

2018

# Cranial and post cranial metric sex estimation in modern Thai and Native American individuals

---

<https://hdl.handle.net/2144/33044>

*"Downloaded from OpenBU. Boston University's institutional repository."*

BOSTON UNIVERSITY  
SCHOOL OF MEDICINE

Thesis

**CRANIAL AND POST CRANIAL METRIC SEX ESTIMATION IN MODERN  
THAI  
AND NATIVE AMERICAN INDIVIDUALS**

by

**MEREDITH M. PATTERSON**

B.A., Drew University, 2016

Submitted in partial fulfillment of the  
requirements for the degree of  
Master of Science

2018

© 2018 by  
MEREDITH M. PATTERSON  
All rights reserved

**Approved by**

First Reader

---

Sean D. Tallman, Ph.D.  
Assistant Professor

Second Reader

---

James T. Pokines, Ph.D., D.-A.B.F.A  
Associate Professor

## **ACKNOWLEDGEMENTS**

First, I would like to thank my family for all their support throughout undergrad and graduate school, this would not have been possible without your love and support. George, thank you for being there for throughout many setbacks and obstacles during my graduate school career, I love you.

In regards to the completion of this thesis, thank you Dr. Sean Tallman, Dr. James Pokines and Dr. Harbaugh for all your help during this process. The research collection would not have been possible without Dr. Nawaporn Techataweewan at Khon Kaen University and Giselle Garcia at the American Museum of Natural History. Thank you for allowing me access to the skeletal collections that made this research project possible.

**CRANIAL AND POSTCRANIAL METRIC SEX ESTIMATION OF MODERN  
THAI AND NATIVE AMERICAN POPULATIONS**

**MEREDITH M. PATTERSON**

**ABSTRACT**

Historically, metric and morphological standards used in forensic anthropology and bioarcheology were derived from individuals of European and African descent and ancient Native Americans. However, it is unlikely that these standards can be accurately applied to modern Asian populations. Due to different population histories, it is hypothesized that ancient Native American and modern Thai individuals are metrically distinct. This study investigates the metric differences in sexual dimorphism between 102 Native American (American Museum of Natural History) and 100 modern Thai (Khon Kaen University) individuals 17 to 96 years of age. A total of 28 cranial, 9 mandibular and 58 postcranial measurements were compared between Native American and Thai individuals. Subsequently, select measurements were tested in Spradley and Jantz's (2011) American Black and White sex estimation equations to see how equations derived from non-Asian populations perform on Native American and Thai individuals and to ascertain if population differences exist in the expression of sexual dimorphism. Lastly, population-specific logistic regression equations were developed for both sample populations.

Using logistic regression equations and discriminant function analyses – quasi-ordinary least squares, the Native American and Thai groups are significantly different in the expression of sexual dimorphism. Further, Spradley and Jantz's (2011) equations

often fail to correctly classify Native American and Thai individuals. In particular, the equations derived from American Black and White individuals frequently classified modern Thai and Native American males as females. Conversely, three American White equations and eight American Black equations classified more females as males for both populations. Therefore, the metric sex estimation methods developed on non-Asian populations do not adequately classify Native American and Thai individuals. The application of sex estimation methods developed on non-Asian populations results in reduced discriminatory power because Native Americans and Thais are less sexually dimorphic than African and European American individuals. The equations developed on the modern Thai sample correctly classified 71.1 - 96.0% of the individuals, while those developed on the Native American samples correctly 78.1 - 97.8%.

## TABLE OF CONTENT

<b>TITLE .....</b>	<b>i</b>
<b>COPYRIGHT PAGE .....</b>	<b>ii</b>
<b>READER APPROVAL PAGE .....</b>	<b>iii</b>
<b>ACKNOWLEDGEMENTS .....</b>	<b>iv</b>
<b>ABSTRACT.....</b>	<b>v</b>
<b>TABLE OF CONTENT .....</b>	<b>vii</b>
<b>LIST OF TABLES .....</b>	<b>x</b>
<b>LIST OF ABBREVIATIONS .....</b>	<b>xii</b>
<b>CHAPTER I: INTRODUCTION .....</b>	<b>1</b>
<b>Hypotheses .....</b>	<b>3</b>
<b>Organization of Chapters .....</b>	<b>3</b>
<b>A Note on Terminology.....</b>	<b>4</b>
<b>CHAPTER II: PREVIOUS RESEARCH – SEX ESTIMATION .....</b>	<b>6</b>
<b>Sex Estimation.....</b>	<b>6</b>
<b>Non-Metric Sex Estimation.....</b>	<b>7</b>
<b>Non-Traditional Morphological Methods .....</b>	<b>15</b>
<b>Metric Sex Estimation.....</b>	<b>18</b>
<b><i>FORDISC</i> .....</b>	<b>22</b>

<b>Conclusion.....</b>	<b>23</b>
<b>CHAPTER III: PREVIOUS RESEARCH – POPULATION HISTORIES OF</b>	
<b>NORTH AMERICA AND THAILAND.....</b>	<b>25</b>
<b>Thailand .....</b>	<b>25</b>
<b>North America .....</b>	<b>33</b>
<b>Conclusion.....</b>	<b>42</b>
<b>CHAPTER IV: MATERIALS AND METHODS .....</b>	<b>45</b>
<b>Skeletal Samples.....</b>	<b>45</b>
<b>Data Collection.....</b>	<b>46</b>
<b>Statistical Analyses.....</b>	<b>53</b>
<b>Testing Spradley and Jantz’s (2011) Equations .....</b>	<b>54</b>
<b>Population-Specific Equations.....</b>	<b>56</b>
<b>Intraobserver Error .....</b>	<b>57</b>
<b>Conclusion.....</b>	<b>57</b>
<b>CHAPTER V: RESULTS .....</b>	<b>58</b>
<b>Population Differences.....</b>	<b>58</b>
<b>Testing Spradley and Jantz’s (2011) Equations .....</b>	<b>66</b>
<b>Population-specific Linear Regression Equations.....</b>	<b>69</b>
<b>Intraobserver Error Rate .....</b>	<b>73</b>
<b>Conclusion.....</b>	<b>76</b>
<b>CHAPTER VI: DISCUSSION.....</b>	<b>78</b>
<b>Population Differences.....</b>	<b>79</b>
<b>Testing Spradley and Jantz’s (2011) Equations.....</b>	<b>82</b>

<b>Population-Specific Equations.....</b>	<b>83</b>
<b>Intraobserver Error Rates.....</b>	<b>84</b>
<b>CHAPTER VII: CONCLUSION.....</b>	<b>87</b>
<b>Population Specific Standards and Daubert .....</b>	<b>88</b>
<b>Future Research.....</b>	<b>89</b>
<b>REFERENCES CITED.....</b>	<b>91</b>
<b>CURRICULUM VITAE .....</b>	<b>97</b>

## LIST OF TABLES

Table	Title	Page
4.1	Description of skull measurements.	47-49
4.2	Description of postcranial measurements.	49-53
4.3	Stepwise selected variables for American Black and classification functions (Spradley and Jantz 2011)	54-55
4.4	Stepwise selected variables for American White and classification functions (Spradley and Jantz 2011)	55-56
5.1	Cranial measurement comparison between Native American and Thai individuals.	59-60
5.2	Mandibular measurement comparisons between Native American and Thai individuals.	60-61
5.3	Clavicle measurements comparison between Native American and Thai individuals.	61
5.4	Scapular measurement comparisons between Native American and Thai individuals.	61
5.5	Humeral measurement comparison between Native American and Thai individuals.	62
5.6	Radial measurements comparison between Native American and Thai individuals.	62

5.7	Ulnar measurement comparison between Native American and Thai individuals.	62-63
5.8	Sacral measurement comparison between Native American and Thai individuals.	63
5.9	Innominate measurement comparison between Native American and Thai individuals.	63-64
5.10	Femoral measurement comparison between Native American and Thai individuals	64-65
5.11	Tibial measurement comparison between Native American and Thai individuals.	65
5.12	Fibular measurement comparison between Native American and Thai individuals.	65
5.13	Calcaneal measurement comparison between Native American and Thai individuals.	66
5.14	American Black equation comparisons.	67-68
5.15	American White equation comparisons	68
5.16	Selected variables for modern Thai and classification functions	69-71
5.17	Selected variables for Native American and classification functions.	71-73
5.18	Intraobserver error rates	73-76

## LIST OF ABBREVIATIONS

AMNH.....	American Museum of Natural History
ASISS.....	Anterior Superior Iliac Spine to Symphision
AST-AST.....	Biasterionic Chord
BA-B.....	Basion-Bregma Breadth
BA-PR.....	Basion-Prosthion Length
B-L.....	Parietal Chord
BP.....	Before Present
CDL-CDL.....	Bicondylar Breadth
D-D.....	Interorbital Breadth
D-EC.....	Orbital Breadth
DNA.....	Deoxyribonucleic Acid
EC-EC.....	Biorbital Breadth
ECM-ECM.....	Maxillo-Alveolar Breadth
EU-EU.....	Maximum Cranial Breadth
FDB.....	Forensic Data Bank
FMT-FMT.....	Upper Facial Breadth
FOB.....	Foramen Magnum Breadth
FOL.....	Foramen Magnum Length
FT-FT.....	Minimum Frontal Breadth
G-OP.....	Maximum Cranial Length
GO-GO.....	Bigonial Breadth

ICC.....	Intraclass Correlation Coefficient
ID-GN.....	Chin Height
ISL.....	Ischial Length
KKU.....	Khon Kaen University
L-O.....	Occipital Chord
MDH.....	Mastoid Height
MDS.....	Multidimensional Scaling
mtDNA.....	Mitochondrial DNA
N <sub>ef</sub> .....	Effect Population Size
N-B.....	Frontal Chord
N-PR.....	Nasion-Prosthion Height
NLB.....	Nasal Breadth
NOL.....	Nasio-occipital Length
OBH.....	Orbital Height
PR-ALV.....	Maxillo-Alveolar Length
PSISS.....	Maximum Posterior Superior Iliac Spine to Symphysis
RA-RA.....	Biauricular Breadth
SW.....	Southwest
WAS.....	Minimum Apical Border to Symphysis
WIB.....	Minimum Iliac Breadth
WISL.....	Minimum Ischial Length
WPL.....	Minimum Pubis Length

XPL.....	Maximum Pubis Length
XIRL.....	Maximum Ischiopubic Ramus
ZMA-ZMA.....	Bimaxillary Breadth
ZO-ZO.....	Zygoorbitale Breadth
ZY-ZY.....	Bizygomatic Breadth

## CHAPTER I: INTRODUCTION

When human remains are discovered, one of the most important tasks in forensic anthropology and bioarchaeology is to create the biological profile. The biological profile includes sex, age, ancestry, and stature estimations; however, age, ancestry, and stature are dependent on the sex of the individual. Two types of methods exist for determining sex; morphological and metric approaches, both of which can be applied to cranial and postcranial elements. Nonmetric methods are based on visual observations of the sexually dimorphic features of the skull, pelvis, humerus, and clavicle, among others (Phenice 1969; Rogers 1999, 2005; Rogers *et al.* 2000; Vance *et al.* 2011; Walker 2008). Metric techniques rely on standardized measurements that are entered into existing formulae or subjected to discriminant function analyses (Rogers 1999; Spradley and Jantz 2011). Historically, nonmetric methods have dominated sex assessment, using both the skull and pelvis (Garvin *et al.* 2014; Klales *et al.* 2012; Spradley and Jantz 2011). However, often in forensic or archaeological cases, the pelvis or cranium may be missing or is too damaged to allow the analyst to estimate the sex of the individual (İşcan *et al.* 1998; King *et al.* 1998; Spradley *et al.* 2008; Spradley and Jantz 2011; Walker 2005). Due to the durability and the survivability of many postcranial elements, methods derived from long bones are often needed. Although only recently standardized for forensic anthropology, much research has been produced on the methods and application of metric methods (Langley *et al.* 2016; Spradley and Jantz 2011; Walker 2008). Modern advances

in the field, such as FORDISC, rely on metric methods to determine sex of an unknown individual (Jantz and Ousley 2005, 2013; Ramasthaler *et al.* 2007).

One of the biggest challenges for forensic anthropologists is to keep abreast of the increasing diversity and variability in world-wide populations (Spradley *et al.* 2008).

Population differences have important implications since they may introduce systematic errors in classification rates. Most standards are derived from American Whites (European American) and Blacks (African American) or European Whites, with little to no information for other demographics, including Hispanic, Native American and Asian groups. Additionally, most of these standards are from anatomical collections, which are not always representative of modern forensic cases (Spradley and Jantz 2011).

Therefore, for sex estimation to be accurate, population-specific estimates of cranial and postcranial measurements must be applied. The development and refinement of accurate methods requires analyzing skeletal collections composed of contemporary individuals of known sex, age, ancestry, and stature (Tallman 2016).

Currently, standards derived from Native American collections are often used in sex estimations of Asian individuals. However, due to distinct population histories, morphological differences between Native American and Asian individuals most likely exist. Therefore, the first goal of the present research is to determine differences between pre-contact Native American populations and modern Thai individuals. Known individuals from Khon Kaen University's Faculty of Medicine with antemortem information were compared to archaeologically derived Native Americans from the American Museum of Natural History. The second goal of the present research is to

compare these results to published standards (e.g., Spradley and Jantz 2011) derived from European American and African American individuals in order to better grasp the inaccuracy of such equations on different populations and reinforce the need for population-specific standards.

## **Hypotheses**

Two primary hypotheses are tested in this study. First, the author hypothesizes that due to divergent population histories (Goebel *et al.* 2008; Hanihara 2006; Karafet *et al.* 1999) Pietrusewsky 2006; Turner 1971), the metric dimensions of both cranial and postcranial elements will be significantly different between modern Thai and Native American individuals. Secondly, Spradley and Jantz's (2011) discriminant function equations derived from European Americans and African Americans will produce inaccurate sex estimations when applied to Native American and modern Thai individuals.

## **Organization of Chapters**

Chapter II of this thesis discusses the theoretical and methodological approach to estimating the sex of unknown individuals. Morphological methods utilizing the cranium, pelvis, clavicle, and humerus are discussed. Additionally, the metric methods developed on the cranium and postcranial elements are presented and are particularly relevant to this study. Chapter III presents the population histories of Thailand and

indigenous North America, presenting both their shared ancestry but also their divergence, which causes morphometric differences between the two population groups. Chapter IV discusses the two skeletal samples, the data collection methods, and the statistical analyses. Chapter V presents the results of the statistical analyses to determine population differences, the accuracy of Spradley and Jantz's (2011) discriminant functions, as well as the population-specific discriminant functions developed for Native American and Thai populations. Chapter VI reviews the results of the statistical analyses, addressing whether they support the hypotheses. Lastly, Chapter VII discusses the broader implications of the study and the potential for future research.

### **A Note on Terminology**

There are multiple definitions of race in anthropology; 1) biological races are groups that share genes and/or phenotypic characters; or 2) race in regard to ancestry, which is defined by the number of features shared by a population (Edgar 2009). The terms Caucasoid, Mongoloid, and Negroid were used to designate biological, cultural, and behavioral differences among populations, and were used by 19<sup>th</sup> and 20<sup>th</sup> century anthropologists to classify human population variation. The suffix “-oid” was used to represent specific and expected craniofacial forms and body types, largely based on geography (Tallman 2016). The term Caucasoid denoted European and light-skinned North American individuals; Mongoloid was used to refer to Asians, Native Americans, and Pacific Islanders; and lastly Negroid was applied to Africans and dark-skinned North Americans. Due to the racist and typological meanings attached to these terms, they were

replaced by a mix of skin color and geographic terms, such as White, Asian, and Black. However, using terms that rely heavily on skin color fails not only to encompass human variation, but it also reinforces the idea that forensic anthropologists can determine skin color, hair, and eye form through the skeleton (Brace 1995). Additionally, definitions of Black and White change over time, due to folk taxonomies that fuse biology and culture (Edgar 2009).

Recently, anthropologists have started to employ ancestral terms that reflect biogeographic and biocultural groups such as African, African American, American Black, European Americans, Hispanics, and Native Americans (e.g., Hefner 2009; Hefner *et al.* Ross *et al.* 2004; Spradley *et al.* 2008; Spradley and Jantz 2011). Biogeographic terms are more valid than simply skin color, because they incorporate underlying micro-evolutionary, genetic, adaptive, and biomechanical processes that can cause differences between populations that are reflected in skeletal morphology (Tallman 2016).

## CHAPTER II: PREVIOUS RESEARCH – SEX ESTIMATION

The purpose of this chapter is to briefly discuss the methods of sex estimation from skeletonized remains. The first section addresses the morphological or nonmetric methods developed from visual observations of the pelvis and cranium. The second section considers non-traditional methods for sex estimation based on visual observations of the distal and posterior humerus and the infero-medial clavicle. The last section discusses metric methods developed on the pelvis and cranium. Additionally, the need for population specific standards will be discussed.

### **Sex Estimation**

One of the most important tasks in forensic anthropology and bioarchaeology is to create the biological profile. The biological profile includes sex, age, ancestry, and stature estimation; however, age, stature, and ancestry are often dependent on the sex of the individual. Two types of methods exist for determining sex; morphological and metric, both of which can be applied to cranial and postcranial elements. Nonmetric methods are based on visual observations of the sexually dimorphic features of the skull, pelvis, humerus, and clavicle (Phenice 1969; Rogers 1999, 2005; Rogers et al. 2000; Vance *et al.* 2011; Walker 2008). On the other hand, metric techniques rely on standardized measurements inserted into existing formulae or subjected to discriminant function analyses (Rogers 1999; Spradley and Jantz 2011). Historically, nonmetric methods have dominated sex assessment, using both the skull and pelvis (Garvin *et al.* 2014; Klales *et al.* 2012; Spradley and Jantz 2011). Often in forensic or archaeological

cases, the pelvis or cranium may be missing or is too damaged to allow the analyst to estimate the sex of the individual (İşcan *et al.* 1998; King *et al.* 1998; Spradley *et al.* 2008; Spradley and Jantz 2011; Walker 2005). Due to the durability and the survivability of long bones, methods derived on long bones are often needed. Although only recently standardized for forensic anthropology, much research has been produced on the methods and application of metric methods (Spradley and Jantz 2011; Walker 2008). Modern advances in the field, such as FORDISC, have incorporated metric methods into the program to determine sex of an unknown individual (Jantz and Ousley 2005, 2013; Ramasthaler *et al.* 2007).

### **Non-Metric Sex Estimation**

Traditionally, biological and forensic anthropologists base sex estimation of unknown remains on subjective visual assessments of sexually dimorphic features of the skull and pelvis (Bass 2005; Buikstra and Ubelaker 1994; Klales *et al.* 2012; Lewis and Garvin 2016; Walker 2008; White *et al.* 2012). The os coxa has been accepted as the best indicator of an individual's sex due to differences between males and females related to childbirth and locomotion (Bass 1995; Garvin *et al.* 2014; Klales *et al.* 2012).

Following the onset of puberty, the female pelvis widens to adjust for childbirth, while the male pelvis retains its prepubescent narrow shape.

