

THE BRACHIAL AND CRURAL INDICES OF MODERN NORTH AMERICAN  
POPULATIONS

by

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## **DEDICATION**

I would like to dedicate this thesis to my parents, Ricky and Rosie Garcia, for their continuous encouragement and support of my education, as well as to my best friend, Amanda Martinez, for her constant support in everything I do.

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## **ABSTRACT**

Intralimb proportions have been shown to negatively correlate with climate in Old World populations, resulting in significant difference in the intralimb proportions of Europeans and Native Africans (Ruff and Walker 1993; Ruff 1994; Holliday 1997a, 1997b, 1999). However, the intralimb proportions of recently relocated and/or admixed populations have not been thoroughly researched. Therefore, this research will assess the intralimb proportions of recent admixed populations of North America, specifically American Whites and Blacks. The goals of this study are to determine if there are significant differences between American Whites and Blacks, as there are between Europeans and Native Africans, and to determine if the intralimb proportions of American Whites and Blacks are still similar to those of their respective ancestral heritage. A modern sample of male individuals, American Whites and Blacks, from the Forensic Anthropology Data Bank and the Texas State Donated Skeletal Collection are used. As well as recent Europeans and West Africans for proxy-ancestry groups. Limb lengths and the intralimb indices (brachial and crural indices) are used for the statistical analyses, which include an analysis of variance, Games-Howell test, correlation analysis, regression analysis with a coefficient of determination, and discriminant function analysis. The results indicate that the limb lengths and intralimb indices for American Whites and Blacks are significantly different from each other. However, American Whites and Blacks are not completely similar to their proxy-ancestry groups. They appear to be shifting towards an intermediate position between Europeans and native

Africans. These findings indicate that American Whites and Blacks are significantly different from each other, like Europeans and Native Africans. However, there appears to be factors affecting the intralimb proportions of American Whites and Blacks causing them to shift away from the intralimb proportions of their ancestral heritage. Further research needs to be conducted to determine what factors can be causing this shift.

# CHAPTER I

## INTRODUCTION

Human variation studies have examined topics such as body proportions and the relationship between limb segments, or limb proportions, in order to answer questions concerning climate adaptation, migration, and even the models of modern human origins (Holliday 1997a; Holliday 1999; Holliday and Ruff 2001; Auerbach 2012). The study of variation in general human body form and its link to environmental variables is a critical component of biological anthropology due to its ability to be directly reconstructed from skeletal remains such as those found in the fossil record. Interpretation of skeletal remains allow for the consideration of potential climatic influences, which can factor into modern human morphological variability (Ruff 1994). The aim of this research is to examine the proportions of modern North American populations and the factors that may have had an effect on them.

Bergmann (1847) and Allen (1877) provided some of the first scientific attempts to explain the variation seen in body morphology in terms of climatic adaptation (Ruff 1994). Their observations on climatic adaptation later became referred to as ecogeographic rules. Bergmann's rule (1847) predicts that homeothermic animals in hot environments will have linear body shapes, while those in cold environments will have less linear body shapes, as well as greater body mass. Allen's rule (1877) applied Bergmann's principles to body limbs and other appendages and predicts that

homeothermic animals in hot environments will have longer, narrower appendages, while those in cold environments should have shorter, bulkier appendages. These two ecogeographic rules revolve around the shape of an object and its relationship to heat production and loss. Heat production is a function of the total volume of a homeothermic animal, while heat loss is a function of the total surface area. The ratio of surface area to volume predicts the heat loss ratio (Holliday 1997a; Auerbach and Sylvester 2011). A lower surface area/volume ratio and thus a lower heat loss ratio indicate better heat retention. On the other hand, a higher surface area/volume ratio and thus a higher heat loss ratio indicate quicker heat loss. Linear body shapes tend to have higher surface area/volume ratios and thus lose heat more quickly compared to less linear body shapes. Therefore, linear body shapes are at an advantage in hot climates, while less linear body shapes are at an advantage in cold climates (Holliday 1997a; Auerbach and Sylvester 2011).

The majority of the research concerning the application of Bergmann's rule and Allen's rule to the ecogeographic variation in human body proportions have focused on modern human origins (Heirnaux and Froment 1976; Ruff 1991, 1994, 2002; Holliday and Trinkaus 1991; Holliday and Falsetti 1995; Holliday 1997a, 1997b, 1999, 2002; Katzmarzyk and Leonard 1998; Pearson 2000; Holliday and Ruff 2001; Weinstein 2005; Auerbach 2007, 2012; Temple et al. 2008; Temple and Matsumura 2011). There has been little exploration into the display of these ecogeographic rules in recently relocated and/or admixed populations, such as those seen in North America (Ruff and Walker 1993; Ruff 1994; Meadows and Jantz 1995; Jantz and Jantz 1999). Therefore, the purpose of this study is testing the application of these ecogeographic rules in the recent admixed

populations of North America, specifically American Whites and Blacks. This thesis research will investigate limb lengths and the brachial and crural indices of American Whites and Blacks, to assess if these populations still reflect the climate of their ancestral heritage or if they have adapted to the relatively temperate North American climate. It will help answer questions regarding significant variation between the indices of different population groups, including American Whites and American Blacks and which elements can potentially be used for ancestry estimation.

