........................................................60
10. Structure Coefficients .........................................................................................................................................62
11. Unstandardized Canonical Discriminant Function Coefficients ........................................................................63
12. Functions at Group Centroids ..........................................................................................................................64
14. Comparison of Structure Coefficients ...........................................................................................................68
15. Original Classification Rates Reported by DiBennardo and Taylor (1983) ................................................69
16. Classification Table for the Reproduction of DiBennardo and Taylor’s Methods ............................................70
17. Unstandardized Canonical Discriminant Function Coefficients ........................................................................72
18. Functions at Group Centroids ..........................................................................................................................73
19. Measurements and Indices of Female Sacra ..................................................................................................75
20. Measurements and Indices of Male Sacra ..............................................................78
21. Measurements and Indices of Female Innominates .............................................82
22. Measurements and Indices of Male Innominates...............................................85
23. Independent Samples T-Tests for New Variables ..............................................86
24. Independent Samples T-Tests for Indices of New Variables..............................87
25. Comparison of Means Between Terry and Bass Skeletal Collections for African American Females .................................................................90
26. Comparison of Means Between Terry and Bass Skeletal Collections for Caucasian American Females .................................................................92
27. Comparison of Means Between Terry and Bass Skeletal Collections for African American Males .................................................................94
28. Comparison of Means Between Terry and Bass Skeletal Collections for Caucasian American Males .................................................................96
29. Paired Samples T-Tests for Intra-Observer Error Observations.........................102
LIST OF ILLUSTRATIONS

Figure

1. Photograph of a Reassembled Pelvic Girdle .......................................................... 37
2. Sacral Angle ........................................................................................................... 44
3. Pelvic Girdle Measurements .............................................................................. 44
4. Innominate Measurements E-H ...................................................................... 44
5. Innominate Measurements J-O ...................................................................... 44
6. Innominate Measurements P-T ...................................................................... 45
7. Symphyseal Angle ............................................................................................... 45
8. Femur Measurements U-X ............................................................................... 45
9. Sacrum Measurements Y-AA .......................................................................... 45
10. Sacrum Measurements BB-CC .......................................................................... 45
11. New Measurements DD-EE ............................................................................... 46
12. New Measurements FF-GG ............................................................................... 46
13. New Femur Measurement ................................................................................ 46
14. Sex and Race Combined-Groups Scatter Plots With Group Centroids ............ 64
15. Sex and Race Combined-Groups Scatter Plots With Group Centroids ............ 73
16. Distribution of Observations of Sacrum Maximum Length for Females ...... 76
17. Distribution of Observations of Sacral Curved Length for Females .......... 76
18. Distribution of Observations of Sacrum Maximum Length for Males .......... 79
19. Distribution of Observations of Sacrum Maximum Breadth for Males .......... 79
20. Distribution of Observations of Sacral Curved Length for Males ................ 80
22. Distribution of Observations of Pelvis Maximum Length for Females.................83
23. Distribution of Observations of the Iliac Breadth for Females..........................84
## LIST OF EQUATIONS

<table>
<thead>
<tr>
<th>Equation</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sacral Index</td>
<td>48</td>
</tr>
<tr>
<td>2. Curvature Index</td>
<td>48</td>
</tr>
<tr>
<td>3. Index of Body of S1</td>
<td>48</td>
</tr>
<tr>
<td>4. Corporo-Basal Index</td>
<td>48</td>
</tr>
<tr>
<td>5. Coxal Index</td>
<td>48</td>
</tr>
<tr>
<td>6. Ischium-Pubis Index</td>
<td>48</td>
</tr>
<tr>
<td>7. Index of the Greater Sciatic Notch</td>
<td>48</td>
</tr>
<tr>
<td>8. Chilotic Index</td>
<td>48</td>
</tr>
<tr>
<td>9. Acetabulum Index I</td>
<td>48</td>
</tr>
<tr>
<td>10. Acetabulum Index II</td>
<td>48</td>
</tr>
<tr>
<td>11. Femoral Head Index</td>
<td>48</td>
</tr>
<tr>
<td>12. Femoral Neck Index</td>
<td>48</td>
</tr>
<tr>
<td>13. Range Rule</td>
<td>51</td>
</tr>
<tr>
<td>14. Discriminant Functions from the Reproduction of İşcan’s Methods</td>
<td>64</td>
</tr>
<tr>
<td>15. Discriminant Functions from the Reproduction of DiBennardo and Taylor’s Methods</td>
<td>72</td>
</tr>
</tbody>
</table>
## LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAPA</td>
<td>American Academy of Physical Anthropologists</td>
</tr>
<tr>
<td>ABFA</td>
<td>American Board of Forensic Anthropology</td>
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<tr>
<td>ANOVA</td>
<td>Analysis of Variance</td>
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<tr>
<td>ASCLAD-LAB</td>
<td>American Society of Crime Laboratory Directors Laboratory-Accreditation Board</td>
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<tr>
<td>DOD</td>
<td>Department of Defense</td>
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<td>DOJ</td>
<td>Department of Justice</td>
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<td>FBI</td>
<td>Federal Bureau of Investigation</td>
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<td>FRE</td>
<td>Federal Rules of Evidence</td>
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<td>FSSB</td>
<td>Forensic Science Standards Board</td>
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<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
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<td>NAS</td>
<td>National Academy of Science</td>
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<td>NIST</td>
<td>National Institute of Standards and Technology</td>
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<tr>
<td>OSAC</td>
<td>Organization of Scientific Area Committees</td>
</tr>
<tr>
<td>POW/MIA</td>
<td>Prisoner of War/Missing in Action</td>
</tr>
<tr>
<td>S1</td>
<td>Sacral Vertebra Number 1</td>
</tr>
<tr>
<td>SAO</td>
<td>Sacral Anatomical Orientation</td>
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<tr>
<td>SOP</td>
<td>Standard Operating Procedure</td>
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<td>SWGANTH</td>
<td>Scientific Working Group for Forensic Anthropology</td>
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CHAPTER I
INTRODUCTION

Physical and forensic anthropologists have primarily used the pelvis and femur as tools for sex and age determination. When used singly or in combination with the femur, dimensions of the pelvis provide the highest accuracy of prediction of all the postcranial bones (Black, 1978; DiBennardo & Taylor, 1979, 1983; Kelly, 1979; Phenice, 1969; Pons, 1955; Richman, Michel, Schulter-Ellis, & Corruccini, 1979; Taylor & DiBennardo, 1984; Thieme & Schull, 1957; Van Gerven, 1972; Washburn, 1948). Research has also been conducted to assess racial differences in the pelvis, which may become necessary in forensic settings when a skull – the usual way to assess race – is missing.

A few studies have shown evidence suggesting that individual measurements from the pelvis can be used reliably for race estimation in an unidentified individual. Those utilizing discriminant function analysis yield the highest levels of predictive accuracy for race estimation. However, the analyses failed to test whether the magnitudes of these differences are large enough to negate the effects of intra- and inter-observer error during data collection. As the criteria by which scientific evidence is deemed admissible in court have become much stricter in the wake of the Supreme Court cases of Daubert v. Merrill Dow Pharmaceuticals, Inc. (1993) and Kumho Tire, Ltd v. Carmichael (1999) (Grivas & Komar, 2008), it is of utmost importance to ensure that the osteometric standards used in forensic analysis are clearly explained, repeatable and reliable (Steyn, Becker, L'Abbé, Scholtz, & Myburgh, 2012).
Research Goals

This thesis assesses previous and new metric methods of estimating race using the pelvic girdle and femur to analyze their applicability, repeatability, and reliability for their utilization in a court of law. It is no longer adequate to state that there are significant differences between human populations without providing empirical information concerning the researcher’s confidence in that significance. The differences must be well defined and validated. It is important, especially in the case of forensic anthropology, that conventional methods be reviewed with the same high standards as new methods so that outdated or ineffective procedures are not perpetuated out of habit or tradition. This research will attempt to reproduce the methods of three major studies of race estimation (and one study of sex determination, which compares results to similar studies conducted among other race groups) to evaluate the results within the Daubert and Kumho guidelines for expert witness testimony. This research will also attempt to answer the call for stricter standards in forensic science by the National Academy of Sciences by following the best-practices guidelines set forth by the FBI’s Scientific Working Group for Forensic Anthropology (SWGANTH).

The sample populations for this research are comprised of known African American and Caucasian American skeletal remains from the Robert J. Terry Skeletal Collection and the William Bass Donated Skeletal Collection. Although these skeletal collections are similar with regard to population demographics, the Terry Collection added its last set of remains in 1966, whereas the Bass Collection continues to add more skeletal specimens year after year. Due to this fact, researchers have begun to question the reliability of the Terry Collection for the development of forensic identification
methods based on the notion that it is no longer representative of populations in the United States. This research will address these concerns by selecting the most recent samples available within the Terry Collection and comparing the data to those recorded from the Bass Collection.

In recent years, physical anthropologists have begun moving away from the concept of racial classification, recognizing that the major features of human biological diversity are polymorphic, clinal, and culturally mediated. Differences within human populations have been found to be greater than those among populations. Human populations do not conform to phylogenetic tree models the way other species do. Likewise, classification based on phenotypic typologies, skeletal morphologies, and even genetic variation, tend to break down when applied to human populations. Furthermore, the term “race” carries historical baggage, especially in the United States. For these reasons, many physical anthropologists are in search of a new paradigm. Because of its ties to law enforcement, forensic anthropology continues to study and utilize methods of race classification, which tend to still heavily rely on categorization. This research will address some of the contentious issues surrounding racial classification and provide suggestions to the field where, and if, relevant.

Hypotheses

The null hypothesis states that there is no statistical significance in pelvic measurements between racial groups within the United States. An alternative hypothesis states that if there are statistically significant differences between these racial groups, the magnitudes of these differences will not be large enough to minimize bias from intra- or inter-observer error and further assessment of the methods will be conducted to determine
if the methods would be valid within the *Kumho* criteria. A second alternative hypothesis states that if the magnitudes of statistically significant results are sufficient to account for intra- and inter-observer error and are consistent with the results of prior research, the results are deemed reliable, reproducible, and scientifically valid under the *Daubert* criteria for expert witness testimony. It is also hypothesized that when the Terry Collection is compared to the Bass Collection no significant differences will be found, because the individuals in both sample populations existed concurrently.

**Significance of Research**

Morphological differences have been shown to exist within the features of the bony pelvis that may lead to positive estimation of race for forensic or historical anthropological applications. However, critical analysis has not fully been conducted to determine whether these differences are large enough to be applicable to unknown skeletal remains, especially for use in court settings. By assessing multiple methods of metric analysis of the pelvic girdle and the femur, this research has the potential to validate or invalidate the results of previous research. Analysis of the magnitudes of differences, should they exist, will illuminate the strengths and weaknesses of these measurements for race determination. Evaluation of these methods with regard to the *Daubert* criteria for admissibility of evidence and expert testimony will further reinforce or discredit their use in legal cases. Despite the fact that strict *Daubert* standards may not be required of anthropological methods due to the *Kumho* decision, it is in the best interest of the field of physical anthropology to use reputable and reliable methodology whenever possible. For the purpose of this research, the *Daubert* criteria are the recommended guidelines for initial evaluation due to the fact that the study employs
metric methods and statistical analyses, which can provide specific confidence intervals and error rates. This research will benefit the anthropological community by determining the reliability of the methods to either support or contradict their use for legal cases.
CHAPTER II
LITERATURE REVIEW

Very few researchers have examined the morphological features of the pelvic girdle to develop methods of race determination to supplement the information obtained from the skull or for use when the skull is absent. The primary literature reports levels of accuracy reaching 95% utilizing metric methods to estimate race from the pelvic girdle and femur. Therefore, potential exists for these methods to meet the Daubert standards of admissible evidence. This literature review will outline the standards for expert witness testimony and anthropological methods, discuss the methods and findings of prior research, and examine some of the controversy surrounding racial classification.

Evidence Standards in Forensic Science

This section will present the history of the rules governing expert witness testimony, beginning with the Frye Rule and the Federal Rules of Evidence (FRE) Rule 702, then go on to discuss the amendments to FRE 702, which were outcomes of the court cases Daubert v. Merrell Dow Pharmaceuticals and Kumho v. Carmichael. Although many researchers investigating forensic methods recognize the significance of the Daubert decision, not all appear to be familiar with all of the rules governing expert witness testimony, as exemplified by the lack of articles that mention the Kumho decision and its impact on the admissibility of expert witness testimony (Grivas & Komer, 2008, p. 774). Without such understanding, forensic anthropologists may struggle to meet unattainable standards, potentially undermining their own testimony (Grivas & Komer, 2008, p. 774).
The Frye Rule

The traditional standard for the admission of medical testimony was established in the Frye case in 1923. The case involved the appeal of a criminal defendant who was convicted based on a systolic blood pressure test – the precursor to the polygraph. The defendant argued that this was an unfounded technique that was not recognized by scientists in the field. The court agreed, and established the following standard:

Just when a scientific principle or discovery crosses the line between the experimental and demonstrable stages is difficult to define. Somewhere in this twilight zone the evidential force of the principle must be recognized, and while courts will go a long way in admitting expert testimony deduced from a well-recognized scientific principle or discovery, the thing from which the deduction is made must be sufficiently established to have gained general acceptance in the particular field in which it belongs. [Frye v. United States, 293 F. 1013, 1014 (App. D.C. Dec. 03, 1923).] (Richards, 2009, para. 2)

The Frye rule became the standard for federal and state courts evaluating expert testimony. Before an expert witness could testify, the judge would have to determine if the testimony met the Frye test and, if it did, if the witness was properly qualified to be an expert (Richards, 2009, para. 3).

The Frye rule, however, has several shortcomings. The general acceptance criterion excludes many new discoveries that have not had time to disseminate through the relevant scientific community, and is hard to establish for narrow areas of inquiry where there may only be a few experts (Richards, 2009, para. 4). It is also problematic if the plaintiff is arguing that what is generally accepted is not true. In contest to the Frye
rule, the tort law recognizes that there are situations in which what is generally accepted is not proper behavior [The T.J. Hooper, 60 F. 2d 7 37 (C.C. Ac2 1932)] (Richards, 2009, para. 4). Finally, the Frye rule proved difficult to administer, encouraging judges to allow broad latitude for the admission of questionable evidence (Richards, 2009, para. 4).

Federal Rules of Evidence Rule 702: Testimony by Expert Witnesses

In 1975, the Federal Rules of Evidence were promulgated to guide criminal and civil litigation in federal courts. The first version of FRE 702 provided that a witness “qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise if the expert’s scientific, technical, or other specialized knowledge will help the trier of fact to understand the evidence or to determine a fact in issue” (Grivas & Komer, 2008, p. 772). After the implementation of Rule 702, debate began as to the merits of Frye, and how and if it should be incorporated with FRE Rule 702. As the realm of science has expanded, the lack of an official standard commonly led to the admission of questionable scientific testimony, otherwise known as “junk science” (Grivas & Komar, 2008, p. 772).

The Daubert Decision

The 1993 product liability case, Daubert v. Merrill Dow Pharmaceuticals (113 S.Ct. 2786), dramatically changed approaches to research, evidence, analysis, and expert witness testimony in forensic anthropology (Dirkmaat, Cabo, Ousley, & Symes, 2008; Feinberg, Krislov, & Straf, 1995; Steadman, Adams, & Konigsberg, 2006). Merrell Dow claimed that the plaintiffs would be unable to offer any “generally accepted” scientific evidence under the Frye rule (Orofino, 1996, p. 109). Daubert offered a reanalysis of the data provided by Merrill Dow as well as several other types of evidence, and argued that
the 1975 Federal Rules of Evidence applied (Orofino, 1996, p. 109). The lower courts sided with Merrell Dow, and invoked the more stringent Frye rule. Daubert then appealed to the Supreme Court, asking to resolve the long-standing controversy over whether or not the FRE superseded the common law Frye rule as the admissibility standard for scientific evidence in court (Orofino, 1996, p. 109). The Court ruled unanimously that the FRE superseded the Frye rule, but were compelled to address the concerns over the reliability of evidence admitted under the more liberal standard.

A gatekeeping role for the judge was recommended to ensure the reliability of scientific evidence and to evaluate the validity of the scientific methodology involved, not on the general acceptability of the conclusions generated (Orofino, 1996, p. 110). Justice Blackmun stated that the science offered in court must be testable, and cautioned that while peer review can be used as a gauge, it should not be viewed as confirmation of reliability (Orofino, 1996, p. 110). The decision from this case stressed that testable, replicable, reliable, and scientifically valid methods are to be used to justify scientific opinions, and that testing and replication of the methods and conclusions are an essential part of reliability (Dirkmaat et al., 2008, p. 35).

The guidelines from the Daubert decision specify that content of testimony must:
1) Be testable and have been tested through the scientific method, 2) Have been subject to peer review, 3) Have established standards, 4) Have a known or potential error rate, and 5) Have widespread acceptance by the relevant scientific community. It requires scientists to substantiate their assertions with scientifically tested methods and, in particular, with probability assessments. In terms of statistics, Daubert demands
estimates of scientific certainty in conclusions (Dirkmaat et al., 2008; Grivas & Komar, 2008).

Although the Supreme Court was unanimous in its decision that the *Frye* rule was dead, a minority declined to endorse Blackmun’s recommendations, stating that the briefs in the case dealt with definitions of scientific knowledge, scientific method, scientific validity, and peer review – matters far afield from the expertise of judges (Orofino, 1996, p. 111). By refusing to address the philosophical and functional differences between science and law, the minority ignored the deeper issues embedded in the debate over admissibility standards and left the majority to recast the relationship between science and law (Orofino, 1996, p. 111). For this reason, the *Daubert* guidelines may prove too rigid to implement across scientific disciplines. Moreover, it may be that the differences between science and law will necessitate the perpetual revision of admissibility criteria to reflect contemporary jurisprudence and contemporary understanding of science. In the meantime, *Daubert* offers an optimistic vision of how science and law can cooperate in the resolution of courtroom conflicts (Orofino, 1996, p.111).

*The Kumho Decision*

In 1999, a diversity suit was brought against Kumho Tire Company and its distributor (collectively, Kumho Tire) after a tire blew out on a vehicle resulting in the death of one passenger and injuries sustained by the others. The plaintiffs claimed that the tire that failed was defective, and rested their case in significant part upon the depositions of a tire failure analyst, whose testimony was based on tactile and visual inspection (*Kumho Tire v. Carmichael*). Kumho Tire moved to exclude his testimony, claiming that the methodology failed to satisfy FRE 702. The District Court granted the
motion, acknowledging that it should act as a reliability “gatekeeper” under *Daubert v. Merrell Dow Pharmaceuticals, Inc.*, but noted that the *Daubert* criteria argued against the reliability of the methodology. On the plaintiffs’ motion for reconsideration, the court agreed that *Daubert* should be applied flexibly, that its factors were simply illustrative, and that other factors could argue in favor of admissibility (*Kumho Tire v. Carmichael*).

The court affirmed its earlier order because it found insufficient indications of the reliability of the methodology, yet, in reversing the decision, the Eleventh Circuit held that the District Court had erred as a matter of law in applying *Daubert*. Believing that *Daubert* was limiting to the scientific context, the court held that the *Daubert* factors did not apply to testimony characterized as skill- or experience-based (*Kumho Tire v. Carmichael*). In determining whether particular expert testimony is reliable, the trial court should consider the specific *Daubert* factors where they are reasonable measures of reliability (*Kumho Tire v. Carmichael*). Reasonable measures of reliability in a particular case are a matter that the law grants the trial judge broad latitude to determine.

From this case, the Supreme Court modified the requirements of *Daubert* and established guidelines as follows: 1) expert witnesses can develop theories based on their observations and experience and then apply those theories to the case before the court, 2) all forms of expert witness testimony should be evaluated with the same level of rigor, and 3) the *Daubert* standards are flexible guidelines that may not be applicable in every instance of expert witness testimony (Grivas & Komar, 2008, p. 772). As a result, judges have the latitude to apply all, some, or none of the *Daubert* standards, depending on the context of the testimony (Grivas & Komar, 2008, p. 772). From this decision, the FRE Rule was expanded to grant all expert witnesses, not just “scientific” ones, testimonial
latitude unavailable to other witnesses on the assumption that the expert’s opinion will have a reliable basis in the knowledge and experience of his/her discipline (Kumho Tire v. Carmichael).

Although the Kumho decision seems to be more lax than Daubert, it has been argued that Kumho represents an acknowledgment by the court that science is too complex to evaluate with a single set of standards (Haack, 2005; Grivas & Komar, 2008). Kumho is not inconsistent with and does not lessen the value of the Daubert decision. For example, the Supreme Court noted that a judge should consider the Daubert standards in situations where they are a reasonable measure of reliability of expert testimony (Grivas & Komer, 2008, p. 773).

In 2001, after other cases affirmed the changes resulting from Daubert, such as Kumho Tire v. Carmichael (119 S.Ct. 1167 [1999]), FRE Rule 702 was appended to emphasize the connection between the data and methods used and served to focus on the admissibility of the conclusions, as opposed to the credentials of the experts. Replicable methods are essential and specify direct results, rather than analogies. In that vein, data analyses using quantitative methods are preferred over those employing qualitative methods (Dirkmaat et al., 2008; Feinberg et al., 1995). The testability and reliability of methods are necessary to establish that the conclusions are objectively arrived at rather than subjectively determined. In essence, Rule 702 merely reminds us that scientific conclusions must be based on accepted scientific principles (Dirkmaat et al., 2008; Feinberg et al., 1995).
Standards Used in Forensic Anthropology

At the request of the United States Congress, the National Academy of Science (NAS) assembled a group of scientific and legal experts to assess the state of forensic science in the United States. In 2009, the National Academy of Sciences (NAS) published a report titled, “Strengthening Forensic Science: A Path Forward”, which highlighted several problem areas and challenges faced by forensic scientists and crime laboratories. One key area addressed in the report was the need for all crime laboratories to be accredited by an external agency, such as the American Society of Crime Laboratory Directors Laboratory-Accreditation Board (ASCLD-LAB) (Love & Warren, 2013, p. 12). As of September 2014, the C.A. Pound Human Identification Laboratory at the University of Florida is the only academic forensic anthropology laboratory to achieve certification or accreditation based on International Organization for Standardization (ISO) 17025 and Supplemental Standards (Christensen, 2014, p. 21). The Joint POW/MIA Accounting Command’s Central Identification Laboratory (CIL) with the Department of Defense (DOD) is the only other ASCLD-LAB accredited forensic anthropology laboratory. The expanding role of forensic anthropology in medical examiner’s offices, crime laboratories, and governmental agencies has heightened the need for such accreditation (Love & Warren, 2013, p. 12). The Scientific Working Group for Forensic Anthropology (SWGANTH) recommends that forensic anthropologists be certified by a Forensic Specialties Accredited Board-accredited organization such as the American Board of Forensic Anthropology (ABFA), if and when available. Nevertheless, there is no nationally required certification to practice forensic anthropology.
Furthermore, there are no universally enforced standard operating procedures (SOPs) for physical anthropologists. Each individual laboratory maintains its own particular SOPs.

Many forensic anthropologists follow the *Standards for Data Collection from Human Skeletal Remains* by Buikstra and Ubelaker (1994). Contemporary journal articles, however, may introduce methods that the authors believe to be more suitable to their research, which diverge from these standards. In 2008, the FBI and Department of Defense Central Identification Laboratory cosponsored the creation of the Scientific Working Group for Forensic Anthropology (SWGANTH) to develop best-practices guidelines and establish minimum standards for the Forensic Anthropology discipline. The guidelines were published between 2010 and 2013 and cover a range of areas from professionalism to best practices of applying specific methods of identification. The pertinent SWGANTH guidelines for ancestry assessment (race estimation) and statistical methods are outlined below. The complete documents can be downloaded from www.swghanth.org/products--drafts.html.