The most reliable and valuable visual traits for sex estimation on the pelvis were first described by Phenice (1969) on the pubic bone of the anterior pelvis; the ventral arc, subpubic concavity, and medial aspect of the ischio-pubic ramus. The ventral arc is

defined as “a slightly elevated ridge of bone which extends from the pubic crest and arcs inferiorly across the ventral surface of the lateral most extension of the subpubic concavity where it blends with the medial border of the ischio-pubic ramus” (Phenice 1969:298). Phenice (1969) only observed the ventral arc in female pelvises. The second criterion is the subpubic concavity; “a lateral recurve which occurs in the ischio-pubic ramus of the female a short distance below the lower margin of the pubic symphysis (Phenice 1969:300). There are two main factors that account for the shape difference between males and females. The two factors focus on the differential bone growth in males and females; while the inferior margin of the ischial tuberosity grows laterally in females, in males the margin grows inferiorly; the middle of the ischio-pubic ramus also exhibits differential directional growth (Klales *et al.* 2012). Females tend to demonstrate an increase in growth in this area of the pubis and ischium which produces a longer pubis, a larger pelvic outlet, and a more obtuse subpubic angle (Klales *et al.* 2012). The final criterion is the medial aspect; in males this is a broad surface, whereas in females the medial aspect is narrower and sometimes will exhibit a sharp ridge (Klales *et al.* 2012; Phenice 1969).

Phenice (1969) tested the effectiveness of these three criteria using a total of 275 American White and Black individuals from the Terry Skeletal Collection. According to Phenice (1969), if one or two criteria are definitely male or female, the success rate was 96%. Females are usually characterized by an angled ventral arc, a large subpubic concavity, and a narrow ischio-pubic ramus ridge, while males generally have a wide ischio-pubic ramus ridge, a straight ridge that is parallel to the symphyseal face rather

than a ventral arc, and no subpubic concavity. Phenice (1969) used the presence or absent of these three criteria to determine the sex of unknown remains.

Multiple studies tested the success rates of Phenice's (1969) method (Klares *et al.* 2012; Lovell 1989; Sutherland and Suchey 1987, 1991). Although the traits have proven reliable and classified most individuals to the correct sex, the overall success rates were significantly lower than Phenice's (1969) original study. Tests conducted by Lovell (1989) on cadavers from Simon Fraser University resulted in a classification rate of 83%. The reduced classification accuracy was credited to the different age range of samples used for the study in comparison to Phenice's (1969). For instance, the ventral arc becomes more irregular due to bone growth as individuals age (Lovell 1989). Additionally, numerous studies noted Phenice's (1969) presence or absence scoring approach was not inclusive of the wide range of human variation (Kelley 1978; Klares *et al.* 2012). For example, in studying 362 os coxae from the skeletal collections at the University of California, Berkley, and Sacramento State University, Kelley (1978) noted that more than half the individuals exhibit one or more intermediate trait.

In order to account for the intermediate traits and the amount of variation, Phenice's (1969) classification system was modified to include ordinal scales. Buikstra and Ubelaker (1994) expanded on the criteria presented by Phenice (1969). Rather than scoring the three criteria on presence or absence, Buikstra and Ubelaker (1994) created an ordinal scale of 1 – female, 2 – ambiguous and 3 – male. Expanding on this, Klares *et al.* (2012) created a five-stage scoring system for all three traits to encompass a wider range of variation and included stage diagrams. Applying the new ordinal system to 310

individuals from the Hamman-Todd and William M. Bass Donated Skeletal Collection, Klales *et al.* (2012) correctly classified 86.2% of individuals. Additionally, Klales *et al.* (2012) created a logistic regression equation to apply all three traits when estimating sex, thus providing probabilities.

In addition to the anterior pubic region, there are two other pelvic features frequently used to determine the sex of an individual; the greater sciatic notch and the preauricular sulcus (Buikstra and Ubelaker 1994; Walker 2005). The greater sciatic notch tends to be highly sexually dimorphic and more resistant to damage than the pubic region (Walker 2005). In males, the sciatic notch tends to be narrow, while in females it is very broad, with a low width-to-depth ratio (Buikstra and Ubelaker 1994; Walker 2005). Similar to the revised method presented by Klales *et al.* (2012), the greater sciatic notch is also scored using an ordinal scale; 1 representing females and 5 representing males (Buikstra and Ubelaker 1994; Walker 2005). Within this five-stage ordinal scale, a 3 would ideally represent a cut-off point for males versus females. However, in the analysis of 296 individuals from the Hamman-Todd, Terry, and St. Bride's collections, Walker (2005) discovered that a scores of 2 (66%) and 3 (88%) was more common among males. The study further revealed that 90% of females exhibited a score of 1, while 90% of individuals with a score of 3 or higher were male. Therefore, Walker (2005) suggested a score of 2 designates an "intermediate" or "probable male" rather than "probable female." The scores of males tend to be more variable due to less severe selective forces acting on their pelvic morphology.

Analysts should be aware of secular changes in the morphology of the pelvic traits. Over the last two centuries secular changes in the human skeleton have been noted, most likely due to increase in standards of living, social and economic improvements, and advancements in science and medicine within the United States (Klales 2016). To determine the reliability of the three pelvic criteria described by Phenice (1969), Klales (2016) analyzed two samples, a historic sample from the Hamann-Todd Skeletal Collection, and a modern sample from the William M. Bass Donated Skeletal Collection. Using an ordinal linear regression following Klales *et al.* (2012), all three traits correctly classified 83.1% of the historic females, 85.1% of historic males, 60.4% of modern females, and 46.1% of the modern males (Klales *et al.* 2016). The analysis determined there was a significant amount of variance in score frequency between the two different temporal populations. Overall, the modern females were more gracile for all three-criteria than expected, while modern males exhibited more variable score distributions compared to their historic counterparts (Klales 2016). However, even with these differences, the three traits prove reliable in estimating the sex of an unknown individual.

The preauricular sulcus is also a useful indicator of an individual's sex (Buikstra and Ubelaker 1994). The preauricular sulcus is a groove along the anteroinferior border of the auricular surface (White *et al.* 2012). Generally, it is thought the preauricular sulcus appears more in females than in males. A score of 0 indicates an absence of the trait that is traditionally representative of males, while the scores 1-4 are associated with females and reflect differences in sulcus morphology (Buikstra and Ubelaker 1994).

Second to the pelvis, the cranium has commonly been used to estimate the sex of an individual. In general, males are more robust in comparison to the gracile characteristics of females (Buikstra and Ubelaker 1994; Walker 2008). Sex estimation of the cranium is based the expression of sexually dimorphic bony characteristics which result from different patterns, rates, and periods of adolescent growth. A longer period of growth produces more pronounced changes in skeletal structure. For instance, large brow ridges, eyes that appear lower in the face, and larger nasal apertures are the result of the extension of the normal downward and forward growth of the male face (Rogers 2005). Testing the thirteen traits introduced by Krogman (1955) and four additional traits, Rogers (2005) determined that characteristics of the facial bones performed better than those relating to the calvarium. While all seventeen traits proved reliable and sexually dimorphic, only five features have been standardized and used in modern forensic case work (Buikstra and Ubelaker 1994; Garvin *et al.* 2014; Walker 2008). These five traits; the nuchal crest, mastoid process, supra-orbital margins, glabella, and mental eminence, were first introduced in 1875 by Paul Broca (Broca 1875; Garvin *et al.* 2014). The five cranial traits are scored using an ordinal scoring system of 1 through 5, with 1 representing a gracile morphology and 5 representing robust morphology (Buikstra and Ubelaker 1994). Ideally, a male cranium would present a well-developed nuchal crest that projects a considerable distance from the bone or a bony ledge, large mastoid processes, thick rounded supraorbital margins, a pronounced glabella, and a large mental eminence that occupies most of the chin. In contrast, a female would present a smooth nuchal region, small mastoid processes, extremely sharp supraorbital margins, a minimal

glabella, and little to no projection of the mental eminence. However, in actuality, there is much overlap between gracile and robust expressions of the traits.

Birkby (1960) noted the importance of population-specific standards in biological profile development. Most standards are derived from American Whites and Blacks or European Whites, with little to no information for other demographic groups, including Hispanic, Native American and Asian groups (King *et al.* 1998; Spradley *et al.* 2008). Additionally, most of these standards are from older anatomical collections, which are not necessarily representative of modern forensic cases (Spradley and Jantz 2011). Therefore, for sex determination to be accurate, population-specific estimates of cranial and postcranial measurements must be applied. The development and refinement of accurate methods requires analyzing skeletal collections composed of contemporary individuals of known sex, age, ancestry, and stature. A further problem with the pelvic and cranial scoring systems is that they were developed and tested on 19<sup>th</sup> and 20<sup>th</sup> century individuals of African American or European ancestry (Rogers 2005; Rogers and Saunders 1994; Walker 2005, 2008).

Population differences have important implications since they may introduce systematic errors in classification rates. For examples, Walker (2005) noted that English sciatic notches are significantly wider on average than those of the American individuals of both European and African ancestry. If an os coxa exhibits a greater sciatic notch score greater than 1 and is classified as a male, 15% of English females and 42% of American females would be classified incorrectly (Walker 2005). Similar population differences are noted in cranial trait expression. Walker (2008) found that within the

same-sex comparison, African Americans and European Americans are more robust than their English counterparts. Traits that were significantly different between the populations were the mental eminence, mastoid processes, and the expression of glabella. For the mental eminence, African American males and females have greater mental eminence development than the English, African American females have larger mastoid processes, and European American females and males have more prominent glabellae development (Walker 2008). Additionally, Native American populations are vastly different from the other modern populations. Some Native American groups are more robust than the English, African and European Americans, but they also show less sexual dimorphism between the sexes (Walker 2008). The increased robusticity is clearest in the supraorbital margin and the nuchal crest.

Tallman (2016) studied nonmetric cranial and pelvic sexual dimorphism and cranial nonmetric variation in Japanese and Thai individuals. The objective was to determine if the standards developed on non-Asian populations performed accurately on modern Asian populations. Overall, males exhibit higher scores but show more variation in cranial scores, while females consistently score lower trait scores with less variation (Tallman 2016). According to Walker (2008), an individual with a trait score of 3 or less for any trait are more likely female, and conversely a score higher than 3 would be indicative of a male. However, for both Japanese and Thai populations, the cutoff points needed revision. Japanese and Thai samples present the same cutoff points for the supraorbital margin between 2 and 3, glabella between 1 and 2, and mental eminence between 2 and 3 (Tallman 2016). In regards to the nuchal crest, the cutoff point is

between 3 and 4 for the Japanese population, while for Thai the point is between 2 and 3. As for the mastoid process, a score of 3 indicates an indeterminate category for the Japanese, and the cutoff point for the Thai population is between 3 and 4 (Tallman 2016). Concerning the pelvic morphology, the cutoff points between male and female traits also need revision. For the ventral arc, the Japanese cutoff point is between 1 and 2, while for Thai the cutoff point is between 2 and 3. Additionally, the cutoff points for the sciatic notch differed for Japanese and Thai, between 2 and 3 for Japanese and between 3 and 4 for Thai (Tallman 2016). Japanese and Thai samples have the same cutoff points for the subpubic concavity (between 2 and 3) and the ischiopubic ramus ridge (between 2 and 3). Overall, this work shows that there are population differences in expressions of sexual dimorphism and that the Japanese and Thai are less sexually dimorphic than non-Asian groups.

### **Non-Traditional Morphological Methods**

When the pelvis or cranium is not present, the morphology of two postcranial elements, the clavicle and humerus, can be examined for sex estimation (Rogers 1999; Rogers *et al.* 2000; Suchey *et al.* 1979; Vance *et al.* 2011). Rogers *et al.* (2000) examined the rhomboid fossa on the clavicle, with the assumption that fossae will be more common in males, to determine if the presence or absence of a fossa or impression is a useful feature in sex assessment. The costoclavicular ligament, or rhomboid ligament, connects the superior portion of the first rib to the inferior sternal end of the clavicle and stabilizes the shoulder girdle (Rogers *et al.* 2000). Additionally, it is

hypothesized that increased muscularity and mechanical usage can produce depressions, tubercles, or pitting on the inferior clavicle. Scored as present or absent, Rogers *et al.* (2000) analyzed 344 clavicle pairs from the William F. McCormick Collection at the University of Tennessee, Knoxville of American Black and White individuals. The study found that 36% of males display a rhomboid fossa on the right clavicle and 31% on the left clavicle, while females display a fossa only 8% of the time on the right and 3% of the time of the left clavicle (Rogers *et al.* 2000). In addition, Rogers *et al.* (2000) calculated the posterior probability and found if a right clavicle exhibited a fossa it indicated a male with an 81.7% posterior probability and a female with a posterior probability of 18.3%. Similarly, if a rhomboid fossa is on the left clavicle, it indicates a male with a 92.2% posterior probability and a female with a posterior probability of 7.8% (Rogers *et al.* 2000).

The distal humerus was examined by Rogers (1999) to establish if morphological differences can predict sex. The elbow joint is known to be sexually dimorphic because of the differences in carrying angle; the lateral deviation ranges from 10° to 15° in males, while it ranges from 20° to 25° in females (Rogers 1999; Vance *et al.* 2011). The ulnar collateral ligament, which originates on the medial epicondyle of the humerus and inserts on the medial aspect of the coronoid process of the ulna, in combination with the trochlea, changes the carrying angle during elbow flexion and prevents misalignment between the arm and forearm (Rogers 1999). In studying 322 individuals from the Grant Skeletal Collection of the University of Toronto, Rogers (1999) determined five features of the distal humerus to be sexually dimorphic; the orientation of the medial aspect of the

trochlea relative to the shaft of the humerus (this feature was later rejected due to poor accuracy), trochlear constriction, trochlear symmetry, olecranon fossa shape and depth, and the angle of the medial epicondyle. Females are characterized as having a more constricted and spool-shaped trochlea, a more symmetrical trochlea, a deep and oval shaped olecranon fossa, and a distinctly raised medial epicondyle (Rogers 1999). In contrast, males typically exhibit a less constricted trochlear which is also asymmetrical, a shallow and triangular epicondyle, and a flat or slightly raised medial epicondyle (Rogers 1999). Testing the criteria on two modern samples from the University of New Mexico and the University of Tennessee Knoxville, the four traits in combination produced an accuracy of 92% (Rogers 1999).

Vance *et al.* (2011) applied Rogers' (1999) distal humerus criteria to a South African population to test the accuracy and reliability of the method. Vance *et al.* (2011) examined 608 individuals from the Pretoria Bone Collection at the University of Pretoria and the Raymond A. Dart Collection from the University of Witwatersrand using three morphological indicators: the angle of the medial epicondyle, the olecranon fossa shape, and the trochlear extension. Building upon the criteria from Rogers (1999), Vance *et al.* (2011), created a five-graded scoring system for the morphological variation in the distal humerus: a designation of 1 or 2 indicates a male, a score of 3 is considered indeterminate, and a score of 4 or 5 signify a female. The final sex assessment was based on composite scores of the three traits; a composite score of 3-8 indicate male, 9 indicates ambiguous, and a scores of 10-15 indicate female (Vance *et al.* 2011). Vance *et al.* (2011) determined that the angle of the medial epicondyle is the best indicator of sex in

isolation, with an accuracy 70% in males and 55% in females. However, in combination the three traits accurately classified males 74% and females 77% of the time (Vance *et al.* 2011). For methods to be considered reliable, an accuracy rate of 80% is needed; therefore, the shape of the distal humerus should be used in conjunction with other methods or when there is no other option.

### **Metric Sex Estimation**

The concept of using metric methods to determine the sex of individuals has been around for over a century. As early as 1915, Karl Pearson began to recognize the possibilities of metric sex estimation. Pearson recognized the need to estimate the sex of an individual when the cranium or pelvis were not available for examination. Pearson (1915) measured the bicondylar width of English femora to determine the reliability of metric methods. The results of the study supported the hypothesis that there are metric differences between sexes, while also providing mean measurements and standard deviations for the femora.

Giles and Elliot (1963) examined 300 crania from the Terry and Hamann-Todd collections. Following the descriptions of Hooton (1946), 11 measurements were taken of each cranium and 21 discriminant functions were developed to classify White, “Negroes” and pooled Whites and “Negroes” (1963). These functions produced an accuracy of 82-89%. Additionally, Giles (1964) examined the mandible in sex estimation. Using the Terry Collection and only nine measurements, Giles created nine equations for estimating the sex of American White and American Black individuals.

Even at this early stage of method development, the functions classified individuals 85% correctly (Giles 1964).

Similar to nonmetric methods, anthropologists held the belief that the cranium was the second-best indicator of sex, with little to no supporting evidence (Byers 2005; Pickering and Bachman 1997; Spradley and Jantz 2011). However, contradicting claims are seen in early material. Bass (2005) states that the skull is probably the second-best indicator of sex, but he also states that the humerus is the second-best bone for sex estimation. Spradley and Jantz (2011) tested the accuracy of these claims to determine whether the cranial or postcranial elements are better indicators of sex. In analyzing American Black and American White individuals from the Forensic Anthropology Data Bank (FDB), Spradley and Jantz (2011) took standard cranial and postcranial measurements of 510 females and 833 males. Discriminant function analyses were performed on the measurements, which resulted in classifications rates between 90% and 91% for the cranium and classification rates of 92% to 94% for postcranial elements (Spradley and Jantz 2011). For American Black individuals, the humerus was the best-performing element, with a classification rate of 93.84%, and for American White individuals the best indicator was the radius, classifying 94.34% of individuals correctly (Spradley and Jantz 2011). Furthermore, univariate analyses indicated that joint surfaces were the best indicators of an individual's sex; the femur epicondylar breadth correctly classified 89% of individuals and the proximal tibial epiphyseal breadth had a classification rate of 90% (Spradley and Jantz 2011).

Population differences are also present in metric methods of sex estimation. İşcan *et al.* (1998) aimed to establish metric standards from the humerus of Chinese, Japanese and Thai individuals. In analyzing 87 Chinese individuals, 90 Japanese individuals, and 104 Thai samples, İşcan *et al.* (1998) noted significant differences in six humeral measurements (maximum length, vertical head diameter, minimum midshaft diameter, midshaft circumference, and epicondylar breadth) between the three populations and within population differences between sexes. Overall, the Chinese individuals exhibited the largest average dimensions, especially maximum length. Between Chinese and Thai individuals, all six dimensions were significantly different, while the only difference between Chinese and Japanese individuals was the maximum length, in which Chinese were longer (İşcan *et al.* 1998). In comparing the Thai and Japanese individuals, the only dimension that exhibited no significant difference was the epicondylar breadth of the humerus. Interestingly, the measurements of epicondylar breadth and vertical head diameter were not significantly different. Using a discriminate function, the humerus correctly classified 87% of Chinese individuals and 97% of Thai individuals (İşcan *et al.* 1998). Cross-validation tests between Chinese, Japanese and Thai individuals confirmed that formulae developed from one population are less discriminating when applied to another (İşcan *et al.* 1998). While the Chinese individuals were the largest, they were the least sexually dimorphic, in comparison to Thais who are generally the smallest but the most sexually dimorphic (İşcan *et al.* 1998; King *et al.* 1998).

King *et al.* (1998) conducted a study of sexual dimorphism in the femur of Thai individuals and compared them to formulae derived from North American, African and

East Asian samples. In studying 104 individuals from the Chiang Mai University Hospital, only the maximum head diameter and bicondylar breadth were useful in sex estimation, reaching a correct classification rate of 94.2%. In comparison to North Americans and South Americans, formulae developed on these populations identified most Thai individuals as females; only 27% of Thai males were correctly classified using the South African White formula (King *et al.* 1998).