Studies into the morphological adaptations of the human body, such as those done by Bergmann (1847) and Allen (1877), use a variety of measurements related to body and limb proportions such as stature, the cormic index (the ratio of sitting height to standing height), body mass, relative sitting height, and relative limb length. Relative limb length variation has been shown to correlate with ambient temperature, resulting in relatively shorter extremities in colder climate populations and longer extremities in warmer climate populations (Ruff and Walker 1993). However, it is difficult to precisely estimate limb length relative to body size in skeletal remains. This difficulty is due to the two main types of methods used to estimate body size or stature in skeletal remains. First, the “anatomical” method, such as the Fully Technique, involves measuring and adding together the lengths or heights of a series of contiguous skeletal elements, from the skull to the foot (Raxter et al. 2006). This is a potential problem due to the necessity of multiple skeletal elements, which may or may not have been found with the skeletal remains. Second, the “mathematical” method uses regression ratios based on the correlation of individual skeletal elements to living stature (Raxter et al. 2006). The most accurate regression methods come from long bone regressions and thus present a logical

fallacy known as circular reasoning (Konigsberg et al. 1998). In other words, the limb bone lengths would be used to estimate the body size or stature with which they were then to be compared.

Therefore, another approach that can be used is the estimation of intralimb length proportions (Ruff and Walker 1993). These intralimb proportions are more commonly known as the brachial and crural indices, which are reflective of the relative lengths of the upper limb and lower limb, respectively (Ruff and Walker 1993; Holliday 1999).

The brachial index is the maximum radius length multiplied by a hundred and then divided by the maximum humerus length ( $RML*100/HML$ ), while the crural index is the maximum tibia length multiplied by a hundred and then divided by the femur bicondylar length ( $TML*100/FBL$ ) (Krogman 1939; Auerbach 2007; Auerbach and Sylvester 2011). While these indices can be potentially influenced by factors including thermoregulation, nutrition, locomotion, and ancestry (Auerbach and Sylvester 2011). However, the majority of the studies that have been conducted to assess these potential influential factors implicate climatic factors as one of the primary influences (Ruff 1994; Holliday 1997a, 1997b, 1999; Temple et al. 2008; Auerbach and Sylvester 2011). These indices provide an alternative method that can easily be measured in skeletal samples. They have a similar developmental basis and geographic variability as seen in limb length to body size indices, such that populations in hot climates have higher indices and longer upper limbs, while those in cold climates have lower indices and shorter upper limbs. The elongation of the distal relative to the proximal limb segments have similar thermoregulatory consequences as the relative elongation of the total limb, meaning that

both elongations result in a higher surface area/volume ratio and thus quicker heat dissipation (Ruff 1993, 1994; Ruff and Walker 1993).

A particular study implicating climatic influences used the brachial and crural indices to assess the idea of cold climate adaptation in European Neanderthals (Holliday 1997b). It had long been considered that the low indices of European Neanderthals were reflective of a cold adaptation. Using the brachial and crural indices of European Neanderthals, Koniag Eskimos, and recent Europeans, North Africans, sub-Saharan Africans, Holliday (1997b) found a significant negative correlation between both indices and latitude. This negative correlation indicated that increases in latitude, and thus generally increasingly colder climates, were associated with decreases in the brachial and crural indices.

In a later study, Holliday (1999) investigated questions regarding the brachial and crural indices of Late Pleistocene hominids from Europe and recent humans from Europe, North Africa, and sub-Saharan Africa. Specifically, he questioned which limb segments were primarily responsible for the variation seen in the two indices, if the indices reflected an elongated limb, and if the Late Upper Paleolithic (LUP) and Mesolithic Europeans retained relatively and/or absolutely long limbs. Holliday found that the radius was not more variable than the humerus, but the tibia was significantly more variable than the femur. He also found a weak positive correlation of 0.13 and 0.20 between the brachial and crural indices and their respective limb lengths. Thus, indicating only a slight tendency of the indices to increase with an increase in overall limb lengths. Lastly, he found that although the LUP and Mesolithic samples had high brachial and crural indices, they did not possess absolutely long limbs. These two studies conducted by

Holliday (1997b, 1999) demonstrate that brachial and crural indices reflect a thermoregulatory adaptation in accordance with Allen's rule.

Allen's rule predicts a thermoregulatory adaptation involving the maximization of the surface area to volume ratio in accordance with Bergmann's rule. According to Ruff and Walker (1993), modern human populations residing in warmer, tropical climates display relatively longer limbs, which are the result of the lengthening of the distal elements of the limb. These lengthened limbs maximize heat loss by increasing surface area relative to volume. The relatively longer limbs express themselves as high brachial and crural indices for warmer, tropical populations, increasing heat dissipation, which is more advantageous for hot, tropical climates (Ruff and Walker 1993; Ruff 1994; Holliday 1999). In addition, shortening of the distal segments relative to the proximal segments may help retain heat in cold environments thus resulting in lower indices.

While the majority of the research studying the brachial and crural indices looked at Old World populations, some research has been done on indigenous New World populations. As part of her dissertation, King (2007) assessed Holliday's (1997b) latitude correlation observation on precontact indigenous populations of North America and found a weak correlation between both indices and latitude. She proposed that the 25 precontact indigenous populations of North America used in her study differed from the recent groups of the Old World Holliday (1997b) used in his study because not enough time had elapsed to attain the same degree of correlation between the indices and latitude as seen in the Old World populations. This suggestion that climatic selection on limb proportions takes place over a long period of time is supported by evidence of weaker ecogeographic correlation for indigenous Native Americans, such as those examined by



King (2007), as well as other studies by Newman (1953) and Hulse (1960). In 2012, Benjamin Auerbach used the brachial and crural indices along with stature, body mass, and body breadth of five of the most complete North American Early Holocene male skeletons to examine the patterns of human morphology for this earliest observable time period. His results indicated that the Early Holocene males he examined had variable postcranial morphologies, but they all had wide bodies, represented by bi-iliac breadth. This wide body trait is associated to cold adaptation. Auerbach (2012) found that people from the Americas exhibited wider bodies than other global populations, which suggests that the common ancestral population of the indigenous American groups did not morphologically vary in this trait. On the other hand, the North American males sampled in Auerbach's study exhibited as great a range of intralimb indices as found throughout the Old World. This finding implies that bi-iliac breadth did not respond to evolutionary forces concurrently with intralimb proportions in the Americas. Thus, it can be concluded that bi-iliac breadth may actually better reflect long-term evolutionary effects due to thermoregulation than intralimb proportions.