In June of 2014, the National Institute of Standards and Technology (NIST) and the Department of Justice (DOJ) established the Forensic Science Standards Board (FSSB), to serve as the governing board for the Organization of Scientific Area Committees (OSAC) (National Institute of Science and Technology, 2014). The OSAC structure will take up the work of the Scientific Working Groups, which will no longer be supported by the DOJ (AAFS listserv communication, September 24, 2014). Members were recently appointed to the Crime Scene/Death Investigation section of the OSAC in September of 2014, which will be responsible for promulgating standards for Forensic Anthropology. However, due to the fact that the FSSB is in its early stages and no
standards have been released as of the publication of this thesis, this research will follow
the best-practices guidelines set forth by SWGANTH. Refer to
www.nist.gov/forensics/osac/index.cfm for the most current information regarding the
scientific standards for forensic anthropology.

Statistical Methods

Statistical models employed for hypothesis testing are only as good as the
reference sample upon which the data are based, and the adequacy of reference
samples is critical to the legitimacy of statistical results. Therefore, samples
should be large and randomly drawn from their population and should be relevant
to the case at hand (e.g., same temporal period, sex, age, and ancestry). Model
performance should ideally be tested using an independent sample (i.e., holdout
group). If the reference sample used to derive the estimation model is used for
validation, appropriate statistical methods should be employed to minimize bias
(e.g., leave-one-out classification). The assumptions of the methods (e.g.,
normality, equal variances, independence of samples) should be met by the data.
Any potential problems arising from errors (e.g., intraobserver, interobserver)
and/or uncertainty of measurements (e.g., sampling, preservation state) that may
affect the accuracy and/or reliability of the test results should be recorded.
Multivariate statistics should typically be employed to: maximize the ability to
detect differences, explain variation within the data set, mitigate problems of
correlation among variables, and reduce the opportunity for Type I error. Care
should be taken to avoid model over-fitting, especially when employing small
samples. It is vital to point out that classification functions will always indicate
the most similar group or individual. Therefore, when an unknown’s true group or reference data is not represented in the reference sample(s), analysts should be cognizant that misleading results may be produced. Since atypical individuals may be encountered in forensic casework, care should be exercised when interpreting typicality probabilities. If the typicality probabilities for all groups are low and the reference samples are truly applicable, a thorough check for measurement errors is prudent. In many circumstances, multiple methods will exist for estimating the same variable. These methods should, therefore, be applied in a prioritized order depending upon their utility (i.e., reliability, applicability, and probative value). Greatest interpretive weight should be given to estimation models with high correlations and low standard errors. (Statistical Methods, SWGANth, 2013b)

**Ancestry (Race) Assessment**

Measurements used in race assessment generally involve cranial size and shape, though post-crania also provide robust estimates (Ancestry Assessment, SWGANth, 2013a). Appropriate measuring instruments, standards and/or software should be employed. As with morphological traits, multiple measurements and multivariate statistical techniques provide greater validity in ancestry assessments. Measurements can be used in ancestry assessment with 1) appropriate reference groups, 2) clear measurement definitions, and 3) appropriate statistical methods of classification. The following practices are recommended by SWGANth:

Ancestry assessment should be made independently of suspected or presumptive identifications. Methods should be based on large appropriate sex- and period-
specific standards/samples following the guidelines for statistical methods. Measurements and non-metric observations should always be recorded, even if samples for DNA analyses will be taken. Adequate traits should be used with appropriate statistical methods of classification. Metric or non-metric trait definitions should be known as well as the appropriate ways to score and record them. Probabilities of certainty should be expressed when reporting ancestry assessments, especially because ancestry assessments should never be given with 100% certainty as expressed in posterior probabilities. All appropriate and available groups should be used for the case, but it is important to remember that the most appropriate reference samples may be unavailable for analysis. The appropriate statistical methods employed in ancestry assessment should be known for proper interpretation of the results. Terminology should be used that is widely accepted within the local vernacular, e.g. these remains likely represent a person who self-identified as Black during life. Anonymized raw data should be submitted to open-access anthropological data repositories to support future research and methodological improvement. (Ancestry Assessment, SWGANTH, 2013a)

Although these standards are currently voluntary and no one agency is in charge of enforcing them, it is understood that the primary goals of forensic anthropology are to aid in the identification of human remains in forensic contexts (Dirkmaat et al., 2008, p. 34) and to identify other factors such as evidence of trauma, and the post-mortem interval to better understand the circumstances surrounding the individual’s death.
Validity, or the measure of how well test results produce correct answers, is to be measured when possible by directly estimated error rates (Dirkmaat et al, 2008, p. 35). Innovative methods can be employed if they can be independently tested (Feinberg et al., 1995). Forensic anthropologists have responded to the Daubert decision by publishing validation studies of previously accepted methods, some of which were found wanting (Steadman et al., 2006; Dirkmaat et al., 2008). For example:

Forensic anthropologists are well versed in methods of personal identification of human skeletal remains, but historically have had very little exposure to statistical methods that quantify the probability of a correct identification. When pressed for a declaration on the strength of an identification, many anthropologists rely on traditional statements that have little legal meaning and no statistical value, e.g. “with a reasonable degree of scientific certainty”. (Steadman et al., 2006, p.15)

Many of the methods employed by forensic anthropologists do not conform to the rigorous tests of reliability set forth by Daubert because they are qualitatively derived. Non-metric methods of estimating sex, age, or race would not be admissible in court under the Daubert criteria because there is no definitive test to assess error rates or reproducibility. Some of these methods include observational assessments of the morphology of the femur and skull to estimate race. Stewart (1979), for example, observed that the femora of African Americans are less curved anteroposteriorly, more flattened anteroposteriorly in midshaft, and have less anterior twist (torsion) at the upper end compared to Caucasian Americans (p. 232). He also presented evidence that the skulls of African Americans have lower orbits, wider interorbital distance, less salient nasal bones, a broader and less sharply defined nasal aperture, and more pronounced
alveolar prognathism than Caucasian Americans (Stewart, 1979, p. 231). He noted, however, that “most African Americans today do not show such extreme African traits; indeed they are uncommon in the Terry Collection. Instead, most African American skulls tend to look more or less like the white stereotype. It is because of this situation that the forensic anthropologist must rely on his experience in deciding for a particular skeleton which racial attribution to make” (Stewart, 1979, p. 231). Hence, these methods would not meet the Daubert criteria for admissible evidence because of their subjective nature, even if they had been subject to peer review and are accepted by the scientific community.

The Kumho decision, therefore, allows for expert testimony based on more observable differences that may not be directly measureable. It appears that Kumho, not Daubert, has a greater impact on most anthropological testimony. Although the admissibility of expert testimony has become tougher, the Kumho decision allows anthropologists latitude in presenting evidence that cannot be empirically tested, provided the analysis is both scientific and rigorous (Grivas & Komer, 2008, p. 774). Thus, judges should consider whether the Daubert standard is appropriate, first, and then consider other factors that may help in the determination of reliability and relevancy to the case at hand (Grivas & Komer, 2008, p. 773).

It is important that methods showing potential to be tested for reliability, reproducibility, and specific error rates be rigorously evaluated with regard to the Daubert criteria so that methods appearing to be sound, but which may not conform to every criterion, may be presented more thoroughly to a judge.
Race Determination

The ability to determine racial characteristics from human skeletal remains is one of the founding principles of physical anthropology. Popular conceptualizations of race were based on externally visible traits, e.g., skin color, features of the face, the shape and size of the head and body, and the underlying skeleton (“AAPA Statement on Biological Aspects of Race”, 1998, p. 714) and these phenotypic traits have been used to classify individuals into racial groupings. These categories of race are rooted in the scientific traditions of the 19th century, and in even earlier philosophical traditions, which presumed that the immutable visible traits could predict the measure of all other traits in an individual or a population. Such notions have often been used to support racist doctrines (“AAPA Statement on Biological Aspects of Race”, 1998, p. 714.), and because of this, the question of biological race as a tool for describing human biological variation has a long history of debate in physical anthropology (Relethford, 2009, p. 16).

For the first half of the 20th century, biological anthropology stagnated in a state in which racial typology was its major theoretical and methodological focus (Armelagos & Gerven, 2003). Arguments for and against application of the race concept to humanity have often focused on the ability to accurately classify individuals into different racial groupings (Relethford, 2009, p. 19). Some physical anthropologists regard human races as oversimplified or nonsensical constructs (Brace, 1964; Cartmill, 1998; Caspari, 2003; Goodman & Armelagos, 1996; Keita & Kittles, 1997; Littlefield, Lieberman, & Reynolds, 1982, Livingstone, 1962; Marks, 1995; Montagu, 1942a, 1942b), while others believe that racial classifications reflect certain facts of human biology and that it is possible to provide racial identifications with a fair degree of certainty (Derry, 1923;
DiBennardo & Taylor, 1983; Handa et al., 2008; Hedlicka, 1920; Hinkes, 1993; Hooten, 1926; İşcan, 1983). This section will discuss the ongoing controversy surrounding the race concept from the perspective of physical anthropologists, the limitations of racial classification, and will provide background information on the proposed methods of race determination using the bones of the pelvic girdle and femur.

The Race Controversy

Historically, biological race was defined as a phenotypically and/or geographically distinctive sub-specific group, possessing characteristic phenotypic and gene frequencies that distinguish it from other such groups (Darwin, [1859] 1910, as cited in Pigliucci & Kaplan, 2003, p. 1162). In 1902, at the inception of the American Anthropology Association (AAA), most anthropologists considered “race” to represent the way the human species was internally subdivided (Caspari, 2003, p. 65). It was widely held that these biological subdivisions corresponded to the social meanings of race, linking physical and behavioral characteristics. Throughout the 20th century, race also had an evolutionary component. Races were effectively thought of as clades, and differences between populations were explained as a product of poorly understood evolutionary processes (Caspari, 2003, p. 65). Then, in 1962, Carleton Coon published The Origin of Races, which suggested that five major races of humans evolved in parallel from Homo erectus at five different times and different rates, correlating with the level of “cultural achievement” of different racial groups. Coon contended that Caucasoids and Mongoloids crossed this threshold considerably earlier than Africans (Negroids and Capoids) and Australians (Australoids) – a claim that clearly has social implications (Caspari, 2003, p. 65). Coon’s book spawned a debate, which ultimately helped usher in a
new physical anthropology incorporating various subjects from primates to genetics, whose populational approaches were incompatible with the essentialism central to the race concept (Caspari, 2003, p.65).

Modern physical anthropology recognizes the major features of human biological diversity as polymorphic, clinal, and culturally mediated. However, the concept of race is still vehemently debated among anthropologists. There are three predominant perspectives held by anthropologists: 1) those who define races in terms of the typical or average properties of regional human populations – geographically delimited biological subspecies (Cartmill, 1998, p. 652); 2) those who reject the concept of biological race in favor of the view that races are social constructs that have no basis in classifying human populations (Andreasen, 1998, p. 201); and 3) those who believe that human races in the biological sense of local populations adapted to particular environments, do in fact exist, yet human ecotypic races do not in general correspond with “folk” racial categories (Pigliucci & Kaplan, 2003, p.1161). The official position of the American Association of Physical Anthropologists (AAPA) states that:

All living populations in each of the earth’s geographic areas have evolved from a common ancestral group over the same amount of time and that humanity cannot be classified into discrete geographic categories with absolute boundaries. There is no necessary concordance between biological characteristics and culturally defined groups. Generally, the traits used to characterize a population are either independently inherited or show only varying degrees of association with one another within each population. Therefore, the combination of these traits in an individual very commonly deviates from the average combination in the
population, which renders untenable the idea of discrete races made up chiefly of typical representatives (“AAPA Statement on Biological Aspects of Race”, 1998, p. 714).

Nonetheless, due to pressure from law enforcement officials who insist on “knowing” the race of unknowns, forensic anthropology has been much more reluctant to divorce itself from the premodern partitioning of human biological variation into races, despite the fact that in genetic markers and skeletal morphology human variation is quantitatively greater within than between major geographic regions or races (Lewontin, 1972; Relethford, 1994; Smay & Armelagos, 2000; Stoneking, 1993; Williams, Belcher, & Armelagos, 2005). Currently, the terms “biological affinity” and “ancestry” are used as alternatives to, or interchangeably with, “race”. The term “ancestry” is used frequently in population genetics to describe evolutionary or genetic lines of decent, effectively replacing phenotypic traits used in racial typologies (e.g., skin color) with the tracking of random mutations shared by specific populations.

The predominant studies of human population genetics follow specific genetic variations that affect the risk of disease in different ethnic groups (Weiss, 1995, p. 318). However, evaluating race from a genetic perspective seems to further complicate the debate because the typological methods of classifying other organisms seem to break down when used for human populations. By most accounts, the level of variation is such that within even a small local population, there is about 85-90% as much genetic variation as there is in the entire human species (Weiss, 1995, p. 316). Geneticist Alan Templeton (1998) noted that, “subspecies do not exist in humans” and emphasized that tree models do not adequately describe human population relationships (p. 646).
Furthermore, environmental changes can play a significant role in both phenotypic and genotypic adaptations of human populations. These changes can result in either genetic mutation to heritable genes, or chemical modifications to the DNA molecule or histones. Epigenetic information is stored through DNA methylation and histone acetylation, and control heritable states of gene expression, which either inhibits or allows gene expression without changing the genome. The epigenome is influenced by both external and internal factors. Smoking habits, physical activity, and diet are external factors proposed to have long-term effects on epigenetic modifications, while internal factors include small defects in transmitting epigenetic information through successive cell divisions (Fraga et al., 2005, p. 10609). At this time it is virtually impossible to parse the effects of genetic and environmental effects on human phenotypes to delineate human populations. Thus, for the purposes of this research, “race” will be used to stress the belief that simply changing the terminology does not change the underlying controversy at the heart of the race concept.

Despite the issues associated with racial classification, physical anthropologists continue to study morphological differences in human skeletal remains in order to separate members of human populations into distinct groupings such as age, sex, and race. Forensic anthropologists utilize these differences to identify unknown remains for medico-legal death investigations. For this reason, it is important that the methods by which identifications are determined are valid and accepted by the scientific community.

Limitations of Racial Classifications

Metric analysis of the human pelvis for identification has predominantly focused on morphological differences between the ages and sexes. Racial factors have typically
been incorporated to support sex determinations but were not the primary research topic (Benazzi, Maestri, Parisini, Vecchi, & Gruppioni, 2009; DiBennardo & Taylor, 1983; Hinkes, 2009; Letterman, 1941; Pellico & Fernandez Camacho, 1992). The majority of research assessing race estimation has concentrated on the skeletal morphology of the skull and face. George Gill argued that differences in skeletal features of the face alone are sufficient to allow separation of over 75% of the members of one of the five major racial groups (Mongoloid, American Indian, Caucasoid, Polynesian, and Negroid) from members of all others (Gill, 1986, p. 149). However, it is not guaranteed that investigators will recover skulls in historic or forensic settings due to intentional separation of the head by a killer, or post-mortem taphonomic events such as animal scavenging. Therefore, it is crucial to analyze post-cranial skeletal elements for potential indicators of racial differences. The following literature review attempts to examine the potential usefulness of the pelvic girdle for positive identification of race using metric analysis. It will also review the statistical analyses used to assess whether there is adequate evidence to exhibit confidence in the methods for expert witness testimony under the Daubert criteria.

According to Hinkes (1993), the most difficult assessment in the biological profile is often race. When the most obvious racial cues are removed, such as skin color, hair morphology, and eye shape, the remaining evidence can be ambiguous (Hinkes, 1993, p. 48). Problems are compounded when individuals who may be classified in the same race vary greatly in physical appearance. For a trait to be racially diagnostic, there must be a geographic component: high frequency in one part of the world, low in others (Hinkes, 1993, p. 49). For a trait to be a useful racial marker—be it a visual observation or a
metric calculation—it must truly discriminate among populations, and there must be a reliable way of comparing a forensic specimen to some norm (Brues, 1990). There are few if any population specific markers, and the amount of admixture has increased rapidly in recent years (Hinkes, 1993, p.48), especially in places like the United States where different racial groups live in close proximity to each other. Furthermore, there has been a secular change occurring in pelvic dimensions since human prehistory (Angel, 1976). Nevertheless, an assessment of racial affinity must be made with some degree of certainty, if the biological remains are to be placed in the antemortem social context (Hinkes, 1993, p. 48).

In order to achieve the most reliable results, population studies should utilize individuals from the same relative time period to minimize the potential effects of secular change. The forces driving secular change are usually considered to be changes in nutritional and disease environments (Jantz & Jantz, 1999, p. 66). The period between 1800-1970 showed a notable positive secular trend in Caucasian American males, in which they gained more than twice as much height as both Caucasian American and African American females. This may reflect differences in sensitivity to environmental changes compared to Caucasian American females and African Americans of either sex (Jantz & Jantz, 1999, p. 65). It is helpful to obtain skeletal samples from individuals of known age, sex, and race, as well as year of birth. For forensic cases, it is suggested that the most contemporary skeletal collections be used. It is also suggested that research be continually updated in order to remain accurate.
Before reviewing results obtained through measuring the features of the pelvis, sacrum, and femur, it is important to discuss reassembly methods of the pelvis for accurately gathering the necessary measurements. Bonneau et al. (2012) developed a standard method to correctly reassemble dry pelvic bones utilizing modeling clay to account for the absence of cartilaginous tissues that make up the two sacroiliac joints and the pubic symphysis, with rubber bands placed in strategic positions that exploit the biomechanical properties of the pelvis (p. 139). They also established that there was no statistically significant effect of sex on the mediolateral thickness of both the sacroiliac joint – estimated based on the sacroiliac breadth – and on the pubic symphysis (P > 0.05) (Bonneau et al., 2012, p. 145).

Obstetrically-oriented radiographical investigations have shown that there are metrical differences among human populations, especially in the dimensions of the pelvic inlet (Aiman, 1976; İşcan, 1983; Scheyer, 1934; Torpin, 1951). However, a study by Todd (1929) on a cadaveric population pointed out that the differences between African Americans and Caucasian Americans are small. Of the research that has been conducted on the pelvis for race estimation, the initial studies focused on the broader ilium, ischium, and pubic bones – specifically, the biiliac breadth, transverse breadth, and antero-posterior height of the reassembled pelvis (İşcan, 1983, p. 205). İşcan (1983) obtained predictive accuracy of 88% using discriminant function analysis with measurements from only these three features. He found that pelves of the Caucasian American population were larger than those of American Indians and African American populations (p. 205), which is consistent with the findings of Howells and Hotelling (1936). Furthermore,
females seem to show better predictive results than do males (İşcan, 1983, p. 206). Specifically, Caucasian Americans were typically shown to have significantly wider biiliac and transverse breadths than African Americans. Caucasians Americans also had significantly longer antero-posterior heights compared to African Americans (İşcan, 1983); however, there is much overlap within just one standard deviation, which may reduce its efficacy.

Due to the large size of the ilium, there are high rates of damage to these features in historical contexts (Taylor & DiBennardo, 1984), which limit sample sizes for the development of standards. For this reason, other attributes of the human pelvis should be assessed for possible racial differences (DiBennardo & Taylor, 1983). Loder, Mehbod, Meyer, and Meisterling (2003) have looked at the hip joint, concluding that there seemed to be significant variation with regards to acetabular depth. Thus, it is reasonable to hypothesize that this feature could be used to determine race in a forensic setting, assuming the magnitude is large enough to avoid intra- and inter-observer error.

Other research has included measurements of the sacrum in conjunction with the innominate to incorporate the sacral contributions to the pelvic girdle. Davivongs (1963) combined measurements across the innominates and sacra of Australian Aborigines and compared the findings from his research on sex differentiating features of the pelvic girdle to similar studies of other racial groups to ascertain potential differences between those groups. Unfortunately, the sacral measurements were only used to compare the two sexes and there was no information provided for other racial groups. Comparison of pubic length, ischial length, and ischium-pubis index, however, showed potential significant differences between Caucasian American and African American groups
When compared to other racial groups, the figures for the Australian aborigines seemed to be smaller than those of others. However, the differences were not great and were deemed insufficient for use as race discrimination (Davivongs, 1963).

In a similar study utilizing analysis of variance, African American women were shown to have smaller posterior and total pelvic areas, narrower transverse diameters of the bony pelvis, and significantly shorter sacra than Caucasian American women (Handa et al., 2008, p. 5). Some of the observed differences were significant but small in absolute magnitude; for example, the difference between the mean length of the sacrum in African American and Caucasian American women was 0.4cm (Handa et al., 2008).

The nature of the sacral anatomical orientation (SAO) is also of considerable anthropological importance (Peleg et al., 2007). The association of sex, ancestry, and age with sacral inclination is still unclear (Amonoo-Kuofi, 1992; Ferdinand & Fox, 1985; Hammberg & Wood, 2003; Hanson, Bridwell, Rhee, & Lenke, 2002; Legaye, Duval-Beaupere, Hecquet, & Marty, 1998; Monser, Bryan, Stull, & Shippee, 1989; Peleg et al., 2007). Peleg et al. (2007) found that lower sacral angle correlated with a more vertically oriented superior articular surface of the first sacral element (S1), indicating a more horizontally oriented sacrum. The reliability of the measurement for SAO angle was high, and intra- and inter-observer reliability had values < 0.001 (Peleg et al., 2007). No significant differences in SAO were found between males and females, regardless of ethnic origin (Peleg et al., 2007). It was also found that the sacrum becomes more horizontally oriented with age. Questions have arisen concerning real or pseudo-increased lumbosacral curvature (lordosis) in African Americans compared with Caucasian Americans. Many researchers have stated that the “greater” lumbosacral angle
seen in African Americans is, in fact, an optical illusion created by the more prominent gluteal muscles and increased subcutaneous adipose tissue in this region (Ferdinand & Fox, 1985; Monser et al., 1989; Peleg et al., 2007; Von Lackum, 1924). Similar lumbar lordosis was found in African Americans and Caucasian Americans showing that SAO is also proportional between both ethnic groups (Ferdinand & Fox, 1985; Monser et al., 1989; Peleg et al., 2007).

However, due to the scarce research using this pelvic feature, it is possible that SAO could be combined with other sacral or pelvic features to determine race. The most discriminating variables of the sacrum for sex determination were the antero-posterior dimension of the S1 body and transverse breadth of the S1 body for both races when race was known. When race was assumed to be unknown, classification accuracy ranged from 54% to 78% (Patel, Gupta, Singel, & Shah, 2005, p. 7). Although the research conducted by Patel et al. (2005) was aimed at sexual dimorphism of the sacrum, it showed that there are differences among human populations, which influence predictability of sex.

The use of a combination of measurements from multiple skeletal elements has been a successful method to estimate race from both the cranial and postcranial skeleton. There are three common analytical procedures that utilize multiple measurements to determine an individual’s membership into a specific group, e.g., sex or race. The simplest method compares each measurement to the sample population means and standard deviations calculated from skeletal remains of known origin. The second method involves the calculation of specific indices, which attempt to establish trends in relationships between skeletal elements. Davivongs (1963), for example, developed various indices from measurements of the innominate and sacrum to use for sex
determination (p. 453). The third method involves multiple discriminant function analysis to predict group membership by assessing multiple variables sequentially in order of their contribution to the discriminant function. İşcan (1983) reported predictive accuracy up to 88% utilizing three variables from the reconstructed pelvic girdle, while DiBennardo and Taylor (1983) obtained predictive accuracy as high as 95% utilizing 15 dimensions of the innominate and femur. DiBennardo and Taylor (1983) attributed the increase in their accuracy over İşcan’s findings to the combined use of the innominate and femur (p. 310), which permits a multivariate expression of the long-noted racial difference in the proportion of lower limb length to torso length (DiBennardo & Taylor, 1983; Krogman, 1962). To test this assumption, they ran an additional discriminant analysis with only femoral length and iliac height as discriminators. The overall accuracy of prediction (race and sex combined) plummeted to 64% (DiBennardo & Taylor, 1983, p. 310). Most of the misclassifications, however, were for sex within each race, while race was predicted with an accuracy of 87%. In other words, the combination of innominate and femoral lengths is primarily a race discriminator (DiBennardo & Taylor, 1983, p. 310). A number of studies have shown marked racial differences in the femur including the intercondylar height, antero-posterior diameter of the proximal femur, the degree of flatness of the proximal femur, and torsion of the femoral neck (Gill, 2001, p. 791). The racial differences emphasized by DiBennardo and Taylor’s (1983) results showed that although Caucasian Americans displayed greater size and robusticity in the innominates, exclusive of joint size (acetabular diameter), the African American femora were longer with more gracile shafts (p. 308).
Although significant differences have been shown to exist within the features of the pelvis, sacrum, and femur, no information was provided as to the magnitude of the differences or the confidence by which one could accurately identify race. There does not seem to be sufficiently large differences in any single measurement to lead to conclusive differentiation of racial groups, especially given that approximately 95% of the sample values lie within two standard deviations of the means. Further assessment of the discriminant function analyses used by these researchers is needed to verify the application of the methods under the Daubert criteria.