Measurements of the cranium and long bones, and the methods used to take them, are only part of the process of estimating an individual's sex via metric methods. Most sex estimation research uses discriminant function analysis or other multivariate quantitative methods (DiGangi and Moore 2012). Discriminant function analysis classifies unknown individuals and the probability of their classifications into certain groups, such as sex. It is important to note that discriminant function analysis assumes that the sample is normally distributed. A discriminant function will produce a posterior probability as well as a typicality probability. The posterior probability is the likelihood that a given individual belongs to a specific group. The typicality probability is the likelihood the individual belongs to a certain group while taking all the different variabilities into account (DiGangi and Moore 2012). The posterior probability combined with the typicality probability allows researchers to assign sex with a degree of confidence.

Although there are guidelines for a majority of the skeletal elements, there is a hierarchy of element's accuracy and reliability. As with nonmetric sex estimation, the cranium and the pelvis are often thought to be the most reliable. While in nonmetric sex

estimation, the pelvis correctly estimates the sex of the individual with the most reliability and accuracy, the metric reliability demonstrates otherwise. Spradley and Jantz (2011) conducted a study in order to determine whether the cranial or postcranial elements are better indicators of an individual's sex. Using American White and American Black individuals from the FDB, Spradley and Jantz (2011) concluded that metric analyses of long bones provide the best estimates of sex. Additionally, a hierarchy of postcranial elements was established for both American White and American Black individuals. For American Whites, the radius, clavicle, femur, humerus, scapula, ulna, and tibia performed the best. On the other hand, the humerus, clavicle, scapula, and femur were the best for American Black individuals.

### ***FORDISC***

*FORDISC*, developed by Stephen Ousley and Richard Jantz in 1993, is a computerized discriminant function application available in many labs around the country and world. It is an interactive discriminant function program that automates metric estimations of sex, ancestry, and stature. *FORDISC* has 13 different reference samples and provides posterior probabilities for every analysis (Jantz and Ousley 2012). If the sex of the individual is known, *FORDISC* can run sex-specific standards to estimate the ancestral population group or stature. On the other hand, if the sex is unknown, *FORDISC* can compare the data with all female and male samples to determine the most probable sex and ancestry of the individual. The data in *FORDISC* comes from the Forensic Anthropology Data Bank (FDB), which is a repository of data collected from

skeletons of Americans with twentieth and twenty-first century birth years (Jantz and Ousley 2012). Ramsthaler *et al.* (2007) compared classification rates of nonmetric analysis to *FORDISC* outputs for 98 crania. Using nonmetric methods 92 crania were classified correctly compared to only 84 correctly classified using *FORDISC* (Ramsthaler *et al.* 2007). However, these results did not indicate a significant difference between the two methods. A major limitation of *FORDISC* is the lack of appropriate reference samples, while American Whites, Black and Hispanics are well represented, there is a small number of Asian groups as well as Native American (Jantz and Ousley 2012).

## **Conclusion**

When establishing the biological profile of an unknown individual, the first step is to estimate the sex of the individual. Methods for estimating age as well as stature are dependent on the sex of the individual. Nonmetric methods for sex assessment rely on visual observations of the sexually dimorphic features of the skull and pelvis. The pelvis has been accepted as the most reliable indicator of sex due to differences in locomotion and accommodating childbirth in females (Bass 1995; Garvin *et al.* 2014; Klales *et al.* 2012). Phenice (1969) determined that the ventral arc, medial aspect of the ischio-pubic ramus, and the subpubic concavity accurately classified individuals 95% of the time. Multiple studies tested the success rates of Phenice's (1969) method to determine the reliability of the traits (Klales *et al.* 2012; Lovell 1989; Sutherland and Suchey 1987, 1991). In addition to the three anterior pubic traits, the greater sciatic notch and preauricular surface have also been determined to be sexually dimorphic (Buikstra and

Ubelaker 1994; Walker 2005). Both the greater sciatic notch and preauricular sulcus were proven to be reliable features to discriminate sex.

Morphological features on the cranium are reliable indicators of sex. Sex estimation of the cranium is centered on the expression of sexually dimorphic characteristics, which result from different patterns, rates, and periods of adolescent growth. Five traits (the nuchal crest, mastoid process, supra-orbital margins, glabella, and mental eminence) are scored using an ordinal system of 1 through 5, with 1 representing a female characteristic and 5 representing a male expression of a trait (Buikstra and Ubelaker 1994; Garvin *et al.* 2014; Walker 2008).

The majority of research and standards for sex estimation were developed on 19<sup>th</sup> and 20<sup>th</sup> century skeletal collections of individuals from African and European descent with little to no information for other demographics, including Hispanic, Native American and Asian groups (King *et al.* 1998; Spradley *et al.* 2008; Spradley and Jantz 2011). Consequently, for sex estimations to be accurate, population-specific estimates of cranial and postcranial measurements must be developed and applied. The development and refinement of accurate methods requires analyzing skeletal collections composed of contemporary individuals of known sex, age, ancestry, and stature. Specifically, there is a gap in the literature and standards for Asian populations.

### **CHAPTER III: PREVIOUS RESEARCH – POPULATION HISTORIES OF NORTH AMERICA AND THAILAND**

The purpose of this chapter is to briefly describe the population histories of Thailand and indigenous North America using genetic, dental, archaeological and skeletal evidence. While sharing a common origin, Native American and modern Thai populations have been separated for thousands of years and undergone different gene flow, environmental and geographical forces to produce distinct populations. Limited research exists on the morphometric sex differences between Native American and modern Thai individuals. The majority of the research combines the Native American and Asian populations under the category “mongoloid” due to their shared population history. The goal of this chapter is to demonstrate that while Thai and Native Americans share a common ancestry, they have undergone drastically different population histories since their divergence.

#### **Thailand**

Thailand was never colonized by a European nation, and Thai scholars have frequently investigated the origins of Thai people to preserve Thai ethnic identity (Baker and Phongpaichit 2005). Southeast Asia lacks a large number of archaeological sites with good enough preservation to accomplish bioarchaeological studies; therefore, the peopling of Southeast Asia is relatively uncertain (Tayles and Oxenham 2006; Shackelford and Demeter 2012). Thailand is at the heart of mainland Southeast Asia and therefore represents the crossroads of ancient human migration paths between North and

East Asia and Island Southeast Asia (Wangkumhang 2013). However, this also makes the population history incredibly complex.

Currently, two theories exist regarding the migration patterns into Thailand: The Two-Layer model and Regional Continuity model (Hanihara 2006; Peitrusewsky 2006; Matsumura 2006). According to both models, modern humans settled in Southeast Asia roughly 40,000 years ago, and an indigenous Australo-Melanesian population occupied Southeast Asia during the late Pleistocene and early Holocene by at least 26,000 years ago (Demeter 2006; Highman 2002). The term Australo-Melanesian is commonly used to refer to the indigenous people of Australia, New Guinea and the island of Melanesia; typical morphological features of Australo-Melanesians include dolichocranic skulls, protruding glabellas, massive jaws with relatively large teeth, alveolar prognathism, and long, slender limbs (Matsumura 2006). Several skeletal remains from Southeast Asia, dating to at least 10,000 years ago display characteristics similar to Australo-Melanesians (Matsumura 2006).

Proponents of the Two-Layer model claim that Neolithic immigrants from North or East Asia moved into Southeast Asia and either replaced or exchanged genes with the Australo-Melanesian population, roughly 5,000-8,000 years ago, resulting in the present Southeast Asian morphology (Hanihara 2006; Matsumura and Hudson 2005; Matsumura 2006). Southeast Asian populations are characterized as having brachiocephalic crania, gracile crania and postcrania, and reduced stature (Howells 1997; Lahr 1996). According to this model, the northern immigrants were likely from the Yangzi Valley of China (Howells 1997; Matsumura 2006).

The majority of the support for the Two-Layer models arises from physical anthropological studies. Matsumura and Hudson (2005), examined metric and nonmetric dental traits of permanent dentition from 4,002 individuals derived from East Asia, Southeast Asia, Australia, and Melanesia to understand population affinities between prehistoric and modern Southeast Asians. The results of the dental analyses add support to the influx of East Asians into Southeast Asia during the Mid-to-Late Holocene (Matsumura and Hudson 2005). The metric analysis yielded a nearly complete separation of modern East/Southeast Asians and Australo-Melanesians. Prehistoric Southeast Asians are divided into two main clusters; the early Holocene Laos, Ban Kao, Dong Son Vietnamese, and Neolithic Southern Chinese; both subdivision are grouped with modern East/Southeast Asian populations (Matsumura and Hudson 2005). Conversely, Guar Kepah, Gua Cha, Non Nok Tha, Bac Son, and Da But Vietnamese form a cluster with Australo-Melanesians (Matsumura and Hudson 2005). Based on a two-dimension analysis of multidimensional scaling (MDS), East Asians, including Urga Mongolians, Buriats, Japanese and early and modern Chinese are situated on the left along with most modern Southeast Asian populations as well (Matsumura and Hudson 2005). On the other hand, Australian Aborigines, Melanesians, Jomon, Ainu, Andaman Islanders, Early to Middle Holocene Malay, Thai, and Vietnamese form a separate cluster (Matsumura and Hudson 2005). The analysis of nonmetric dental traits had similar results. Smith's distances analysis divided the sample into two main clusters; the first cluster consists of East Asian samples and Neolithic southern Chinese, while the second cluster consists of the remaining early and modern Southeast Asians, Australians

Aborigines, Melanesians, and Andaman Islanders (Matsumura and Hudson 2005).

Additionally, the two-dimensional expression of MDS resulted in a tripartite division; the first group encompassed the East Asian population groups, on the opposite side was the prehistoric Southeast Asians, Australian Aborigines and Melanesians, and in the middle of the former two groups were the modern Southeast Asians (Matsumura and Hudson 2005). The results add support to the Two-Layer model by providing evidence for an influx of East Asians into Southeast Asia from the Mid-Late Holocene.

Similarly, Matsumura (2006) examined 21 nonmetric dental traits from 25 Southeast Asian archaeological sites. The results of the study indicated a cluster of Northeast Asians (Mongolians, Chinese, and Japanese) and a distinct cluster of pre-Neolithic and Neolithic Southeast Asians along with the Andaman Islanders and Australian Aborigines (Matsumura 2006). Since the majority of modern Southeast Asian populations are located in an intermediate position, it suggests that Southeast Asian populations were genetically influenced by Northeast Asian populations (Matsumura 2006).

Further support of the Two-Layer theory comes from Matsumura and Oxenham (2014). The authors analyzed 21 nonmetric dental traits from 7,247 individuals from Northeast and Southeast Asia, Oceania, the Pacific and America to provide a comprehensive geographical and temporal study of the two-layer hypothesis (Matsumura and Oxenham 2014). Frequencies for the nonmetric dental traits created two groupings; recent Northeast Asian populations (modern and historic Japanese and Chinese), an early Southeast concentration (early Vietnam and Laos, early Flores and Malay) with the

Melanesian sample, including New Guinea, New Britain Islanders, and closely linked with the Australian Aborigines (Matsumura and Oxenham 2014). The majority of modern Southeast Asian populations were distributed between the two main groups. Additionally, a comparison of spatial and chronological variability of 15 dental traits suggests a close affinity between early Southeast Asians and Australo-Melanesians; Northeast Asians and Native Americans; and significant dissimilarity between these two groupings (Matsumura and Oxenham 2014). Matsumura and Oxenham (2014) conclude that modern Southeast Asian populations share many dental traits with modern Northeast Asian populations, supporting the Two-Layer model.

The Two-Layer model is also supported by mtDNA analysis (Lertrit *et al.* 2008). Lertrit *et al.* (2008) analyzed ancient human mtDNA from two prehistoric populations in northeastern Thailand, spanning from 3,500 to 1,500 years BP and compared the sequences to various contemporary ethnic populations from East and Southeast Asia. The study found that Southeast Asian groups tended to cluster together and northern groups form a separate cluster. Interestingly, the Southeast Asia cluster is closest to modern Chinese (Lertrit *et al.* 2008). Based on their results, Lertrit *et al.* (2008) determined that groups migrated from Southern China into modern day Thailand during the second millennium. Afterwards, people living in Thailand intermixed with Khmer populations, who migrated into modern Cambodia around 4,000 years ago (Lertrit *et al.* 2008).

Conversely, the Regional Continuity theory states that the populations in Southeast Asia evolved *in situ* and subsequently migrated north. Regional Continuity is

supported by Turner's (1990) observations of dental patterns. Turner (1990) identified a dental pattern characterized by a comparatively generalized morphology, with low frequencies of incisor shoveling, double-shoveling, lower first molar cusp 6, lower second molar cusp 5, and 3-rooted first molars in the Southeast Asian crania from the late Pleistocene. The generalized morphology found in late Pleistocene Southeast Asian individuals was labeled sundadont. In contrast to the sundadont complex is the sinodont complex found in Eastern and Northeast Asian populations as well as Amerindians. The sinodont complex is characterized by the intensification of dental traits and more complexity. Higher frequencies of incisor shoveling, double-shoveling, 3-rooted first molars, and lower first molar cusp 6 characterize the sinodont complex (Turner 1990). Therefore, Turner (1990) proposed sinodonty evolved from sundadont, supporting the claim that Southeast Asian populations evolved *in situ* and migrated north.

Turner's (1990) hypothesis is further supported by chronological timing. The Jomon population from Japan has been isolated from the Asian mainland for 12,000 years according to archaeological evidence; therefore, the Sundadont complex has to be at least 12,000 years old (Turner 1990). The existence of sundadonty in Japan pre-dates the southern migration of Northeastern Asians into Southeast Asia; thus, signifying that Asian populations could not have evolved in the North and migrated South. Additionally, Turner (1990) notes the little change in dental patterns of Neolithic and metal age Southeast Asian groups and modern individuals from Thailand.

Building on the Regional Continuity, Pietrusewsky (2006) measured crania from archaeological sites in Thailand, Laos, Vietnam, North China, and Japan and compared

them to modern crania from Oceania, Australia, Southeast Asia, and East Asia. The author found that the minimum frontal breadth, nasion-bregma chord, maximum cranial breadth, and maximum cranial length contribute to population differences between the groups. Pietrusewsky's (2006) examination of modern individuals from East and Southeast Asian populations produced separate clusters with little overlap, signifying separate origins for East and Southeast Asian groups. In addition, the groups from Australia, Tasmania, New Guinea, and Melanesia are significantly different than groups from East and Southeast Asia (Pietrusewsky 2006). Furthermore, there is division between eastern Asia and the Pacific; the first group includes populations from Australia, Tasmania, New Guinea, and Melanesia, while the second group encompasses all crania from East Asia, Southeast Asia, Micronesia, and Polynesia (Pietrusewsky 2006). The distinct division between the two clusters suggests separate origins for the groups. Therefore, Pietrusewsky (2006) argues for the long-term *in situ* evolution of the populations rather than a model for displacement.

A Southeast Asian origin is supported by studies of the Y-chromosome haplogroup (Shi *et al.* 2005; Su *et al.* 1999). The markers on the nonrecombinant part of the Y-chromosome, which does not exhibit the results of genetic recombination, allows for the reconstruction of intact haplotypes and are highly information for retracing ancient human migration (Su *et al.* 1999). Su *et al.* (1999) analyzed DNA samples from 925 males to examine the genetic structure of Eastern-Asian populations. The results show that all northern population cluster together and are separated from the Southeast Asian populations. Furthermore, Southeast Asian populations are more diversified, and

Cambodians and Thai are the most polymorphic because they exhibit almost all of the Asian-specific haplotypes (Su *et al.* 1999). Based on the results, Su *et al.* (1999) conclude that northern populations derived from the Southeastern Asian populations and the first settlement of African immigrants landed in mainland Southeast Asia.

Shi *et al.* (2005) studied the distribution of the O3-M122 haplotypes in Southeast and Northeast Asia from 2,332 males. There are regionally distributed through Asia; the O3-M122 has the highest frequency in East Asians and is absent outside of East Asia, while O2-M95 and O1-M119 are prevalent in Southeast Asia (Shi *et al.* 2005). The distribution of the O3-M122 haplotypes in East Asian populations, promote a southern origin of the haplotype (Shi *et al.* 2005). They concluded that Asian populations originated in the south and then subsequently migrated north 25,000 – 30,000 years ago. The northward migration coincides with glaciers receding in the last Ice Age (Su 1999).

Hanihara's (2006) study supports neither the Two-Layer nor the Regional Continuity models. Hanihara (2006) analyzed 34 cranial measurements from 103 populations from Northeast, Southeast and South Asia, Australia, Melanesia, and the Middle East. The results of the distance matrix demonstrate a clear separation among Australian/Melanesian groups, East/Southeast Asian groups, and Northeast Asian samples (Hanihara 2006). Therefore, Hanihara (2006) argues that a Northern population did not replace individuals in Southeast Asia. Instead, East/Northeast Asia and Southeast Asia represent two separate phylogenetic units, with some gene flow between the two groups (Hanihara 2006).

Due to the paucity of archaeological sites in Southeast Asia, less is certain about the peopling of Southeast Asia. However, the majority of the skeletal evidence supports the Two-Layer model, in which Australo-Melanesian populations inhabited Southeast Asia and interbred with Northern Asian population groups that migrated southward (Matsumura 2006; Shackelford and Demeter 2012). The southward migration is estimated to coincide with the expansion of wet-rice agriculture approximately 5,000 years ago (Oxenham and Tayles 2006; Matsumura 2006; Shackelford and Demeter 2012). A complete replacement of Southeast Asian groups by northern migrations is unlikely due to the retention of Australo-Melanesian populations. Supporters of the Regional Continuity model rely on craniometric and dental variation between East or Northeast Asian population and Southeast Asia populations for two unrelated populations (Pietrusewsky 2006; Turner 1990). Generally, it is argued that modern Southeast Asian populations are a mix between Australo-Melanesians and northern Asian populations who migrated southward (Letrit *et al.* 2008; Matsumura 2006; Oxenham and Tayles 2006).

### **North America**

A significant amount of research has been conducted on the peopling of the Americas (Jantz and Owsley 2001; Lahr 1995; Perez *et al.* 2009; Powell and Neves 1999; Scott *et al.* 2016). The study of North American Native Americans was first mentioned by Jesuit Jose de Acosta in 1589, and the first analysis of Native American skeletal remains was completed by French naturalist Georges-Louis Leclerc de Buffon in the 20<sup>th</sup> century using extinct and extant Amerindians (Mazières 2011). Early research into the

migration patterns focused on linguistic, dental morphology and craniometric evidence to determine migratory waves and timings of the migrations (Greenberg 1986; Lahr 1995; Powell 1993; Powell and Neves 1999; Turner 1990). Researchers generally agree that the early ancestors to North America are of Asian descent; however, the exact number of founding groups and migration waves remains a debated topic.

There are two main models regarding the peopling of the Americas that persist: The Migratory and Local Diversification Hypothesis. Both models agree that an Asian population is ancestral to the Native American populations; however, the number of migratory waves and timing of the waves remain contested.