Although Auerbach's (2012) study suggested that intralimb indices may not reflect long-term evolutionary effects as well as bi-iliac breadth, studies conducted over the ontogeny of limb proportions have suggested a genetic contribution to intralimb morphological patterns. Temple et al. (2011) reported on the developmental patterning of the brachial and crural indices of the Late/Final Jomon period people from Hokkaido, Japan. Among the Jomon adults, the brachial indices are high and similar to a warm climate adaptation, while the crural indices are intermediate and similar to mediate/average climates. Temple et al. (2011) concluded that brachial and crural indices

maintained the ecogeographic relationships throughout development and appear as early as fetal development, suggesting genetic conservation. Using subadult anthropometric data from Eveleth and Tanner's (1976) skeletal data from six different samples, Eleazer et al. (2010) suggested that the variation seen in the brachial and crural indices conformed to what were expected based on adult limb proportions. Using the same data from Eveleth and Tanner's (1976) skeletal data alongside limb proportion measurements from eight different skeletal samples, Cowgill et al. (2012) concluded that the brachial and crural indices displayed similar correlations with latitude as seen in adults and that these indices remained constant over the course of growth.

Although studies, such as those conducted by Temple et al. (2011), Eleazer et al. (2010), and Cowgill et al. (2012), indicate that the thermoregulatory adaptation predicted by Allen's rule is genetically determined, the heritability of extremity length is unknown. In fact, Serrat et al. (2008) reproduced similar phenotypes, shorter or longer extremities, in laboratory mammals, specifically mice, by modifying their ambient rearing temperature. Traditionally, these temperature-growth effects in skeletal extremities can be explained by vasomotor changes or changes in the blood flow, thus resulting in an altered supply of essential nutrients and growth factors. Serrat et al. (2008) addressed this central vascularity hypothesis by housing outbred mice in three different ambient temperatures, cold, control-intermediate, and warm from weaning through maturity (3.5-12 weeks age). They confirmed that the mice raised in the warm temperature had significantly longer ears, limbs, and tails than their counterparts in the cold temperature. However, their results do not fully support the traditional vascularity hypothesis; rather they showed that vasomotor changes indirectly modulated extremity growth through the

effects on appendage temperature as opposed to disruptions in vascular nutrient delivery. More specifically, vasomotor changes modulated extremity growth by inducing physiological responses in peripheral tissue temperature. This can then have a direct effect on cell proliferation and matrix production in cartilage and thus affect extremity size. These results indicate that Allen's rule may not actually reflect a functional genetic adaptation in some homeotherms; instead, it may be partially or entirely dependent on environmental temperature. In other words, Allen's rule may be a secondary growth response to environmental temperature.

While many studies have assessed Allen's rule in humans for populations in specific geographic regions with regards to modern human origins, the application of this rule has yet to be sufficiently analyzed for the recent admixed populations of North America, which are predominantly individuals of African, European, and/or indigenous descent (Parra 2007; Halder et al. 2009; Lao et al. 2010; Galanter et al. 2012; Guo et al. 2014; Bryc et al. 2015). It is important to examine Allen's Rule in recent North American populations simply for the sake of scientific knowledge, but as well as to gain a better understanding of these ecogeographic rules. The recent North American populations present an interesting mixture of cultures and ancestries. Unlike most locations, North America, especially the United States, contains many diverse groups with different cultural and genetic backgrounds.

Given the correlation found by Holliday (1997b) is due to thermoregulation adaptation, the suggestion that this adaptation requires considerable time (Newman 1953; Hulse 1960; Holliday and Falsetti 1995; King 2007), and the studies that demonstrate a genetic basis for this climatic adaptation (Eleazer et al. 2010; Temple et al. 2011; Cowgill

et al. 2012), the question remains whether the approximate 520 years of North American occupation was enough time has elapsed for American Whites and Blacks to adapt to the relatively temperate North American climate (National Oceanic and Atmosphere Administration) or do their brachial and crural indices still reflect the climate of their respective ancestral heritage, a warmer, tropical climate for West Africans and a colder climate for Western and Eastern Europeans.

The first question to be assessed with this research is whether American Whites and Blacks have retained similar intralimb proportions as their respective ancestral groups. An appropriate null hypothesis would be that there are no significant differences between American Whites and Blacks and their ancestral groups due to an insufficient amount of time for climate adaptation. If American Whites and Blacks reflect their ancestral intralimb proportions, then a second question to be assessed is if there are significant differences between the intralimb proportions of American Whites and Blacks. Therefore, a second hypothesis to be tested is that there are no significant differences between American White and American Blacks. If there are significant differences in the intralimb proportions of American Whites and Blacks, then another question to be assessed is if these intralimb indices can be used in ancestry estimation for American Whites and Blacks.