In summary, contemporary studies have observed increased accuracy in sex determination when race is known, have established discriminant function analyses to simultaneously assess sex and race, and have hypothesized that racial determinants can be found in the pelvic girdle (DiBennardo & Taylor, 1983; Handa et al., 2008; Hanson, Magnusson, & Simonsen, 1998; Hinkes, 2009; İşcan, 1983; Maruyama, Feinberg, Capello, & D’Antonio, 2001; Peleg et al., 2007; Taylor & DiBennardo, 1984). It is obvious through the review of these articles that more research is needed to assess whether the acetabulum, sacrum and femur can be used to determine race of an individual. Additionally, the correlation among these features could give more insight into morphological differences among racial groups. However, if there is no significant statistical correlation between these traits and racial determinations, it is still vitally important that the research be completed and reported so that other researchers have the ability to utilize the information. No previous research has been found that expressly studied all of the elements listed above in conjunction with one another in an attempt to correlate them with race markers.
CHAPTER III
MATERIALS AND METHODS

This chapter will present the materials and methods selected from Bonneau et al. (2012), Davivongs (1963), DiBennardo and Taylor (1983), İşcan (1983), and Peleg (2007) to evaluate their admissibility as evidence in a court of law under the Daubert guidelines for expert witness testimony. Original methods were also developed for this research as potential supplements to the established methods and are described below. The criteria for sample selection from the William Bass Donated Skeletal Collection and the Robert J. Terry Skeletal Collection are given along with the sample sizes for each population. Results from the literature are provided for comparison. Finally, statistical procedures and indices utilized for data analysis are discussed.

Skeletal Collections

This research requires a skeletal collection with known demographic information in order to compare its findings to those of prior research methods and results. It is important that age, year of birth, sex, and race be known to get an accurate picture of variation within racial groups as well as to ensure contemporary sample populations. The sample populations for this research are comprised of skeletal remains from the Robert J. Terry Skeletal Collection housed at the Smithsonian Institution’s Museum Support Center in Suitland, MD and the William Bass Donated Skeletal Collection at the University of Tennessee. The Robert J. Terry Skeletal Collection was chosen because both DiBennardo and Taylor (1983) and İşcan (1983) utilized this collection for the development of their discriminant functions. In an attempt to adequately assess the
validity of the methods developed from previous research, this study strove to keep as many variables constant with the prior research as possible.

The Terry collection is the result of the joint efforts of Dr. Robert J. Terry and Dr. Mildred Trotter over six decades at the medical school at Washington University in St. Louis, Missouri (Albanese, 2003, p. 2). It was created in 1927 and is currently comprised of approximately 1729 individuals of known age, sex, race, cause of death and antemortem pathology (Novak, 2007, p. 14). The age at death of individuals in the collection ranges from 14 to 102 years of age with the majority of individuals being older than 45 years of age. Years of birth range from 1828 to 1943 (Hunt & Albanese, 2005, p. 415).

There are concerns, however, that the Robert J. Terry skeletal collection and collections like it are no longer representative of populations in the United States and may not be useful for the development of forensic identification methods (Albanese, 2003, p. 2). In spite of these concerns, it is believed that with careful sampling and consideration of the demographic data (age, year of birth, etc.) and the historical details such as socioeconomic, political and legal issues associated with the construction of the collection, representativeness of human variation can be maximized and bias can be minimized (Albanese, 2003, p. 2). Therefore, to address these concerns, the results from the Robert J. Terry Skeletal Collection will be compared to those of the more contemporary William Bass Donated Skeletal Collection.

The William Bass Donated Collection was chosen, in part, to evaluate the concerns that the Robert J. Terry Collection is no longer representative of contemporary populations, and because a large proportion of the Caucasian American remains in the
Robert J. Terry Collection did not meet the selection criteria because their years of birth were earlier than 1890. The William Bass Donated Collection was created in 1981 as a result of Dr. William Bass’ establishment of a body donation program to further his research on time since death (http://fac.utk.edu/collection.html, para. 1). This program provides the necessary cadavers needed to conduct research at the Anthropological Research Facility at the University of Tennessee. The collection is continually growing and currently holds just under 1000 individuals of known age, sex, and race distribution. Birth-years range from 1892 to 2011, and most individuals have birth-years after 1940 (‘William Bass Donated Skeletal Collection,’ para. 2). Age at death ranges from 16 to 100 years. Many of the early donations to the program were made by medical examiners, but have been a declining aspect of the donation program. Currently, over two-thirds of the donations are from families of decedents or directly by individuals (‘William Bass Donated Skeletal Collection,’ para. 2).

Sample Selection

Some 100 individuals were chosen from the Robert J. Terry Skeletal Collection and 100 individuals were chosen from the William Bass Skeletal Collection based on racial classification, sex, a year of birth after 1890, age at death, and completeness of skeletal preservation. The individuals were selected so that there would be 50 individuals belonging to each of four subgroups: African American females, African American males, Caucasian American females, and Caucasian American males. Within these subgroups, an attempt was made to select the same number of individuals from each of six age groups separated into 10-year increments (and those individuals age 17-19, and 60 and above): 17-19, 20-29, 30-39, 40-49, 50-59, 60+. The purpose of these delineations
is to obtain the largest contemporary sample population possible to control for potential secular change as well as to account for developmental differences within racial groups, which may skew results when all individuals are combined into the larger sample of the population.

Skeletal elements were rejected if they showed signs of pre- or postmortem trauma or pathologies including extreme osteoarthritis, medical implants, or other visible extreme variations in morphology of unknown causes that inhibited measurements. Elements were also excluded if preservation methods resulted in fragile or excessively greasy bones that would not hold up during the reassembly procedure. Sacra were not excluded from the sample if they displayed unilateral or bilateral sacro-iliac fusion, or sacralization unless it obstructed measurements. Individuals displaying damaged sacra or femora were not excluded from the sample when the damaged area did not affect the measurements, or in the event that the right-sided element could be used in its place.

Samples from the Robert J. Terry Collection were first selected from the Microsoft Excel spreadsheet of samples provided by Dr. David Hunt, the collection’s curator, before arriving at the Smithsonian Institution. The samples were organized first by racial classification, then by sex, and then by age at death. Sample selection proceeded down the list, attempting to find approximately eight individuals from each of the 10-year age groups who were born after 1890. It was suspected that some of these samples would not meet the preservation criteria, so a list of backup samples were prepared for each group in an attempt to maximize the available research time in the laboratory. The chosen samples were highlighted in Excel and then reorganized by catalog number to minimize the time required to collect the skeletal remains for measurement.
Alternatively, Dr. Dawnie Steadman, director of the Forensic Anthropology Center at The University of Tennessee, selected the samples from the William Bass Donated Collection according to the selection criteria. Unfortunately, the remains of only eight African American females have been donated to the William Bass Collection, and no more than six met the criteria for this research. This is not expected to affect the results of any of the evaluations in which the combined populations are used, but will definitely affect the comparisons of the two skeletal collections.

Materials

The materials for data collection include two large folder rubber bands, two large envelope rubber bands, Sticky Tack temporary adhesive, large and small digital sliding calipers, digital inside calipers, osteometric board, measuring tape, and digital angle finder. The specific measurements, unless otherwise noted, were taken following the standards outlined by İşcan (1983), DiBennardo and Taylor (1983), Davivongs (1963), Peleg et al. (2007), and Bonneau et al. (2012) to most accurately reproduce their findings.

Methods

The methods for reassembling the pelvis were derived from Bonneau et al. (2012) and Peleg et al. (2007) and presented in Figure 1. Sticky Tack was used to mimic cartilaginous tissues because, unlike plasticine, it does not leave any residue on the bones. The Sticky Tack was rolled into a ball with a diameter roughly the size of a fifty-cent piece. From this, two pieces were pulled off and stretched to a thickness of approximately 2mm and the remaining Sticky Tack was rolled into a cylinder with a diameter around 7mm. The 2mm strips were gently pressed onto the auricular surfaces of the sacrum. Next, the right innominate was affixed to the sacrum at the sacro-iliac joint. The bones
were held together gently as the cylinder was pressed onto the pubic symphysis of the right innominate. The right innominate was braced against the researcher’s chest for extra support while the left innominate was carefully aligned at the auricular surface of the sacrum and then to the pubic symphysis of the right innominate. The three bones were gently pressed together to adhere them to one another. While still holding the reassembled pelvis firmly against the chest, one of the large folder rubber bands was carefully stretched from the right iliac crest to the left ischial tuberosity. Next, the second folder rubber band was stretched from the left iliac crest to the right ischial tuberosity. This process was then repeated with the envelope rubber bands while continuing to hold the pelvic girdle firmly in anatomical position. According to Bonneau et al. (2012), the average thickness of cartilaginous tissue between the pubic symphyses equals 6.84mm and the average thickness at each sacro-iliac joint is approximately 1.3mm (p. 145). The current research discovered that the pelvic girdle typically stayed assembled only when the correct thickness for the individual was achieved and that the reassembled pelvic girdle should be manipulated, regardless of Sticky Tack thickness, until it stays together on its own. Upon measuring, these thicknesses were usually close to the averages reported by Bonneau et al. (2012).

Figure 1. Photograph of a reassembled pelvic girdle.
Measurements

The 32 metric measurements of the pelvic girdle, left innominate, sacrum, and left femur recorded for each individual are defined in Table 1 and shown in Figures 2-8. The reassembled pelvic girdle was measured utilizing the methods described by İşcan (1983). The four İşcan measurements were recorded first and the bones were then disassembled to record the remaining measurements. The method of obtaining the sacral orientation angle was modified from Peleg et al. (2007) to employ a digital angle finder rather than constructing the apparatus used for their research. The other 26 measurements were obtained following the methods outlined in Davivongs (1963) and DiBennardo and Taylor (1983). In addition, six new measurements were developed for this research to assess the potential of other features of the pelvis and femur to determine race or to supplement the methods developed by the other authors. In cases of unilateral and bilateral sacro-iliac fusion, measurements were conducted as carefully as possible to ensure that they were properly recorded.

Peleg et al. Measurement

1. Sacral Angle: Reassembled pelvis is positioned on a flat surface, resting on its anterior-superior iliac spine (ASIS) and the anterior-superior edge of the pubic symphysis. Sacral Angle is then measured with a digital angle finder by setting one leg of the angle finder vertically on the flat surface with the hinge just below and behind the first sacral element. The other leg is then raised – keeping the first leg stationary – until it becomes flush with both the anterior and posterior margins of the first sacral elements. The measurement is then read directly from the readout on the angle finder. This method was modified from Peleg et al. (2007) to utilize the digital angle finder (Figure 2).
İşcan Measurements

1. Biiliac Breadth: Reassembled pelvic girdle is positioned on an osteometric board resting on the superior iliac spine of each innominate and the maximum breadth between the widest portions of the iliac spines is measured (Figure 3 A).

2. Transverse Breadth of the Pelvic Inlet: Reassembled pelvic girdle is positioned upright in anatomical position and the transverse breadth of the pelvic inlet is measured at the widest diameter using large inside calipers (Figure 3 B).

3. Antero-Posterior Breadth of the Pelvic Inlet: Reassembled pelvic girdle is positioned upright and in anatomical position and measured from the sacral promontory to the pubic crest of the left innominate with sliding calipers. This method was modified from İşcan (1983) to utilize the digital angle finder (Figure 3 C).

DiBennardo and Taylor Measurements

1. Maximum Length of the Pelvis: Maximum length of the innominate taken from the superior-most point on the iliac crest to the inferior-most point of the ischium (osteometric board) (Figure 4 D).

2. Acetabulum Vertical Diameter: The diameter of the acetabular rim measured parallel to the axis of the ischium (Figure 4 F)

3. Inferior Pubic Ramus Height: Measured at the maximum constriction on the inferior pubic ramus between the lower margin of the obturator foramen and the lower border of the ramus using sliding calipers (Figure 4 H)

4. Oblique Length of the Pubic Ramus: The distance between the superior point used in measuring the Pubic Ramus minimum height of the inferior pubic ramus and the lowest point on the pubic symphysis using sliding calipers (Figure 4 I)
5. *Iliac Height*: Vertical height of the ilium, from the superior-most point of the iliac crest to the notch in the cotyloid point in the inner border of the lunate articular surface measured with sliding calipers (Figure 5 J).

6. *Pubic Length*: The distance between the cotyloid point in the inner border of the lunate articular surface and symphysis, measured using sliding calipers (Figure 5 K).

7. *Tuberculosymphyseal Length*: The distance between the summit of the pubic tubercle and symphysis (Figure 5 M).

8. *Cotylosciatic Breadth*: Taken perpendicular to the long axis of the ischium, between the midpoint on the inferior “leg” of the greater sciatic notch and the posterior margin of the acetabular rim (Figure 5 N).

9. *Greater Sciatic Notch Height*: The height of the greater sciatic notch measured between the points of Lazorthes: the tubercle of Bouisson and the tip of the ischial spine measured with sliding calipers (Figure 6 P).

10. *Greater Sciatic Notch Position*: The distance from the tip of the ischial spine to the intersection of the line of notch height by the perpendicular dropped to it from the deepest point in the notch (Figure 6 Q).

11. *Symphyseal Angle*: The angle of the pubic symphysis to a line marking the central long axis of the ramus of the pubis and ischium (Figure 7).

12. *Maximum Length of the Femur*: Measured with an osteometric board. Place the medial epicondyle flush against the fixed upright end of the osteometric board and measure to the head, anterior face up (Figure 8 U).
13. *Epicondylar Breadth*: Maximum transverse diameter of the distal end of the femur, with the medial epicondyle against the fixed upright of the measuring board (Figure 8 V).

14. *Circumference at Mid-Shaft of the Femur*: Taken with measuring tape at midpoint of maximum length (Figure 8 W).

15. *Carrying Angle of the Femur*: Measured using a digital angle finder with support from an osteometric board or other fixed implement with a firm 90°. Place the femur on the osteometric board with both epicondyles flush against the fixed upright of the board. Place the digital angle finder square against the board with the hinge flush with the medial epicondyle. Swing one leg of the angle finder out and flush with the mid-shaft, keeping the other leg flush with the board. Be sure that the inside edge of the angle finder is running along the mid-shaft all the way to the epicondyle (Figure 8 X).

*Davinongs Measurements*

1. *Maximum Length of the Pelvis*: Same methods as DiBennardo and Taylor Measurements (Figure 4 D).

2. *Iliac Breadth*: Maximum Width of the iliac blade, measured on an osteometric board (Figure 4 E).

3. *Acetabulum Vertical Diameter*: Same method as DiBennardo and Taylor (Figure 4 F).

4. *Acetabulum Horizontal Diameter*: The diameter of the acetabular rim measured perpendicular with the axis of the ischium (Figure 4 G).

5. *Pubic Length*: Same method as DiBennardo and Taylor (Figure 5 K).
6. **Ischial Length**: Measured from the cotyloid point in the inner lunate surface to the most projecting point on the ischial tuberocity using sliding calipers (Figure 5 L).

7. **Greater Sciatic Notch Height**: Same as DiBennardo and Taylor (Figure 6 P).

8. **Greater Sciatic Notch Position**: Same as DiBennardo and Taylor (Figure 6 Q).

9. **Ilium Chilotic Line**: First the pubo-iliac and auricular points were located. As described by Derry (1923), the pubo-iliac point is situated on the ilio-pectineal line at the site of original union of the pubis and ilium. It is sometimes ill defined and the ilio-pectineal eminence is a useful landmark in that case. The auricular point is on the anterior margin of the auricular facet where this approaches nearest to the pubo-iliac point. A line connecting these two points is projected to the iliac crest and is called the chilotic line. The pelvic portion of the line spans from the ilio-pectineal line to the anterior margin of the auricular facet closest to the pubo-iliac point and is measured using sliding calipers (Figure 6 R).

10. **Sacral Chilotic Line**: Following along the same projected line for the Ilium Chilotic Line, the sacral portion starts at the anterior margin of the auricular facet and extends to the iliac crest. Measured with sliding calipers (Figure 6 S).

11. **Pubic Symphysis Length**: Measured between the superior and inferior margins of the Pubic Symphysis with sliding calipers (Figure 6 T).

12. **Sacrum Max Breadth**: The maximum distance between the anterior and posterior points on the iliac blade using an osteometric board (Figure 9 Y).

13. **Sacrum Max Length**: The maximum distance between the highest point on the iliac crest and the lowest point on the ischium, using an osteometric board (Figure 9 Z).
14. **Mid-Ventral Curved Length of the Sacrum**: The length from the midline of the most superior point on the S1 body to the superior ridge of the Apex, measured along the median line on the curved anterior surface of the bone with a tape measure (Figure 9 AA).

15. **Number of Sacral Elements**: Count the number of sacral elements, excluding coccyx (Figure 9).

16. **Antero-Posterior Diameter of the body of S1**: Measured on the midline of S1 from the most anterior to the most posterior margins (Figure 10 BB).

17. **Transverse Diameter of the body of S1**: Measured perpendicular to the A-P diameter along the midline from the outer-most ridges of the S1 body. Where arthritis or other pathology exists, avoid including any lipping in the measurement (Figure 10 CC).

**New Measurements**

1. **Depth of the Acetabulum**: The maximum depth of the acetabulum. Using a rubber band pulled taut across the midline of the acetabulum, the depth is measured with the sliding arm of the sliding calipers, lining the arm next to, but not touching, the rubber band and finding the deepest area of the acetabulum. Once this position was found, the calipers were opened so that the fixed part of the calipers was flush with the rubber band and the sliding arm of the calipers was placed at the deepest point (Figure 5 O).

2. **Femoral Head Vertical Diameter**: The maximum distance measured, holding the femur in upright anatomical position from the most superior point of the femoral head to the most inferior point of the femoral head where it meets the neck of the femur (Figure 11 DD).
4. **Femur Upper Neck Length**: The distance measured, holding the femur in upright anatomical position, from the superior crest of the femoral head to a point directly across at the base of the greater trochanter, using the inside caliper jaws of sliding calipers (Figure 12).

5. **Femur Lower Neck Length**: The distance measured, holding the femur in reverse anatomical position, from the inferior crest of the femoral head to the intertrochanteric line at the most medial point at the base of the lesser trochanter (Figure 12).

6. **Femoral Head Horizontal Diameter**: The maximum width of the femoral head measured perpendicular to the shaft (Figure 13).

7. **Femoral Neck Angle**: Measured using a digital angle finder. Place the hinge of the digital angle finder on the intertrochanteric line on the anterior surface, slightly closer to the greater trochanter. Line up the inside edge of one arm of the angle finder with the vertical midline of the femoral shaft. Swing the other arm out and line it up with the midline of the head of the femur, making sure that the angle is formed at the intersection between the two midlines (Figure 11 EE).

*Figure 2 Sacral Angle (Adapted from Peleg et al., 2007, AJPA vol. 133, p. 970).*
Figure 3 Pelvic Girdle Measurements (Adapted from Peleg et al., 2007, AJPA vol. 133, p. 170).

Figure 4 Innominate Measurements E-H (Adapted from Davivongs, 1963, AJPA vol. 21 issue 4, p. 444).

Figure 5 Innominate Measurements J-O (Adapted from DiBennardo & Taylor, 1983, AJPA vol. 61, p. 307).
Figure 6 Innominate Measurements P-T (Adapted from Davivongs, 1963, AJPA vol. 21 issue 4, p. 445).

Figure 7 Symphyseal Angle (Adapted from DiBennardo & Taylor, 1983, AJPA vol. 61, p. 307).

Figure 8 Femur Measurements U-X (Adapted from DiBennardo & Taylor, 1983, AJPA vol. 61, p. 308).
Figure 9 Sacrum Measurements Y-AA (Adapted from Davivongs, 1963, AJPA vol. 21 issue 4, p. 444).

Figure 10 Sacrum Measurements BB-CC (Adapted from Davivongs, 1963, AJPA vol. 21 issue 4, p. 445).

Figure 11 New Measurements DD-EE (Adapted from DiBennardo & Taylor, 1983, AJPA vol. 61, p. 308).
Figure 12 New Measurements FF-GG (Adapted from DiBennardo & Taylor, 1983, AJPA vol. 61, p. 308).

Figure 13 New Femur Measurement

Calculations

Indices are calculated following the methods of Davivongs (1963) and are utilized to identify potential relationships between skeletal elements, such as sacral max breadth and sacral max length, which are converted to a ratio and evaluated for group trends. These trends can then be used for classification if they are able to separate members of different groups to a high degree of statistical significance (p < 0.05). The indices developed by Davivongs (1963) were originally used to classify sex, but will be reevaluated for their ability to classify race. Some additional indices were developed for
measurements taken from other research and for the new measurements developed for this research.

Sacral Indices:

Sacral Index = (max breadth/max length) X 100
Curvature Index = (max length/mid-ventral curved length) X 100
Index of Body of S1 = (a-p diameter/trans diameter) X 100
Corporo-Basal Index = (trans diameter/max breadth) X 100

Innominate Indices:

Coxal Index: (iliac breadth/max length) X 100
Ischium-Pubis Index = (pubic length/ischial length) X 100
Index of the Greater Sciatic Notch = (OB length/greatest width) X 100
Chilotic Index = (sacral chilotic line/pelvic chilotic line) X 100

New Indices:

Acetabulum Index 1 = (Horizontal Diameter/Vertical Diameter) X 100
Acetabulum Index 2 = (Horizontal Diameter/Acetabulum Depth) X 100
Femoral Head Index = (Antero-Posterior Height/Medial-Lateral Breadth) X 100
Femoral Neck Index = (Upper Neck Length/Lower Neck Length) X 100

Statistical Analysis

Statistical analysis will be conducted using SPSS and Excel software and will include descriptive statistics, independent samples t-tests, analysis of variance (ANOVA), and multiple discriminant function analysis. Statistical significance for metric evaluations is typically set at 95% confidence, meaning that there would be a 5% probability (p < 0.05) that the difference between groups is caused by chance alone. In order to evaluate
the validity of the methods under the *Daubert* decision, the level of confidence for this research will be set at $p < 0.05$. Magnitudes of statistical significance will be calculated as Cohen’s $d$, and effect-size $r$ or eta squared ($\eta^2$), to be compared to those calculated from previous research. Interpretation of these effect sizes will follow the rules of thumb outlined by Cohen (1988): 1) Cohen’s $d$ – 0.20 is small, 0.50 is medium, 0.80 is large; 2) $r$ – 0.10 is small, 0.30 is medium, and 0.70 is large; 3) eta squared ($\eta^2$) for ANOVA – 0.02 is small, 0.13 is medium, and 0.26 is large (p. 26).

In the event that the methods do not meet this criterion, further analysis will be conducted to evaluate how well the methods meet the other *Daubert* criteria. This will allow for a comprehensive assessment of whether the methods may still be useful in a court of law under the *Kumho* ruling. In addition to testing the validity of the methods, evaluations of reliability and reproducibility will be performed. To address concerns regarding the Robert J. Terry Skeletal Collection, an independent samples t-test will be used to compare the group means of each dimension from the Robert J. Terry Collection to those of the William Bass Donated Collection. Intra- and inter-observer error statistics will be performed to test method reliability and reproducibility. First, the frequencies of the differences between the first and second measurements for each variable will be evaluated and then a paired samples t-test will be conducted to determine the amount of intra-observer error. The level of inter-observer error will be determined by first evaluating each observer’s standard error of the mean for each variable, and then conducting a one-way analysis of variance (ANOVA) to establish whether statistically significant differences exist between the observers.
CHAPTER IV
RESULTS

This chapter presents the results of the investigation to establish validity and reliability of the methods developed by a number of researchers exploring the use of the pelvis in race determination. Each study’s original summarized data and results were provided to directly compare with the results of the replicated methods. Some of the statistical procedures were modified from the original methods when necessary to strengthen or update them to conform to current standards. These modifications were clearly stated and explained. This chapter also assessed new dimensions of the pelvis and femur that were hypothesized to have utility as racial indicators. The Robert J. Terry Skeletal Collection was then compared to the William Bass Donated Skeletal Collection to test its efficacy in the formulation of forensic anthropological methods. Finally, this chapter presents the findings of intra- and inter-observer error studies to examine the reproducibility of the methods.