Proponents of the Migratory Hypothesis or Three-migration Model argue that the biological variations among Native Americans resulted from multiple migratory waves made by populations of different biological stocks that successively entered the continent (Gobel *et al.* 2008; Lahr 1995; Mazières 2011; Perez *et al.* 2009; Powell 1993). The Migratory Hypothesis is supported by craniofacial morphology, linguistic, dental and genetic evidence.

Turner (1971) examined three-rooted mandibular first molars (3RM1) of Asian, Africa, Europe, and New World populations to determine the frequency of the trait and determine the number of migratory waves of Asian populations into the New World. Turner (1971) found that the presences of 3RM1 ranges from 0 to 11% in Indians and from 25 to 44% in Aleut-Eskimos. There low frequency variation of 3RM1 within and between prehistoric American Indian groups can be interpreted as indicating a moderately strong selection (Turner 1971). Geographic variation of 3RM1 in the

Americas is slightly greater than temporal variation. Turner (1971) interprets this to mean that the trait was probably non-adaptive and relatively stable; therefore, the New World variation appears to be due to differences between founding groups, rather than microevolution. Assuming the variation is due to different migrations, Turner (1971) concludes that there were three separate migrations occurred. The first Indians that migrated into the New World possessed a 3RM1 with a frequency around 5% (Turner 1971). The second migration, the Na-Dene, had an original 3RM1 frequency of 25-30% (Turner 1971). Lastly, the third migration corresponds with the arrival of the Aleut-Eskimo populations. Approximately 60% of Aleut-Eskimo individuals possess 3RM1 (Turner 1971). Turner (1971) concludes that three-rooted mandibular first molars frequency is nonadaptive, meaning the differences are due to separate origins, and there are three ancestral migrations into the New World.

Greenberg *et al.* (1986) analyzed linguistic, dental, and genetic evidence in regards to the peopling of the Americas and the differences between Native American populations. Greenberg *et al.*(1986) classified the languages of North America into three main groups; Amerind, Na-Dene, and Aleut-Eskimo. Based on this division, Greenberg *et al.* (1986) infers that there were three migrations or at least three linguistic traces. The oldest migratory wave is most likely Amerind, because it centers farther to the south and has greater internal differentiation (Greenberg *et al.* 1986). Following the Amerinds, Na-Dene is proposed as the second migration into North America; Na-Dene has a deeper internal division and is geographically less peripheral than Aleut-Eskimo, it is found in Southeastern Alaska and northern British Columbia (Greenberg *et al.* 1986). The most

recent migration into North America is Aleut-Eskimo. Aleut-Eskimo has a less deep internal division than Na-Dene; the shallow internal differences suggest a recent migration (Greenberg *et al.* 1986). In order to date the divergences of the languages, glottochronology was used. Glottochronology examines the rate of retention of a specific list of words. The glottochronological results date the divergence of Aleut-Eskimo to 2,900-5,600 B.P., while the Na-Dene arrived around 9,000 years B.P. and finally the Amerind languages arrived around 11,000 years before present (Greenberg *et al.* 1986).

Lahr (1995) examined cranial morphological features of South American cranial from Fuegian-Patagonia and compared their morphological to crania from Eskimos and the five geographic regions (Europe, Africa, Southeast Asia, East Asia, and Australia) to determine the origins of the Amerindians. Lahr's (1995) analysis determined that while the Fuegian-Patagonina sample shows a generalized "Mongoloid" form, with broad faces, broad cranial bases, high cheekbones and tall noses, the sample also departs from the typical Mongoloid morphology due to their large size, high nasal saddle, flat frontals, angled occipitals, and pronounced cranial robusticity (Lahr 1995). The differences in morphology were argued to reflect morphology of early Amerindians. In addition, the results of the study support the hypothesis of more than one ancestral population of Native Americans. Lahr (1995) presents a three-migration model for the peopling of the Americas based on the premise that all Amerindians share a single common ancestry. In the first wave South and Central America were occupied, followed by the interior of Alaska and the North Pacific coast, and lastly the Inuit of the Arctic (Lahr 1995).

Similarly, González-José *et al.* (2001) argue for separate migrations of ancestral populations from an East Asian population into the New World. González-José *et al.* (2001) studied 656 individuals from Asia, Greenland, North America, and South America in order to estimate craniometric variability among Asian and Native American populations and to determine the model of dispersal into the New World. Phenotypic data was examined to describe the genetic characteristics of the Asian and American populations; this analysis works off the assumption that phenotypic variation sufficiently reflects genetic variation. The results of the analysis determined that there is higher within-group genetic heterogeneity in Amerindian populations than any other major human ethnic group (González-José *et al.* 2001). González-José *et al.*'s (2001) study was conclusive on two points; models involving a single migration or a single ancestor of all Native Americans have little support from craniometric variability, and Paleoamerican morphology is most likely a departure from a typical East Asian morphology.

Karafet *et al.* (1999) analyzed 2,198 males from 60 worldwide populations to determine the number of founding populations for Native Americans. Haplotype research on Native Americans supports the theory that all Native Americans can be traced to an ancestral founder population that lived in the region of Mongolia/North China (Karafet *et al.* 1999). Through haplotype analysis, nine unique haplotypes were found in Native American populations. The two most popular, 1C and 1G, are found in all North, Central, and South American populations. Additionally, the haplotype 1C was widespread in both Asian and the Native American populations (Karafet *et al.* 1999). Haplotype 1C best fits the criteria for a New World founding lineage because it is

prevalent in both Asia and the New World. Additionally, the Haplotype 1F was present in about 4% of Native American samples; the haplotype was also found with relatively high frequency in Tanana and Cheyenne, with additional high frequencies within Asia, but absent in Africa and Europe (Karafet *et al.* 1999). Consequently, Karafet *et al.* (1999) hypothesized that haplotype 1F could be a second New World founder haplotype. Karafet *et al.* (1999) conclude that there were two migrations into the New World; the first migration brought haplotype 1C to the New World and a second migration brought the haplotype 1F into America.

In contrast to the Migratory Hypothesis, the Local Diversification Hypothesis claims that all South and North American populations descend from the same ancestral population with a high level of gene diversity followed by local random (genetic drift) and non-random (selection) factors causes the genetic diversity (Mazières 2011; Perez *et al.* 2009).

Goebel *et al.* (2008) examined the ancient DNA evidence for a single origin of all Native Americans. Native Americans fit within five mtDNA (A, B, C, D, and X) as well as two Y-chromosome (C and Q) founding haplotypes, which are also found in populations from southern Siberia (Goebel *et al.* 2008). Analysis of mtDNA data estimate the divergence of Asian and Native American haplogroup lineages to have occurred 25,000 to 20,000 years ago, while Y-chromosome variability indicates a divergence after 22,500 years ago and possibly as late as 20,000 to 15,000 years ago (Goebel *et al.* 2008). Recent analysis of haplogroups have determined that three subclades of mtDNA subhaplogroup C1 are distributed throughout North, Central, and

South America but are absent in Asian populations. The lack of these sub-haplogroups in Asian populations suggests that they evolved as the founding population was dispersing into the New World from Beringia (Goebel *et al.* 2008). Therefore, Goebel *et al.* (2008) interpret the genetic evidence as supporting the claim that all major Native Americans came from the same region of central Asia and share similar coalescent dates and that there is a single origin for all Native American populations.

Perez *et al.* (2009) examined 283 individuals from Late Holocene Argentina to compare the morphological and mtDNA in regards to the founding population of the Native Americans. Accordingly, the morphological variations among South Americans supports the migratory hypothesis; but the mtDNA data supports the Local Diversification Model. The molecular evidence supports a single origin for all Native Americans in Northeast Asia approximately 15,000 years BP (Perez *et al.* 2009). The study detected four major Pan-American founding haplotypes (A2, B2, C1, and D1) which were also frequent throughout Asia (Perez *et al.* 2009).

Positioned somewhere in between the Migratory Hypothesis and the Local Diversification Hypothesis is the Beringian Standstill Model. Radiocarbon dates have been obtained from Asian Beringia, suggesting that human populations reached north of western Beringia around 30,000 years ago; however, Beringia was isolated from continental North American until approximately 14,000 years ago when the intracontinental ice-free corridor opened between the Laurentide and Cordilleran Ice Sheets (Kitchen *et al.* 2008; Scott *et al.* 2016). Therefore, the Beringian Standstill Model

assumes that an Upper Paleolithic population from East Asia lived in Beringia for an extended period of time before dispersal into the New World.

Kitchen *et al.* (2008) studied mitochondrial DNA (mtDNA) from Asian and Native American populations. Mitochondrial DNA provides the most extensive comparative database for human populations because mtDNA is more sensitive to demographic changes due to its smaller effective population size (Kitchen *et al.* 2008). An analysis of the mitochondrial coding genomes produced two distinct increases in Amerind female effective population size ( $N_{ef}$ ) ~40,000 years ago and ~15,000 years ago. The  $N_{ef}$  increases from 640 to 4,400 at the first inflation point and from 4,400 to 64,000 at the second inflation point (Kitchen *et al.* 2008). Based on the  $N_{ef}$  inflation points, Kitchen *et al.* (2008) argue for a three-stage model in which a rapid expansion into Americas was preceded by a long period of population stability in Beringia. The first stage, which consists of a gradual population growth as Amerind ancestors diverged from the central Asian gene pool, most likely occurred prior to 50,000 years ago and lasted until 36,000 years ago (Kitchen *et al.* 2008). There was also a severe population bottleneck during this period which would have reduced genetic variation. From roughly 36,000 years ago to 16,000 years ago, greater Beringia experienced a period of population stability and allowed for substantial genetic diversification. The third stage of the Beringian Standstill Model is marked by a rapid population expansion as Amerinds colonized the New World from 16,000 years ago until 9,000 years ago (Kitchen *et al.* 2008).

Scott *et al.* (2016) analyzed tooth crown and root morphology from over 100 samples from the New World, Asia and the Pacific to evaluate if dental morphology is consistent with the Beringian Standstill Model. Dental morphology was compared to four models, which represent the different theories regarding the timing and rate of movement into the New World; the models are based on the assumptions regarding skeletal sample affinity. The models are Sinodont only, with all Native Americans exhibiting trait frequencies in line with East Asian populations; Beringian Standstill, where Native Americans differ from all Asian populations but exhibit relative uniformity within the New World; Sinodont only plus Beringian Standstill, where New World populations are distinct from Asians but closer to East Asians than Southeast Asians; and Sundadont early, followed by Sinodont, where trait frequencies are closer to Southeast Asians with later groups closer to East (Scott *et al.* 2016). Out of 15 dental traits analyzed, six corresponded with Sinodont only plus Beringian Standstill, five corresponded with Beringian Standstill, one Sinodont only, and three Sundadont early followed by Sinodont (Scott *et al.* 2016). Therefore, Scott *et al.* (2016) argue the results support the hypothesis that the Northeast Asian population that would be ancestral to all Native Americans reached Beringia, and due to environmental constraints could not disperse into North America until the environmental changes during the late Pleistocene, after which the founding populations diverged quickly and dispersed throughout North America.

Mazières (2011) compared both morphological and genetic data to create a more accurate model for the peopling of North America. Similar to Kitchen *et al.* (2008) and

Scott *et al.* (2016), the study noted archaeological and paleoecological evidence of a human standstill in Beringia during the Last Glacial Maximum, roughly 21,000-11,000 years before present. Therefore, Beringia is the best candidate for place of Amerindian mtDNA polymorphisms that are not present in the Asian population (Mazières 2011). Mazières (2011) compiled both morphological and mtDNA data into the Consensus Model. According to the Consensus Model, during the Late Pleistocene, from 26,000 to 18,000 years before present, Asian populations migrated towards the northeastern Siberia carrying a broadly non-derived cranial morphology and at least the Eurasian A-D, X mtDNAs, and the P\* Y-chromosome, which is ancestral to Q (Mazières 2011). Therefore, the early inhabitants of Beringia possessed genetic and morphological components of an Asian origin. Then between 18,000 years BP and the end of the Pleistocene, sea levels rose and reduced the size of Beringia, forcing populations to move eastward, and by 12,000 years BP humans were present in the New World (Mazières 2011). It was not until the Holocene, roughly 12,000 years BP to present, that significant biological specialization with the emergence of derived craniofacial morphology.

## **Conclusion**

Although Native American and Thai populations share a common ancestor, the two populations have undergone different environmental, geographical, and genetic influences causing the two population groups to be significantly different. The population history of Thailand is confounded by the paucity of archaeological remains from Southeast Asia. However, two main hypotheses have been proposed for the history

of Thailand; the Two-Layer model and Regional Continuity model (Hanihara 2006; Peitrusewsky 2006; Matsumura 2006). Both models propose modern humans settled in Southeast Asia roughly 40,000 years ago, and an indigenous Australo-Melanesian population occupied Southeast Asia during the late Pleistocene and early Holocene by at least 26,000 years ago (Demeter 2006; Highman 2002). The majority of the skeletal evidence supports the Two-Layer model; in which Australo-Melanesian population inhabited Southeast Asia and interbred with Northern Asian population groups that migrated southward (Matsumura 2006; Shackelford and Demeter 2012). The southward migration is estimated to correspond with the growth of wet-rice agriculture roughly 5,000 years ago (Oxenham and Tayles 2006; Matsumura 2006; Shackelford and Demeter 2012).

While the ancestral origin of Native Americans is agreed upon, the number of migratory waves and the cause of the diversity between Native American groups remains debated. Similar to Thailand, there are two main models concerning the peopling of the America: The Migratory and Local Diversification Hypothesis; both models agree that an Asian population is ancestral to the Native American populations. The Migratory Hypothesis is supported mainly by dental, morphological, and linguistic evidence (Greenberg *et al.* 1986; Lahr 1995; Turner 1971). On the other hand, the Local Diversification Hypothesis is mainly supported by ancient DNA studies (Goebel *et al.* 2008; Perez *et al.* 2009). In recent years, the Beringian Standstill Model has been proposed to reconcile the discrepancies between cranial morphology and genetic evidence. It is due to the differences in cranial morphology and genetic evidence

between Asian populations and Native American populations that there is a need to create and modify standards for each population group.

## CHAPTER IV: MATERIALS AND METHODS

The purpose of this chapter is to discuss the skeletal samples, data collection methods, and statistical analyses used to address the author's two hypotheses. The first section discusses the demographics of the two skeletal samples studied. The second section explains the methods of data collection, including methods of sex estimation for the Native American individuals, and the standard measurements taken. Lastly, the statistical methods used to analyze the data and create formulae for both populations will be discussed.

### **Skeletal Samples**

In Thailand, the collection housed at Khon Kaen University's (KKU) Faculty of Medicine was analyzed. A total of 100 individuals, 50 females and 50 males, were analyzed. The age of the individuals studied ranged from 17-96 years. The collection is comprised of 745 skeletons of known individuals from Isan Region in Thailand, which is the largest region of Thailand and bordered by Cambodia in the south and Laos in the north (Mann 2013; Techataweewan *et al.* 2017). The KKU individuals are obtained through the medical school's body donation program. The individuals are primarily middle-aged and elderly individuals, including Thai monks, farmers and some faculty members (Mann 2013; Techataweewan *et al.* 2017). In regards to the demographics of the collection, there is a sex ration of close to 2:1, in favor of males and the mean age is 63.3 years for females and 61.4 years for males (Techataweewan *et al.* 2017). The predominance of males is assumed to be a result of the period of accumulation of the

collection rather than reflecting the Thai population. Many of the skeletons exhibit untreated and advanced stages of cancer as well as trauma from motor vehicle accidents (Mann *et al.* 2013). Cancer, particularly of the liver, lungs, bowels (in males) and breast (in females) is identified as the most frequent cause of death (Techataweewan *et al.* 2017).

The Native American sample is housed at the American Museum of Natural History (AMNH) in New York City. The osteological collection at the AMNH consists of roughly 12,000 individuals from 50 countries, mainly from archaeological sites. The 102 Native Americans studied were recovered from the Southwest, including New Mexico, Colorado, Utah, and Arizona. Due to the nature of the archaeological remains, the sample consists of individuals with only crania or just the postcranial elements, but the majority had both cranial and postcranial elements. The breakdown of the male sample consists of 16 crania, 11 postcranial remains, and 26 relatively complete skeletons. For the females, the breakdown consists of 12 crania, 10 postcranial remains, and 27 relatively complete skeletons. Since the remains are from archaeological sites, the sex of the individuals was unknown. In order to estimate the sex of the individuals, the author used the morphological features of the skull and pelvis following Klales *et al.* (2012), Phenice (1969), and Walker (2005; 2008).

### **Data Collection**

Measurements of 13 elements including the cranium, mandible, clavicle, humerus, radius, ulna, os coxa, femur, tibia, fibula, and calcaneus, were taken following

Langley *et al.* (2016). The elements from the left side were analyzed, unless damaged or missing. The 26 cranial measurements were collected using sliding and spreading calipers and a mandibulometer. Postcranial measurements were taken with a sliding caliper, an osteometric board, and a measuring tape. Tables 4.1 and 4.2 list the cranial and postcranial measurements that were taken following Langely *et al.* (2016). To account for intraobserver error, 10% of the sample (n = 20) were re-measured.

<b>Table 4.1. Descriptions of skull measurements following Langley <i>et al.</i> (2016).</b>		
<b>Measurement</b>	<b>Abbreviation</b>	<b>Definition</b>
Maximum cranial length	g-op	The straight-line distance from glabella (g) to opisthocranium (op).
Nasio-occipital length	NOL	Maximum length in the mid-sagittal plane, measured from nasion.
Maximum cranial breadth	eu-eu	The maximum width of the skull perpendicular to the mid-sagittal plane wherever it is located with the exception of the inferior temporal line and the immediate area surround the latter.
Bizygomatic breadth	zy-zy	The maximum breadth across the zygomatic arches.
Basion-bregma height	ba-b	The distance from basion to bregma.
Basion-Prosthion length	ba-pr	The distance from basion to prosthion.
Maxillo-Alveolar breadth	ecm-ecm	The maximum breadth across the alveolar borders of the maxilla measured on the lateral surfaces at the location of the second maxillary molars.
Maxillo-Alveolar length	pr-alv	The distance from prosthion to alveolon.
Biauricular breadth	ra-ra	The least exterior breadth across the roots of the zygomatic processes.
Nasion-Prosthion height	n-pr	The distance from nasion to prosthion.
Minimum Frontal breadth	ft-ft	The distance between the right and left frontotemporale.
Upper Facial breadth	fmt-fmt	The distance between the right and the left frontomalare temporale.
Nasal height		The average height from nasion to the lowest point on the border of the nasal aperture on either side.