In order to test these hypotheses, recent skeletal data will be used representing American Whites and Blacks and European and West African groups. The European and West Africans will serve as proxy-ancestral groups. The proxy-ancestral populations were chosen for comparison based on the notion that American Whites are generally from Western and Eastern Europe, having arrived during the European colonization of

the Americas (Warren and Twine 1997; Campbell et al. 2005; Roediger 2006; Edgar 2009). The start of European colonization of the Americas was around 1492, when Columbus and his men arrived in what is now known as the U.S. territory (Paschou et al. 2008). Initially, colonization of this region during the 16th and 17th centuries was by the Dutch, English, French, Germans, Irish, Italians, Portuguese, Scots, Spanish, and Swedes (Paschou et al. 2008). The following 19th and early 20th century was characterized by “newcomers originating from the northwestern to the southeastern corners of Europe” (Paschou et al. 2008). Price et al. (2008) show that American Whites have major components corresponding to northwest Europeans, southeast Europeans, as well as Ashkenazi Jewish ancestry.

On the other hand, the majority of American Blacks come from West Africa based on historical, linguistic, and genetic data of the African Diaspora (Sudarkasa 1988; Smitherman 1991; Thomas 1999; Eltis and Richardson 1997; Parra et al. 2001, 2004; Salas et al. 2004; Salas et al. 2005; Reed and Tishkoff 2006; Diegoli et al. 2009; Bryc et al. 2010; Stefflova et al. 2011). Yaeger et al. (2008), used the admixture frequencies of their African American sample, revealing that ancestry was approximately 83% West African, 15% European, and 2% Native American. Therefore the self-identification as African American agreed well with inferred West African ancestry. Their findings suggest that self-reported race and ancestry of American Blacks can predict ancestral clusters, however they do not reveal the extent of admixture (Yaeger et al. 2008). Other recent studies have used mtDNA haplotypes and autosomal microsatellite markers and corroborated that West Africa are the likely roots of most African Americans (Salas et al. 2005; Tishkoff et al. 2009). These type of genetic studies are in agreement with historical

evidence, which attribute major contributions from Western Africa to both North and Central America with an estimation of approximately 8 million people transported to the New World (Fage 1969; Thomas 1999). On the other hand, approximately 4 million people were transported from west-central Africa and 1 million from southeast Africa (Fage 1969; Salas et al. 2004; Reed and Tishkoff 2006). Various studies have shown ranges of 55% to 83% of West African ancestry within African Americans (Salas et al. 2004; Salas et al. 2005; Yaeger et al. 2008; Stefflova et al. 2011).

It has also been noted by Ely et al. (2006) that few African Americans may be able to actually trace their mtDNA lineages to a specific region of Africa, let alone a single ethnic group. They compared general African American and specific Gullah/Geechee HVS-I haplotypes with two databases of these haplotypes from sub-Saharan Africa. They found that more than half were matched common haplotypes that were shared among multiple African ethnic groups, while 40% did not match any sequence in the database, and less than 10% were an exact match to only one specific African ethnic group (Ely et al. 2006). Their results indicated that African American haplotypes were more likely to match haplotypes from ethnic groups located in West or West Central African over those found in eastern or southern Africa.

A limitation to the use of West Africans as a proxy-ancestral population is the knowledge that migration has occurred within Africa over the last 400 years and thus the mtDNA and Y-chromosome lineages found in present-day populations do not necessarily reflect those present at the time of the African Diaspora (Shriver and Kittles 2004; Reed and Tishkoff 2006). However, due to the historic and genetic evidence that West Africa had major contributions to the United States during the African Diaspora, as well as the

evidence that North Africa, East Africa, Southern Africa, and even South-Eastern Africa do not show a significant mtDNA contribution to African Americans of the U.S. (Salas et al. 2005), it is reasonable to conclude that West Africans can be a reliable proxy-ancestral population for American Blacks.

This study contributes to the field of anthropology by aiding in the actual investigation of the brachial and crural indices of American Whites and Blacks, which is a topic that has not been thoroughly researched. The investigation into the indices of these populations can add to the understanding of admixed populations and the appearance of Bergmann's (1847) and Allen's (1877) ecogeographic rules. Further research into limb proportions can be used to evaluate locomotor energetics and the assessment of allometric constraints and/or functional morphology (Holliday and Ruff 2001). Studies have demonstrated an empirical, clinal pattern in intralimb proportions among modern humans and other hominids (Holliday 1997a; Auerbach 2007; Holliday 1999; Temple et al. 2008; Auerbach and Sylvester 2011). This research will aid in the assessment of this pattern in admixed populations like those in recent North America. Additionally, if there are significant differences between the brachial and crural indices of the recent individuals in North America, this may provide information that can be used to estimate ancestry in medicolegal death investigations.

## **CHAPTER II**

### **MATERIALS AND METHODS**

#### Materials

##### Samples

The samples for this study are from the Texas State Donated Skeletal Collection (TSDSC) and the Forensic Anthropology Data Bank (FDB). All samples are adult male individuals with known ancestry. The samples from the TSDSC and FDB are either self-reported social race categories provided by the individuals or their next of kin (Table 1). Comparison data include previously collected data of recent European and West African males provided by Dr. Trenton Holliday (Table 2).

Recent Europeans were chosen as a proxy-ancestry group for American Whites due to the assertion that American Whites have ancestral ties to Western and Eastern Europe (Warren and Twine 1997). West African data were chosen as a proxy-ancestry group for American Blacks due to the historical, linguistic, and genetic data linking the majority of American Blacks to a West African parental population due to the African Diaspora (Sudarkasa 1988; Smitherman 1991; Thomas 1999; Eltis and Richardson 1997; Parra et al. 2001, 2004; Salas et al. 2004, 2005; Reed and Tishkoff 2006; Yaeger et al. 2008; Diegoli et al. 2009; Bryc et al. 2010; Stefflova et al. 2011).