General Analysis

A general analysis of the statistically significant results reported in previous research of the pelvis (Davivongs, 1963; DiBennardo and Taylor, 1983; İşcan, 1983; Peleg et al., 2007) was conducted, specifically comparing results of African Americans to those of Caucasian Americans. Table 1 presents the magnitudes of the statistically significant differences (Cohen’s d and effect size r), which were calculated from the reported means and standard deviations to update them to conform to current statistical standards and to properly compare them to the current research. Standard deviations were not originally provided for ischial length, pubic length, or the ischium-pubis index. An
approximate standard deviation was calculated for these three measurements using the
range rule, which states that the standard deviation of a sample is approximately equal to
one fourth of the range of the data; in other words, \( s = \frac{\text{maximum} - \text{minimum}}{4} \)
(Ramirez & Cox, 2012, p. 2).

Table 1

*Means, Standard Deviations, and Effect Sizes of Pelvic Elements from Prior Research*

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<th>Variable</th>
<th>C.A. ♂</th>
<th>A.A. ♂</th>
<th>C.A. ♀</th>
<th>A.A. ♀</th>
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<th>Effect Size r</th>
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<td>95.0</td>
<td>♂ 0.77</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>5.3</td>
<td>4.3</td>
<td>6.0</td>
<td>5.5</td>
<td>♀ 0.78</td>
</tr>
<tr>
<td>Biiliac Breadth</td>
<td>Mean</td>
<td>274.0</td>
<td>254.6</td>
<td>278.0</td>
<td>252.8</td>
<td>♂ 1.23</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>16.1</td>
<td>15.3</td>
<td>17.1</td>
<td>16.0</td>
<td>♀ 1.52</td>
</tr>
<tr>
<td>Transverse Breadth</td>
<td>Mean</td>
<td>123.6</td>
<td>112.0</td>
<td>134.0</td>
<td>120.6</td>
<td>♂ 1.52</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>8.0</td>
<td>7.4</td>
<td>8.1</td>
<td>6.8</td>
<td>♀ 1.79</td>
</tr>
<tr>
<td>Antero-Posterior Breadth</td>
<td>Mean</td>
<td>108.7</td>
<td>102.0</td>
<td>116.6</td>
<td>110.8</td>
<td>♂ 0.74</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>9.6</td>
<td>8.5</td>
<td>10.5</td>
<td>9.3</td>
<td>♀ 0.59</td>
</tr>
</tbody>
</table>

Note. * SD was calculated from the range using the “range rule”.

The results of these calculations indicate that the differences between African American and Caucasian American males are greater across more variables than those differences between the females of the same race groups. Of the 15 variables, males displayed high Cohen’s d scores for eight variables, whereas only five variables showed high Cohen’s d scores for females. However, neither of the groups displayed high effect size r-values for any of the statistically significant results. Therefore, while there appear to be morphological differences among African Americans and Caucasian Americans, it cannot be stated with certainty that these differences are affected by race. The subsequent sections will further examine the methods provided in the literature to determine whether they can be effectively used to classify unknown individuals by race.
Peleg et al. (2007) Measurements

Peleg et al. (2007) investigated the anthropological importance of the sacral angle, specifically with regards to its utility in determining age, sex, and race. For the purposes of this study, sacral angle was evaluated for its utility as a race indicator. The original descriptive statistics reported by Peleg et al. (2007) are provided in Table 2 and were used to compare to the findings of the current study, which are provided in Table 3. It is clear that the methods utilized in this study produced very similar results to those obtained by Peleg et al. (2007). The means and standard deviations for each group are within a few millimeters of one another and the ranges are very similar, which meets expectations. Additionally, these results show that the females of each racial group displayed wider sacral angles than males, and Caucasian Americans of either sex were larger than their African American counterparts.

Table 2

*Means and Standard Deviations for Sacral Angle in African Americans and Caucasian Americans as Reported by Peleg et al. (2007)*

<table>
<thead>
<tr>
<th>Race and Sex</th>
<th>Mean</th>
<th>N</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>African American Female</td>
<td>48.28</td>
<td>87</td>
<td>10.87</td>
<td>20.00 – 70.00</td>
</tr>
<tr>
<td>Caucasian American Female</td>
<td>50.33</td>
<td>74</td>
<td>10.72</td>
<td>22.00 – 81.00</td>
</tr>
<tr>
<td>African American Male</td>
<td>48.16</td>
<td>116</td>
<td>10.02</td>
<td>18.00 – 73.00</td>
</tr>
<tr>
<td>Caucasian American Male</td>
<td>49.45</td>
<td>147</td>
<td>9.52</td>
<td>28.00 – 77.00</td>
</tr>
<tr>
<td>Total</td>
<td>49.06</td>
<td>424</td>
<td>10.28</td>
<td>18.00 – 81.00</td>
</tr>
</tbody>
</table>
Table 3

Descriptive Statistics of Sacral Angle

<table>
<thead>
<tr>
<th>Race and Sex</th>
<th>Mean</th>
<th>N</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>African American Female</td>
<td>49.33</td>
<td>44</td>
<td>11.32</td>
<td>29.70 – 73.60</td>
</tr>
<tr>
<td>Caucasian American Female</td>
<td>54.73</td>
<td>50</td>
<td>9.78</td>
<td>32.20 – 71.20</td>
</tr>
<tr>
<td>African American Male</td>
<td>47.69</td>
<td>52</td>
<td>8.37</td>
<td>29.60 – 64.80</td>
</tr>
<tr>
<td>Caucasian American Male</td>
<td>49.35</td>
<td>51</td>
<td>9.08</td>
<td>23.00 – 70.10</td>
</tr>
<tr>
<td>Total</td>
<td>50.27</td>
<td>197</td>
<td>9.63</td>
<td>23.00 – 73.60</td>
</tr>
</tbody>
</table>

Table 4 shows the results of the analysis of variance for sacral angle. Although the results show statistically significant differences between racial groups, the proportion of variance, eta-squared ($\eta^2$), is very small (0.074), meaning that only 7.4% of the difference between groups can be attributed to race.

Table 4

Analysis of Variance for Sacral Angle

<table>
<thead>
<tr>
<th></th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>$\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sacral Angle /</td>
<td>1422.8</td>
<td>3</td>
<td>474.26</td>
<td>5.12</td>
<td>0.002</td>
<td>0.074</td>
</tr>
<tr>
<td>Race and Sex</td>
<td>(Combined)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>17889.9</td>
<td>193</td>
<td>92.69</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within Groups</td>
<td>19312.7</td>
<td>196</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To summarize, sacral angle is not useful as a race indicator on its own. However, further analysis was conducted in the present study to examine whether it can be used
with other dimensions of the pelvic girdle and femur to strengthen methods of race
determination. The results of that examination are presented in the New Variables section
of this chapter.

İşcan (1983) Discriminant Function Analysis

The methods outlined by İşcan (1983) utilize biiliac breadth, transverse breadth of
the pelvic inlet, and antero-posterior breadth of the pelvic inlet along with age at death to
estimate race from the reassembled pelvic girdle. Table 5 compares the descriptive
statistics between İşcan’s original results and the results obtained from the reproduction
of his methods. In general, Caucasian Americans exhibit broader pelvic girdles compared
to African Americans regardless of sex. Cohen’s d and eta squared ($\eta^2$) were calculated
from İşcan’s original results to test the strengths of the relationships between the
variables and racial differences. These calculations showed that although Cohen’s d was
large or relatively large for all variables across all groups, the proportion of variance ($\eta^2$)
was very small – less than 10% for any one variable – meaning that only a very small
percentage of the variability can be explained by racial differences. The effect sizes were
then calculated from the results of the reproduction of İşcan’s methods for comparison.
These results show higher proportions of variance, with females exhibiting the highest
rates of variability (biiliac breadth: $\eta^2 = 0.25$; transverse breadth: $\eta^2 = 0.21$; antero-
posterior breadth: $\eta^2 = 0.17$) from racial differences compared to males (biiliac breadth:
$\eta^2 = 0.12$; transverse breadth: $\eta^2 = 0.23$; antero-posterior breadth: $\eta^2 = 0.16$). However,
these proportions of variance fall in the medium range, meaning that racial differences
only account for at most 25% of the variation between groups.
Table 5

*Means, SD, F, t² Comparisons Between İşcan (1983) and Yurka*

<table>
<thead>
<tr>
<th>Variables</th>
<th>African Americans</th>
<th>Caucasian Americans</th>
<th>F</th>
<th>t²</th>
<th>d</th>
<th>η²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>d</td>
<td>η²</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>İşcan (1983)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>47.88</td>
<td>20.70</td>
<td>65.24</td>
<td>15.94</td>
<td>1.69</td>
<td>5.75</td>
</tr>
<tr>
<td>Biiliac Breadth</td>
<td>252.81</td>
<td>15.95</td>
<td>277.99</td>
<td>17.11</td>
<td>1.15</td>
<td>9.32</td>
</tr>
<tr>
<td>Transverse Breadth</td>
<td>120.56</td>
<td>6.82</td>
<td>133.93</td>
<td>8.09</td>
<td>1.40</td>
<td>10.95</td>
</tr>
<tr>
<td>Antero-Posterior Breadth</td>
<td>110.75</td>
<td>9.26</td>
<td>116.64</td>
<td>10.51</td>
<td>1.29</td>
<td>3.64</td>
</tr>
<tr>
<td>Male</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>49.36</td>
<td>15.40</td>
<td>58.52</td>
<td>13.07</td>
<td>1.39</td>
<td>3.93</td>
</tr>
<tr>
<td>Biiliac Breadth</td>
<td>254.60</td>
<td>15.27</td>
<td>273.96</td>
<td>16.10</td>
<td>1.11</td>
<td>7.55</td>
</tr>
<tr>
<td>Transverse Breadth</td>
<td>111.96</td>
<td>7.39</td>
<td>123.59</td>
<td>7.95</td>
<td>1.16</td>
<td>9.28</td>
</tr>
<tr>
<td>Antero-Posterior Breadth</td>
<td>102.01</td>
<td>8.54</td>
<td>108.73</td>
<td>9.62</td>
<td>1.27</td>
<td>4.53</td>
</tr>
<tr>
<td><strong>Yurka</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>40.23</td>
<td>18.03</td>
<td>46.92</td>
<td>12.21</td>
<td>5.66</td>
<td>4.54</td>
</tr>
<tr>
<td>Biiliac Breadth</td>
<td>246.02</td>
<td>15.36</td>
<td>266.03</td>
<td>19.27</td>
<td>2.36</td>
<td>30.47</td>
</tr>
<tr>
<td>Transverse Breadth</td>
<td>121.78</td>
<td>7.83</td>
<td>130.73</td>
<td>9.52</td>
<td>3.32</td>
<td>24.40</td>
</tr>
<tr>
<td>Antero-Posterior Breadth</td>
<td>111.58</td>
<td>10.59</td>
<td>120.31</td>
<td>8.95</td>
<td>1.12</td>
<td>18.75</td>
</tr>
<tr>
<td>Variables</td>
<td>African Americans</td>
<td>Caucasian Americans</td>
<td>F</td>
<td>t²</td>
<td>d</td>
<td>η²</td>
</tr>
<tr>
<td>----------------------</td>
<td>-------------------</td>
<td>---------------------</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>43.12</td>
<td>16.48</td>
<td>43.88</td>
<td>14.45</td>
<td>0.62</td>
<td>0.06</td>
</tr>
<tr>
<td>Biiliac Breadth</td>
<td>254.06</td>
<td>21.12</td>
<td>269.39</td>
<td>21.22</td>
<td>0.07</td>
<td>13.54</td>
</tr>
<tr>
<td>Transverse Breadth</td>
<td>114.70</td>
<td>8.73</td>
<td>123.07</td>
<td>6.34</td>
<td>4.74</td>
<td>30.91</td>
</tr>
<tr>
<td>Antero-Posterior Breadth</td>
<td>106.27</td>
<td>9.88</td>
<td>114.62</td>
<td>9.71</td>
<td>0.03</td>
<td>18.66</td>
</tr>
</tbody>
</table>

İşcan’s original tests of equality of group means showed statistically significant differences (p<0.001) among the means for all variables of both male and female groups. The results of the reproduction showed statistically significant differences (p<0.05) for the means of biiliac breadth, transverse breadth, and antero-posterior breadth across both sexes. Age, however, was found to have significantly different means for the female groups (p = 0.04), but not for the male groups (p = 0.80), meaning that age at death most likely does not contribute to the discriminant function analysis for males.

İşcan’s methods utilized a stepwise procedure to select variables that contribute the most to the discriminant function. However, statisticians currently caution against using stepwise procedures, because some discriminatory power is lost when exclusion of variables is based solely on the smallest information content (Huberty, 1989). There is also greater potential to increase Type I error than when selecting variables manually. The reproduction of İşcan’s methods did not utilize a stepwise procedure in an attempt to produce results that conform to current standards. However, this decision should not have
any effect on the results, as the reproduction of the methods did not require variable selection. Additionally, in order to examine the efficacy of the methods when age is unknown, a second discriminant function analysis was performed on the three dimensions of the pelvic girdle independent of age at death. Table 6 shows the original classification tables reported by İşcan (1983) for functions without age at death and with age at death of his stepwise procedure for comparison.

Table 6

*Original Classification Rates Reported by İşcan (1983)*

<table>
<thead>
<tr>
<th></th>
<th>Caucasian American</th>
<th>Base African American</th>
<th>Average</th>
<th>Caucasian American</th>
<th>Test African American</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Age at Death</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>74.7</td>
<td>80.0</td>
<td>77.3</td>
<td>88.0</td>
<td>88.0</td>
<td>88.0</td>
</tr>
<tr>
<td>Females</td>
<td>80.0</td>
<td>86.7</td>
<td>83.3</td>
<td>76.0</td>
<td>88.0</td>
<td>82.0</td>
</tr>
<tr>
<td>With Age at Death</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>82.7</td>
<td>82.7</td>
<td>82.7</td>
<td>88.0</td>
<td>88.0</td>
<td>88.0</td>
</tr>
<tr>
<td>Females</td>
<td>88.0</td>
<td>88.0</td>
<td>88.0</td>
<td>88.0</td>
<td>88.0</td>
<td>84.0</td>
</tr>
</tbody>
</table>

İşcan’s methods analyzed males separately from females, which, when applied to unknown individuals, is expected to compound errors associated with different methods of sex determination; this may have led to the application of an incorrect discriminant function for the particular individual. For the purposes of this research, two discriminant functions were conducted to compare the results when the sexes were analyzed separately, but the final discriminant functions analyzed males and females.
simultaneously. Table 7 shows the classification rates from the discriminant function when the sexes are treated separately.

**Table 7**

*Classification Results When Sexes are Treated Separately*

<table>
<thead>
<tr>
<th></th>
<th>Caucasian American</th>
<th>Original African American</th>
<th>Average</th>
<th>Caucasian American</th>
<th>Cross-Validated African American</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>72.5</td>
<td>73.1</td>
<td>72.8</td>
<td>70.6</td>
<td>69.2</td>
<td>69.9</td>
</tr>
<tr>
<td>Females</td>
<td>80.0</td>
<td>68.2</td>
<td>74.1</td>
<td>80</td>
<td>68.2</td>
<td>74.1</td>
</tr>
</tbody>
</table>

Table 8 shows the classification rates from the discriminant function analysis for the reproduced methods when including age at death. It is clear that the functions predict group membership by sex much more accurately than by race. Caucasian American females and African American males were most accurately classified (66.0% and 65.4% respectively), and the cross-validated samples show the same trend, though there was a slight reduction in accuracy. Caucasian American males and African American females had the lowest classification rates at 52.9% and 50.0%, respectively. An evaluation of the results revealed that Caucasian American males and African American females were more likely to be misclassified by sex. This may be due to the fact that the mean measurements of the transverse diameter of the pelvic inlet and the antero-posterior diameter of the pelvic inlet of Caucasian American males and African American females fall between the means of the other two groups. Caucasian American males may show a higher classification rate than the African American females because the mean measurement for biiliac breadth is the largest of all four groups, whereas the mean
measurement for African American females falls within the means of African American males and Caucasian American females.

Table 8

**Classification Table for Reproduction of İşcan’s Methods**

<table>
<thead>
<tr>
<th>Predicted Group Membership</th>
<th>Race and Sex</th>
<th>A.A. Female</th>
<th>C.A. Female</th>
<th>A. A. Male</th>
<th>C.A. Male</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>African American Female</td>
<td>22</td>
<td>11</td>
<td>8</td>
<td>3</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>Caucasian American Female</td>
<td>8</td>
<td>33</td>
<td>2</td>
<td>7</td>
<td>50</td>
</tr>
<tr>
<td>Count</td>
<td>African American Male</td>
<td>4</td>
<td>0</td>
<td>34</td>
<td>14</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>Caucasian American Male</td>
<td>7</td>
<td>7</td>
<td>10</td>
<td>27</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>African American Female</td>
<td>50.0</td>
<td>25.0</td>
<td>18.2</td>
<td>6.8</td>
<td>100.0</td>
</tr>
<tr>
<td></td>
<td>Caucasian American Female</td>
<td>16.0</td>
<td>66.0</td>
<td>4.0</td>
<td>14.0</td>
<td>100.0</td>
</tr>
<tr>
<td>%</td>
<td>African American Male</td>
<td>7.7</td>
<td>.0</td>
<td>65.4</td>
<td>26.9</td>
<td>100.0</td>
</tr>
<tr>
<td></td>
<td>Caucasian American Male</td>
<td>13.7</td>
<td>13.7</td>
<td>19.6</td>
<td>52.9</td>
<td>100.0</td>
</tr>
<tr>
<td>Cross-Validated</td>
<td>African American Female</td>
<td>21</td>
<td>11</td>
<td>8</td>
<td>4</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>Caucasian American Female</td>
<td>8</td>
<td>32</td>
<td>2</td>
<td>8</td>
<td>50</td>
</tr>
<tr>
<td>Count</td>
<td>African American Male</td>
<td>5</td>
<td>0</td>
<td>33</td>
<td>14</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>Caucasian American Male</td>
<td>7</td>
<td>7</td>
<td>11</td>
<td>26</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>African American Female</td>
<td>47.7</td>
<td>25.0</td>
<td>18.2</td>
<td>9.1</td>
<td>100.0</td>
</tr>
<tr>
<td></td>
<td>Caucasian American Female</td>
<td>16.0</td>
<td>64.0</td>
<td>4.0</td>
<td>16.0</td>
<td>100.0</td>
</tr>
<tr>
<td>%</td>
<td>African American Male</td>
<td>9.6</td>
<td>.0</td>
<td>63.5</td>
<td>26.9</td>
<td>100.0</td>
</tr>
<tr>
<td></td>
<td>Caucasian American Male</td>
<td>13.7</td>
<td>13.7</td>
<td>21.6</td>
<td>51.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

a. 58.9% of original grouped cases correctly classified.

b. Cross validation is done only for the cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case. 56.9% of cross-validated grouped cases correctly classified.
Table 9 shows the classification table for the discriminant function when age at death is omitted. For the final discussion, only the discriminant function without age at death will be evaluated for its validity within the Daubert criteria. The results show that Caucasian American females and African American males were once again most accurately classified, followed by Caucasian American males and African American females. Surprisingly, the number of correctly classified cases from both the original grouped cases and the cross-validated cases increased with the omission of age at death.

Table 9

*Classification Table for the Reproduction of İşcan’s Methods Without Age at Death*

<table>
<thead>
<tr>
<th>Original Race and Sex</th>
<th>Predicted Group Membership</th>
<th>A.A. Female</th>
<th>C.A. Female</th>
<th>A. A. Male</th>
<th>C.A. Male</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>African American Female</td>
<td>22</td>
<td>11</td>
<td>8</td>
<td>3</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>Caucasian American Female</td>
<td>8</td>
<td>33</td>
<td>2</td>
<td>7</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>African American Male</td>
<td>5</td>
<td>0</td>
<td>35</td>
<td>12</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>Caucasian American Male</td>
<td>7</td>
<td>7</td>
<td>8</td>
<td>29</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td>African American Female</td>
<td>50.0</td>
<td>25.0</td>
<td>18.2</td>
<td>6.8</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>Caucasian American Female</td>
<td>16.0</td>
<td>66.0</td>
<td>4.0</td>
<td>14.0</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>African American Male</td>
<td>9.6</td>
<td>.0</td>
<td>67.3</td>
<td>23.1</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>Caucasian American Male</td>
<td>13.7</td>
<td>13.7</td>
<td>15.7</td>
<td>56.9</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>

a. 60.4% of original grouped cases correctly classified.
Table 9 (continued).

<table>
<thead>
<tr>
<th>Cross-Validated Race and Sex</th>
<th>Predicted Group Membership</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A.A. Female</td>
</tr>
<tr>
<td>African American Female</td>
<td>22</td>
</tr>
<tr>
<td>Caucasian American Female</td>
<td>8</td>
</tr>
<tr>
<td>African American Male</td>
<td>5</td>
</tr>
<tr>
<td>Caucasian American Male</td>
<td>7</td>
</tr>
<tr>
<td>African American Female</td>
<td>50.0</td>
</tr>
<tr>
<td>Caucasian American Female</td>
<td>16.0</td>
</tr>
<tr>
<td>African American Male</td>
<td>9.6</td>
</tr>
<tr>
<td>Caucasian American Male</td>
<td>13.7</td>
</tr>
</tbody>
</table>

b. Cross validation is done only for the cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

c. 58.9% of cross-validated grouped cases correctly classified.

Table 10 shows the structure coefficients from the reproduction of İşcan’s discriminant function analysis. Measuring the simple linear correlation between each independent variable and the discriminant function, the structure coefficients reflect the variance that the independent variables share with the discriminant function, and can be interpreted like factor loadings in assessing the relative contribution of each independent variable to the discriminant function. Variables that exhibit structure coefficients of ±0.40 or higher are considered substantive. An assessment of the structure coefficients was
conducted with respect to the group means for each variable. Function 2 most likely discriminates the groups by sex, as seen by the high discriminating power of the biiliac breadth, which is shown to be significantly larger in males than in females in both race groups. Similarly, the transverse and antero-posterior breadths of the pelvic inlet are significantly larger in females than males, which are also reflected in the high discriminating powers of these structure coefficients. Conversely, the discriminating power of the biiliac breadth for Function 1 is not substantive and does not contribute to the function, which supports the notion that Function 1 most likely classifies into racial groups, as the combined discriminant functions are a much better predictor of sex than of race. Transverse and antero-posterior breadths of the pelvic inlet show the highest discriminating power for classifying race, while biiliac breadth has the highest discriminating power for classifying sex.

Table 10

Structure Coefficients

<table>
<thead>
<tr>
<th>Structure Coefficients</th>
<th>Function 1</th>
<th>Function 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse Breadth of Pelvic Inlet</td>
<td>0.684*</td>
<td>0.520*</td>
</tr>
<tr>
<td>Biiliac Breadth</td>
<td>0.095</td>
<td>0.941*</td>
</tr>
<tr>
<td>Antero-Posterior Breadth of Pelvic Inlet</td>
<td>0.483</td>
<td>0.513*</td>
</tr>
</tbody>
</table>

Pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions

Variables ordered by absolute size of correlation with function.