<b>Table 4.1. Descriptions of skull measurements following Langley <i>et al.</i> (2016).</b>		
Nasal breadth	NLB	The maximum breadth of the nasal aperture.
Orbital breadth	d-ec	The distance from dacryon to ectoconchion.
Orbital height	OBH	The distance between the superior and inferior orbital margins perpendicular to orbital breadth and bisecting the orbit into equal medial and lateral halves.
Biorbital breadth	ec-ec	The distance from left to right ectoconchion.
Interorbital breadth	d-d	The distance between right and left dacryon.
Frontal chord	n-b	The distance from nasion to bregma.
Parietal chord	b-l	The distance from bregma to lambda.
Occipital chord	l-o	The distance from lambda to opisthion.
Foramen Magnum length	FOL	The mid-sagittal distance from the most anterior point on the foramen magnum margin to opisthion.
Foramen Magnum breadth	FOB	The distance between the lateral margins of the foramen magnum at the point of greatest lateral curvature.
Mastoid height	MDH	The direct distance between porion and mastoidale.
Biasterionic Breadth	ast-ast	Straight-line distance from left to right asterion.
Bimaxillary breadth	zma-zma	The breadth across the maxillae, from left to right zygomaxillare anterior.
Zygoorbitale breadth	zo-zo	The distance between right and left zygoorbitale.
<b>Mandibular Measurements</b>		
Chin height	id-gn	The distance from infradentale to gnathion.
Height of the mandibular body		The distance from the alveolar process to the inferior border of the mandible at the level of the mental foramen.
Breadth of mandibular body		The maximum breadth measured at the level of the mental foramen perpendicular to the long axis of the mandibular body.
Bigonial breadth	go-go	The distance between the right and left gonion.
Bicondylar breadth	cdl-cdl	The distance between the most lateral points on the mandibular condyles.

Minimum ramus breadth		The minimum breadth of the mandibular ramus measured perpendicular to the height of the ramus
Maximum ramus height		The distance from gonion to the highest point on the mandibular condyle.
Mandibular length		The distance from the anterior margin of the chin to the midpoint of a straight line extending from the posterior border of the right and left mandibular angles.
Mandibular angle		The angle formed by inferior border of the corpus and the posterior border of the ramus.

<b>Measurements</b>	<b>Definition</b>
<b>Clavicle</b>	
Maximum length of clavicle	The maximum distance between the most extreme ends of the clavicle.
Maximum diameter of the clavicle at midshaft	The diameter of the bone measured at midshaft.
Minimum diameter of the clavicle at midshaft	The minimum diameter of the bone measured at midshaft.
<b>Scapula</b>	
Height of the scapula	The distance from the most superior point of the cranial angle to the most interior point on the caudal angle.
Breadth of the scapula	The distance from the midpoint on the dorsal border of the glenoid fossa to midway between the two ridges of the scapular spine on the vertebral border.
Glenoid cavity breadth	Maximum distance from the ventral to dorsal margins of the glenoid cavity, taken perpendicular to glenoid cavity height.
Glenoid cavity height	The distance from the most superiorly located point on the margin of the glenoid cavity
<b>Humerus</b>	
Maximum length of the humerus	The distance from the most superior point on the head of the humerus to the inferior point on the trochlea.
Epicondylar breadth of the humerus	The distance from the most laterally protruding point on the lateral epicondyle to the corresponding projection on the medial epicondyle.

<b>Table 4.2. Descriptions of postcranial measurements following Langley <i>et al.</i> (2016).</b>	
Maximum vertical diameter of the head of the humerus	The distance between the most superior and inferior points on the border of the articular surface.
Maximum diameter of the humerus at midshaft	The maximum diameter of the humeral shaft at midshaft.
Minimum diameter of the humerus at midshaft	The minimum diameter of the humeral shaft at midshaft.
<b>Radius</b>	
Maximum length of the radius	The distance from the most proximally positioned point on the head of the radius to the tip of the styloid process.
Maximum diameter of the radius at midshaft	The maximum diameter of the radial shaft taken at midshaft.
Minimum diameter of the radius at midshaft	The minimum diameter of the radial shaft taken at midshaft.
Maximum diameter of the radial head	The maximum diameter of the radial head measured on the margin of the head that articulates with the ulna.
<b>Ulna</b>	
Maximum length of the ulna	The distance between the most proximal point on the olecranon and the most distal point on the styloid process.
Maximum midshaft diameter of the ulna	The maximum diameter of the diaphysis at midshaft.
Minimum midshaft diameter of the ulna	The minimum diameter of the diaphysis at midshaft.
Physiological length of the ulna	The distance between the deepest point on the articular surface of the coronoid process on the guiding ridge and most interior point on the distal articular surface.
Minimum circumference of the ulna	The least circumference of the ulna.
Olecranon breadth	The maximum breadth of the olecranon process, taken perpendicular to the longitudinal axis of the semilunar notch.
<b>Sacrum</b>	
Anterior height of the sacrum.	Distance from the point on the promontory in the mid-sagittal plane to the corresponding point on the anterior border of the distal tip of the sacrum
Anterior breadth of the sacrum	Maximum transverse breadth of the sacrum at the most anterior projection of the auricular surface
Transverse diameter of sacral segment 1	Distance between the two most lateral points on the superior articular surface measured perpendicular to the mid-sagittal plane

<b>Table 4.2. Descriptions of postcranial measurements following Langley <i>et al.</i> (2016).</b>	
Anterior-posterior diameter of sacral segment 1	The distance between the anterior and posterior borders of the superior articular surface of S1, taken in mid-sagittal plane.
<b>Innominate/Os Coxae</b>	
Maximum innominate height	The distance from the most superior point on the iliac crest to the most inferior point on the ischial tuberosity.
Maximum iliac breadth	The distance from the anterior superior iliac spine to the posterior superior iliac spine.
Minimum iliac breadth (WIB)	The minimum distance measured from the area below the anterior inferior iliac spine to the most inward curvature of the greater sciatic notch.
Maximum pubis length (XPL)	The distance between symphysis (the most superior point on the symphyseal face) to the farthest point on the acetabular rim.
Minimum Pubis Length (WPL)	The distance between symphysis to the closest point on the acetabular rim.
Ischial length (ISL)	The distance from the point on the acetabular rim where the iliac blade meets the acetabulum to the most medial point on the epiphysis of the ischial tuberosity.
Minimum ischial length (WISL)	The distance from the most inferior point on the symphyseal face to the most distant point on the ischial tuberosity.
Maximum ischiopubic ramus (XIRL)	The distance from the most inferior point on the symphyseal face to the most distant point on the ischial tuberosity.
Anterior superior iliac spine to symphysis (ASISS)	Measurement from the apex of the anterior superior iliac spine (most projecting area or point) to the symphysis.
Maximum posterior superior iliac spine to symphysis (PSISS)	Maximum measurement from the posterior border of the posterior superior iliac spine to symphysis.
Minimum apical border to symphysis (WAS)	Minimum measurement from symphysis to the apex (anterior border) of the auricular surface.
<b>Femur</b>	
Maximum length of the femur	The distance from the most proximal point on the head of the femur to the most distal point on the medial or lateral femoral condyle.
Bicondylar length of the femur	The distance from the most proximal point on the head of the femur to a plane drawn between the inferior surfaces of the distal condyles.

<b>Table 4.2. Descriptions of postcranial measurements following Langley <i>et al.</i> (2016).</b>	
Epicondylar breadth of the femur	The distance between the two most projecting points on the epicondyle.
Maximum diameter of the femur head	The maximum diameter of the femur head measured on the border of the articular surface.
Transverse subtrochanteric diameter of the femur	The transverse diameter of the proximal portion of the diaphysis at the point of its greatest lateral expansion.
Anterio-posterior subtrochanteric diameter of the femur	The anterior-posterior diameter of the proximal end of the diaphysis measured perpendicular to the transverse diameter at the point of the greatest lateral expansion.
Maximum midshaft diameter	The maximum diameter of the femoral shaft taken at midshaft
Minimum midshaft diameter of the femur	The minimum diameter of the femoral shaft taken at midshaft.
Circumference of the femur at midshaft	The circumference measured at the midshaft.
Maximum antero-posterior length of the lateral condyle	The distance between the most anterior and posterior points on the articular surface of the lateral condyle.
Maximum antero-posterior length of the medial condyle	The distance between the most anterior and posterior points on the articular surface of the medial condyle.
<b>Tibia</b>	
Length of the tibia	The distance from the superior articular surface of the lateral condyle of the tibia to the tip of the medial malleolus
Maximum proximal epiphyseal breadth of the tibia	The maximum distance between the two most projecting points on the margins of the medial and lateral condyles of the proximal epiphysis
Distal epiphyseal breadth of the tibia	The distance between the most medial point on the medial malleolus and the lateral surface of the distal epiphysis.
Maximum midshaft diameter of the tibia	The maximum diameter of the tibial shaft taken at midshaft.
Minimum midshaft diameter of the tibia	The minimum diameter of the tibial shaft taken at midshaft.
Circumference of the tibia at midshaft	The circumference measured at the level at the midshaft.
<b>Fibula</b>	
Maximum length of the fibula	The maximum distance between the most superior point on the fibular head and the most inferior point on the lateral malleolus.

<b>Table 4.2. Descriptions of postcranial measurements following Langley <i>et al.</i> (2016).</b>	
Maximum diameter of the fibula at midshaft	The maximum diameter at the midshaft.
<b>Calcaneus</b>	
Maximum length of the calcaneus	The distance between the most posteriorly projecting point on the calcaneal tuberosity and the most anterior point of the superior margin of the articular facet for the cuboid measured in the sagittal plane.
Middle breadth of the calcaneus	The distance between the most laterally projecting point on the dorsal articular facet and the most medial point on the sustentaculum tali.

### **Statistical Analyses**

After the data were collected for all individuals, select measurements were entered into the sex determination equations created by Spradley and Jantz. (2011). Spradley and Jantz. (2011) created classification equations for American Black and American White individuals using samples from the FDB. Spradley and Jantz (2011) created stepwise classification functions for cranial and postcranial elements. The measurements from both Native American and Thai individuals were entered into the equations created for American White individuals. Second, the numbers will be tested in the equation for American Black. This was done to prove that population specific standards are needed.

All statistical analyses were conducted in IBM SPSS (version 25.0). First, a factor analysis was performed on each element. T-tests were used to compare Thai males to Native American males and Thai females to Native American females to determine if there are significant differences between the two populations. A t-test compares differences in mean scores of normally distributed data. The t-test also determines how

significant the differences are, and if they could happen by chance. Values that are closer to a p-value of 0.000 are statistically significant, meaning that the difference is the not the result of random chance. The cutoff point is 0.05 for a p-value, meaning that any p-value greater than 0.05 indicates that the difference is minimal and not statistically significant.

### Testing Spradley and Jantz's (2011) Equations

Spradley and Jantz (2011) developed discriminant functions to estimate the sex of unknown individuals from American Black and White populations in the FDB (Table 4.3). Spradley and Jantz's (2011) classification equations have a cut-off point of 0, females are indicated by negative values and males are indicated by positive values. To ascertain if population-specific standards are necessary and thus determining the accuracy of Spradley and Jantz's (2001) discriminant functions on Thai and Native American populations, the equations were tested with the data collected by the author.

<b>Table 4.3. Stepwise selected variables for American Black and classification functions (Spradley and Jantz 2011)</b>	
<b>Element</b>	<b>Classification Function with Stepwise Selected Variables</b>
Clavicle	$(0.2877 * \text{maximum length}) + (0.9636 * \text{sagittal diameter at midshaft}) + (1.1065 * \text{vertical diameter at midshaft}) + (-66.6844)$
Scapula	$(0.25647 * \text{height}) + (0.2157 * \text{breadth}) + (-60.55)$
Humerus	$(0.42616 * \text{epicondylar breadth}) + (0.92 * \text{head diameter}) + (0.49507 * \text{maximum diameter at midshaft}) + (-74.5878)$
Radius	$(0.12149 * \text{maximum length}) + (0.65603 * \text{sagittal diameter at midshaft}) + (0.60906 * \text{transverse diameter at midshaft}) + (-47.861)$
Ulna	$(0.07912 * \text{maximum length}) + (0.8104 * \text{dorso-volar diameter at midshaft}) + (0.74434 * \text{transverse diameter at midshaft}) + (-44.2026)$
Sacrum	$(0.09686 * \text{transverse diameter of segment 1}) + (-4.69561)$
Os Coxa	$(0.21749 * \text{height of ox coxa}) + (-0.11432 * \text{iliac breadth}) + (-0.16143 * \text{pubis length}) + (0.37051 * \text{ischium length}) + (-45.1877)$
Femur	$(0.41661 * \text{epicondylar breadth}) + (0.59516 * \text{maximum diameter of head}) + (-58.836)$
Tibia	$(0.42495 * \text{maximum proximal epiphyseal breadth}) + (0.34828 * \text{maximum distal epiphyseal breadth}) + (-48.2631)$

Fibula	$(0.073 * \text{maximum length}) + (0.09111 * \text{maximum diameter at midshaft}) + (-29.4408)$
Calcaneus	$(0.29971 * \text{maximum length}) + (0.547 * \text{middle breadth}) + (-46.8862)$
Cranium	$(0.71406 * \text{bizygomatic breadth}) + (0.43318 * \text{mastoid height}) + (-0.59308 * \text{biauricular breadth}) + (0.34451 * \text{upper facial height}) + (-0.14842 * \text{minimum frontal breadth}) + (0.53049 * \text{foramen magnum breadth}) + (-0.60805 * \text{orbital height}) + (0.32505 * \text{nasal height}) + (-54.2458)$
Mandible	$(0.13874 * \text{bigonial width}) + (0.19311 * \text{bicondylar breadth}) + (-34.6986)$

<b>Table 4.4. Stepwise selected variables for American White and classification functions (Spradley and Jantz 2011)</b>	
<b>Element</b>	<b>Classification Function with Stepwise Selected Variables</b>
Clavicle	$(0.23645 * \text{maximum length}) + (0.88675 * \text{sagittal diameter at midshaft}) + (0.60941 * \text{vertical diameter at midshaft}) + (-51.7722)$
Scapula	$(0.19365 * \text{height}) + (0.25609 * \text{breadth}) + (-55.6564)$
Humerus	$(0.04008 * \text{maximum length}) + (0.4011 * \text{epicondylar breadth}) + (0.26862 * \text{maximum vertical head diameter}) + (0.62205 * \text{maximum diameter at midshaft}) + (-59.6723)$
Radius	$(0.11151 * \text{maximum length}) + (1.17296 * \text{sagittal diameter at midshaft}) + (0.7476 * \text{transverse diameter at midshaft}) + (-51.8801)$
Ulna	$(0.1189 * \text{maximum length}) + (0.98611 * \text{dorso-volar diameter at midshaft}) + (0.89642 * \text{transverse diameter at midshaft}) + (-0.09097 * \text{minimum circumference}) + (-54.2634)$
Sacrum	$(0.23919 * \text{anterior breadth}) + (-0.03177 * \text{transverse diameter of segment 1}) + (-8.09535)$
Os Coxa	$(0.15836 * \text{height}) + (-0.08458 * \text{breadth}) + (-0.12135 * \text{pubis length}) + (0.1338 * \text{ischium length}) + (-21.4996)$
Femur	$(0.36448 * \text{epicondylar breadth}) + (0.52629 * \text{maximum diameter of head}) + (0.02826 * \text{bicondylar length}) + (-65.70614)$
Tibia	$(0.02828 * \text{length}) + (0.6134 * \text{maximum proximal epiphyseal breadth}) + (0.424 * \text{maximum diameter at nutrient foramen}) + (-0.13118 * \text{circumference at nutrient foramen}) + (-58.633)$
Fibula	$(0.07437 * \text{maximum length}) + (0.14191 * \text{maximum diameter at midshaft}) + (-29.5745)$
Calcaneus	$(0.18618 * \text{maximum length}) + (0.11285 * \text{middle breadth}) + (-32.3714)$
Cranium	$(0.50255 * \text{bizygomatic breadth}) + (-0.07786 * \text{basion nasion length}) + (0.24989 * \text{mastoid height}) + (0.19553 * \text{nasal height}) + (0.24263 * \text{basion-bregma height}) + (-0.15875 * \text{minimum frontal breadth}) + (-0.13224 * \text{biauricular breadth}) + (0.21776 * \text{glabella occipital length}) + (-0.09443 * \text{frontal chord}) + (-0.08327 * \text{parietal chord}) + (-0.13411 * \text{occipital chord}) + (-81.1812)$

Mandible	$(0.15798 * \text{maximum ramus height}) + (0.21951 * \text{bigonial width}) + (0.06335 * \text{mandibular length}) + (-35.0107)$
----------	---

### Population-Specific Equations

In order to create discriminant functions, two steps were conducted. First, a factor analysis was performed on each element. A factor analysis is used to identify latent variables or constructs; or to reduce the number of variables and simplify the data (Field 2009). In addition, factor analysis can be used to construct indices and determine which variables have greater explanatory power than others; therefore, a factor analysis determines which measurements are the most diagnostic between sexes.

The second step involved performing a linear regression. Linear regressions address two questions; does a set of variables predict an outcome (dependent) variable well, and which variables are significant predictors of the outcome (Field 2009). The results of a regression equation are used to explain relationships between the dependent variables and multiple independent variables. A linear regression was run using the measurements that were determined to be significant predictors of sex from the factor analysis. The outcome of the linear regression produced a constant and coefficients for each measurement in the analysis. The constant and coefficients are used to create the discriminant functions for both the Thai population and Native American population.

A crosstab analysis explores the frequency data and contains the number of cases that fall into each category (Field 2009). Therefore, it determines the accuracy of the discrimination functions created. Crosstab analysis was run on the equations developed by the author to determine their accuracies.

### **Intraobserver Error**

As stated previously, 10% (n=20) of the original sample size was remeasured at the end of the study. An intraclass correlation was run to calculate the intraobserver error rates for the measurements. Intraclass correlation measures the reliability of measurements or how well they are related (Fields 2009). A high intraclass correlation coefficient (ICC) close to 1.0 indicates high similarity between the two measurements (Fields 2009). On the other hand, a low ICC, closer to 0.0 means that two measurements were not similar.

### **Conclusion**

This study examined a sample of 100 modern Thai and 102 Native American individuals to identify metric differences between the two population groups and to create classification questions for the populations. Both cranial and postcranial measurements were taken according to Langley *et al.* (2016). Multiple statistical analyses were performed on the data collected. T-tests were performed to compare the Thai and Native Americans element by element to determine if the two populations are significantly different. Factor analyses followed by linear regressions were performed to create discriminant functions to estimate the sex of Thai and Native Americans.

## CHAPTER V: RESULTS

This chapter presents the results of the metric analyses conducted on the Khon Kaen (KKU) and American Museum of Natural History collections discussed in Chapter IV. Unfortunately, due to broken elements and lack of measurements not every individual is included in all analyses. The maximum number of individuals with each measurement was utilized. The first section of this chapter presents the results of the t-tests that compare the Native American and modern Thai samples. The second section discusses the result of the factor analyses and regression and presents the population-specific discriminant functions. The results of testing the data in the Spradley and Jantz (2011) discriminant functions will be discussed in the third section.

### **Population Differences**

The results of the independent t-tests determined that there were numerous statistically significant differences between the Native American and modern Thai populations. For the females, the mandible, clavicle, scapula, and the tibia were significantly different. On the other hand, the radius, sacrum, femur, and calcaneus had no statistically significant differences. For the males, the mandible, clavicle, humerus, and tibia were significantly different between the Native Americans and Thai. Conversely, the scapula, fibula, and calcaneus had no significant differences. In total, there were 40 out of 96 (41.7%) measurements different for males and 35 out of 96 (36.5%) measurements different for females. In general, the Native Americans were slightly larger than their Thai counterparts. When examining the trends between the

Native American and Thai samples, the majority of long bone midshaft diameters were statistically different between the two groups. Interestingly, the maximum lengths of the long bones were not significantly different between the populations. The Native American and Thai measurement differences are presented in Tables 5.1 through 5.13.