**Table 1: Sample sizes for American Whites and Blacks**

	<u>American Whites</u>	<u>American Blacks</u>
TSDSC:	16	0
FDB:	643	208
<b>Total:</b>	659	208

**Table 2: Sample sizes for Recent Europeans and West Africans broken down by measurement provided**

	<u>Europeans</u>	<u>West Africans</u>
Brachial Index:	239	16
Crural Index:	273	16

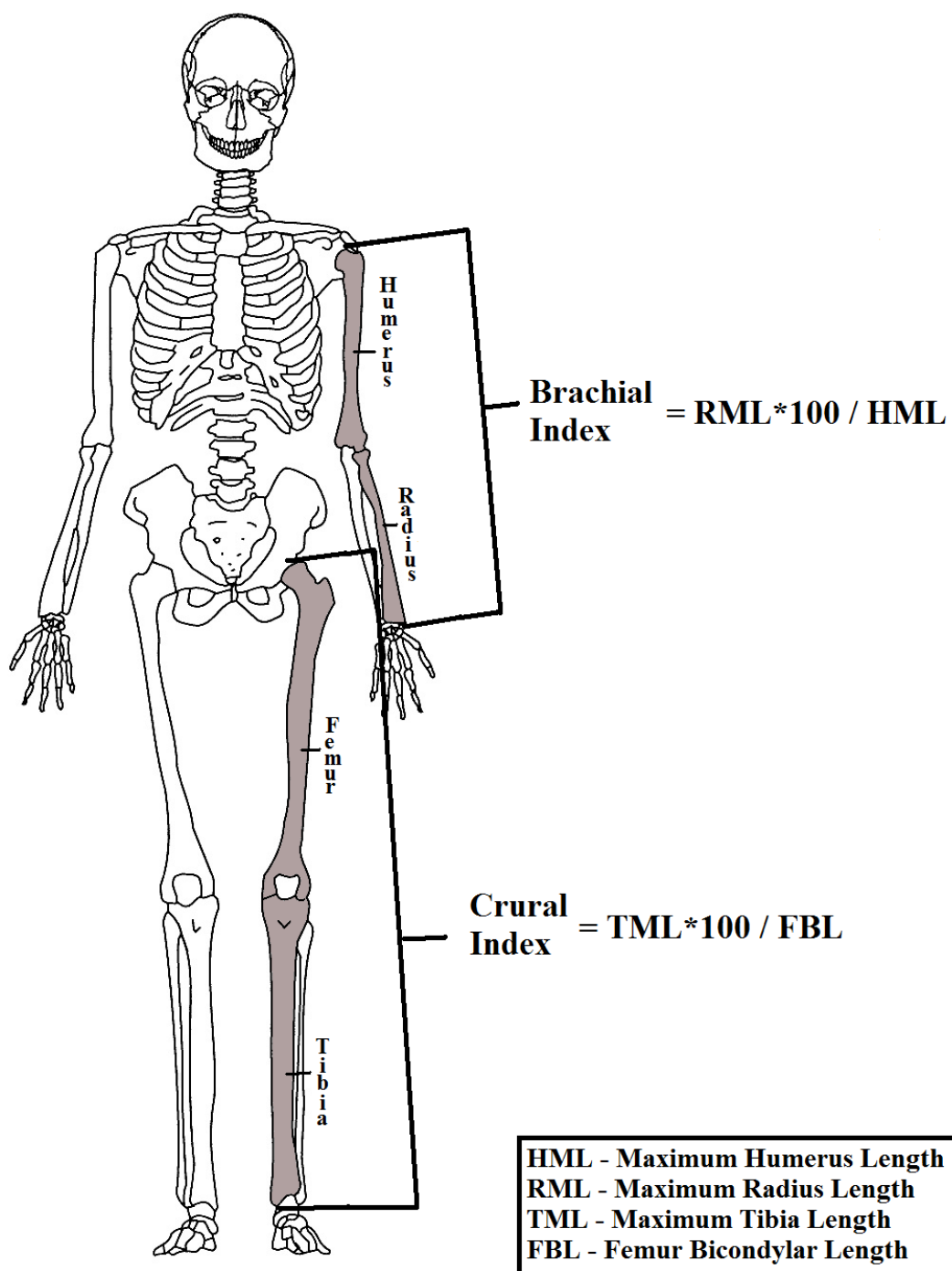
## Methods

### Data Collection

The measurements used for this study include the maximum lengths of the radius, humerus, and tibia and the bicondylar length of the femur as defined by Moore-Jansen et al. (1994) (Table 3). Measurements from the left side of the skeleton were utilized, unless unavailable, then the right side was substituted. The samples from the TSDSC were measured by the author using an osteometric board. The sample from the FDB consists of previously collected data submitted by forensic anthropology practitioners around the country, but mostly come from University of Tennessee, Knoxville. These long bone lengths were then used to calculate limb lengths (humerus + radius and femur + tibia) and the brachial ( $RML \times 100 / HML$ ) and crural indices ( $TML \times 100 / FBL$ ) (Figure 1).

**Table 3: Postcranial measurement definitions (Moore-Jansen et al. 1994)**

<b>Measurement</b>	<b>Definition</b>
Humerus Maximum Length (HML)	Direct distance from the most superior point on the head of the humerus to the most inferior point on the trochlea. Humerus shaft should be positioned parallel to the long axis of the osteometric board.
Radius Maximum Length (RML)	Distance from the most proximally positioned point on the head of radius to the tip of the styloid process without regard for the long axis of the bone.
Femur Bicondylar Length (FBL)	Distance from the most superior point on the head to a plane drawn along the inferior surfaces of the distal condyles.
Tibia Maximum Length (TML)	Distance from the superior articular surface of the lateral condyle to the tip of the medial malleolus.