* Largest absolute size of correlation between each variable and any discriminant function.
The unstandardized canonical coefficients are utilized to calculate the Z-score for each observation. The SPSS software does these calculations internally and reports the unstandardized coefficients in order to calculate the discriminant scores of unknown samples to predict group membership. Table 11 provides the specific unstandardized coefficients for each variable, which were used to create the two discriminant functions below:

\[
D_1 = -0.049a + 0.154b + 0.048c - 11.623
\]
\[
D_2 = 0.057a - 0.041b + 0.027c - 12.687
\]

Table 11

<table>
<thead>
<tr>
<th>Unstandardized Canonical Discriminant Function Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function</td>
</tr>
<tr>
<td>Biiliac Breadth (a)</td>
</tr>
<tr>
<td>Transverse Breadth of the Pelvic Inlet (b)</td>
</tr>
<tr>
<td>Antero-Posterior Breadth of the Pelvic Inlet (c)</td>
</tr>
<tr>
<td>(Constant)</td>
</tr>
</tbody>
</table>

Figure 14 displays the scatter plots of the individual discriminant scores for each observation along with the group centroids (Table 12), calculated as the average of all discriminant scores for each of the four groups.
Figure 14. Sex and Race Combined-Groups Scatter Plots with Group Centroids.

Table 12

*Functions at Group Centroids*

<table>
<thead>
<tr>
<th>Race and Sex</th>
<th>Function 1</th>
<th>Function 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>African American Female</td>
<td>0.457</td>
<td>-0.764</td>
</tr>
<tr>
<td>Caucasian American Female</td>
<td>1.277</td>
<td>0.236</td>
</tr>
<tr>
<td>African American Male</td>
<td>-1.280</td>
<td>-0.159</td>
</tr>
<tr>
<td>Caucasian American Male</td>
<td>-0.341</td>
<td>0.590</td>
</tr>
</tbody>
</table>

The methods outlined by İşcan (1983) did not adequately hold up to current statistical standards, primarily due to the stepwise procedure for variable selection, treating males and females separately, and including age at death as a discriminating
variable, which all tend to increase Type I error. The methods were modified to conform
to current standards. However, this ultimately decreased the success of the methods to
accurately discriminate individuals into their correct race groups.

DiBennardo and Taylor (1983) Discriminant Function Analysis

DiBennardo and Taylor (1983) utilized fifteen variables from the pelvis and femur to create a discriminant function that was found to correctly classify 95% of individuals as African American males, African American females, Caucasian American males, and Caucasian American females. The first step in evaluating the validity of their discriminant function analysis was to assess whether it was possible to repeat the procedure using a different sample set consisting of skeletal remains of known race to produce similar descriptive statistics. Table 13 shows the means and standard deviations calculated in the present analysis for the 15 variables used in the discriminant function analysis. The means were compared to the results of DiBennardo and Taylor (1983). Those means that fell outside of one standard deviation of the mean reported by DiBennardo and Taylor (1983) were highlighted. African American and Caucasian American males both displayed significantly smaller symphyseal angle means as well as shorter greater sciatic notch position means than those reported by DiBennardo and Taylor (1983). The mean carrying angle of African American females was found to be just slightly greater than one standard deviation of that reported by DiBennardo and Taylor (1983), but it is not likely to be significant as the mean is only 0.1mm greater than one standard deviation (SD = 2.0). None of the Caucasian American female means were outside one standard deviation, and most were within 0.5 standard deviation of the DiBennardo and Taylor (1983) means. This indicates that the variables were very similar.
and that it is unlikely that any disparities observed in the reproduction of DiBennardo and Taylor’s discriminant analysis were caused by dissimilarities of variable means.

Table 13

Means and Standard Deviations for the 15 DiBennardo and Taylor (1983) Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>A.A. Female</th>
<th>C.A. Female</th>
<th>A.A. Male</th>
<th>C.A. Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symphyseal Angle</td>
<td>Mean 134.5</td>
<td>133.5</td>
<td><strong>137.4</strong></td>
<td><strong>138.9</strong></td>
</tr>
<tr>
<td></td>
<td>SD 7.7</td>
<td>6.7</td>
<td>4.8</td>
<td>5.5</td>
</tr>
<tr>
<td>Maximum Length of Pelvis</td>
<td>Mean 192.9</td>
<td>205.2</td>
<td>206.5</td>
<td>216.1</td>
</tr>
<tr>
<td></td>
<td>SD 10.9</td>
<td>9.2</td>
<td>11.5</td>
<td>12.71</td>
</tr>
<tr>
<td>Pubic Length</td>
<td>Mean 70.9</td>
<td>76.1</td>
<td>70.9</td>
<td>73.8</td>
</tr>
<tr>
<td></td>
<td>SD 6.9</td>
<td>4.4</td>
<td>5.1</td>
<td>5.7</td>
</tr>
<tr>
<td>Femoral Length</td>
<td>Mean 431.2</td>
<td>435.2</td>
<td>480.8</td>
<td>467.2</td>
</tr>
<tr>
<td></td>
<td>SD 24.3</td>
<td>22.6</td>
<td>29.7</td>
<td>27.2</td>
</tr>
<tr>
<td>Iliac Height</td>
<td>Mean 126.4</td>
<td>134.3</td>
<td>137.5</td>
<td>146.6</td>
</tr>
<tr>
<td></td>
<td>SD 6.9</td>
<td>7.6</td>
<td>9.0</td>
<td>8.9</td>
</tr>
<tr>
<td>Acetabulum Vertical Diameter</td>
<td>Mean 49.3</td>
<td>50.6</td>
<td>55.8</td>
<td>55.8</td>
</tr>
<tr>
<td></td>
<td>SD 2.9</td>
<td>2.6</td>
<td>3.1</td>
<td>3.7</td>
</tr>
<tr>
<td>Greater Sciatic Notch Height</td>
<td>Mean 45.6</td>
<td>49.8</td>
<td>42.3</td>
<td>46.5</td>
</tr>
<tr>
<td></td>
<td>SD 6.7</td>
<td>5.4</td>
<td>5.2</td>
<td>6.0</td>
</tr>
<tr>
<td>Oblique Length</td>
<td>Mean 26.3</td>
<td>28.4</td>
<td>23.0</td>
<td>24.7</td>
</tr>
<tr>
<td></td>
<td>SD 4.6</td>
<td>3.1</td>
<td>3.5</td>
<td>2.9</td>
</tr>
<tr>
<td>Greater Sciatic Notch Position</td>
<td>Mean 29.7</td>
<td>31.1</td>
<td><strong>31.1</strong></td>
<td><strong>32.0</strong></td>
</tr>
<tr>
<td></td>
<td>SD 3.9</td>
<td>4.5</td>
<td>4.7</td>
<td>4.9</td>
</tr>
<tr>
<td>Inferior Pubic Ramus Height</td>
<td>Mean 10.4</td>
<td>12.2</td>
<td>13.9</td>
<td>15.5</td>
</tr>
<tr>
<td></td>
<td>SD 1.9</td>
<td>2.1</td>
<td>2.5</td>
<td>3.0</td>
</tr>
</tbody>
</table>
Table 13 (continued).

<table>
<thead>
<tr>
<th>Variable</th>
<th>A.A. Female</th>
<th>C.A. Female</th>
<th>A.A. Male</th>
<th>C.A. Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tuberculosymphyseal Length</td>
<td>Mean 22.0</td>
<td>26.2</td>
<td>22.3</td>
<td>24.9</td>
</tr>
<tr>
<td></td>
<td>SD 4.0</td>
<td>4.9</td>
<td>4.1</td>
<td>3.8</td>
</tr>
<tr>
<td>Epicondylar Breadth</td>
<td>Mean 73.0</td>
<td>75.4</td>
<td>83.4</td>
<td>84.1</td>
</tr>
<tr>
<td></td>
<td>SD 3.2</td>
<td>3.1</td>
<td>4.3</td>
<td>6.0</td>
</tr>
<tr>
<td>Circumference at Midshaft</td>
<td>Mean 83.2</td>
<td>83.7</td>
<td>94.9</td>
<td>91.4</td>
</tr>
<tr>
<td></td>
<td>SD 5.6</td>
<td>6.6</td>
<td>7.3</td>
<td>8.5</td>
</tr>
<tr>
<td>Carrying Angle</td>
<td>Mean $79.3$</td>
<td>79.7</td>
<td>80.4</td>
<td>80.5</td>
</tr>
<tr>
<td></td>
<td>SD 3.2</td>
<td>2.2</td>
<td>2.4</td>
<td>2.4</td>
</tr>
<tr>
<td>Cotylosciatic Breadth</td>
<td>Mean 34.4</td>
<td>36.1</td>
<td>39.9</td>
<td>39.5</td>
</tr>
<tr>
<td></td>
<td>SD 3.6</td>
<td>3.3</td>
<td>4.7</td>
<td>3.8</td>
</tr>
</tbody>
</table>

Linear dimensions in millimeters, angles in degrees

Next, a discriminant function analysis was conducted using SPSS. Like İşcan (1983), DiBennardo and Taylor (1983) conducted a stepwise procedure, which was not utilized in this study for the reasons listed above. The structure coefficients from the reproduction were then compared to DiBennardo and Taylor’s (1983) original results. The structure coefficients are listed in Table 14 and follow the order recorded by DiBennardo and Taylor (1983), which report the variables with the strongest absolute correlation to the discriminant functions first. Those variables from the reproduction with the strongest absolute correlation to the discriminant functions are denoted with an asterisk. The variables were compared both for absolute size as well as their projected contributions to the discriminant functions. The most striking difference between DiBennardo and Taylor’s results and the reproduction can be seen in the symphyseal...
angle, which was the strongest variable for DiBennardo and Taylor, but one of the weakest variables for the reproduction.

Table 14

*Comparison of Structure Coefficients*

<table>
<thead>
<tr>
<th>Variable</th>
<th>DiBennardo and Taylor</th>
<th>Yurka</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Function 1</td>
<td>Function 2</td>
</tr>
<tr>
<td>Symphyseal Angle</td>
<td>0.79</td>
<td>0.16</td>
</tr>
<tr>
<td>Maximum Length of Pelvis</td>
<td>0.56</td>
<td>0.58</td>
</tr>
<tr>
<td>Pubic Length</td>
<td>0.35</td>
<td>0.52</td>
</tr>
<tr>
<td>Femoral Length</td>
<td>0.52</td>
<td>-0.20</td>
</tr>
<tr>
<td>Iliac Height</td>
<td>0.33</td>
<td>0.64</td>
</tr>
<tr>
<td>Acetabulum Vertical Diameter</td>
<td>0.73</td>
<td>0.28</td>
</tr>
<tr>
<td>Greater Sciatic Notch Height</td>
<td>-0.40</td>
<td>0.26</td>
</tr>
<tr>
<td>Oblique Length</td>
<td>-0.70</td>
<td>0.22</td>
</tr>
<tr>
<td>Greater Sciatic Notch Position</td>
<td>0.44</td>
<td>0.25</td>
</tr>
<tr>
<td>Inferior Pubic Ramus Height</td>
<td>0.33</td>
<td>0.56</td>
</tr>
<tr>
<td>Tuberculosymphysedal Length</td>
<td>-0.24</td>
<td>0.32</td>
</tr>
<tr>
<td>Epicondylar Breadth</td>
<td>0.75</td>
<td>0.25</td>
</tr>
<tr>
<td>Circumference at Midshaft</td>
<td>0.63</td>
<td>0.14</td>
</tr>
<tr>
<td>Carrying Angle</td>
<td>0.31</td>
<td>0.33</td>
</tr>
<tr>
<td>Cotylosciatic Breadth</td>
<td>0.41</td>
<td>0.49</td>
</tr>
</tbody>
</table>

Pooled within-groups correlations between discriminating variables are standardized canonical discriminant functions.

* Largest absolute correlation between each variable and any Yurka discriminant function
An evaluation of the structure coefficients of the reproduction indicates that of the 15 variables, only three from Function 1 and three from Function 2 show values greater than ±0.40. The three variables from function 1 include the femoral length, acetabulum vertical diameter, and epicondylar breadth. The variables from function 2 include the maximum length of the pelvis, iliac height, and inferior pubic ramus height. This means that only these six variables should be considered substantive to the discriminant function analysis.

Table 15 displays the original classification table reported by DiBennardo and Taylor (1983). These results show that the discriminant functions almost perfectly discriminate by sex – African American males were the only individuals misidentified by sex – and only a few individuals from each group were misclassified by race (African American females had the highest misclassification at 7.7%).

Table 15

*Original Classification Rates Reported by DiBennardo and Taylor (1983)*

<table>
<thead>
<tr>
<th>Actual Group Membership</th>
<th>Number of Cases</th>
<th>Predicted Group Membership</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Actual Cases</td>
<td></td>
</tr>
<tr>
<td>Caucasian American ♂</td>
<td>65</td>
<td>C.A. Males 93.8 C.A. Females 0.0 A.A. Males 6.2 A.A. Females 0.0</td>
</tr>
<tr>
<td>Caucasian American ♀</td>
<td>65</td>
<td>C.A. Males 0.0 C.A. Females 96.9 A.A. Males 0.0 A.A. Females 3.1</td>
</tr>
<tr>
<td>African American ♂</td>
<td>65</td>
<td>C.A. Males 1.5 C.A. Females 0.0 A.A. Males 96.9 A.A. Females 1.5</td>
</tr>
<tr>
<td>African American ♀</td>
<td>65</td>
<td>C.A. Males 0.0 C.A. Females 7.7 A.A. Males 0.0 A.A. Females 92.3</td>
</tr>
</tbody>
</table>

The percentage of total cases correctly predicted is 95.0%. The percent correctly assigned is underlined for each group.

Table 16 shows the classification table for the reproduction of DiBennardo and Taylor’s methods. The results were similar to those of the original in that they do a
sufficient job of discriminating the sexes; however, the accuracy was not as good as the original (85.8%), and the cross-validation results showed even lower accuracy (80.7%), well below the 95% accuracy reported by DiBennardo and Taylor (1983). Additionally, Caucasian American males are shown to have a higher chance of being misclassified by sex and race than members of the other groups. The results of the cross-validation show that both African American females and Caucasian American males have a high rate of misclassification by both sex and race.

Table 16

*Classification Table for the Reproduction of DiBennardo and Taylor’s Methods*

<table>
<thead>
<tr>
<th>Original Race and Sex</th>
<th>Predicted Group Membership</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A.A. Female</td>
<td>C.A. Female</td>
</tr>
<tr>
<td>----------------------</td>
<td>-------------</td>
<td>-------------</td>
</tr>
<tr>
<td>African American ♀</td>
<td>39</td>
<td>5</td>
</tr>
<tr>
<td>Caucasian American ♀</td>
<td>8</td>
<td>42</td>
</tr>
<tr>
<td>African American ♂</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Caucasian American ♂</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>African American ♀</td>
<td>88.6</td>
<td>11.4</td>
</tr>
<tr>
<td>Caucasian American ♀</td>
<td>16.0</td>
<td>84.0</td>
</tr>
<tr>
<td>African American ♂</td>
<td>1.9</td>
<td>.0</td>
</tr>
<tr>
<td>Caucasian American ♂</td>
<td>3.9</td>
<td>3.9</td>
</tr>
</tbody>
</table>

a. 85.8% of original grouped cases correctly classified.
Table 16 (continued).

<table>
<thead>
<tr>
<th>Cross-Validated Race and Sex</th>
<th>Predicted Group Membership</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A.A. Female</td>
<td>C.A. Female</td>
</tr>
<tr>
<td>African American ♀</td>
<td>33</td>
<td>8</td>
</tr>
<tr>
<td>Caucasian American ♀</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>African American ♂</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Caucasian American ♂</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>African American ♀</td>
<td>75.0</td>
<td>18.2</td>
</tr>
<tr>
<td>Caucasian American ♀</td>
<td>20.0</td>
<td>80.0</td>
</tr>
<tr>
<td>%</td>
<td>3.8</td>
<td>.0</td>
</tr>
<tr>
<td>Caucasian American ♂</td>
<td>3.9</td>
<td>3.9</td>
</tr>
</tbody>
</table>

b. Cross validation is done only for the cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

c. 80.7% of cross-validated grouped cases correctly classified.

Table 17 shows the unstandardized discriminant function coefficients, which were used to create the discriminant functions listed below:

\[ D_1 = 0.011a + 0.015b - 0.075c + 0.019d - 0.011e + 0.070f - 0.111g - 0.125h + 0.070i + 0.129j - 0.070k + 0.082 + 0.008m + 0.094n + 0.006o - 18.800 \]

\[ D_2 = 0.001a + 0.034b + 0.034c - 0.020d + 0.099e + 0.013f + 0.028g - 0.079h - 0.048i + 0.196j + 0.066k + 0.031l - 0.113m + 0.089n - 0.061o - 13.639 \]
Table 17

*Unstandardized Canonical Discriminant Function Coefficients*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Function 1</th>
<th>Function 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symphyseal Angle (a)</td>
<td>0.011</td>
<td>0.001</td>
</tr>
<tr>
<td>Maximum Length of Pelvis (b)</td>
<td>0.015</td>
<td>0.034</td>
</tr>
<tr>
<td>Pubic Length (c)</td>
<td>-0.075</td>
<td>0.034</td>
</tr>
<tr>
<td>Femoral Length (d)</td>
<td>0.019</td>
<td>-0.020</td>
</tr>
<tr>
<td>Iliac Height (e)</td>
<td>-0.011</td>
<td>0.099</td>
</tr>
<tr>
<td>Acetabulum Vertical Diameter (f)</td>
<td>0.070</td>
<td>0.013</td>
</tr>
<tr>
<td>Greater Sciatic Notch Height (g)</td>
<td>-0.111</td>
<td>0.028</td>
</tr>
<tr>
<td>Oblique Length (h)</td>
<td>-0.125</td>
<td>-0.079</td>
</tr>
<tr>
<td>Greater Sciatic Notch Position (i)</td>
<td>0.070</td>
<td>-0.048</td>
</tr>
<tr>
<td>Inferior Pubic Ramus Height (j)</td>
<td>0.129</td>
<td>0.196</td>
</tr>
<tr>
<td>Tuberculosymphyseal Length (k)</td>
<td>-0.070</td>
<td>0.066</td>
</tr>
<tr>
<td>Epicondylar Breadth (l)</td>
<td>0.082</td>
<td>0.031</td>
</tr>
<tr>
<td>Circumference at Midshaft (m)</td>
<td>0.008</td>
<td>-0.113</td>
</tr>
<tr>
<td>Carrying Angle (n)</td>
<td>0.094</td>
<td>0.089</td>
</tr>
<tr>
<td>Cotylosciatic Breadth (o)</td>
<td>0.006</td>
<td>-0.061</td>
</tr>
<tr>
<td>(Constant)</td>
<td>-18.800</td>
<td>-13.639</td>
</tr>
</tbody>
</table>

Figure 15 shows the scatter plots of the individual discriminant scores for each observation along with the group centroids (Table 18), calculated as the average of all
discriminant scores for each of the four groups. The group centroids are well defined; however, there is considerable overlap among the scatter areas for individual cases by race and sex.

Figure 15. Sex and Race Combined-Groups Scatter Plots with Group Centroids.

Table 18

Functions at Group Centroids

<table>
<thead>
<tr>
<th>Race and Sex</th>
<th>Function 1</th>
<th>Function 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>African American Female</td>
<td>-1.638</td>
<td>-1.182</td>
</tr>
<tr>
<td>Caucasian American Female</td>
<td>-2.230</td>
<td>0.576</td>
</tr>
<tr>
<td>African American Male</td>
<td>2.263</td>
<td>-1.008</td>
</tr>
<tr>
<td>Caucasian American Male</td>
<td>1.292</td>
<td>1.482</td>
</tr>
</tbody>
</table>
Overall, the discriminant functions proposed by DiBennardo and Taylor (1983) showed a high rate of classification for both sex and race. However, the original methods did not conform to current statistical standards, specifically due to the use of stepwise procedures for variable selection. When the methods were modified to conform to these standards, the accuracy fell considerably. Unfortunately, this means that these methods no longer meet the 95% accuracy level reported by DiBennardo and Taylor (1983), nor do they meet the 95% level of scientific certainty required by the Daubert guidelines for admissible evidence.

Davivongs (1963) Measurements and Indices

The methods derived from Davivongs (1963) were analyzed using descriptive statistics as well as independent samples t-tests to compare means between the two races. Males were treated separately from females. Cohen’s d and effect size r were calculated for those variables showing statistically significant differences. In order to be deemed reliable for the purposes of this study, statistically significant results (p < 0.05) must have a large Cohen’s d (≥ 0.80) and a large effect size r (≥ 0.70). Any variables that meet these criteria were evaluated further to assess whether the differences among the racial groups are large enough to be applicable in the field (e.g., a statistically significant difference of 1mm may have a large Cohen’s d and effect size r, which meet the criteria, but which would not be applicable in the field).

Table 19 shows the results of the descriptive statistics, independent samples t-tests, Cohen’s d, and effect size r for the measurements and indices of the sacra of the female samples. Six of the nine variables showed statistically significant results. However, on closer inspection, only three of these variables (sacrum maximum length,
sacrum maximum breadth, and sacral curved length) showed a large Cohen’s d, and none of the variables had a large r-value. An assessment of the descriptive statistics revealed that there was a very large proportion of overlap among African American and Caucasian American females seen within each of the variables. Figures 16 and 17 display the overlapping observations for the variables with the highest effect sizes from the measurements and indices of the sacrum, which includes the Sacrum Maximum Length (d = -1.216, r = -0.519) and Sacral Curved Length (d = -1.536, r = -0.609).
### Table 19

**Measurements and Indices of Female Sacra**

<table>
<thead>
<tr>
<th>Measurements and Indices</th>
<th>African American Female</th>
<th>Caucasian American Female</th>
<th>Cohen’s d</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sacrum Maximum Length</td>
<td>44 (N)</td>
<td>50</td>
<td>102.93</td>
<td>116.94</td>
</tr>
<tr>
<td>Sacrum Maximum Breadth</td>
<td>44 (N)</td>
<td>50</td>
<td>109.15</td>
<td>116.36</td>
</tr>
<tr>
<td>Sacral Index</td>
<td>44 (N)</td>
<td>50</td>
<td>107.06</td>
<td>100.19</td>
</tr>
<tr>
<td>Sacral Curved Length</td>
<td>44 (N)</td>
<td>50</td>
<td>108.09</td>
<td>125.46</td>
</tr>
<tr>
<td>Curvature Index</td>
<td>44 (N)</td>
<td>50</td>
<td>95.22</td>
<td>93.33</td>
</tr>
<tr>
<td>Antero-Posterior Diameter of S1</td>
<td>44 (N)</td>
<td>50</td>
<td>27.94</td>
<td>29.50</td>
</tr>
<tr>
<td>Transverse Diameter of S1</td>
<td>44 (N)</td>
<td>50</td>
<td>45.38</td>
<td>46.03</td>
</tr>
<tr>
<td>Index of S1 Body</td>
<td>44 (N)</td>
<td>50</td>
<td>62.03</td>
<td>63.88</td>
</tr>
<tr>
<td>Corporo-Basal Index</td>
<td>44 (N)</td>
<td>50</td>
<td>41.65</td>
<td>39.97</td>
</tr>
</tbody>
</table>
Figure 16. Distribution of observations of sacrum maximum length for females. Based on the ranges, measurements below 86.36mm predict African American females, while measurements above 122.35mm predict Caucasian American females. Those measurements that fall within the range of 86.36mm and 122.35mm cannot be accurately predicted.

Figure 17. Distribution of observations of sacral curved length for females. Measurements below 100mm predict African American females, while measurements above 128mm predict Caucasian American females. Those measurements that fall within the range of 100mm to 128mm cannot be accurately predicted.