<b>Table 5.1. Cranial measurement comparisons between Native American and Thai individuals.</b>		
<b>Measurement</b>	<b>Sex</b>	<b>P-Value</b>
Maximum Cranial Length	Females (n=88)	0.000*
	Males (n=90)	0.105
Nasio-occipital Length	Females (n=88)	0.000*
	Males (n=90)	0.146
Maximum Cranial Breadth	Females (n=84)	0.000*
	Males (n=89)	0.000*
Bizygomatic Breadth	Females (n=79)	0.201
	Males (n=88)	0.106
Basion-Bregma Height	Females (n=80)	0.098
	Males (n=90)	0.284
Cranial Base Length	Females (n=82)	0.010*
	Males (n=90)	0.301
Basion-Prosthion Length	Females (n=60)	0.094
	Males (n=68)	0.792
Maxillo-Alveolar Breadth	Females (n=42)	0.693
	Males (n=42)	0.722
Maxillo-Alveolar Length	Females (n=64)	0.242
	Males (n=68)	0.696
Biauricular Breadth	Females (n=88)	0.000*
	Males (n=90)	0.000*
Nasion-Prosthion Height	Females (n=65)	0.001*
	Males (n=68)	0.020*
Minimum Frontal Breadth	Females (n=88)	0.160
	Males (n=90)	0.009*
Upper Facial Breadth	Females (n=86)	0.673
	Males (n=89)	0.904
Nasal Height	Females (n=87)	0.583
	Males (n=90)	0.003*
Nasal Breadth	Females (n=86)	0.000*

<b>Table 5.1. Cranial measurement comparisons between Native American and Thai individuals.</b>		
	Males (n=89)	0.000*
Orbital Breadth	Females (n=88)	0.056
	Males (n=89)	0.952
Orbital Height	Females (n=88)	0.071
	Males (n=90)	0.350
Biorbital Breadth	Females (n=87)	0.319
	Males (n=88)	0.701
Interorbital Breadth	Females (n=86)	0.311
	Males (n=88)	0.005*
Parietal Chord	Females (n=80)	0.731
	Males (n=90)	0.633
Occipital Chord	Females (n=80)	0.306
	Males (n=85)	0.072
Frontal Chord	Females (n=84)	0.006*
	Males (n=82)	0.059
Foramen Magnum Length	Females (n=83)	0.903
	Males (n=86)	0.235
Foramen Magnum Breadth	Females (n=83)	0.002*
	Males (n=87)	0.035*
Mastoid Height	Females (n=88)	0.184
	Males (n=90)	0.005*
Mastoid Length	Females (n=88)	0.060
	Males (n=90)	0.755
Biasterrionic Breadth	Females (n=79)	0.002*
	Males (n=86)	0.034*
Bimaxillary Breadth	Females (n=84)	0.003*
	Males (n=71)	0.013*
Zygoorbitale Breadth	Females (n=85)	0.013*
	Males (n=67)	0.044*
*statistically significant at the 0.50 level.		

<b>Table 5.2. Mandibular measurement comparisons between Native American and Thai individuals.</b>		
<b>Measurement</b>	<b>Sex</b>	<b>P-Value</b>
Chin Height	Female (n=56)	0.000*
	Male (n=56)	0.002*
Height of Mandibular Body	Female (n=57)	0.026*
	Male (n=66)	0.001*
Breadth of Mandibular Body	Female (n=59)	0.050*

	Male (n=66)	0.000*
Bigonial Breadth	Female (n=81)	0.161
	Male (n=87)	0.010*
Bicondylar Breadth	Female (n=80)	0.000*
	Male (n=87)	0.002*
Minimum Ramus Breadth	Female (n=89)	0.061
	Male (n=92)	0.002*
Maximum Ramus Height	Female (n=85)	0.089
	Male (n=90)	0.922
Mandibular Length	Female (n=84)	0.000*
	Male (n=91)	0.101
Mandibular Angle	Female (n=85)	0.179
	Male (n=91)	0.000*

\*statistically significant at the 0.050 level.

**Table 5.3. Clavicle measurement comparisons between Native American and Thai individuals.**

Measurement	Sex	P-Value
Maximum Length	Female (n=79)	0.090
	Male (n=81)	0.173
Maximum Diameter	Female (n=79)	0.000*
	Male (n=81)	0.000*
Minimum Diameter	Female (n=79)	0.001*
	Male (n=81)	0.000*

\*statistically significant at the 0.050 level.

**Table 5.4. Scapular measurement comparisons between Native American and Thai individuals.**

Measurement	Sex	P-Value
Scapula Height	Female (n=68)	0.037*
	Male (n=72)	0.261
Scapula Breadth	Female (n=74)	0.002*
	Male (n=73)	0.189
Glenoid Cavity Breadth	Female (n=79)	0.985
	Male (n=77)	0.071
Glenoid Cavity Height	Female (n=79)	0.047*
	Male (n=77)	0.551

\*statistically significant at the 0.050 level.

<b>Table 5.5. Humeral measurement comparisons between Native American and Thai individuals.</b>		
<b>Measurement</b>	<b>Sex</b>	<b>P-Value</b>
Maximum Length	Female (n=81)	0.641
	Male (n=81)	0.483
Epicondylar Breadth	Female (n=82)	0.207
	Male (n=84)	0.001*
Maximum Vertical Head Diameter	Female (n=82)	0.046*
	Male (n=80)	0.000*
Maximum Diameter at Midshaft	Female (n=83)	0.000*
	Male (n=85)	0.001*
Minimum Diameter at Midshaft	Female (n=83)	0.094
	Male (n=85)	0.000*

\* statistically significant at the 0.050 level.

<b>Table 5.6. Radial measurements comparisons between Native American and Thai individuals.</b>		
<b>Measurement</b>	<b>Sex</b>	<b>P-Value</b>
Maximum Length	Female (n=80)	0.757
	Male (n=82)	0.986
Maximum Diameter at Midshaft	Female (n=81)	0.143
	Male (n=83)	0.000*
Minimum Diameter at Midshaft	Female (n=81)	0.179
	Male (n=83)	0.000*
Maximum Diameter of Radial Head	Female (n=82)	0.333
	Male (n=83)	0.000*

\*statistically significant at the 0.050 level.

<b>Table 5.7. Ulnar measurement comparisons between Native American and Thai individuals.</b>		
<b>Measurement</b>	<b>Sex</b>	<b>P-Value</b>
Maximum Length	Female (n=78)	0.945
	Male (n=79)	0.926
Maximum Midshaft Diameter	Female (n=83)	0.070
	Male (n=83)	0.000*

Minimum Midshaft Diameter	Female (n=83)	0.000*
	Male (n=83)	0.180
Physiological Length	Female (n=80)	0.758
	Male (n=80)	0.946
Minimum Circumference	Female (n=81)	0.141
	Male (n=82)	0.417
Olecranon Breadth	Female (n=79)	0.000*
	Male (n=81)	0.534

\*statistically significant at the 0.050 level.

<b>Table 5.8. Sacral measurement comparisons between Native American and Thai individuals.</b>		
<b>Measurement</b>	<b>Sex</b>	<b>P-Value</b>
Anterior Height of Sacrum	Female (n=59)	0.568
	Male (n=70)	0.934
Anterior Breadth of Sacrum	Female (n=68)	0.000*
	Male (n=74)	0.000*
Transverse Diameter of Sacral Segment 1	Female (n=57)	0.751
	Male (n=66)	0.723
Anterior Posterior Diameter of S1	Female (n=63)	0.253
	Male (n=70)	0.165

\*statistically significant at the 0.050 level.

<b>Table 5.9. Os coxa measurement comparisons between Native American and Thai individuals.</b>		
<b>Measurement</b>	<b>Sex</b>	<b>P-Value</b>
Maximum Innominate Height	Female (n=77)	0.491
	Male (n=77)	0.866
Maximum Iliac Breadth	Female (n=75)	0.489
	Male (n=72)	0.894
Minimum Iliac Breadth	Female (n=79)	0.000*
	Male (n=83)	0.000*
Maximum Pubis Length	Female (n=72)	0.230
	Male (n=74)	0.691
Minimum Pubis Length	Female (n=74)	0.528
	Male (n=76)	0.033*
Ischial Length	Female (n=77)	0.374
	Male (n=75)	0.010*

Minimum Ischial Length	Female (n=78)	0.198
	Male (n=76)	0.630
Maximum Ischiopubic Ramus Length	Female (n=73)	0.757
	Male (n=74)	0.151
Anterior Superior Iliac Spine to Symphysis	Female (n=69)	0.002*
	Male (n=75)	0.000*
Maximum Posterior Superior Iliac Spine to Symphysis	Female (n=66)	0.021*
	Male (n=69)	0.449
Minimum Apical Border to Symphysis	Female (n=71)	0.616
	Male (n=75)	0.736
*statistically significant at the 0.050 level.		

<b>Table 5.10. Femoral measurement comparisons between Native American and Thai individuals.</b>		
<b>Measurement</b>	<b>Sex</b>	<b>P-Value</b>
Maximum Length	Female (n=78)	0.289
	Male (n=76)	0.823
Bicondylar Length	Female (n=76)	0.221
	Male (n=75)	0.919
Epicondylar Breadth	Female (n=77)	0.135
	Male (n=76)	0.042*
Maximum Diameter of Femoral Head	Female (n=80)	0.060
	Male (n=80)	0.116
Transverse Subtrochanteric Diameter	Female (n=83)	0.127
	Male (n=80)	0.479
Anterio-Posterior Subtrochanteric Diameter	Female (n=83)	0.748
	Male (n=81)	0.068
Maximum Midshaft Diameter	Female (n=83)	0.209
	Male (n=80)	0.112
Minimum Midshaft Diameter	Female (n=83)	0.153
	Male (n=80)	0.045*
Circumference at Midshaft	Female (n=83)	0.899
	Male (n=80)	0.802
Maximum Antero-Posterior Length of Lateral Condyle	Female (n=78)	0.666

<b>Table 5.10. Femoral measurement comparisons between Native American and Thai individuals.</b>		
	Male (n=75)	0.679
Maximum Antero-Posterior Length of Medial Condyle	Female (n=74)	0.320
	Male (n=25)	0.590
*statistically significant at the 0.050 level.		

<b>Table 5.11. Tibial measurement comparisons between Native American and Thai individuals.</b>		
<b>Measurement</b>	<b>Sex</b>	<b>P-Value</b>
Maximum Length	Female (n=76)	0.712
	Male (n=77)	0.159
Maximum Proximal Epiphyseal Breadth	Female (n=76)	0.014*
	Male (n=79)	0.001*
Distal Epiphyseal Breadth of Tibia	Female (n=80)	0.003*
	Male (n=78)	0.009*
Maximum Midshaft Diameter	Female (n=81)	0.000*
	Male (n=80)	0.002*
Minimum Midshaft Diameter	Female (n=81)	0.473
	Male (n=80)	0.958
Circumference at Midshaft	Female (n=81)	0.000*
	Male (n=80)	0.002*
*statistically significant at the 0.050 level.		

<b>Table 5.12. Fibular measurement comparisons between Native American and Thai individuals.</b>		
<b>Measurement</b>	<b>Sex</b>	<b>P-Value</b>
Maximum Length	Female (n=70)	0.828
	Male (n=73)	0.638
Maximum Diameter at Midshaft	Female (n=73)	0.033*
	Male (n=79)	0.420
*statistically significant at the 0.050 level.		

<b>Table 5.13. Calcaneal measurement comparisons between Native American and Thai individuals.</b>		
<b>Measurement</b>	<b>Sex</b>	<b>P-Value</b>
Maximum Length	Female (n=78)	0.149
	Male (n=74)	0.515
Middle Breadth	Female (n=78)	0.887
	Male (n=74)	0.700
*statistically significant at the 0.050 level.		

### **Testing Spradley and Jantz's (2011) Equations**

The discriminant functions developed by Spradley and Jantz (2011) for American White and American Black individuals were tested using the data collected on the Native American and Thai collections (Tables 5.14 and 5.15). Spradley and Jantz's (2011) classification equations have a cut-off point of 0, females are indicated by negative values and males are indicated by positive values. The majority of the elements performed with lower accuracies when applied to the Native American and modern Thai individuals. A total of 40 fell below 80% accuracy. The results of the Thai individuals will be presented first, followed by the Native Americans. Interestingly, the American White equations for the sacrum and the calcaneus did not work for either group; the sacrum equation produced extremely high positive values and the calcaneus produced all negative values for both the Thai and Native American females and males.

However, Spradley and Jantz's (2011) equations for the os coxa were omitted from the present analysis due to differences in the way in which the pubis and ischium are now measured. Spradley and Jantz (2011) utilized Moore-Jansen et al.'s (1994) definition of pubis and ischium lengths, which involve measuring from where the three regions of the os coxa meet in the acetabulum (estimated) to the end of the pubic symphysis or ischial

tuberosity. Due to the difficulties in estimating the fusion point in the acetabulum, which results in significant intra- and inter-observer error (Adams and Byrd 2002), Langley et al. (2016) omitted these two measurements. Instead, the authors define a minimum pubis length (symphysis to the closest point on acetabular ring), maximum pubis length (symphysis to the farthest point on acetabular ring), ischial length (point on the acetabular rim where the iliac blade meets the acetabulum to the most medial point on the epiphysis of the ischial tuberosity), and minimum ischial length (medial point on the epiphysis of the ischial tuberosity to the closest point on acetabular ring), which are not included in Spradley and Jantz's (2011) equations.

<b>Table 5.14. Spradley and Jantz's (2011) American Black equation performance accuracies in the Native American and Thai individuals.</b>			
<b>Spradley and Jantz (2011) Equations</b>	<b>Spradley and Jantz (2011) Accuracy (%)</b>	<b>Native American Accuracy (%)</b>	<b>Thai Accuracy (%)</b>
Humerus	Female: 94.12	100.0	93.75
	Male: 93.55	58.0	90.0
Clavicle	Female: 93.94	100.0	100.0
	Male: 92.86	12.50	57.0
Scapula	Female: 91.67	100.0	100.0
	Male: 92.06	43.0	48.0
Femur	Female: 90.91	100.0	98.0
	Male: 92.31	56.0	86.0
Cranium	Female: 90.70	9.0	64.6
	Male: 90.57	100.0	97.8
Ulna	Female: 92.86	13.0	100.0
	Male: 88.24	100.0	15.0
Os Coxa	Female: 90.00	--	--
	Male: 90.57	--	--
Tibia	Female: 89.29	100.0	90.0
	Male: 87.93	82.0	98.0
Calcaneus	Female: 88.89	96.5	96.0
	Male: 87.76	46.0	36.0

Radius	Female: 83.87	100.0	100.0
	Male: 87.50	4.0	26.0
Fibula	Female: 88.46	100.0	100.0
	Male: 82.76	0.0	4.0
Mandible	Female: 75.5	54.0	30.0
	Male: 81.03	89.0	100.0
Sacrum	Female: 77.27	33.0	50.0
	Male: 66.67	85.0	82.0

<b>Table 5.15. Spradley and Jantz's (2011) American White equation performance accuracies in the Native American and Thai individuals.</b>			
<b>Spradley and Jantz (2011) Equations</b>	<b>Spradley and Jantz (2011) Accuracy (%)</b>	<b>Native American Accuracy (%)</b>	<b>Thai Accuracy (%)</b>
Radius	Female: 96.43	100.0	100.0
	Male: 92.24	12.5	68.0
Clavicle	Female: 97.20	100.0	100.0
	Male: 90.00	35.0	68.0
Femur	Female: 95.87	100.0	100.0
	Male: 91.21	45.0	60.0
Humerus	Female: 95.20	94.0	92.0
	Male: 90.91	73.0	82.0
Scapula	Female: 95.20	100.0	100.0
	Male: 90.87	44.0	44.0
Ulna	Female: 91.75	100.0	100.0
	Male: 93.88	26.0	45.0
Tibia	Female: 91.40	100.0	100.0
	Male: 91.89	50.0	82.0
Cranium	Female: 88.49	56.0	87.5
	Male: 91.53	93.75	83.0
Os Coxa	Female: 90.70	--	--
	Male: 87.92	--	--
Calcaneus	Female: 81.93	--	--
	Male: 83.52	--	--
Fibula	Female: 81.05	100.0	100.0
	Male: 81.50	23.0	32.0
Mandible	Female: 85.92	84.0	70.0
	Male: 75.68	79.0	90.0
Sacrum	Female: 73.81	--	--
	Male: 69.94	--	--

### Population-specific Linear Regression Equations

Population-specific equations were created via a factor analysis and linear regression (Tables 5.16 and 5.17). The threshold for differentiating between males and females was 0.50, therefore if the equation has a value greater than 0.50 the individual is estimated to be a male and vice versa for the females.

<b>Table 5.16. Population-specific linear regression equations for sex estimation in modern Thai individuals.</b>		
<b>Element</b>	<b>Equations (coefficients, measurements, and constants)</b>	<b>Accuracy (%)</b>
Cranium	$= (-0.030*\text{Nasion-Occipital}) + (0.076*\text{Maximum Cranial Length}) + (0.057*\text{Upper Facial Height}) + (0.011*\text{Basion Bregman}) + (-0.027*\text{Cranial Base Length}) + (-0.070*\text{Biorbital Breadth}) + (0.001*\text{Frontal Chord}) + (0.005*\text{Bizygomatic Breadth}) + (-0.034*\text{Interorbital Breadth}) + (-0.008*\text{Bimaxillary}) + (-0.002*\text{Partial Chord}) + (-0.013*\text{Maximum Alveolar Breadth}) + (0.007*\text{Minimum Frontal Breadth}) + (-0.005*\text{Biauricular Breadth}) + (0.062*\text{Nasion Prosthion}) + (-0.003*\text{Biasterionic}) + (-7.975)$	T: 91.3
		M: 88.2
		F: 94.4
Mandible	$= (0.037*\text{Mandibular Angle}) + (0.012*\text{Mandibular Length}) + (0.050*\text{Maximum Ramus Height}) + (0.017*\text{Minimum Ramus Breadth}) + (-8.542)$	T: 82.0
		M: 74.0
		F: 90.0
Clavicle	$= (0.072*\text{Maximum Diameter}) + (0.047*\text{Minimum Diameter}) + (0.025*\text{Length}) + (-4.270)$	T: 88.9
		M: 83.7
		F: 94.0
Scapula*	$= (0.011*\text{Scapula Height}) + (0.004*\text{Scapula Breadth}) + (0.29*\text{Glenoid Cavity Breadth}) + (0.064*\text{Glenoid Cavity Height}) + (-4.476)$	T:96.0
		M: 97.9
		F: 94.0

<b>Table 5.16. Population-specific linear regression equations for sex estimation in modern Thai individuals.</b>		
Humerus	= (0.037*Epicondylar Breadth) + (0.058*Maximum Vertical Head Diameter) + (0.017*Maximum Diameter at Midshaft) + (-4.439)	T: 94.0
		M: 98.0
		F: 90.0
Radius	= (0.134*Minimum Midshaft Diameter)+(0.112*Maximum Head Diameter)+(0.005*Maximum Length)+(-4.419)	T: 91.0
		M: 90.0
		F: 92.0
Ulna	= (-0.009*Maximum Length) + (0.102*Maximum Diameter at Midshaft) + (0.145*Minimum Diameter at Midshaft) + (0.019*Psychological Length) + (-4.471)	T: 92.9
		M: 91.8
		F: 94.0
Sacrum	= (0.003*Anterior Height of Sacrum) + (0.005*Transverse Diameter of S1) + (0.073*Anterior-Posterior Diameter of S1) + (-2.319)	T: 71.1
		M: 74.4
		F: 67.7
Os Coxa	= (0.014*Maximum Innominate Height) + (0.036*Ischial Length) + (0.052*Minimum Iliac Breadth) + (0.006*Minimum Ischial Length) + (-0.033*Maximum Iliac Breadth) + (-4.131)	Tl: 91.8
		M: 91.8
		F: 91.8
Femur	= (0.059*Epicondylar Breadth) + (0.004*Maximum Anterior-Posterior Length of Medial Condyle) + (0.008*Circumference at Midshaft) + (-4.962)	T: 92.0
		M: 88.0
		F: 95.9
Tibia	= (0.010*Circumference at Midshaft) + (0.032*Distal Epiphyseal Breadth) + (0.048*Maximum Proximal Epiphyseal Breadth) + (-5.397)	T: 89.9
		M: 89.8
		F: 90.0
Fibula	= (0.014*Maximum Length) + (0.003*Maximum Midshaft Diameter) + (-4.330)	T: 77.0
		M: 76.0
		F: 78.0

<b>Table 5.16. Population-specific linear regression equations for sex estimation in modern Thai individuals.</b>		
Calcaneus	= (0.028*Maximum Length) + (0.062*Middle Breadth) + (-4.072)	T: 80.0
		M: 80.0
		F: 80.0
*Elements with the highest correct classification rates; scapula, humerus and ulna.		