**Figure 1: Brachial and Crural Indices reflected on the skeleton adapted from Attachment 3a of Standards (Buikstra and Ubelaker 1994)**

## Statistical Analyses

The limb lengths of American Whites and Blacks were run through an ANOVA in Microsoft Excel® to test for significant variation between the limb lengths of these two groups. Then, the limb lengths and their respective indices were used in a correlation analysis run in Excel® to assess the relationship between limb lengths and their respective indices. It is used to understand if there is a positive or negative relationship between the limb lengths and their respective indices. In other words, as limbs get longer, do indices get higher or lower. Additionally, this analysis will help understand the strength of the relationship between the limb lengths and indices. A regression analysis along with an ANOVA and coefficient of determination were then performed to assess the percentage of the variance limb length is responsible for in the indices. Next, the brachial and crural indices of the American White and Black samples and the proxy-ancestral groups were run through an ANOVA in Excel® using the Real Statistics Resource Pack, which tests for significant variation between the groups. If a significant difference was detected in the ANOVA, a Games-Howell test was then performed to ascertain which of the pairwise comparisons was responsible for the difference. A Games-Howell test was chosen due to the unequal sample sizes between all population groups. These tests were done to ascertain any significant differences among the American White and Black, as well as between these North American groups and the proxy-ancestry groups. Additionally, the limb lengths and indices were each run through a separate discriminant function analysis to assess if limb lengths or indices correctly allocate group membership. Then both the limb lengths and indices together were run through a discriminant function analysis, to assess if use of both measurements increase overall group allocation results.

## CHAPTER III

### RESULTS

#### Limb Lengths, Brachial Indices, and Crural Indices

Limb lengths, brachial indices, and crural indices were calculated for each sample population. Summary statistics for each population are listed in Tables 4 and 5.

**Table 4: Summary statistics for American Whites and Blacks**

	<u>American Whites</u>		<u>American Blacks</u>	
	<u>N</u>	<u>Mean (SD)</u>	<u>N</u>	<u>Mean (SD)</u>
Upper Limb Length (mm)	659	588.0 (28.8)	208	606.5 (32.5)
Lower Limb Length (mm)	646	860.8 (52.4)	198	885.9 (51.9)
Brachial Index (mm)	659	75.7 (2.3)	208	78.4 (3.0)
Crural Index (mm)	646	83.4 (2.3)	198	84.5 (2.4)

**Table 5: Summary statistics for Recent Europeans and West Africans**

	<u>Europeans<sup>1</sup></u>		<u>West Africans<sup>1</sup></u>	
	<u>N</u>	<u>Mean (SD)</u>	<u>N</u>	<u>Mean (SD)</u>
Brachial Index (mm)	239	75.5 (2.4)	16	81.4 (2.3)
Crural Index (mm)	273	82.8 (2.5)	16	85.8 (2.5)

<sup>1</sup>Data provided by Dr. Trenton Holliday

### Limb Length ANOVA

The results of the analysis of variance show that there are significant differences between American Whites and American Blacks for both upper and lower limb lengths (Tables 6 and 7).

**Table 6: Upper Limb Length ANOVA results for American Whites and Blacks**

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	52430.267	1	52430.267	55.816	< .00001	3.852
Within Groups	813464.697	866	939.336			
Total	865894.963	867				

**Table 7: Lower Limb Length ANOVA results for American Whites and Blacks**

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	95114.869	1	95114.869	34.759	< .00001	3.853
Within Groups	2304061.808	842	2736.415			
Total	2399176.677	843				

### Correlation Analysis

The results of the correlation analyses show that limb lengths have a weak positive correlation with their respective index. However, lower limb length has a stronger correlation to the crural index with a 0.25 correlation coefficient,  $r$ , as opposed to the 0.07 correlation the upper limb length has to the brachial index.

### Regression Analysis and Coefficient of Determination

Performing a regression analysis and calculating a coefficient of determination,  $R^2$ , showed that upper limb length accounts for only 3.8% of the variance in brachial index. On the other hand, lower limb length accounts for 6.5% of the variance in crural index.

### Brachial and Crural Indices ANOVA

The results of the analysis of variance show that both the brachial and crural indices are significantly different for all sample groups (Tables 8 and 9).

**Table 8: Brachial index ANOVA results**

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1715.317	3	571.772	61.732	< .00001	2.613
Within Groups	10364.331	1119	9.262			
Total	12079.648	1122				

**Table 9: Crural index ANOVA results**

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	429.249	3	143.083	25.665	< .00001	2.613
Within Groups	6294.319	1129	5.575			
Total	6723.568	1132				

### Brachial and Crural Indices Games-Howell Test

The results of the Games-Howell test for the brachial indices show that all of the populations are significantly different from each other with the exception of American

Whites compared to recent Europeans (Table 10). The results of the Games-Howell test for crural indices show that all of the populations are significantly different from each other with the exception of American Blacks compared to West Africans (Table 11).

**Table 10: Brachial index Games-Howell results**

	American Whites	American Blacks	West Africans
American Whites	-		
American Blacks	<b>Sign.*</b>	-	
West Africans	<b>Sign.*</b>	<b>Sign.*</b>	-
Recent Europeans	Not Sign.	<b>Sign.*</b>	<b>Sign.*</b>
* = significant at $P < 0.05$			

**Table 11: Crural index Games-Howell results**

	American Whites	American Blacks	West Africans
American Whites	-		
American Blacks	<b>Sign,*</b>	-	
West Africans	<b>Sign.*</b>	Not Sign.	-
Recent Europeans	<b>Sign.*</b>	<b>Sign.*</b>	<b>Sign.*</b>
* = significant at $P < 0.05$			

### Discriminant Function Analysis

The results of the discriminant function analysis for the limb lengths of American Whites and American Blacks are seen in Table 12. The results of the discriminant function analysis for the indices of American Whites and American Blacks are seen in Table 13. Table 14 shows the results of the discriminant function analysis for the limb lengths and indices used together.