Table 20 shows the results of the descriptive statistics, independent samples t-tests, Cohen’s d, and effect size r for the measurements and indices of the sacra of the
male samples. Four of the nine variables were found to have statistically significant differences between the racial groups. Although all four of these variables (sacrum maximum length, sacrum maximum breadth, sacral curved length, and the corporo-basal index) had a large Cohen’s d, none had a large r-value. An assessment of the descriptive statistics revealed that, similar to the results of the female measurements, there was a very high proportion of overlap among the male groups. Upon further analysis, it was discovered that for sacrum maximum length and sacrum maximum breadth, the range for Caucasian American males encompassed all of the observations of the African American males. Although African American males tend to have shorter, narrower sacra than Caucasian American males, these variables are insufficient for separating the two racial groups. Figures 18-21 display the overlapping observations for sacrum maximum length (d = -0.809, r = -0.375), sacrum maximum breadth (d = -0.857, r = -0.393), sacral curved length (d = -0.963, r = -0.434), and the corporo-basal index (d = 0.892, r = 0.407).
### Table 20

**Measurements and Indices of Male Sacra**

<table>
<thead>
<tr>
<th>Measurements and Indices</th>
<th>African American Male</th>
<th>Caucasian American Male</th>
<th>Cohen’s d</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
<td>Range</td>
<td>SD</td>
</tr>
<tr>
<td>Sacrum Maximum Length</td>
<td>52</td>
<td>109.07</td>
<td>92.12 – 139.73</td>
<td>9.55</td>
</tr>
<tr>
<td>Sacrum Maximum Breadth</td>
<td>52</td>
<td>111.37</td>
<td>93.00 – 122.00</td>
<td>6.55</td>
</tr>
<tr>
<td>Sacral Index</td>
<td>52</td>
<td>102.70</td>
<td>75.14 – 118.56</td>
<td>8.97</td>
</tr>
<tr>
<td>Sacral Curved Length</td>
<td>52</td>
<td>115.63</td>
<td>94.00 – 148.00</td>
<td>11.30</td>
</tr>
<tr>
<td>Curvature Index</td>
<td>52</td>
<td>94.50</td>
<td>86.24 – 102.91</td>
<td>3.91</td>
</tr>
<tr>
<td>Antero-Posterior Diameter of S1</td>
<td>52</td>
<td>32.83</td>
<td>24.66 – 42.76</td>
<td>3.32</td>
</tr>
<tr>
<td>Transverse Diameter of S1</td>
<td>52</td>
<td>52.19</td>
<td>44.72 – 63.76</td>
<td>3.94</td>
</tr>
<tr>
<td>Index of S1 Body</td>
<td>52</td>
<td>62.96</td>
<td>53.43 – 79.17</td>
<td>5.18</td>
</tr>
<tr>
<td>Corpo-Basal Index</td>
<td>52</td>
<td>46.91</td>
<td>40.17 – 53.08</td>
<td>3.07</td>
</tr>
</tbody>
</table>
Figure 18. Distribution of observations of sacrum maximum length for males. Based on the ranges for African American and Caucasian American males, Caucasian American males completely overlap African American males, making this variable insufficient for race determination.

Figure 19. Distribution of observations of sacrum maximum breadth for males. Caucasian American males completely overlap African American males, making this variable insufficient for race determination.
Figure 20. Distribution of observations of sacral curved length for males. Measurements below 100mm predict African American males, while measurements above 148mm predict Caucasian American males. Those measurements that fall within the range of 100mm and 148mm cannot be accurately predicted.

Figure 21. Distribution of observations of the corporo-basal index for males. Measurements below 40.17mm predict Caucasian American males, while measurements above 50.53mm predict African American males. Those measurements that fall within the range of 40.17mm and 50.53mm cannot be accurately predicted.

Table 21 shows the results of the descriptive statistics, independent samples t-tests, Cohen’s d, and effect size r for the measurements and indices of the female innominate. Ten of the 15 variables show statistically significant differences between
African Americans and Caucasian Americans. However, only three variables show a large Cohen’s d, and none have a large r-value. An assessment of the descriptive statistics revealed that, just like the measurements of the sacrum, there were very high proportions of overlap between the two groups across all variables. Figures 22 and 23 display the overlapping observations for the variables with the highest effect sizes, which include the pelvis maximum length ($d = -1.224, r = -0.522$) and the iliac breadth ($d = -1.166, r = 0.503$).
Table 21

*Measurements and Indices of Female Innominates*

<table>
<thead>
<tr>
<th>Measurements and Indices</th>
<th>African American Females</th>
<th>Caucasian American Females</th>
<th>Cohen’s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
<td>Range</td>
</tr>
<tr>
<td>Pelvis Maximum Length</td>
<td>44</td>
<td>192.93</td>
<td>171.50 – 220.50</td>
</tr>
<tr>
<td>Iliac Breadth</td>
<td>44</td>
<td>147.12</td>
<td>130.5 – 170.00</td>
</tr>
<tr>
<td>Coxal Index</td>
<td>44</td>
<td>76.31</td>
<td>67.53 – 83.24</td>
</tr>
<tr>
<td>Pubic Symphysis Length</td>
<td>44</td>
<td>33.86</td>
<td>24.77 – 42.02</td>
</tr>
<tr>
<td>Acetabulum Vert. Diameter</td>
<td>44</td>
<td>49.31</td>
<td>42.73 – 55.48</td>
</tr>
<tr>
<td>Acetabulum Hor. diameter</td>
<td>44</td>
<td>48.23</td>
<td>41.41 – 53.20</td>
</tr>
<tr>
<td>Pubic Length</td>
<td>44</td>
<td>70.93</td>
<td>57.96 – 95.34</td>
</tr>
<tr>
<td>Ischium Length</td>
<td>44</td>
<td>79.69</td>
<td>67.47 – 93.05</td>
</tr>
<tr>
<td>Ischium-Pubis Index</td>
<td>44</td>
<td>89.05</td>
<td>77.51 – 116.11</td>
</tr>
<tr>
<td>Gr. Sciatic Notch Height</td>
<td>44</td>
<td>45.60</td>
<td>31.46 – 63.02</td>
</tr>
<tr>
<td>Gr. Sciatic Notch Position</td>
<td>44</td>
<td>29.71</td>
<td>23.23 – 39.05</td>
</tr>
<tr>
<td>Gr. Sciatic Notch Index</td>
<td>44</td>
<td>65.62</td>
<td>51.38 – 80.25</td>
</tr>
</tbody>
</table>
Table 21 (continued).

<table>
<thead>
<tr>
<th>Measurements and Indices</th>
<th>African American Females</th>
<th>Caucasian American Females</th>
<th>Cohen’s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
<td>Range</td>
</tr>
<tr>
<td>Sacral Chilotic Line</td>
<td>44</td>
<td>64.38</td>
<td>51.02 – 77.00</td>
</tr>
<tr>
<td>Ilium Chilotic Line</td>
<td>44</td>
<td>55.36</td>
<td>42.84 – 67.39</td>
</tr>
<tr>
<td>Chilotic Index</td>
<td>44</td>
<td>117.45</td>
<td>87.43 – 156.05</td>
</tr>
</tbody>
</table>

Figure 22. Distribution of observations of the pelvis maximum length for females. Measurements below 185.0mm predict Caucasian American males, while measurements above 220.5mm predict African American males. Those measurements that fall within the range of 185.0mm and 220.5mm cannot be accurately predicted.
Figure 23. Distribution of observations of the iliac breadth for females. Measurements below 141.5mm predict African American females, while measurements above 170.0mm predict Caucasian American females. Those measurements that fall within the range of 141.5mm and 170.0mm cannot be accurately predicted.

Table 22 shows the results of the descriptive statistics, independent samples t-tests, Cohen’s d, and effect size r for the measurements and indices of the male innominates. Eight of the 15 variables showed statistically significant differences between African American males and Caucasian American males. However, none of those eight variables had Cohen’s d or effect size r-values large enough to be considered substantive for the purposes of this research. The pelvis maximum length (d = 0.791, r = 0.367) variable has a Cohen’s d just below 0.8, but its r-value is barely large enough to be considered to have a medium effect. Furthermore, there was a very high proportion of overlap between African American and Caucasian American males with regard to both this variable and the other eight variables that were found to have statistically significant differences.
Table 22

Measurements and Indices of Male Innominates

<table>
<thead>
<tr>
<th>Measurements and Indices</th>
<th>African American Male</th>
<th></th>
<th></th>
<th>Caucasian American Male</th>
<th></th>
<th></th>
<th>t</th>
<th>Sig.</th>
<th>d</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N Mean Range SD</td>
<td></td>
<td>N Mean Range SD</td>
<td></td>
<td></td>
<td>t</td>
<td>Sig.</td>
<td>d</td>
<td>r</td>
<td></td>
</tr>
<tr>
<td>Pelvis Maximum Length</td>
<td>52 206.45 181.00 – 227.50 11.53</td>
<td>51 216.05 188.00 – 251.00 12.71</td>
<td>-4.015</td>
<td>.000</td>
<td>-0.791</td>
<td>-0.367</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iliac Breadth</td>
<td>52 156.07 119.50 – 186.00 11.14</td>
<td>51 160.99 143.00 – 190.00 9.07</td>
<td>-2.456</td>
<td>.016</td>
<td>-0.484</td>
<td>-0.235</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coxal Index</td>
<td>52 75.61 66.02 – 83.04 3.76</td>
<td>51 74.56 69.29 – 79.07 2.38</td>
<td>1.681</td>
<td>.096</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pubic Symphysis Length</td>
<td>52 38.00 27.22 – 44.16 3.43</td>
<td>51 40.34 31.80 – 52.68 4.61</td>
<td>-2.929</td>
<td>.004</td>
<td>-0.575</td>
<td>-0.276</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetabulum Vert. Diameter</td>
<td>52 55.77 49.13 – 62.46 3.09</td>
<td>51 55.81 46.87 – 63.22 3.67</td>
<td>-0.068</td>
<td>.946</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetabulum Hor. Diameter</td>
<td>52 54.67 48.60 – 61.11 3.12</td>
<td>51 54.13 46.16 – 58.98 2.91</td>
<td>0.906</td>
<td>.367</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pubic Length</td>
<td>52 70.93 57.50 – 80.62 5.06</td>
<td>51 73.81 60.79 – 85.02 5.70</td>
<td>-2.711</td>
<td>.008</td>
<td>-0.534</td>
<td>-0.258</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ischium Length</td>
<td>52 90.84 73.65 – 102.18 5.97</td>
<td>51 91.85 72.26 – 108.10 7.24</td>
<td>-0.777</td>
<td>.439</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ischium-Pubis Index</td>
<td>52 78.20 67.68 – 94.62 4.80</td>
<td>51 80.48 71.08 – 89.19 4.18</td>
<td>-2.567</td>
<td>.012</td>
<td>-0.506</td>
<td>-0.245</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gr. Sciatic Notch Height</td>
<td>52 42.27 29.22 – 56.69 5.16</td>
<td>51 46.52 35.21 – 63.57 5.99</td>
<td>-3.862</td>
<td>.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gr. Sciatic Notch Position</td>
<td>52 31.05 17.44 – 41.73 4.74</td>
<td>51 31.95 21.19 – 50.15 4.92</td>
<td>-0.946</td>
<td>.346</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gr. Sciatic Notch Index</td>
<td>52 73.42 58.93 – 92.34 6.88</td>
<td>51 68.77 55.47 – 83.11 6.65</td>
<td>3.481</td>
<td>.001</td>
<td>0.687</td>
<td>0.325</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 22 (continued).

<table>
<thead>
<tr>
<th>Measurements and Indices</th>
<th>African American Male</th>
<th>Caucasian American Male</th>
<th>Cohen’s d</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
<td>Range</td>
<td>SD</td>
</tr>
<tr>
<td>Sacral Chilotic Line</td>
<td>52</td>
<td>74.06</td>
<td>60.05 – 86.12</td>
<td>6.42</td>
</tr>
<tr>
<td>Ilium Chilotic Line</td>
<td>52</td>
<td>50.08</td>
<td>32.26 – 69.71</td>
<td>7.03</td>
</tr>
<tr>
<td>Chilotic Index</td>
<td>52</td>
<td>151.15</td>
<td>102.19 – 241.63</td>
<td>27.61</td>
</tr>
</tbody>
</table>
In summary, the reproduction of Davivongs’ methods did not sufficiently separate individuals into race groups because none of the variables showing statistically significant differences among race groups had large enough effect sizes to indicate that morphological differences in the skeletal elements were caused by racial characteristics. Further research was conducted to determine whether the variables proposed by Davivongs (1983) are useful for race determination when utilized together in a discriminant function analysis. The results of this analysis will be reported in the New Variables section.

New Variables

An independent samples t-test was conducted to assess whether differences exist within the variables developed specifically for this research. The variables proposed for this study included the depth of the acetabulum, femoral head vertical diameter, femoral head horizontal diameter, femur upper neck length, femur lower neck length, and femoral neck angle. The males were treated separately from the females. Table 23 shows the results of the independent samples t-tests for each of the variables for the males and females of each race group. No statistically significant differences between African Americans and Caucasian Americans were observed for any of the variables regardless of sex.
Table 23

*Independent Samples T-Tests for New Variables*

<table>
<thead>
<tr>
<th>Variables</th>
<th>African Americans</th>
<th>Caucasian Americans</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>Females</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetabulum Depth</td>
<td>46</td>
<td>23.54</td>
</tr>
<tr>
<td>Femoral Head Vertical Diameter</td>
<td>46</td>
<td>39.94</td>
</tr>
<tr>
<td>Femoral Head Horizontal Diameter</td>
<td>46</td>
<td>41.15</td>
</tr>
<tr>
<td>Femur Upper Neck Length</td>
<td>46</td>
<td>26.13</td>
</tr>
<tr>
<td>Femur Lower Neck Length</td>
<td>46</td>
<td>36.45</td>
</tr>
<tr>
<td>Femoral Neck Angle</td>
<td>46</td>
<td>132.32</td>
</tr>
<tr>
<td>Males</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetabulum Depth</td>
<td>51</td>
<td>25.87</td>
</tr>
<tr>
<td>Femoral Head Vertical Diameter</td>
<td>51</td>
<td>45.53</td>
</tr>
<tr>
<td>Femoral Head Horizontal Diameter</td>
<td>51</td>
<td>47.07</td>
</tr>
<tr>
<td>Femur Upper Neck Length</td>
<td>51</td>
<td>27.55</td>
</tr>
<tr>
<td>Femur Lower Neck Length</td>
<td>51</td>
<td>41.06</td>
</tr>
<tr>
<td>Femoral Neck Angle</td>
<td>51</td>
<td>130.44</td>
</tr>
</tbody>
</table>

Indices were then calculated to determine whether specific trends exist among the races, with regard to the size and shape of particular skeletal elements. These indices included the acetabulum index I and acetabulum index II – which utilized the data for acetabulum horizontal diameter and acetabulum vertical diameter from other areas of this study – and the femoral head index. Table 24 shows the results of an independent
samples t-test for the indices. There were no significant effects observed for the acetabulum index I, acetabulum index II, femoral head index, or the femoral neck index. Due to the fact that none of the variables yielded statistically significant results, it was determined that the null hypothesis could not be rejected, thus these variables are not useful to discriminate individuals by race.

Table 24

Independent Samples T-Tests for Indices of New Variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>African Americans</th>
<th>Caucasian Americans</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
<td>SD</td>
<td>N</td>
</tr>
<tr>
<td>Females</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetabulum Index I</td>
<td>46</td>
<td>102.69</td>
<td>2.91</td>
<td>30</td>
</tr>
<tr>
<td>Acetabulum Index II</td>
<td>46</td>
<td>212.40</td>
<td>20.23</td>
<td>30</td>
</tr>
<tr>
<td>Femoral Head Index</td>
<td>46</td>
<td>97.10</td>
<td>2.18</td>
<td>30</td>
</tr>
<tr>
<td>Femoral Neck Index</td>
<td>46</td>
<td>72.29</td>
<td>14.00</td>
<td>30</td>
</tr>
<tr>
<td>Males</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetabulum Index I</td>
<td>51</td>
<td>103.64</td>
<td>3.61</td>
<td>44</td>
</tr>
<tr>
<td>Acetabulum Index II</td>
<td>51</td>
<td>218.55</td>
<td>20.23</td>
<td>44</td>
</tr>
<tr>
<td>Femoral Head Index</td>
<td>51</td>
<td>96.73</td>
<td>2.74</td>
<td>44</td>
</tr>
<tr>
<td>Femoral Neck Index</td>
<td>51</td>
<td>68.74</td>
<td>15.84</td>
<td>44</td>
</tr>
</tbody>
</table>

Further analysis was conducted to determine whether sacral angle and the variables proposed by Davivongs (1983) could be used as racial indicators when utilized alongside other elements of the pelvis, sacrum, and femur. A discriminant function analysis was performed using all of the variables examined in this research except for the
new variables. The results showed that 90.4% of the original grouped cases were correctly classified, but that accuracy fell to 78.7% for the cross-validated cases. To investigate these results further, the standardized canonical discriminant function coefficients were evaluated to determine whether they were substantive to the discriminant function. This revealed that only 10 of the 33 variables had coefficients greater than ±0.40. These 10 variables (pelvis maximum length, oblique length, pubic symphysis length, greater sciatic notch height, number of sacral elements, maximum length of the femur, iliac height, sacrum maximum length, sacral curved length, and circumference at midshaft) were then selected to perform a final discriminant function analysis. The results showed that 78.2% of the original grouped cases were correctly classified and 74.1% of the cross-validated grouped cases were correctly classified. These results were deemed statistically insignificant for the purposes of this research. Thus, Sacral Angle and Davivongs’ variables did not make significant contributions to the discriminant functions.

Comparison of Skeletal Collections

To address concerns about the utility of the Robert J. Terry Skeletal Collection in the construction of forensic anthropological methods, an independent samples t-test was conducted to compare the Robert J. Terry Collection to the William Bass Donated Skeletal Collection. Each of the four sex/race groups were evaluated separately and the analysis was conducted assuming unequal variance due to the differing sample sizes. Any results found to have statistically significant differences between the two skeletal collections were highlighted. Cohen’s d and effect size r were then calculated for those variables with statistically significant differences to evaluate the magnitudes of the
differences as well as the strengths of the relationships between the variables and the skeletal collections. For the purposes of this research, a large Cohen’s d (0.8) must be accompanied by a large r-value (0.7) to be considered substantive. Those results that have both a large Cohen’s d and a large effect size r will be highlighted and the potential consequences of the differences will be discussed.

Table 25 shows the means, standard deviations, and results of the independent samples t-tests for the African American females. Of the 34 variables evaluated, only four (age at death, year of birth, oblique length, and sacral chilotic line) were found to have statistically significant differences between the skeletal collections. Year of birth was the only variable found to have a large Cohen’s d and effect size r, meaning that the relationship between the variable and skeletal collections was considered large enough to have a potential effect on the data. It is important to note that the sample size from the Terry Collection was much larger than that from the Bass Collection due to a disproportionate number of African American female remains available in the Terry Collection. This, however, does not influence effect size r, as its magnitude is independent of sample size.
Table 25

*Comparison of Means Between Terry and Bass Skeletal Collections for African American Females*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Terry Collection</th>
<th>Bass Collection</th>
<th>t</th>
<th>Sig.</th>
<th>d</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at Death</td>
<td>38   36.32  14.38</td>
<td>6   65.00  20.27</td>
<td>3.34</td>
<td>.016</td>
<td>1.63</td>
<td>0.63</td>
</tr>
<tr>
<td>Year of Birth</td>
<td>38   1902  9.00</td>
<td>6   1938  22.00</td>
<td>3.90</td>
<td>.011</td>
<td>2.14</td>
<td>0.73</td>
</tr>
<tr>
<td>Sacral Angle</td>
<td>38   50.11  10.97</td>
<td>6   40.44  13.28</td>
<td>1.000</td>
<td>.356</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biiilic Breadth</td>
<td>38   244.64  15.11</td>
<td>6   254.75  15.26</td>
<td>1.519</td>
<td>.175</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transverse Breadth</td>
<td>38   121.15  7.85</td>
<td>6   125.77  6.98</td>
<td>1.448</td>
<td>.183</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antero-Posterior Breadth</td>
<td>38   110.27  10.27</td>
<td>6   119.92  9.30</td>
<td>2.327</td>
<td>.053</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pelvis Max Length</td>
<td>38   191.80  10.86</td>
<td>6   200.08  8.35</td>
<td>2.159</td>
<td>.063</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iliac Width</td>
<td>38   146.55  9.21</td>
<td>6   150.72  7.03</td>
<td>1.287</td>
<td>.234</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iliac Height</td>
<td>38   125.91  6.99</td>
<td>6   129.72  5.44</td>
<td>1.532</td>
<td>.164</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pubic Length</td>
<td>38   69.97  5.98</td>
<td>6   77.03  9.66</td>
<td>1.737</td>
<td>.133</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ischium Length</td>
<td>38   79.48  5.03</td>
<td>6   80.97  3.02</td>
<td>1.009</td>
<td>.337</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inferior Pubic Ramus Height</td>
<td>38   10.39  1.69</td>
<td>6   10.72  3.06</td>
<td>0.258</td>
<td>.807</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oblique Length</td>
<td>38   25.92  4.76</td>
<td>6   28.74  4.28</td>
<td>2.215</td>
<td>.047</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pubic Symphysis Height</td>
<td>38   33.95  3.45</td>
<td>6   33.30  2.87</td>
<td>0.504</td>
<td>.630</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tuberculosymphyseal Length</td>
<td>38   21.50  3.88</td>
<td>6   24.80  3.40</td>
<td>2.163</td>
<td>.067</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greater Sciatic Notch Height</td>
<td>38   44.97  6.77</td>
<td>6   49.62  4.98</td>
<td>2.014</td>
<td>.079</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greater Sciatic Notch Position</td>
<td>38  29.44  3.97</td>
<td>6   31.43  2.86</td>
<td>1.487</td>
<td>.175</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cotylosciatic Breadth</td>
<td>38   34.31  3.70</td>
<td>6   34.87  3.23</td>
<td>0.385</td>
<td>.711</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ilium Chilotic Line</td>
<td>38   55.50  5.23</td>
<td>6   54.48  8.71</td>
<td>0.279</td>
<td>.790</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 25 (continued).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Terry Collection</th>
<th>Bass Collection</th>
<th>t</th>
<th>Sig.</th>
<th>d</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
<td>SD</td>
<td>N</td>
<td>Mean</td>
<td>SD</td>
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<tr>
<td>Sacral Chilotic Line</td>
<td>38</td>
<td>63.63</td>
<td>5.83</td>
<td>6</td>
<td>69.14</td>
<td>4.50</td>
</tr>
<tr>
<td>Acetabulum Vert. Diameter</td>
<td>38</td>
<td>49.53</td>
<td>2.92</td>
<td>6</td>
<td>47.95</td>
<td>2.70</td>
</tr>
<tr>
<td>Acetabulum Hor. Diameter</td>
<td>38</td>
<td>48.20</td>
<td>2.70</td>
<td>6</td>
<td>48.46</td>
<td>2.99</td>
</tr>
<tr>
<td>Symphyseal Angle</td>
<td>38</td>
<td>135.43</td>
<td>7.30</td>
<td>6</td>
<td>128.82</td>
<td>7.95</td>
</tr>
<tr>
<td>Sacral Max Length</td>
<td>38</td>
<td>103.21</td>
<td>11.68</td>
<td>6</td>
<td>101.21</td>
<td>11.70</td>
</tr>
<tr>
<td>Sacral Max Breadth</td>
<td>38</td>
<td>108.68</td>
<td>6.81</td>
<td>6</td>
<td>112.10</td>
<td>5.10</td>
</tr>
<tr>
<td>Sacral Curved Length</td>
<td>38</td>
<td>107.63</td>
<td>11.18</td>
<td>6</td>
<td>111.00</td>
<td>10.00</td>
</tr>
<tr>
<td>Sacral A-P Diameter of S1</td>
<td>38</td>
<td>27.97</td>
<td>2.25</td>
<td>6</td>
<td>27.83</td>
<td>2.65</td>
</tr>
<tr>
<td>Sacral Trans Diameter S1</td>
<td>38</td>
<td>45.67</td>
<td>4.82</td>
<td>6</td>
<td>43.53</td>
<td>4.92</td>
</tr>
<tr>
<td>Number of Sacral Elements</td>
<td>38</td>
<td>5.21</td>
<td>0.47</td>
<td>6</td>
<td>5.33</td>
<td>0.52</td>
</tr>
<tr>
<td>Femur Max Length</td>
<td>38</td>
<td>429.22</td>
<td>24.79</td>
<td>6</td>
<td>443.83</td>
<td>17.76</td>
</tr>
<tr>
<td>Carrying Angle</td>
<td>38</td>
<td>79.17</td>
<td>3.38</td>
<td>6</td>
<td>79.93</td>
<td>1.78</td>
</tr>
<tr>
<td>Circumference at Midshaft</td>
<td>38</td>
<td>82.58</td>
<td>5.29</td>
<td>6</td>
<td>87.00</td>
<td>6.63</td>
</tr>
<tr>
<td>Epicondylar Breadth</td>
<td>38</td>
<td>72.97</td>
<td>3.32</td>
<td>6</td>
<td>73.00</td>
<td>2.41</td>
</tr>
</tbody>
</table>

The results of the independent samples t-tests for the Caucasian American females are shown in Table 26. Only three of the 34 variables (year at birth, greater sciatic notch height, and symphyseal angle) were found to have statistically significant differences between the skeletal collections. Like the African American females, year of birth was the only variable with a large Cohen’s d and effect size r. In light of the fact that none of the other variables were found to have a large effect on the results, it was
determined that a birth year after 1890 should not affect the results for females of either race.