<b>Table 5.17. Population-specific linear regression equations for sex estimation in SW Native American individuals. Put thresholds here if the same for all elements.</b>		
<b>Element</b>	<b>Equations (coefficients, measurements, and constants)</b>	<b>Accuracy (%)</b>
Cranium*	= (0.019*Biauricular Breadth) + (0.020*Bimaxillary Breadth) + (-0.007*Maximum Cranial Breadth) + (0.009*Bizygomatic Breadth) + (0.023*Basion-Bregma Height) + (10.088*Nasal Height) + (-0.006 Frontal Chord) + (0.037*Foramen Magnum Breadth) + (0.063*Nasion-Prosthion Height) + (0.027*Mastoid Height) + (0.003*Upper Facial Breadth) + (-8.548)	T: 97.8
		M: 100
		F: 95.5
Mandible	= (0.028*Bicondylar Breadth) + (0.010*Bigonial Breadth) + (0.025*Maximum Ramus Height) + (-4.697)	T: 83.3
		M: 83.8
		F: 82.8
Clavicle	= (0.088*Maximum Diameter) + (0.052*Minimum Diameter) + (0.026*Maximum Length) + (-4.556)	T: 88.8
		M: 84.4
		F: 93.1
Scapula	= (0.030*Height of Scapula) + (0.011*Breadth of Scapula) + (-4.877)	T: 84.2
		M: 87.0
		F: 81.3
Humerus	= (0.003*Maximum Length of the Humerus) + (0.029*Epicondylar Breadth of Humerus) + (0.071*Maximum Vertical Diameter of Head of Humerus) + (-5.068)	T: 95.1
		M: 96.7

<b>Table 5.17. Population-specific linear regression equations for sex estimation in SW Native American individuals. Put thresholds here if the same for all elements.</b>		
		F: 93.5
Radius	= (0.020*Maximum Length) + (0.73*Maximum Diameter of Radial Head) + (-5.592)	T: 83.9
		M: 84.4
		F: 83.3
Ulna	= (-0.028*Maximum Length of Ulna) + (0.050*Physiological Length) + (0.080*Olecranon Breadth) + (-5.651)	T: 87.3
		M: 85.7
		F: 88.9
Sacrum	= (-0.015*Transverse Diameter of S1) + (0.116*Anterior-Posterior Diameter of S1) + (0.009*Anterior Height of Sacrum) + (-3.363)	T: 78.1
		M: 73.7
		F: 82.4
Os Coxa	= (0.022*Ischial Length) + (0.021*Maximum Innominate Height) + (-0.031*Maximum Iliac Breadth) + (-0.014*Minimum Ischial Length) + (0.056*Minimum Iliac Breadth) + (-3.613)	T: 83.1
		M: 76.2
		F: 90.0
Femur	= (0.130*Maximum Diameter of Femur Head) + (0.030*Epicondylar Breadth of Femur) + (-0.016*Maximum Antero-Posterior Length of Medial Condyle) + (-0.025*Maximum Antero-posterior Length of Lateral Condyle) + (-4.696)	T: 95.2
		M: 96.0
		F: 92.3
Tibia	= (0.009*Circumference at Midshaft) + (0.015*Maximum Midshaft Diameter) + (0.083*Distal Epiphysis Breadth) + (-4.683)	T: 86.2
		F: 85.7
		M: 86.7
Fibula	= (0.012*Maximum Length) + (0.093*Maximum Midshaft Diameter) + (-4.902)	T: 84.5

<b>Table 5.17. Population-specific linear regression equations for sex estimation in SW Native American individuals. Put thresholds here if the same for all elements.</b>		
		M: 85.5
		F: 80.8
Calcaneus	= (0.039*Maximum Length) + (0.036*Middle Breadth) + (-3.805)	T: 82.5
		M: 85.7
		F: 79.2
*Elements with the highest correct classification rates cranium, femur, and humerus.		

### **Intraobserver Error Rate**

Intraobserver error rates were calculated using 10% (n=20) of the original sample size (Table 5.18). A bivariate analysis was used to calculate the rates. For a bivariate analysis, the error rate ideally equals 1.0, meaning the measurements are a complete match. Therefore, values ranging from 0.700 to 1.0 are considered to have a high level of correlation. Values that are less than 0.699 are considered to have a low level of correlation. The present study had two measurements, the ischial length and maximum diameter of the radius at midshaft, with low levels of correlation.

<b>Table 5.18. Intraclass correlation coefficients.</b>	
Measurement	ICC
Maximum cranial length	0.997
Nasio-occipital length	0.997
Maximum cranial breadth	0.994
Bizygomatic breadth	0.997
Basion-bregma height	0.986
Cranial base length	0.971
Basion-prosthion length	0.957
Maxio-alveolar breadth	0.997
Maxillo-alveolar length	0.885
Bauricular breadth	0.921

<b>Table 5.18. Intraclass correlation coefficients.</b>	
Nasion-prosthion height	0.987
Minimum frontal breadth	0.984
Upper facial breadth	0.962
Nasal height	0.937
Nasal breadth	0.766
Orbital breadth	0.971
Orbital height	0.939
Biorbital breadth	0.923
Interorbital breadth	0.989
Frontal chord	0.958
Parietal chord	0.970
Occipital chord	0.921
Foramen magnum length	0.972
Foramen magnum breadth	0.908
Mastoid height	0.764
Mastoid length	0.816
Biasterionic breadth	0.991
Bimaxillary breadth	0.925
Zygoorbitale breadth	0.985
Chin height	0.969
Height of mandibular body	0.738
Breadth of mandibular body	0.992
Bigonial breadth	0.998
Bicondylar breadth	0.856
Minimum ramus breadth	0.972
Maximum ramus height	0.791
Mandibular length	0.962
Mandibular angle	0.997
Maximum length of the clavicle	0.967
Maximum diameter of the clavicle at midshaft	0.954
Minimum diameter of the clavicle at midshaft	0.988
Height of the scapula	0.993
Breadth of the scapula	0.951
Glenoid cavity breadth	0.891
Glenoid cavity height	1.0
Maximum length of the humerus	0.980
Epicondylar breadth of the humerus	0.983
Maximum vertical diameter of the head of the humerus	0.934
Maximum diameter of the humerus at midshaft	0.964
Minimum diameter of the humerus at midshaft	0.999
Maximum length of the radius	0.984

<b>Table 5.18. Intraclass correlation coefficients.</b>	
Maximum diameter of the radius at midshaft	0.619*
Minimum diameter of the radius at midshaft	0.949
Maximum diameter of the radial head	0.996
Maximum length of the ulna	0.962
Maximum midshaft diameter of the ulna	0.922
Minimum midshaft diameter of the ulna	0.987
Physiological length of the ulna	0.774
Minimum circumference of the ulna	0.935
Olecranon breadth	0.958
Anterior height of the sacrum	0.986
Anterior breadth of the sacrum	0.736
Transverse diameter of the sacral segment 1	0.984
Anterior-posterior diameter of sacral segment 1	0.999
Maximum innominate height	0.993
Maximum iliac breadth	0.982
Minimum iliac breadth	0.975
Maximum pubis length	0.993
Minimum pubis length	0.966
Ischial length	0.673*
Minimum ischial length	0.988
Maximum ischiopubis ramus length	0.931
Anterior superior iliac spine to symphysis	0.976
Maximum posterior superior iliac spine to symphysis	0.973
Minimum apical border to symphysis	1.0
Maximum length of the femur	0.999
Bicondylar length of the femur	0.997
Epicondylar breadth of the femur	0.993
Maximum diameter of the femur head	0.915
Transverse subtrochanteric diameter of the femur	0.918
Anterio-posterior subtrochanteric diameter of the femur	0.974
Maximum midshaft diameter of the femur	0.840
Minimum midshaft diameter of the femur	0.985
Circumference of the femur at midshaft	0.988
Maximum antero-posterior length of the lateral condyle	0.991
Maximum antero-posterior length of the medial condyle	1.0
Length of tibia	0.988
Maximum proximal epiphyseal breadth of the tibia	0.976
Distal epiphyseal breadth of the tibia	0.988
Maximum midshaft diameter of the tibia	0.988
Minimum midshaft diameter of the tibia	0.898
Circumference of the tibia at the midshaft	0.982

<b>Table 5.18. Intraclass correlation coefficients.</b>	
Maximum length of the fibula	0.997
Maximum diameter of the fibula at midshaft	0.956
Maximum length of the calcaneus	0.823
Middle breadth of the calcaneus	0.962
*Poor correlation	

## **Conclusion**

The results of the study indicate that there are significant population differences between the Native American and modern Thai individuals. Out of the 13 elements measured, five exhibited statistically significant differences. These results indicate that while Native Americans and Thai individuals share a common ancestry, the two groups are now morphologically different due to years of separation. Native Americans are generally more robust than their Thai counterparts.

Additionally, the equations developed by Spradley and Jantz (2011) on American White and American Black individuals performed with a significantly lower correct classification rates than for those developed specifically for SW Native American and Thai individuals. The correct classification rate for Native Americans ranged 0-100%, while the correct classification rate for the Thai population ranged 4-100%. For both Native American and Thai individuals, the equations had a higher success rate for females than for males.

Population-specific standards were created using the data collected on the modern Thai and archaeological SW Native American individuals. The new equations performed with an overall higher correct classification rate for the two populations. For Native

Americans, the best indicator was the cranium. On the other hand, the element which performed the best for Thai individuals was the scapula.

## CHAPTER VI: DISCUSSION

This chapter discusses the results presented in the previous chapter for metric sexual dimorphism between Native American and modern Thai populations. This chapter will address the results in regards to the two hypotheses presented in the first chapter: that due to separate population histories (Goebel *et al.* 2008; Hanihara 2006; Karafet *et al.* 1999; Pietrusewsky 2006; Turner 1971), the metric dimensions of both cranial and postcranial elements will be significantly different between modern Thai and Native American individuals. Secondly, Spradley and Jantz's (2011) discriminant function equations derived from European Americans and African Americans will produce inaccurate sex estimations when applied to Native American and modern Thai individuals. Additionally, the accuracy of both the American White and American Black discriminant functions developed by Spradley and Jantz (2011) on the Native American and Thai data will be discussed. Lastly, the discriminant functions developed on the Native American and Thai individuals will be discussed.

A total of 96 measurements (37 cranial and 59 postcranial) were recorded on 202 individuals from two documented modern or historic skeletal collections in Thailand and New York City. Statistical analysis found: 1) there are significant differences between SW Native American and modern Thai individuals; 2) discriminant functions developed on non-Asian/Native American populations (Spradley and Jantz 2011) performed poorly when classifying the two samples; and 3) population-specific discriminant functions developed on the SW Native American and Thai samples correctly classified more individuals than those provided by Spradley and Jantz (2011).

## **Population Differences**

The first hypothesis stated that due to different population histories, the metric measurements of both cranial and postcranial elements will differ between the Thai and Native American individuals. This hypothesis was supported by the results of several of the t-tests presented in Chapter V (see Tables 5.1 – 5.13). The study found differences in both sex and ancestry in the cranium, mandible and postcranial elements. In regards to the Native American and Thai females, nine out of 13 elements exhibited statistically different dimensions between the two groups. Overall, Thai females were smaller than their Native American counterparts. However, for the radius, ulna, and calcaneus the measurements for the two populations were of similar size. It is not surprising that the two populations were relatively equal for the radius, sacrum, and calcaneus because these elements had no measurements statistically different when compared. Additionally, there were only two measurements that were significant on the ulna, so this could help explain why there two populations were relatively equal in size.

For the Native American and Thai males, 10 out of 13 elements showed statistically different dimensions between the two groups. Unlike the females, the Native American males were smaller on average compared to the Thai males. Interestingly, the sacrum, tibia, and fibula were relatively equal in size. The fibula had no measurements statistically significant differences between the two male groups which could explain why their sizes are roughly equivalent. On the other hand, the tibia exhibited four

measurements (66.7%) statistically different measurements between the two populations, which makes it more surprisingly that the two are relatively equal in the mean values for the measurements.

Previous research has shown that population differences exist in sexual dimorphism within Asian. İşcan *et al.* (1998) explored metric variability of the humerus in Chinese, Japanese and Thai individuals. They noted significant differences in six humeral measurements (maximum length, vertical head diameter, minimum midshaft diameter, midshaft circumference, and epicondylar breadth) between the three populations and within population differences between sexes. The results of the current study also found that epicondylar breadth and vertical head diameter are significantly different between the sexes and ancestral groups. However, İşcan *et al.* (1998) also found the maximum midshaft diameter to be indicative of within population sexual dimorphism rather than the minimum midshaft diameter. Moreover, cross-validation tests between the Chinese, Japanese and Thai individuals confirmed that formulae established for one population are less discriminating when applied to another (İşcan *et al.* 1998). While the Chinese individuals were the largest, they were the least sexually dimorphic, in comparison to Thai who are generally the smallest but the most sexually dimorphic (İşcan *et al.* 1998; King *et al.* 1998). Similarly, when comparing modern the Thai to the Native American sample, the Thai individuals were generally smaller than their Native American counterparts.

Similar to İşcan *et al.* (1998), King *et al.* (1998) explored sexual dimorphism in the femur of Thai individuals and compared Thai measurements to those derived from

North American, African and East Asian samples. King *et al.* (1998) found only the maximum head diameter and bicondylar breadth were useful in sex estimation, reaching a correct classification rate of 94.2%. The current study found vastly different results regarding the measurements that are useful in sex estimation for the Thai sample. The discriminant function developed on the femur includes the epicondylar breadth, maximum anterior-posterior length of the medial condyle and the circumference at midshaft, which are significant predictors of sex for Thai individuals. However, the current study's femur equation resulted in an overall classification rate of 92.0%, which is slightly lower than King *et al.*'s (1998) classification rate. In comparison to North Americans and South Americans, discriminant functions developed on these populations identified most Thai individuals as females; only 27% of Thai males were correctly classified using the South African White equations (King *et al.* 1998). Similarly, the American Black and American White equations developed by Spradley and Jantz (2011) identified most Thai individuals as female. The results of both King *et al.* (1998) and the current study indicate that Thai individuals are more gracile than North and South American populations.

Walker (2008) found that within the same-sex comparison, African Americans and European Americans are more robust than their English counterparts. Traits that were significantly different between the populations were the mental eminence, mastoid processes, and the expression of glabella. For the mental eminence, African American males and females have greater mental eminence development than the English, African American females have larger mastoid processes, and European American females and

males have more prominent glabellae development (Walker 2008). Similar to the current study, Walker (2008) found that Native American populations are vastly different from the other modern populations. Some Native American groups are more robust than the English, African and European Americans, but they also show less sexual dimorphism between the sexes (Walker 2008). The increased robusticity is clearest in the supraorbital margin and the nuchal crest.

### **Testing Spradley and Jantz's (2011) Equations**

As predicted in the second hypothesis, the equations developed by Spradley and Jantz (2011) for American Black and White individuals performed with lower accuracies when applied to the Native American and Thai samples. The equations had accuracy rates ranging 0-100% for Native Americans and 4-100% for Thai samples, with 40 values falling under 80%. The majority of the equations misclassified Thai and Native American males as females, due to the smaller stature and less sexual dimorphism from differing environmental and genetic actors, and because males are more variable than females. However, the American White equations for the, cranium, and mandible and the American Black equations for the sacrum, and mandible misclassified more Thai females. Additionally, the American White equation for the and the American Black equation for the sacrum, and cranium misclassified more Native American females.

Tallman (2016) had similar results in regards to Asian populations being misclassified using standards derived on European-derived and African-derived populations. When applied to the Japanese and Thai samples, Garvin *et al.*'s (2014)

discriminant functions correct classification ranged 30.6-97.6% (Tallman 2016). The results of Garvin *et al.*'s (2014) discriminant equations largely favored females; similar to the results of Spradley and Jantz's (2011) discriminant functions when applied to Native American and Thai individuals in the current study. Similarly, Walker's (2008) cranial discriminant function equations performed poorly when applied to Japanese and Thai individuals. Correct classification rates ranged 31.6-97.4%, with a majority of the rates falling below the acceptable 80% for Thai and Japanese individuals, compared to classification rates ranging 62.2-90.1%, with a majority of them above 80% for Walker's (2008) American samples (Tallman 2016). Additionally, the standards for nonmetric traits on the pelvis performed similarly when applied to Japanese and Thai populations. In regards to the greater sciatic notch, the cutoff point for Thai populations is 4, while Walker's (2005) study found score of 2 indicated an indeterminate sex for non-Asian groups (Tallman 2016). Classification rates using the population specific standards ranged from 65.5% to 97.5% (Tallman 2016). The results of Tallman (2016) and the current study, demonstrate the need for population specific standards based on the poor classification rates when applying standards derived on non-Asian or non-Native American populations.

### **Population-Specific Equations**

The population-specific equations developed on the SW Native American and Thai individuals performed significantly better than those of Spradley and Jantz (2011) (Tables 5.16 and 5.17). Similar to Spradley and Jantz (2011) this study found that

differences in sex and ancestry exist in both the cranium and postcranial elements. The results of Spradley and Jantz (2011) determined that the cranium was the second-best indicator compared to postcranial elements. Interestingly, the results of the Native American equations found that the cranium had the highest correct classification rate. One possible reason for this outcome is the larger number of crania measured compared to postcranial elements, which may have produced sampling error. Due to the nature of the AMNH collection, not all elements were present for each individual. Following the cranium, the femur, humerus and clavicle performed the best for Native Americans. All equations developed on the Native Americans, minus the calcaneus and sacrum, performed above the accepted 80.0% correct classification rate. Similar to Spradley and Jantz (2011), postcranial elements performed with a higher accuracy for the modern Thai sample than crania. The best element for the Thai individuals was the scapula, followed by the humerus, ulna, and femur; the cranium was the sixth best indicator for the Thai individuals.