**Table 12: Limb Lengths DFA results**

	Classification Rate (%)
American Whites	65.9
American Blacks	68.2

**Table 13: Indices DFA results**

	Classification Rate (%)
American Whites	75.2
American Blacks	71.7

**Table 14: Limb Lengths and Indices DFA results**

	Classification Rate (%)
American Whites	78.0
American Blacks	73.7

## CHAPTER IV

### DISCUSSION

#### Limb Lengths

The significant differences seen in the results of the limb lengths ANOVA can be due to the primary factor of climate, implying that American Blacks reflect limb lengths of a warmer, tropical climate. This would be expected due to American Black's primarily African ancestry (Sudarkasa 1988; Smitherman 1991; Thomas 1999; Eltis and Richardson 1997; Parra et al. 2001, 2004; Salas et al. 2004, 2005; Reed and Tishkoff 2006; Diegoli et al. 2009; Bryc et al. 2010; Stefflova et al. 2011). Previous studies have shown that South African samples have greater adult tibial and femoral lengths compared to West Europeans due to faster growth during the pubertal growth spurt (Frelat and Mittereocker 2011). However, it is known that the pubertal growth spurt is influenced by environmental and nutritional factors, thus population differences in limb lengths are probably influenced by both genetic and environmental factors (Bogin 1999; Frelat and Mittereocker 2011). Regardless, it appears that limb lengths also show evidence of clinal patterning, which is consistent with previous studies (Holliday 1995, 1999).

#### Relationship between Limb Lengths and Indices

The results of the correlation analyses for limb lengths and their respective indices for American Whites and Blacks are consistent with Holliday (1999), who found a weak

significant correlation between the limb lengths and their respective indices of recent Europeans, North Africans, and sub-Saharan Africans. However, Holliday noted the significant correlation was not particularly high and thus brachial and crural indices only slightly correlate with overall limb lengths. This was contradictory to what Holliday expected based on the idea that both indices and the overall limb lengths tended to decrease the further away from the equator. Holliday (1999) explained that this low correlation could be due, in part, by the variability of both the proximal and distal limb segments.

The low correlation of brachial and crural indices and overall limb length for American Whites and American Blacks support Holliday's (1999) findings for recent Europeans, North Africans, and sub-Saharan Africans. The regression analysis shows that while the lower limb length accounts for a slightly higher percentage of the variance in crural index than upper limb length does for the variance in brachial index, overall limb length does not appear to account for a high percentage of the variance in the indices.

### Indices and Ancestry

The results of the ANOVA for all groups suggest that American Whites and American Blacks retain enough of their ancestral influences on the brachial and crural indices to be significantly different from each other, which is consistent with previous findings, despite moderate to high European admixture (Stegmann 2005). This is not surprising, given that King (2007) found only a weak correlation between both indices and latitude for precontact indigenous populations of North America. The correlation for brachial index and latitude was -0.455 and for crural index and latitude, -0.448.

Meanwhile, Holliday (1997b) found a significant negative correlation between the brachial and crural index and latitude for Old World populations, including Koniag “Eskimos”, recent Europeans, North Africans, and sub-Saharanans. Specifically, he found a -0.75 correlation between the brachial index and latitude and a -0.88 correlation between the crural index and latitude. King (2007) proposed that her findings differed from Holliday (1997b) because not enough time had elapsed for the precontact indigenous North American populations to attain the same degree of correlation seen in the Old World populations.

If King’s suggestion for inadequate time is correct, that means that approximately 13,500 years of occupation of North America by the indigenous population was not enough time to adapt to the North American climate to the same caliber as seen in the Old World. Other studies have also showed the reduced amount of ecogeographical variation in limb proportions among Native Americans, compared to those of the Old World, suggesting that climatic selection on limb proportions requires a long period of time (Newman 1953; Hulse 1960; Holliday and Falsetti 1995). This would suggest that a European occupation of approximately 520 years since Christopher Columbus discovered North America would not be an adequate amount of time to adapt to the new climate.

The difference in intralimb proportions seen between American Blacks and American Whites is consistent with previous studies (Ruff and Walker 1993; Holliday and Falsetti 1995, 1999). In fact, Schultz (1926) found significant differences in both the crural indices and leg length/trunk ratios of African American and European American fetuses. Given that these features appear to manifest early in fetal life, suggests a genetic encoding (Holliday and Falsetti 1995). Other studies have also suggested a strong genetic

component to the development of human body proportions (Martorell et al. 1988; Holliday and Falsetti 1995; Katzmarzyk and Leonard 1998; Bogin and Rios 2003; Ruff 1994, 2002; Auerbach and Sylvester 2011; Frelat and Mittereocker 2011). Evidence supporting this claim is seen in migrant and ontogenetic studies (Holliday and Falsetti 1995). For example, modern African populations have relatively long limbs compared to European populations despite having a generally poorer diet and health (Bogin and Rios 2003). Despite an increase in stature, African Americans reflect similar intralimb proportions as their West African proxy-ancestral group (Trotter and Gleser 1952, 1958; Martorell et al. 1988). Ontogenetic studies have shown that brachial and crural indices remain constant over the course of growth and display consistent correlation with latitude across ontogeny, with indices similar to adult limb proportions (Eleazer et al. 2010; Cowgill et al. 2012).