Table 26

*Comparison of Means Between Terry and Bass Skeletal Collections Caucasian American Females*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Terry Collection</th>
<th>Bass Collection</th>
<th>t</th>
<th>Sig.</th>
<th>d</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>Mean</td>
<td>SD</td>
<td>N</td>
<td>Mean</td>
<td>SD</td>
<td></td>
</tr>
<tr>
<td>Age at Death</td>
<td>25</td>
<td>43.84</td>
<td>12.30</td>
<td>25</td>
<td>50.00</td>
<td>11.55</td>
</tr>
<tr>
<td>Year of Birth</td>
<td>25</td>
<td>1910</td>
<td>12.10</td>
<td>25</td>
<td>1951</td>
<td>15.26</td>
</tr>
<tr>
<td>Sacral Angle</td>
<td>25</td>
<td>57.12</td>
<td>9.22</td>
<td>25</td>
<td>52.34</td>
<td>9.92</td>
</tr>
<tr>
<td>Biiilac Breadth</td>
<td>25</td>
<td>267.46</td>
<td>17.06</td>
<td>25</td>
<td>264.60</td>
<td>21.51</td>
</tr>
<tr>
<td>Transverse Breadth</td>
<td>25</td>
<td>136.68</td>
<td>30.76</td>
<td>25</td>
<td>130.89</td>
<td>10.10</td>
</tr>
<tr>
<td>Antero-Posterior Breadth</td>
<td>25</td>
<td>121.34</td>
<td>8.83</td>
<td>25</td>
<td>119.29</td>
<td>9.13</td>
</tr>
<tr>
<td>Pelvis Max Length</td>
<td>25</td>
<td>205.88</td>
<td>9.77</td>
<td>25</td>
<td>204.58</td>
<td>8.68</td>
</tr>
<tr>
<td>Iliac Width</td>
<td>25</td>
<td>156.82</td>
<td>9.14</td>
<td>25</td>
<td>157.68</td>
<td>7.66</td>
</tr>
<tr>
<td>Iliac Height</td>
<td>25</td>
<td>135.08</td>
<td>8.33</td>
<td>25</td>
<td>133.57</td>
<td>6.78</td>
</tr>
<tr>
<td>Pubic Length</td>
<td>25</td>
<td>75.61</td>
<td>4.14</td>
<td>25</td>
<td>76.52</td>
<td>4.72</td>
</tr>
<tr>
<td>Ischium Length</td>
<td>25</td>
<td>82.18</td>
<td>5.05</td>
<td>25</td>
<td>82.74</td>
<td>4.46</td>
</tr>
<tr>
<td>Inferior Pubic Ramus Height</td>
<td>25</td>
<td>12.14</td>
<td>2.35</td>
<td>25</td>
<td>12.19</td>
<td>1.77</td>
</tr>
<tr>
<td>Oblique Length</td>
<td>25</td>
<td>29.00</td>
<td>3.05</td>
<td>25</td>
<td>27.85</td>
<td>3.07</td>
</tr>
<tr>
<td>Pubic Symphysis Height</td>
<td>25</td>
<td>35.32</td>
<td>4.86</td>
<td>25</td>
<td>36.92</td>
<td>4.25</td>
</tr>
<tr>
<td>Tuberculosymphysal Length</td>
<td>25</td>
<td>26.58</td>
<td>4.88</td>
<td>25</td>
<td>25.81</td>
<td>4.95</td>
</tr>
<tr>
<td>Greater Sciatic Notch Height</td>
<td>25</td>
<td>48.10</td>
<td>5.54</td>
<td>25</td>
<td>51.48</td>
<td>4.75</td>
</tr>
<tr>
<td>Greater Sciatic Notch Position</td>
<td>25</td>
<td>31.53</td>
<td>5.01</td>
<td>25</td>
<td>30.64</td>
<td>3.99</td>
</tr>
</tbody>
</table>
The results of the independent samples t-tests for the African American males are shown in Table 27. Ten of the 34 variables were found to have statistically significantly differences between skeletal collections. However, only age at death and year of birth were found to have a large enough Cohen’s d and effect size r to be considered substantive for this research.
Table 27

*Comparison of Means Between Terry and Bass Skeletal Collections African American Males*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Terry Collection</th>
<th>Bass Collection</th>
<th>t</th>
<th>Sig.</th>
<th>d</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at Death</td>
<td>20 27.65 6.88</td>
<td>32 52.78 12.92</td>
<td>9.128</td>
<td>2.43</td>
<td>0.77</td>
<td></td>
</tr>
<tr>
<td>Year of Birth</td>
<td>20 1904 11.09</td>
<td>32 1945 14.80</td>
<td>11.39</td>
<td>0.000</td>
<td>3.14</td>
<td>0.84</td>
</tr>
<tr>
<td>Sacral Angle</td>
<td>20 47.61 6.17</td>
<td>32 47.74 9.58</td>
<td>0.053</td>
<td>.958</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biliiac Breadth</td>
<td>20 248.85 23.84</td>
<td>32 257.31 18.90</td>
<td>1.345</td>
<td>.187</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transverse Breadth</td>
<td>20 113.58 10.37</td>
<td>32 115.40 7.63</td>
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Table 28 shows the results of the independent samples t-tests for the Caucasian American males. Of the 34 variables, 17 were found to have statistically significant differences between the skeletal collections. Once again, year of birth was found to be the only variable with a large Cohen’s d and a large effect size r to affect the results of this study. However, future research may find it necessary to do a more inclusive comparison
of the skeletal collections utilizing all individuals, regardless of age at death or year of birth.

Table 28

*Comparison of Means Between Terry and Bass Skeletal Collections Caucasian American Males*

<table>
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<tr>
<th>Variable</th>
<th>Terry Collection</th>
<th>Bass Collection</th>
<th>t</th>
<th>Sig.</th>
<th>d</th>
<th>r</th>
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<td>Year of Birth</td>
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<td>34 123.91 5.65</td>
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Table 28 (continued).

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The results of the comparisons of the Robert J. Terry collection to the William Bass Donated Skeletal Collection show that there does seem to be potential for a secular trend occurring, which may be influencing males much more than females. In both African American males and Caucasian American males, all of the variables had larger
means in the Bass Collection than in the Robert J. Terry Collection, however, it was also noted that the average age at death was higher in the Bass Collection, which may be more indicative of morphological changes due to age, rather than an indication of secular change. Further research may be necessary to determine the causes of these differences.

Intra- and Inter-Observer Error

The purpose of the intra- and inter-observer error analyses was to evaluate the reliability and repeatability of the methods utilized to measure each skeletal element. The first objective was to evaluate whether an observer can obtain reliably precise measurements for the same variable after multiple observations. The second objective was to test whether other observers can accurately repeat those measurements. The reliability assessment was conducted using four observers, three of whom had no prior experience and were selected in an attempt to eliminate bias caused by preconceived notions of anthropological methods and measurements. The observers were each required to record two separate measurements from the 36 variables for each of two sets of skeletal remains (USM 10 and USM 11) from the University of Southern Mississippi’s Physical Anthropology Laboratory. The tests were conducted in the same order each time – the measurements from the reassembled pelvic girdle were taken first, then repeated, before disassembling the three bones to take the remaining measurements. The reassembled pelvic girdle was measured first to ensure that the results were not skewed by possible differences caused by reassembling the bones multiple times.

The data were then analyzed for precision of measurements by comparing the differences between observation 1 and observation 2 for each of the 36 measurements from both skeletal remains. The minimum and maximum differences were assessed to
evaluate the actual size of the differences, as they are directly proportional to the length in millimeters. The mean differences between the observations were then evaluated for their association with overall precision of the measurements – a mean difference of 0.00 is optimal. Any variables with large differences between observations were further assessed with regards to the magnitudes of those differences (e.g., a difference of 6.00mm is much more detrimental to the reliability of the measure of an oblique length of 27.62mm than to a maximum length of the femur of 483.00mm, because the room for error is so much smaller for the oblique length).

The comparisons of the mean differences showed that Observer 4 had the most precise measurements across all of the variables, followed by Observer 1, Observer 2, and Observer 3, respectively. Of the 36 variables, sacral angle, iliac breadth, sacrum maximum breadth, number of sacral elements, femur head diameter, maximum length of the femur, and carrying angle were the most reliable measurements across all four observers. Of the remaining variables, pelvis maximum length, sacral curved length, sacral chilotic line, transverse diameter of S1, greater sciatic notch position, epicondylar breadth, and symphyseal angle were the least reliable measurements across all four observers. However, an evaluation of the magnitudes of the differences with regard to the overall size of each element observed revealed that it is unlikely that any of the differences would have an adverse effect on the applicability of the measurements, as the differences are at most only a few millimeters and the smallest of these elements was the greater sciatic notch position, which on average was 34.21mm. There seemed to be a couple of instances of transcription or equipment error for both Observer 1 and Observer 4. Observer 1 had a maximum difference of 16.08mm for the transverse diameter of S1
for USM 11. Observer 4 had a minimum difference of 9.90mm for the pelvis maximum length of USM 10, and a maximum difference of 9.60mm for the symphyseal angle of USM 11.

A one-way ANOVA procedure was then used to compare the mean differences of the four observers across all variables to determine the accuracy of the measurements. Six of the 36 variables showed statistically significant differences (p < 0.05) between the four observers, revealing poor accuracy. These variables included the sacral angle (p = 0.027), oblique length (p = 0.033), sacral chilotic line (p = 0.046), acetabulum vertical diameter (p = 0.027), sacrum maximum breadth (p = 0.037), and femur neck angle (p = 0.022). Further inspection of the data revealed that the measurement differences for sacral angle, acetabulum vertical diameter, and sacrum maximum length between observers were less than or equal to 6.00mm, which was less than the standard deviations for sacral angle (female SD = 10.82, male SD = 8.72) and sacrum maximum length (female SD = 11.57, male SD = 9.55), but greater than the standard deviations for acetabulum vertical diameter (female SD = 2.91, male SD = 3.09). The magnitudes of the differences were calculated by dividing the combined means for each sex group by the maximum measurement difference of 6.00mm and multiplying by 100 to obtain a percent of maximum error attributed to measurement error. Sacrum maximum breadth had very small magnitudes of difference between observers (female = 5.3%, male = 5.2%), which was just outside of the cutoff criteria (5.0%). More research should be conducted to test the repeatability of this variable. Conversely, the magnitudes of differences between observers for the sacral angle (female = 11.5%, male = 12.4%) and acetabulum vertical diameter (female = 12.0%, male = 10.8%) were too large, and have very little potential to
be repeatable with further testing. However, these variables may be more reliably measured via alternative methods. The fact that sacral angle and sacrum maximum breadth were found to be two of the most reliable and precise measurements in the intra-observer error analysis, yet were not found to be accurately repeatable by multiple observers shows how important inter-observer error evaluations are for method validation.

One final intra-observer error study was conducted during data collection to evaluate the precision of the measurements taken. A paired samples t-test was used to analyze the differences from the 30 variables obtained to test the validity of the methods reported by Davivongs (1963), DiBennardo and Taylor (1983), İşcan (1983), and Peleg et al. (2007). Table 29 shows the mean, standard error of the mean, t-value, degrees of freedom, and two-tailed significance for each of the variables. Any variables showing statistically significant differences between observation 1 and observation 2 were highlighted and Cohen’s d and effect size r were calculated to demonstrate the magnitudes of the differences. Carrying angle was the only variable that showed statistically significant differences between observations (p = 0.003, d = 0.249, r = 0.12), however both effect sizes were small. Furthermore, the largest difference between observations was only 1.20°, and the mean difference of all observations was only 0.48°, which indicates that the statistically significant difference reported by the paired samples t-test was not due to measurement error. It was decided that the differences between observations were not large enough to invalidate the data collected for carrying angle.
Table 29

*Paired Samples T-Tests for Intra-Observer Error Observations*

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Overall, the most precise measurements, identified by both the intra-observer error studies as well as the inter-observer error study, were those with the most objectively derived points of measurement. For instance, it is fairly simple to identify the maximum length of the femur when utilizing an osteometric board, because it is obvious once the maximum length is obtained. Conversely, it is much more difficult to reliably obtain measurements derived from more subjective reference points. For example, the
point on the anterior margin of the auricular facet that separates the ilium chilotic line from the sacral chilotic line is much more nuanced and requires the judgment of the observer.

It may be necessary to modify the methods to employ alternative instruments and to more adequately define the variables to reduce the amount of subjectivity. Although some of the variables were more difficult to obtain consistently – either between or among observers – none of the measurement differences were great enough to indicate an adverse effect on the data from observer error.
CHAPTER V
DISCUSSION AND CONCLUSIONS

The primary goal of this research was to examine previously published metric methods of race estimation, utilizing the pelvic girdle and femur, to assess their applicability for expert witness testimony under the Daubert and Kumho guidelines for admissible evidence. Within this goal, the research also aimed to ensure that best-practices guidelines – set forth by the FBI’s Scientific Working Group for Anthropology (SWGANTH) – are being followed, and that outdated or ineffective methods are either updated to conform to the most current scientific standards or abandoned to avoid perpetuation of unreliable methods. Previous literature on this subject, specifically with regard to the statistical analyses performed, is inadequate in its current state to sufficiently meet the criteria of the Daubert guidelines or the best-practices guidelines of statistically significant results. A secondary goal of this research was to address concerns that the Robert J. Terry Skeletal Collection is no longer representative of populations in the United States and should not be used in the formation of forensic anthropological methods. This study sought to answer three questions to determine whether the methods are indeed applicable for expert witness testimony:

1. Do the methods produce reliable, reproducible, and accurate results that conform to current statistical standards that can separate individuals into race groups?

2. Do the methods meet the Daubert criteria for the admissibility of expert witness testimony? If not, do the methods meet the criteria of the Kumho decision, which would allow them to be admissible in a court of law?
3. Can the Robert J. Terry collection be used for the creation of forensic anthropological methods if sample selection is properly conducted to take demographic data and historical details into account to minimize error?

Best- Practices Guidelines

The reliability, reproducibility, and accuracy of the methods of race estimation from the pelvic girdle reviewed in this research were examined within the best-practices guidelines for ancestry assessment set forth by SWGANTH, which were introduced in Chapter II. The statistical methods utilized by the previous researchers were analyzed within the SWGANTH best-practices guidelines for statistical methods as well as statistical standards set forth by an authority in the field of statistics (i.e., Educational and Psychological Measurement Journal). The methods were modified for this study when they did not conform to current standards, most notably when discriminant function analyses employed stepwise procedures for variable selection or when males were treated separately from females in multivariate statistical modeling.

Guidelines for Expert Witness Testimony

The methods of race estimation from the pelvic girdle utilized in this research were first analyzed under the Daubert decision. The first two criteria have been met simply by conducting this research, as the methods were tested through the scientific method, and this research subjected them to peer review (Daubert v. Merrell Dow Pharmaceuticals). To be admissible under the Daubert criteria, the methods must meet each of remaining guidelines listed below:

1. The methods have established standards.

2. The methods have known or potential error rates.
3. The statistical results stand up to the estimates of scientific certainty set up by the relevant scientific community (i.e., 95% for social sciences).

4. The methods have widespread acceptance by the scientific community.

In the event that the methods did not meet one or more of these criteria, they were assessed utilizing the *Kumho* guidelines. To be considered applicable under the *Kumho* decision, the results must show a level of certainty at or above 90% accuracy, and descriptive statistics must show statistically significant differences (p < 0.10) among the groups, as well as large effect sizes for those significant differences. Any methods that meet these criteria were recommended for use in a court of law with the caveat that they only be entered as evidence when accompanied by other accepted methods that support the conclusions made by the expert witness (e.g., other aspects of the biological profile, medical and/or dental records, DNA evidence). It is paramount that as much information is included as possible that speaks to the reliability and reproducibility of the methods so that trial judges can make informed decisions when utilizing the *Kumho* guidelines to assess expert witness testimony. Any methods that do not meet these criteria were not recommended for use as evidence in court proceedings and may be subject to abandonment by the anthropological community altogether.

**Empirical Findings**

This section presents a synthesis of the empirical findings of each study with an analysis of the methods under the *Daubert* and *Kumho* guidelines. Next, possible contributions to the field and implications of this research are discussed followed by recommendations for future research, limitations of the study, and the final conclusions.
**Peleg et al. Sacral Angle**

The analysis of the methods proposed by Peleg et al. revealed that sacral angle was not able to sufficiently separate individuals into race groups. Furthermore, when sacral angle was assessed alongside other variables, it did not make a significant contribution to the discriminant function analysis to classify individuals by either race or sex. The statistical results for sacral angle did not stand up to the estimates of scientific certainty, and thus do not meet the criteria set forth by the Daubert decision. Due to the fact that sacral angle is not applicable to race estimation, it is not necessary to evaluate its admissibility for expert testimony under the Kumho decision and should not be utilized for estimation of race. Future researchers, however, may be interested in the findings reported by Peleg et al. (2007), which showed that sacral angle is age-dependent; the inclination of the sacrum is more vertically oriented in young individuals and becomes more horizontally oriented in the older population (p. 975).

**İşcan**

The examination of the reproduction of İşcan’s methods revealed a general trend in which the pelvic girdles of Caucasian Americans are broader than those of African Americans in both males and females. The descriptive statistics showed that there are statistically significant differences across the three features of the pelvic girdle. However, the effect sizes of those differences proved to be too small for race to have any meaningful effect on the variation between the groups.

The classification results from the discriminant function analysis, modified from İşcan’s original methods, showed that the measurements of the pelvic girdle did not adequately classify individuals by race. At only 58.9% accuracy for the original grouped
cases and 56.9% for the cross-validated grouped cases, these methods did not produce statistical results that stand up to the 95% certainty set by the relevant scientific community. In light of the fact that these methods are not reliable for race estimation, it is not necessary to evaluate their admissibility in a court of law under the *Kumho* decision.

It is important to note that the original article published by İşcan claimed 88% accuracy. This level of accuracy is presumed to be due to the fact that İşcan analyzed males separately from females. The results from the reproduction of İşcan’s methods when the sexes were treated separately, showed average classification rates of 72.8% and 74.1% for the original grouped cases of males and females, respectively. The average classification rate for the cross-validated grouped cases for females stayed constant, while that of the males fell to 69.9%. Caucasian American females showed the greatest accuracy for correct classification at 80.0%; however, none of the classification rates met the 88% accuracy reported by İşcan (1983), nor did the original methods conform to current best-practices guidelines. Therefore, these results were only used for comparison to assess the reproducibility of the original methods, and should not be utilized for race estimation.

Further inspection of the classification results showed that these methods are relatively successful in separating males from females. When the classification rates for the females of both race groups were pooled separately from the males, the original grouped cases had accuracy rates of 78% and 83%, respectively, while the cross-validated grouped cases show accuracy rates of 77% and 82%, respectively. However, other methods of sex determination have shown levels of accuracy higher than 95%
(Meindl, Lovejoy, Mensforth, & Don Carlos, 1985; Schulter-Ellis, Schmidt, Hayek, & Craig, 1983), potentially rendering this method substandard for sex determination.

_DiBennardo and Taylor_

The results of DiBennardo and Taylor’s discriminant function analysis proved to be the most reliable and applicable method for determining race from the bones of the pelvic girdle and femur. The comparison of the descriptive statistics between DiBennardo and Taylor’s reported results and those of this study revealed that the methods for variable measurement were reproducible, with little room for mechanical or human error. There was, however, divergence between the two studies with respect to the results of the discriminant analysis.

DiBennardo and Taylor’s structure coefficients showed 10 variables from Function 1 and five variables from Function 2 that were substantive to the discriminant analysis, whereas the structure coefficients of the present study showed only three substantive variables from each function. Furthermore, symphyseal angle was reported as the variable with the strongest contribution to Function 1 of DiBennardo and Taylor’s discriminant analysis, yet it contributed very little to either function in the reproduction. An evaluation of the descriptive statistics for symphyseal angle revealed that the means for each group in this study were smaller and less varied than those reported by DiBennardo and Taylor (1983). This may have been caused by measurement error due to a misinterpretation of the definition of the symphyseal angle variable. Another source for this divergence could be sample selection, as DiBennardo and Taylor’s materials consisted of a random selection of skeletons from the entire Robert J. Terry Skeletal Collection, whereas this research employed only individuals born after 1890 and included
individuals from the William Bass Donated Skeletal Collection in addition to the Terry Collection.

DiBennardo and Taylor’s discriminant analysis showed almost complete separation of the sexes, while the results of this research showed higher rates of misclassification by sex. African American males were the only individuals to be misidentified by sex in DiBennardo and Taylor’s study, whereas in the present study, only one African American male was misidentified by sex while four Caucasian American males were misidentified by sex. None of the females were misidentified by sex. The classification rates reported by DiBennardo and Taylor (1983) for Caucasian American females and African American males were higher than 95% (96.9% each), while the classification rates for Caucasian American males and African American females were slightly lower than 95% (93.8% and 92.8%, respectively). The classification rates for the reproduction, however, were all lower than 90% (African American females = 88.6%, Caucasian American females = 84.0%, African American males = 86.5%, and Caucasian American males = 84.3%).

The differences between DiBennardo and Taylor’s original results and those of the current study are not likely due to the method modification, which omitted stepwise procedure, because variable selection was not a factor in this study. It is possible that the lower rates of accurate classification in this study are due to sample selection, as secular change occurring in the Terry Collection may have exaggerated the racial differences found by DiBennardo and Taylor. It is also possible that the percentages of admixture in American populations have increased as an outcome of the 1967 Supreme Court decision that deemed anti-miscegenation laws unconstitutional (Gullickson, 2006; Morello, 2012).
For instance, more than 7% of the 3.5 million children born in the United States in 2009 were of two or more races and the number of children born to black and white couples almost doubled from those reported in the 2000 census (Morello, 2012, para. 2). Additionally, interracial marriages made up 0.4% of all marriages in the US reported in the 1960 census, which increased to 2% in the 1980 census and to 10% (of opposite-sex marriages) in the 2010 census (United States Census Bureau, 2012). It is important to note that not all married couples reproduce, and that 1% of children born just prior to the 2010 census were born to unmarried women (Shattuck & Kreider, 2013, p. 3). These increases in admixture would likely manifest as greater homogenization among the racial groups examined in the present study compared to those of DiBennardo and Taylor (1983). This is a consequence of sample selection, as age at death post-1890 was a criterion for this research, but not for DiBennardo and Taylor’s investigation. The average year of birth across the entire Terry Collection is 1883, while the average year of birth for the current study is 1927. Further research may be necessary to identify the precise factors influencing the deviation from the original results reported by DiBennardo and Taylor (1983).

DiBennardo and Taylor’s original methods have been widely accepted by the scientific community, have been cited in numerous publications, and have been fundamental to the establishment of postcranial methods of race estimation. However, the analysis of DiBennardo and Taylor’s original methods revealed that they do not stand up to the rigorous guidelines set forth by the Daubert decision. Nor do the established standards provided by the authors conform to current statistical standards, namely the stepwise procedure used for variable selection and the use of the entire Robert J. Terry
Collection for the formation of their discriminant functions. Consequently, this raises doubt with respect to the 95% accuracy as well as the known and potential error rates of the methods.