### **Intraobserver Error Rates**

The intraobserver error rates of the current study indicate a high correlation for the majority of the measurements, with only two measurements having lower correlation. Adams and Byrd (2002) tested the interobserver variation in 13 standard and nine non-standard measurements between 68 anthropologists with varying levels of experience. Their results demonstrated that the pubis length was the most problematic, followed by the subtrochanteric femur measurements; however, there was good agreement between participants on most other measurements (Adams and Byrd 2002). Therefore, their study

indicates that metric methods are reliable even with differing levels of experience. While the current study did not test for interobserver variation, the present study found similar results with intraobserver error. The majority of the measurements were in a high level of agreement, with only two measurements (maximum diameter of the radius and the ischial length) that performed less successfully. In the current study pubis length was not problematic; however, this can be attributed to the updated measurement guidelines that have been published since Adams and Byrd (2002) published their study (i.e., Langley et al. 2016).

However, Spradley and Jantz's (2011) equations for the os coxa were omitted from the present analysis due to differences in the way in which the pubis and ischium are now measured. Spradley and Jantz (2011) utilized Moore-Jansen et al.'s (1994) definition of pubis and ischium lengths, which involve measuring from where the three regions of the os coxa meet in the acetabulum (estimated) to the end of the pubic symphysis or ischial tuberosity. Langley et al. (2016) omitted these two measurements; instead, the authors define a minimum pubis length (symphysis to the closest point on acetabular ring), maximum pubis length (symphysis to the farthest point on acetabular ring), ischial length (point on the acetabular rim where the iliac blade meets the acetabulum to the most medial point on the epiphysis of the ischial tuberosity), and minimum ischial length (medial point on the epiphysis of the ischial tuberosity to the closest point on acetabular ring), which are not included in Spradley and Jantz's (2011) equations. Additionally, the subtrochanteric measurements were not problematic and were in fact highly correlated with values of 0.918 for the transverse subtrochanteric diameter of the femur and 0.974

for the antero-posterior subtrochanteric diameter of the femur. Therefore, the current study shows that the majority of measurement descriptions produced minimal intraobserver error rates, indicating that the descriptions by Langley et al. (2016) are sufficient.

## CHAPTER VII: CONCLUSION

The goals of this study were to determine if the SW Native American and modern Thai individuals were statistically different in cranial and postcranial dimensions, test the reliability of non-population-specific equations on the two groups, and create population-specific standards for modern Thai and SW Native American individuals. The current study provides much needed metric data on Asian and Native American individuals. Additionally, this study highlights the differences between Native Americans and modern Thai individuals, despite their shared ancestry. In addition, the current study also supports the need for population-specific standards, developed on modern and diverse skeletal samples.

While some correct classifications achieved 100% when Spradley and Jantz's (2011) American Black and White equations were applied to Native American and Thai equations, 22 Native American and 18 Thai applications exhibited correct classification below 80%; however, only six equations fell below 80% for Spradley and Jantz (2011). The majority of these equations misclassified Thai and Native American males as females. As previously stated, Native American and Thai individuals are more gracile than the American Black and American White individuals, since the majority of those misclassified were males. Therefore, the application of sex estimation methods developed on non-Asian populations results in reduced discriminatory power because the Native Americans and Thais are less sexually dimorphic than African and European American individuals. The differences in sexual dimorphism are due to differing environmental and genetic factors between African and European American populations

compared to the Native American and modern Thai individuals. In particular, nutritional intake is significantly different, and impacts the development of skeletal structures.

The results of the statistical analysis of 96 standard cranial and postcranial measurements indicate that Native American and Thai populations are morphometrically different and thus require separate population standards. The most marked differences between the two groups are seen with the cranium, mandible, clavicle, humerus, radius, and tibia. On top of indicating differences between the two populations, it was proven that standards derived from non-Asian or Native American populations perform with a lower accuracy. Moreover, the slightly reduced performance of the Thai equations in comparison to those of the Native Americans suggests that the Thai are less sexually dimorphic than the Native Americans. Similar to Tallman (2016), this study demonstrates that using Native Americans as a biological proxy for modern Asians is inaccurate.

In absence of modern Asian remains available for study, Native Americans have been used as proxies for Asian populations; however, the results of the current study indicate that this practice is inaccurate. The Native Americans and Thai differ in their expressions of sexual dimorphism, and the two groups are likewise dissimilar to non-Asian populations. Therefore, the population -specific equations presented here are better suited for bioarchaeological and forensic contexts.

### **Population Specific Standards and Daubert**

In recent years, there has emerged a need for more rigorous testing and statistical backing for scientific methods used in the medicolegal context. The criteria for the admissibility of scientific testimony is standardized by the court decision in *Daubert vs. Merrell Dow Pharmaceuticals (1993)*. After *Daubert*, in order for scientific expert testimony to be empirically test with known error, peer reviewed, and generally accepted in the scientific community (National Research Council 2009; U.S. Supreme Court 1993). Methods that are used to establish the biological profile are especially held to the *Daubert* standards.

The current study provides valuable information regarding the statistical methods used to estimate the sex of an unknown individual for Asian and Native American individuals. Additionally, the results of this study contribute to the effort in forensic anthropology to develop more quantifiable, precise, and statistically backed methods for creating the biological profile needed.

### **Future Research**

While this study provides information on metric methods for sex determination for Native American and modern Thai individuals, there much research remains that is not addressed in the current study. A larger sample size of both Native American and Thai individuals would help to validate the current results. Additionally, incorporating more Asian populations is necessary, because while Thailand is in Asia, Thai individuals likely cannot be used as proxies for all Asian populations. As mentioned in previous chapters, there are significant differences are present between Asian populations (İşcan *et*

*al.* 1998; Tallman 2016). Future research, should focus on create discriminant functions for the estimation of sex for more Asian populations.

## REFERENCES CITED

- Adams BJ, Byrd JE. 2002. Interobserver variation of selected postcranial skeletal measurements. *Journal of Forensic Science* 46(6): 1-10.
- Azevedo S, Bortolini MC, Bonatto SL, Hunemeir T, Santas FR. 2015. Brief communication: Ancient Remains and the first peopling of the Americas: Reassessing the Hoyo Negro Skull. *American Journal of Physical Anthropology* 158:514-521.
- Barnes J, Wescott DJ. 2007. Sex determination of Mississippian skeletal remains from humeral measurements. *The Missouri Archaeologist*.
- Broca P. 1875. Instructions cranilogiques et craniométriques de la Société d'Anthropologie de Paris. *Bulletin de la Societe Anthropologie* 16:534-536.
- Brace CL. 1995. Region does not mean "race"-reality versus convention in forensic anthropology. *Journal of Forensic Sciences* 4-:171-175.
- Buikstra JE, Ubelaker DH, editors. 1994. *Standards for the Data Collection from Human Skeletal Remains*. Fayetteville, AR: Arkansas Archaeological Research Series No. 44.
- Dabbs GR, Moore-Jansen PH. 2010. A method for estimating sex using metric analysis of the scapula. *Journal of Forensic Sciences* 55: 149-152.
- Demeter F. 2006. New perspectives on the peopling of Southeast and East Asia during the late upper Pleistocene. In: Oxenham M, Tayles N, editors. *Bioarchaeology of Southeast Asia*. New York: Cambridge University Press p. 112-132.
- DiGangi EA, Moore MK, editors. 2012 *Research Methods in Human Skeletal Biology*. Waltham, MA: Academic Press.
- Edgar HJH. 2009. Biohistorical approaches to "race" in the United States: Biological distances among African Americans, European Americans, and their ancestors. *American Journal of Physical Anthropology* 139:58-67.
- Field A. 2009. *Discovering Statistics Using SPSS, 3<sup>rd</sup> Edition*. Thousand Oaks, CA. Sage Publications Ltd.
- Freas LE. 2011. Patterns of craniometric variation in modern Thai population: application in forensic anthropology and implication for population history. Unpublished Ph. D dissertation for University of Florida.

- Garvin HM, Ruff CB. 2012. Sexual dimorphism in skeletal browridge and chin morphologies determined using a new quantitative method. *American Journal of Physical Anthropology* 147:661-670.
- Garvin HM, Sholts SB, Mosca LA. 2014. Sexual dimorphism in human cranial trait scores: Effects of population, age and body size. *American Journal of Physical Anthropology* 154:259-269.
- Giles E. 1964. Sex determination by discriminant function analysis of the mandible. *American Journal of Physical Anthropology* 22:129-135.
- Giles E. 1966. Statistical techniques for sex and race determination. Some comments in defense. *American Journal of Physical Anthropology* 25:85-86.
- Giles E, Elliot Orville. 1963. Sex determination by discriminant function analysis of crania. *American Journal of Physical Anthropology* 21:53-68.
- Goebel T, Waters MR, O'Rourke DH. 2008. The late Pleistocene dispersal of modern humans in the Americas. *Science*. 319: 1497-1502.
- González-José R, Dahinten SL, Luis MA, Hernández M, Pucciarelli HM. 2001. Craniometric variation and the settlement of the Americas: Testing hypotheses by means of r-matrix and matrix correlation analyses. *American Journal of Physical Anthropology* 116:154-165.
- González-José R, Neves W, Lahr MM, González S, Pucciarelli H, Martínez, Correal G. 2005. Late Pleistocene/Holocene craniofacial morphology in Mesoamerican Paleoindians: Implication for the peopling of the New World. *American Journal of Physical Anthropology* 128:772-780.
- González-José R, Bortolini MC, Santos FR, Bonatto SL. 2008. The peopling of America: Craniofacial shape variation on a continental scale and its interpretation from an interdisciplinary view. *American Journal of Physical Anthropology* 137:175-187.
- Greenberg JH, Turner CG, Zegura SL, Campbell L, Fox JA, Laughlin WS, Szathmary EJE, Weiss KM, Woolford E. 1986. The settlement of the Americas: A comparison of the linguistic, dental, and genetic evidence [and comments and reply]. *Current Anthropology* 27(5):477-497.
- Hanihara T. 2006. Interpretation of craniofacial variation and diversification of East and Southeast Asians. Oxenham M, Tayles N, editors. *Bioarchaeology of Southeast Asia*. Cambridge. Cambridge University Press. p 91-111.

- İşcan MY, Loth SR, King CA, Shihai D, Yoshino M. 1998. Sexual dimorphism in the humerus: A comparative analysis of Chinese, Japanese, and Thais. *Forensic Science International* 98:17-29.
- Jantz RL, Owsley DW. 2001. Variation among early North American crania. *American Journal of Physical Anthropology* 114:146-155.
- Jantz, R. and S. Ousley (2005) *FORDISC 3.1*. University of Tennessee Press, Knoxville, TN.
- Jantz, R. L. and S. D. Ousley (2013) Introduction to Fordisc 3. In *Forensic Anthropology: An Introduction* ed. by M. A. Tersigni-Tarrant and N. R. Shirley, pp. 253-269. CRC Press, Boca Raton, FL.
- Karafet TM, Zegura SL, Posukh O, Osipova L, Bergen A, Long J, Goldman D, Klitz W *et al* 1999. Ancestral Asian source(s) of New World Y-chromosome founder haplotypes. *American Journal of Human Genetics* 64:817-831.
- King CA, İşcan MY, Loth SR. 1998. Metric and comparative analysis of sexual dimorphism in the Thai femur. *Journal of Forensic Science* 43(5):954-958.
- Kimmerle EH, Ross A, Slice D. 2008. Sexual dimorphism in America: Geometric morphometric analysis of the craniofacial region. *Journal of Forensic Sciences* 53(1):54-57.
- Kitchen A, Miyamoto MM, Mulligan CJ. 2008. A three-stage colonization model for the peopling of the Americas. *PLoS ONE* 3(2):1-7.
- Klales AR, Ousley SD, Vollner JM. 2012. A revised method of sexing the human innominate using Phenice's nonmetric traits and statistical methods. *American Journal of Physical Anthropology* 149:104-114.
- Klales AR. 2016. Secular change in morphological pelvic traits used for sex estimation. *Journal of Forensic Sciences* 61(2):295-301.
- Lahr MM. 1995. Modern human diversification: implications for Amerindian origins. *Yearbook of Physical Anthropology* 38:163-198.
- Langley NR, Jantz LM, Ousley SD, Jantz RL, Milner G. 2016. *Data Collection Procedures for Forensic Skeletal Material 2.0*. Knoxville: University of Tennessee Forensic Anthropology Series.
- Lewis CJ, Garvin HM. 2016. Reliability of the Walker cranial nonmetric method and implications for sex estimation. *Journal of Forensic Sciences* 61(3): 743-751.

- Lovell NC. 1989. Test of Phenice's technique for determining sex from the Os Pubis. *American Journal of Physical Anthropology* 79:117-120.
- Mahakkanukrauh P, Sinthubua A, Prasitwattanaseree S, Ruengdit S, Singsowan P, Praneatpolgrang S, Duangto S. 2015. Craniometric study for sex determination in a Thai population. *Anatomy and Cell Biology* 48:275-283.
- Mall G, Graw M, Gehring KD, Hubig M. 2000. Determination of sex from femora. *Forensic Science International* 113:315-321.
- Mann RW. 2013. Our bones: the need for diverse human skeletal collections. *Anthropology* 1:e103.
- Matsumura H, Hudson M. 2005. Dental perspectives on the population history of Southeast Asia. *American Journal of Physical Anthropology* 127:182-209.
- Matsumura H. 2006. The population history of southeast Asia viewed from morphometric analyses of human skeletal and dental remains. In: Oxenham M, Tayles N, editors. *Bioarchaeology of Southeast Asia*. Cambridge: Cambridge University Press. p. 33-59.
- Matsumura H, Oxenham MF. 2014. Demographic transitions and migration in prehistoric East/Southeast Asia through the lens of nonmetric dental traits. *American Journal of Physical Anthropology* 155:45-65.
- Mazières S. 2011. Towards a reconciling model about the initial peopling of America. *Comptes Rendus Biologies*. 334:497-504.
- Pearson K. 1915. On the problem of sexing osteometric material. *Biometrika* 10:479-487.
- Perez SI, Bernal V, Gonzalez PN, Sardi M, Politis GG. 2009. Discrepancy between cranial and DNA data of early Americans: Implications for American peopling. *PLoS ONE* 4(5):e5746.
- Phenice TW. 1969. A newly developed visual method of sexing the Os Pubis. *American Journal of Physical Anthropology* 30:297-302.
- Pietrusewsky M. 2006. A multivariate craniometric study of the prehistoric and modern inhabitants of Southeast Asia, East Asia and surrounding regions: a human kaleidoscope: Oxenham M., Tayles N., editors. 2006. *Bioarchaeology of Southeast Asia*. Cambridge: Cambridge University Press. p 59-90.
- Powell JF, Neves WA. 1999. Craniofacial morphology of the first Americans: pattern and

- process in the peopling of the new world. *Yearbook of Physical Anthropology* 42:153-188.
- Powell JF. 1993. Dental evidence for the peopling of the New World: Some methodological considerations. *Human Biology* 65(2):799-819.
- Ramsthaler F, Kreutz K, Verhoff MA. 2007. Accuracy of metric sex analysis of skeletal remains using Fordisc based on a recent skull collection. *International Journal of Legal Medicine* 12:477-482.
- Rogers NL, Flournoy FE, McCormick WF. 2000. The rhomboid fossa of the clavicle as a sex and age estimator. *Journal of Forensic Sciences* 45(1):61-67.
- Rogers TL. 1999. A visual method of determining the sex of skeletal remains using the distal humerus. *Journal of Forensic Sciences* 44(1):57-60.
- Rogers TL. 2005. Determining the sex of human remains through cranial morphology. *Journal of Forensic Science* 50(3):1-8.
- Scott GR, Schmitz K, Heim KN, Paul KS, Schomberg R, Pilloud MA. 2016. Sinodonty, sundadonty, and the Beringian standstill model: Issues of timing and migrations into the New World. *Quaternary International* xxx:1-14.
- Shi H, Dong Y, Wen B, Xiao C, Underhill PA, Shen P, Chakraborty R, Jin L, Su B. 2005. Y-chromosome evidence of southern origin of the east Asian-specific haplogroup O3-M122. *American Journal of Human Genetics* 77:408-419.
- Spradley MK, Jantz RL. 2011. Sex estimation in forensic anthropology: skull versus postcranial elements. *Journal of Forensic Sciences* 56(2): 289-296.
- Spradley MK, Jantz RL, Robinson A, Peccerelli F. 2008. Demographic change and forensic identification: Problems in metric identification of Hispanic skeletons. *Journal of Forensic Science* 53(1): 21-28.
- Steele DG, Powell JF. 1992. Peopling of the Americas: Paleobiological evidence. *Human Biology* 64(3):303-336.
- Su B *et al.* 1999. Y-chromosome evidence for a northward migration of modern humans into eastern Asia during the last ice age. *American Journal of Human Genetics* 65:1718-1724.
- Sutherland LD, Suchey JM. 1987. Use of the ventral arc in sex determination of the os pubis [Abstract] Proc Am Acad Forensic Sci. Colorado Springs, CO: American Academy of Forensic Sciences.

- Tallman SD. 2016. The evaluation and refinement of nonmetric sex and ancestry assessment methods in modern Japanese and Thai individuals. Unpublished dissertation, University of Tennessee, Knoxville, TN.
- Techataweewan N, Tuamsuk P, Toomsan Y, Woraputtaporn W, Prachaney P, Tayles N. 2017. A large modern Southeast Asian human skeletal collection from Thailand. *Forensic Science International* 278:406.e1-406.e6.
- Turner CG. 1971. Three-rooted mandibular first permanent molars and the question of American Indian origins. *American Journal of Physical Anthropology* 34:229-242.
- Turner CG. 1990. Major features of sundadonty and sinodonty, including suggestions about east Asian microevolution, population history, and late Pleistocene relationships with Australian aboriginals. *American Journal of Physical Anthropology* 82:295-317.
- Vance VL, Steyn M, L'Abbé EN. 2011. Nonmetric sex determination from the distal and posterior humerus in black and white South Africans. *Journal of Forensic Sciences* 56(3):710-714.
- Walker PL. 2005. Greater sciatic notch morphology: Sex, age, and population differences. *American Journal of Physical Anthropology* 127:385-391.
- Walker PL. 2008. Sexing skulls using discriminant function analysis of visually assessed traits. *American Journal of Physical Anthropology* 135:39-50.
- Wangkumhang P, Shaw PJ, Chaichoempu K, Ngamphiq C, Assawamakin A, Nuinon M, Sripichai O, Svasti S, Fucharoen S, Praphanphoj V, Tongsimma S. 2013. Insight into the peopling of mainland southeast Asia from Thai population genetic structure. *PLOS One* 8:1-12.
- White TD, Black MT, Folkens PA. 2012. *Human Osteology, Third Edition*. Burlington: Academic Press.
- Wrobel GD, Danforth ME, Armstrong C. 2002. Estimating sex of Maya skeletons by discriminant function analysis of long-bone measurements from the protohistoric Maya site of Tipu, Belize. *Ancient Mesoamerica* 13:255-263.

**CURRICULUM VITAE**