To correct these issues, the present study modified the methods to conform to the SWGANTH best-practices guidelines for statistical methods and ancestry assessment, and current standards outlined by the academic journal *Education and Psychological Measurement* (an authority in the field of statistics). The reported classification rates supply known and potential error rates, as the percent of cases accurately classified is directly proportional to the discriminating power of the discriminant functions. However, by modifying the methods to improve reliability and confidence in the data, the overall accuracy fell significantly, causing the classification rates to no longer meet the 95% accuracy criterion of the *Daubert* guidelines. Therefore, the methods must be evaluated for their admissibility as evidence for expert testimony under the guidelines of the *Kumho* decision.

Based on the average classification rate for the original grouped cases (85.8%), the known error rate of the discriminant analysis is 14.2%, whereas the potential error rate, based on the cross-validated grouped cases (80.7%), is 19.3%. Unfortunately, these levels of error are well above the 10% allowed by the standards for this research, meaning that there is not enough confidence in the methods to recommend they be used for forensic casework, regardless of other supporting methods, nor should they be admissible in a court of law under the *Kumho* decision. It is important to note that methods of race estimation are utilized to determine sex, age, stature, and other aspects of the biological profile. The high levels of error associated with the modified methods
produced by this research would only increase errors associated with these other methods, leading to less confidence in the final results. Therefore, it is recommended that these methods be abandoned by physical anthropologists.

Davivongs

The results of the reproduction of Davivongs’ methods showed that there are some statistically significant differences in the features of the pelvic girdle among African Americans and Caucasian Americans in the United States. Furthermore, while some of the indices revealed specific trends about the size and shape of the pelvic elements (e.g., sacral chilotic line is generally longer than the ilium chilotic line, ischium is generally larger than the pubis), there were very few differences among the race groups with regard to the indices. In general, African Americans tended to show less divergence between the measurements of the paired elements, resulting in indices with values closer to 100% than those of Caucasian Americans, regardless of sex. However, the proportion of the differences among the two race groups was at most 8%, which explains the insufficient effect sizes. The graphical representations of the frequency distributions for each of the statistically significant results revealed that there was an astonishing amount of overlap between the two races. The majority of individuals fell within the overlap ranges, meaning that only a very few outliers of either race would be correctly classified utilizing these methods.

The results of this study were insufficient to classify individuals into race groups. It was, therefore, unnecessary to evaluate the methods under the Daubert or Kumho guidelines for expert witness testimony. Davivongs’ methods were originally developed for sex determination. The skeletal collection utilized for his study was comprised of
Australian Aboriginal skeletons. An additional study could be conducted to evaluate the application of the methods to North American skeletal collections. Furthermore, due to the fact that the original analysis was performed in 1963, research should be conducted to update the reference data using a more contemporary skeletal collection.

New Measurements

The new measurements proposed for this research consisted of the depth of the acetabulum, femoral head vertical diameter, femoral head horizontal diameter, femur upper neck length, femur lower neck length, and the femoral neck angle, and were utilized to calculate the two indices of the acetabulum, femoral head index, and the femoral neck index. The descriptive statistics for these variables did not produce statistically significant differences among African Americans and Caucasian Americans for either sex. Therefore, it was not necessary to evaluate the variables within the Daubert and Kumho standards for admissible evidence.

Similarly, the results of the discriminant function analysis that utilized all of the variables from the previous research reviewed herein showed an insufficient level of discriminating power to separate individuals by race. Thus, it was not necessary to evaluate the applicability of this method under the Daubert or Kumho criteria for expert witness testimony. The variables were, however, sufficient in separating individuals by sex. Further research could be conducted to evaluate the accuracy and reliability of these methods for use in sex determination.

Terry Collection

The results of the comparison of the Robert J. Terry Skeletal Collection to the William Bass Donated Skeletal Collection revealed that the most significant differences
between the collections are the age at death and year of birth of the individuals. On their own, these variables do not have much value for this study, since the research design only included individuals born after 1890 and the number of samples from each 10-year age range was dependent upon the skeletons present in the two collections. Due to the fact that these demographic aspects were the only statistically significant variables accompanied by a large Cohen’s d and effect size r, the more contemporary skeletons in the Robert J. Terry Skeletal Collection were deemed appropriate for this study.

It is important to note, however, the possible evidence of secular change occurring within the males of the Terry Collection. The comparison of African American males between the two skeletal collections yielded statistically significant differences in nine of the 31 variables, whereas the comparison of Caucasian American males yielded statistically significant differences in 14 of the 31 variables. Conversely, the female groups each yielded statistically significant differences for only two variables. Although none of these statistically significant differences were accompanied by large effect sizes, they do indicate some influence on the male morphology. There are many factors that could influence skeletal morphology (e.g., nutrition, socioeconomic status, occupation) (Jantz & Jantz, 1999; Pearson, 2000; Wescott, 2006). Further research should compare the entire Robert J. Terry Skeletal Collection to the William Bass Donated Skeletal Collection in an attempt to confirm these differences and identify potential causes of these changes. The differences between the collections may be more statistically significant and observable when years of birth prior to 1890 are included.
Intraobserver and Interobserver Error

The results of the intra- and inter-observer error statistics revealed that the majority of the variables were easily reproduced and repeated without statistically significant differences between observations. Seven variables were deemed most reliable by the intra-observer error study employing the four researchers. These variables included sacral angle, iliac width, sacrum maximum breadth, number of sacral elements, femur head diameter, maximum length of the femur, and carrying angle. The least reliable variables included pelvis maximum length, sacral curved length, sacral chilotic line, transverse diameter of S1, greater sciatic notch position, epicondylar breadth, and symphyseal angle. These variables may be less reliable than the others due to the subjective nature of the measurements. It is unlikely, however, that the magnitudes of the differences between observation 1 and observation 2 for these variables would have an adverse effect on the applicability of the measurements.

Six variables showed statistically significant differences between the four observers when interobserver error was evaluated. These variables included sacral angle, oblique length, sacral chilotic line, acetabulum vertical diameter, sacrum maximum breadth, and femur neck angle. Of these variables, only three displayed magnitudes of differences large enough to potentially negatively affect the results of this research. Sacrum max breadth showed just over 5% error, and should be retested to determine its validity. Conversely, sacral angle and acetabulum vertical diameter showed levels of error greater than 10%, which raises doubt as to whether they would become more precise with further testing. Future research should be conducted to determine if
alternative measurement methods yield more precise and reproducible data for these two variables.

The results of the intraobserver error study conducted in the field revealed that carrying angle was the only variable to show statistically significant differences between observation 1 and observation 2. However, the largest difference between observations was only $1.20^\circ$, which is not expected to adversely affect the results. Furthermore, when Cohen’s $d$ and effect size $r$ were calculated to assess the magnitude of this difference, only a very weak effect from measurement error was observed. Although some questions may be raised about the repeatability of some of these measurements due to the interobserver error evaluation, the very low incidence of measurement error observed in this intraobserver error study reflect high confidence in the data obtained for this research.

Additional interobserver error studies for these methods may be necessary to evaluate potential differences in error rates when observers are chosen who have prior experience measuring skeletal remains. The motivations for choosing observers with no prior experience for this study were to 1) test the efficacy of the variable definitions, and 2) eliminate potential for bias from prior experience of the observer with similar methods. Future research may want to test for this bias by comparing interobserver error rates among multiple observers with no prior experience measuring skeletal remains to those with varying degrees of prior experience.

**Implications of This Research**

After reviewing the results of this study, it is apparent that none of the reproductions of previously reported methods of race estimation from the bones of the
pelvic girdle and femur sufficiently separate individuals by race under either the Daubert or Kumho guidelines for admissible evidence. Furthermore, it is suggested that all of the methods be abandoned so as not to perpetuate unacceptable methods. This section discusses how the findings of this research may impact the field of anthropology, potential theoretical and policy implications specifically.

Theoretical Implications: The Race Concept

The concept of races for human classification traces back to Linnaeus in 1758, who described it as both the morphological and behavioral characteristics that were considered the essence of the category (Caspari, 2003, p. 66). These characteristics were implicitly understood to be part of the intrinsic biology of the race, and were clearly influenced by European prejudices (Caspari, 2003, p. 66). From its very inception, the race concept embodied both essentialism and biological determinism, which in many cases has rendered thinking about race very similar to thinking about biological species. In 1977, Brues defined race as a division of a species, which differs from other divisions by the frequency with which certain hereditary traits appear among its members (p. 89). However, studies of human populations conducted prior to, and following Brues’ publication, have shown that greater variation exists within populations than among them (Boas, 1894; Brace, 1964; Goodman, 1997; Livingstone, 1962; Montague, 1942b; Templeton, 1998).

The controversy surrounding the race concept hinges on the fact that although the majority of anthropologists have rejected biological determinism and the notion that races are subspecies, essentialism and the concomitant rendering of races as clades have continued to influence how anthropologists view populations. In an attempt to establish a
formal position on race, the American Association of Physical Anthropologists (AAPA) published a formal statement on biological aspects of race in 1998, which stated that:

There are obvious physical differences between populations living in different geographic areas of the world. Some of these differences are strongly inherited, while others, such as body size and shape, are strongly influenced by nutrition, way of life, and other aspects of the environment. However, humanity cannot be classified into discrete geographic categories with absolute boundaries, and the traits generally used to characterize a population are either independently inherited or show only varying degrees of association with one another within each population. Therefore, the combination of these traits in an individual very commonly deviates from the average combination of the population. (“AAPA Biological Aspects of Race,” 1998, p. 714)

Despite this resolution, the use of racial categories persists in certain aspects of the field. Forensic anthropology has especially struggled to distance itself from the race concept, in large part due to its close ties to law enforcement, which relies heavily on racial characteristics for identification.

In his article titled “Forensic Anthropology and the Concept of Race”, Sauer (1992) posed the question “If races don’t exist, why are forensic anthropologists so good at identifying them?” Although the general consensus among academic scholars is that race is a cultural construct that does not accurately or productively describe human biological variation (Andreasen, 1998; Brues, 1990; Edgar & Hunley, 2009; Goodman, 1997; Keita & Kittles, 1997; Konigsberg, Algee-Hewitt, & Steadman, 2009; Ousley, Jantz, & Fried, 2009; Sauer, 1992; Templeton, 1998; Williams & Armelagos, 2007),
disagreement remains with regard to the geographic distribution or evolutionary causes of patterns of human biological variation (Edgar & Hunley, 2009). While arguably the majority of forensic anthropologists feel that human biological races do not exist, the assignment of a race to a set of skeletal remains is a routine part of most forensic anthropology evaluations (Sauer, 1992, p. 109). Sauer’s rhetorical question sparked much interdisciplinary discourse among scholars who specialize in human biology, genetics, forensics, bioarchaeology, and paleoanthropology.

The Maxwell Museum and the Department of Anthropology of the University of New Mexico hosted a symposium in 2007 to foster open dialog across academic disciplines, drawing from historical contexts as well as empirical research to better communicate the heterogeneous views within and outside of the various disciplines as well as the data and methods used to arrive at those views (Edgar & Hunley, 2009). The general consensus from those who attended this symposium was that both morphological and genetic variation among individuals within a population is substantially greater than among populations, however, many anthropologists remain reluctant to abandon racial thinking all together.

Relethford (2009), for example, posits that rather than argue about whether race is a cultural construct (an idea that many take as being equivalent to a denial of variation) or that race is real, it might be more useful to consider race as a culturally constructed label that crudely and imprecisely describes real variation (p. 20). He goes on to caution that there is an inherent loss of statistical information when the cultural construction of race is transformed from a continuous variable into an ordinal-level or nominal-level variable. However, he perpetuates the exception for forensic anthropology, stating that one could
make the case that there are times when a crude division into major geographic regions may be useful in certain cases such as forensic contexts in which one might want to assign a specimen to a broad ancestral group (Relethford, 2009, p. 21). Conversely, Konigsberg et al. (2009) suspect that forensic anthropologists are so good at identifying races because although practicing forensic anthropologists typically ask not to be given any prior information when they conduct an osteological analysis, they do often know something about the origin of the case (Konigsberg et al., 2009, p. 86).

Racial thinking rests on the belief that visible human variation connotes fundamental deep differences within the species, which can be packaged into units of near-uniform individuals (Keita & Kittles, 1997, p. 534). In its classical form, racial thinking requires the explanation of certain kinds of variation as necessarily the result of gene flow between entities conceptualized as having different traits as the result of natural selection. However, approximately 85% of human genetic variation is between individuals within the same local populations, while about 8% is between the local populations found within major racial groups, and the remaining 7% is between races (Andreasen, 1998; Templeton, 1998). Genetic distances, when properly analyzed, undermine the biological validity of human races as evolutionary lineages, yet even a casual review of the literature reveals that raciotypological thinking persists (Keita & Kittles, 1997, p. 536). Similarly, human variation does not produce static discrete groups but is an evolutionary phenomenon that is roughly distributed along geographical gradients with a predominant signal of greater heterogeneity within rather than between groups (Lewontin, 1972; Relethford, 1994; Marks, 1995; Williams & Armelagos, 2007). Geneticists and anthropologists still frequently interpret data in terms of interacting
It may be more appropriate, then, to answer the questions about race by noting that race is a crude first-order approximation to human biological variation that is arbitrary in terms of the number and definition of races, and may not provide the best way of describing or analyzing human variation (Relethford, 2009). The applications of human variation are context-specific and depend on the particular research objectives. Therefore, assigning individuals to local or regional populations rather than broad ancestral groupings may maximize statistical information in certain contexts. Instead of perpetuating the decades-old debate about whether races exist, perhaps physical anthropologists should focus on alternative applications of human variation. As long as race is used as shorthand to describe human biological variation – variations that blur from one race into the next, and are greatest within so-called races rather than among them – misidentifications are inevitable. Whether it is used in police work, medical studies, or countless everyday situations where people are grouped biologically, the answer is the same: race science is bad science (Goodman, 1997, p. 21).

The most troubling, but not surprising, revelation to come out of this study is the very high degree of error reported for each set of methods evaluated, especially with respect to the discriminant function analyses. The reproduction of İşcan’s (1983) methods, which were modified to increase reliability, produced extremely high misclassification rates for both the original grouped cases and the cross-validated grouped cases (39.6% and 62.1%, respectively). Even the results from the reproduction of DiBennardo and Taylor’s (1983) discriminant functions showed an overall
misclassification rate of 14.2% for the original grouped cases and 19.3% for the cross-validated grouped cases. This raises serious doubts about the accuracy of any determinations of race for unknown skeletal remains that have been decided on the basis of these methods. It also raises urgent concerns about the discriminant functions established utilizing craniometric variables, in large part because they also employ stepwise procedures for variable selection. To echo Goodman (1997), “How many bodies and body parts are sending investigators down the wrong paths because the wrong box was checked off?” (p. 23)

Policy Implications

Science ought not to be based on an ill-defined, constantly changing and contextually loaded variable (Goodman, 1997, p. 23). In the interest of producing the most unbiased and scientifically sound results, future research in the areas of physical and forensic anthropology should thoroughly evaluate the proposed statistical procedures before any analysis is conducted to ensure that they conform to the statistical standards recommended by an authority in the statistics field (e.g., Journal of Educational and Psychological Measurement). Discriminant analysis should use hierarchical procedures for variable selection, regardless of the methods utilized in previously published research. When, and if possible, future research should attempt to conduct double-blind studies in which skeletal remains are given a coded item number by a third party so that the researcher(s) taking measurements and entering the data do not have any prior knowledge of the demographic information of the skeletal samples. If the goal of forensic anthropologists is to produce the most scientifically accurate and reliable methods, more focus must be placed on peer-reviewed validation of established methods.
One significant systemic issue in physical anthropology that this research has uncovered is that methodology is continually adopted into the field without first being rigorously evaluated for reproducibility and reliability. Likewise, discriminant functions have been published in textbooks and have been utilized by researchers without mention of the temporal period of the sample population(s) (e.g., Ditch & Rose, 1972; Giles & Elliot, 1962). Methods unsuitable for use with contemporary populations must be published with a clear explanation of which skeletal collection was used in the construction of the functions so that those based on prehistoric or historic populations are not being utilized for contemporary unknown remains. For example, Davivongs utilized samples from a variety of sources, but made no mention of temporal period and did not record age at death or sex of the skeletal samples. It is of utmost importance that anthropologists understand the statistical procedures they are using, ensure that the data meet the assumptions of those procedures, and report any limitations or caveats of the results.

The objective of discriminant analysis is to find the set of linear combinations or discriminant functions of collected variables, which best maximizes the separation of two or more groups. Further manipulation of the discriminant functions produces classification functions, which allow the researcher to classify a case of unknown origin into one of the given groups based on the measured values on the set of discriminating variables (Gondek, 1981, p. 268). Unfortunately, the inexperienced or unwary user of statistical packages such as SPSS may be in danger of seriously misinterpreting the results because of a lack of understanding of the output provided (Gondek, 1981, p. 269). Gondek (1981) explains that a major reason for this misunderstanding is lack of
correspondence between what the package output gives the user and what the user may expect (p. 269). For instance, classification functions will always indicate the most similar group or individual. Therefore, it is imperative for the researcher to understand that when an unknown’s true group or reference data is not represented in the reference sample(s), misleading results may be produced (SWGANTH, Statistical Methods, 2013b, p. 3).

The literature reviewed to date by this author revealed that the constructions of discriminant functions for use in establishing both race and sex have all utilized stepwise procedures for variable selection (DiBennardo & Taylor, 1983; Ditch & Rose, 1972; Giles & Elliot, 1963; Hubbe & Neves, 2007; İşcan, 1983; Ousley & Jantz, 2013; Owsley, 1982; Patriquin, Styen, & Loth, 2012; Williams & Armelagos, 2007). Various methods have been modified within the research designs to test the ability of the discriminant functions to correctly classify individuals into these groups, including the selection of different independent variables, inclusion of larger sample sizes, introduction of additional racial groups, and testing of racial categories by changing the definitions of geographic regions to alter how groups of individuals are pooled. However, none, so far, have evaluated how utilizing hierarchical rather than stepwise procedures for variable selection affects the accuracy and efficacy of the classifications.

In light of the results of this study as well as the known errors associated with stepwise procedures, it is suggested that all morphometric methods that employ discriminant analysis models be reevaluated using hierarchical variable selection. Similarly, there has been very little discussion in the literature of the fact that statistical software packages, such as SPSS, do not correctly calculate degrees of freedom in
stepwise analysis, nor do they print any warning that this is the case, which makes them extremely prone to Type I errors (Cliff, 1987; Thompson, 1995; Wilkinson, 1979). Therefore, it is the opinion of this author that all published methods that rely on discriminant function analysis or logistical regression be reevaluated utilizing the hierarchical procedures for variable selection, as it relies on interpreted values based on the expertise of the researcher, instead of the stepwise procedure, which is an arbitrary decision based solely on each variable’s correlation to the discriminant function.

Furthermore, it is of utmost importance that researchers conduct assessments of normality, homogeneity of variance, multicollinearity, and independence of variables to ensure that the data meet the assumptions of discriminant analysis. For example, multicollinearity can negatively affect the accuracy of the discriminant analysis, because addition of highly correlated predictor variables decreases the predictive power of the functions but is hard to avoid when using skeletal data. The methods should also be evaluated to ensure that a sufficient number of variables are used along with a sample population of adequate size. Huberty (1994) suggests that the sample size be larger than three times the number of variables (p. 156). There is no recommended optimal number of independent variables because the researcher must decide which independent variables to include based on either prior research models or knowledge and intuition about the proposed variables to decide, logically, which one(s) might be related to predicting the desired groups (Hair, Black, Babin, Anderson, & Tatham, 2006, p. 286). The most appropriate independent variables are those that differ across at least two of the groups of the dependent variables; variables that do not differ across the groups are of little use in discriminant analysis (Hair et al., 2006, p. 286). Usually, researchers include several
variables in a study in order to see which one(s) contribute to the discrimination of the groups: they first perform the multivariate test and if statistically significant, proceed to identify which of the variables have significantly different means among the groups. Thus, even though the computations with multiple variables are more complex, the principle reasoning still applies, namely, that the researcher is looking for variables that discriminate between groups, as evident in observed mean differences (Hill & Lewicki, 2007).

As demonstrated throughout the literature, another important aspect of race differences concerns their effect on the determination of other demographic characteristics such as age, sex, and stature (DiBennardo & Taylor, 1983; Loth & İşcan, 2000a, 2000b; Macho, 1990; Patriquin et al., 2002). Methods for determining these other aspects of the biological profile should also be reevaluated with respect to population differences. Likewise, software programs, such as Fordisc – statistical software for forensic anthropology that performs linear discriminant function analysis to aid in the estimation of ancestry and sex from unidentified skeletal remains (Ousley & Jantz, 2013, p. 97) – must be overhauled to replace algorithms that rely on stepwise analysis. This would, no doubt, be a huge undertaking because: 1) separate discriminant analyses must be conducted for all possible combinations of independent variables utilizing all available samples and dependent groupings; 2) the accuracy and applicability of each resulting function must be evaluated independently of all others; and 3) this procedure must be followed every time new samples or groups are added to update the database.

SWGANTH has been attempting to strengthen the field of anthropology by producing and implementing stricter standards for professionals and academics alike.
Until the OSAC guidelines are published and enacted through NIST, it is the responsibility of the researcher to ensure that the SWGANTH best-practices guidelines are being followed, and that the methods produce scientifically sound results. Furthermore, the anthropological community has an obligation to only accept those methods which have been peer-reviewed and thoroughly validated.

Limitations

There were a few limitations to this research, which were not likely to adversely affect the data or the results, but are necessary to disclose nonetheless. There is a disparity among the Robert J. Terry Skeletal Collection and the William Bass Donated Skeletal Collection with regard to the skeletal remains from each race group. The majority of Caucasian American individuals in the Robert J. Terry Collection have years of birth prior to 1890, whereas the majority of African American individuals in the same collection have years of birth after 1890. The William Bass Donated Skeletal Collection, on the other hand, is comprised of far more Caucasian American individuals than African American individuals. This created a skewed sample population where the majority of African American individuals were selected from the Robert J. Terry Collection, while the majority of Caucasian American males were selected from the William Bass Donated Skeletal Collection. The Caucasian American females were evenly selected from the two skeletal collections. African American females, on the other hand, are extremely underrepresented in the William Bass Donated Skeletal Collection; only eight individuals were available for this study, and of these, two had medical implants rendering them unacceptable for use.
After completing the initial intra- and inter-observer error studies, it was realized that six of the variables were missing. These variables were measured by the same four observers, but were analyzed separately, since a significant amount of time had elapsed since the first round of data collection. This limitation is not expected to adversely affect either the results of the intra- and inter-observer error studies, or the results of this research, because adequate care was taken to minimize bias.

Conclusions

The methods, explored herein, for estimating race using the pelvic girdle and femur do not meet the Daubert or Kumho criteria for expert witness testimony. Furthermore, the methods reported in the literature do not conform to current statistical standards, and when modified show a decrease in the ability to accurately classify individuals on the basis of race. The results of this research show the need for more rigorous validation before physical and forensic anthropologists adopt morphometric methods for use in casework. It is apparent that many of the methods currently used by forensic anthropologists may not be as accurate as previously believed. It is vital that forensic anthropologists, and forensic scientists alike, continually evaluate the methods utilized in the field to: 1) ensure that outdated or ineffective methods are not perpetuated out of habit; 2) become more cognizant of limitations inherent in previous methods in order to update them to conform to current standards; and 3) build upon only those methods which have been shown to meet the criteria of current standards, especially with respect to the fast pace of development of new methods and procedures. Likewise, anthropologists need to revise all methods that employ discriminant function analysis and
logistical regression to replace stepwise variable selection procedures with hierarchical procedures.

The FSSB should include this revision in its guidelines for statistical methods. It is the opinion of this author that all methods of race estimation, as well as any methods that rely on those estimations, be evaluated under the guidelines for statistical methods and ancestry assessments to ensure that outdated and ineffective methods are not perpetuated in the field. Anthropologists should become familiar with the standards outlined by SWGANTH (until the OSAC is fully operational), as well as those provided by an authority in the field of statistics. Finally, the implications of this research reveal a need to change the dialog with respect to the race concept to acknowledge that while variations do exist within human populations, research continues to show more variation within than among those populations. This should prompt anthropologists to investigate alternative ways of thinking about and utilizing human variation.
APPENDIX A

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