Studies have shown that despite genetic admixture with Europeans and living in a temperate environment, American Blacks have similar tropical proportions to the populations on the continent from which the majority of their ancestors derive (Holliday and Falsetti 1999; Bogin and Rios 2003). Though American Blacks have similar tropical proportions, they are not completely representative of native Africans; rather, they are intermediate in many respects between American Whites and native Africans (Ruff and Walker 1993; Ruff 1994). This intermediate position can be possibly due to genetic admixture, environmental effects, or other factors (Ruff and Walker 1993).

While American Whites and Blacks have retained enough of their ancestral influences to have significantly different intralimb proportions from each other, they both are not completely similar to their respective ancestral heritages. In fact, based on the

data for this study, the intralimb proportions of both appear to be shifting towards an intermediate position between recent Europeans and West Africans. The factors affecting this shift in intralimb proportions are unknown. However, factors associated with socioeconomic status, such as nutrition, have been shown to have an effect on human growth and development (Ruff 1994). Environmental forces such as nutrition and disease affect secular change in overall size (Jantz and Jantz 1999). However, the affect they have on the variation seen in human body proportions is debated. Some studies suggest that nutrition can play a role (Ruff 1994; Katzmarzyk and Leonard 1998; Bogin and Varela-Silva 2010), while other studies suggest that it cannot explain variation seen in proportions (Ruff 1993; Ruff and Walker 1993). Ruff (1994) suggests that nutritional level may actually be blunting observable clinal variation in relative limb length, which leads to the reduced geographic variation seen among modern humans. Other studies also suggest that the effect of Allen's rule may be partially hidden by the influence of environmental factors such as nutrition (Bogin and Rios 2003; Weinstein 2005; Frelat and Mitteroecker 2011).

The results of the ANOVA and Games-Howell test show that the brachial index of American Blacks and West Africans are significantly different, while the crural index is not, suggesting that American Blacks have retained the lower limb proportions of their ancestral heritage. This could potentially be explained by genetic admixture with Europeans, resulting in lower limb lengths and indices. However, the secular changes seen in stature result in the lower limb bones becoming proportionally longer as stature increases, while the upper limb bones maintain a constant proportion to stature (Meadows and Jantz 1995). It has also been shown that distal elements change more than proximal

elements, especially in the lower limb, thus resulting in higher crural indices (Jantz and Jantz 1999). Therefore, American Blacks have maintained tropical lower limb proportions similar to those of West Africans. On the other hand, the varying degree of European genetic admixture of American Blacks (20-80%) and the differences in socioeconomic status could have potentially influenced their brachial indices (Chakraborty et al. 1992; Parra et al. 1998; Parra et al. 2001; Salas et al. 2005; Reed and Tishkoff 2006; Lind et al. 2007; Campbell and Tishkoff 2008; Tishkoff et al. 2009). However, the results for West Africans in this study may not be completely representative of the entire West African population group due to the limited sample size of 16, used in this study.

American Whites and recent Europeans show a pattern opposite that of American Blacks and West Africans. The significant difference in the crural indices of these two sample populations can also potentially be explained by the secular trends in stature. The increases in stature coincided with the lower limb bones becoming proportionally longer (Meadows and Jantz 1995; Jantz and Jantz 1999). With the increases in lower limb bones, the distal element (tibia) also increased, resulting in higher crural indices. Therefore, American Whites show higher crural indices, with an average of 83.36mm, than recent Europeans, whose average is 82.76mm. At the same time, the upper limb bones were isometric with stature, maintaining a constant proportion to stature (Meadows and Jantz 1995; Jantz and Jantz 1999). This could potentially explain why American Whites and recent Europeans have similar brachial indices, with averages of 75.76mm and 75.53mm respectively.

### Ancestry Estimation

With the American Whites and Blacks population groups having been used in the discriminant function analysis, the limb lengths of American Whites and Blacks provide classification rates of 65.9 and 68.2% respectively, slightly better than random chance, 50%. This indicates that the limb lengths of American Whites and Blacks can be a potential aid for ancestry estimation, alongside other more reliable ancestry estimation methods. On the other hand, the brachial and crural indices of American Whites and Blacks provide classification rates (75.2% and 71.7%, respectively) slightly better than the limb lengths. The use of both the limb lengths and the indices for American Whites and Blacks resulted in higher classification rates of 78.0% and 73.7%, respectively. Therefore, the combined use of limb length and brachial and crural indices can provide another tool to add to ancestry estimation methods. While the measurements used to calculate limb lengths are the same as those used to calculate the intralimb indices, the weak correlation between the limb lengths and indices allow for the use of them together for ancestry estimation.

It should be noted that there are more accurate ancestry estimation methods to use before utilizing limb lengths and intralimb indices. However, adding limb lengths and intralimb indices in combination with other ancestry estimation methods would allow for higher classification rates. Additionally, if the limbs are all that is recovered, the limb lengths and intralimb indices can thus be used to estimate ancestry. Nonetheless, the overall group allocation results for limb lengths and intralimb indices potentially validate the utility of postcranial skeleton for ancestry estimation.



## CHAPTER V

### CONCLUSION

Long limbs do not specifically mean high brachial or crural indices. In fact, for this study, upper limb length only accounts for 3.9% of the variation seen in the brachial index, while lower limb length accounts for 6.5% of the variance seen in the crural index. American Whites and American Blacks retain enough ancestral influence that they are significantly different from each other, despite admixture. It does not seem the approximately 520 years since colonization of North America was enough time for American Whites and Blacks to fully adapt to the relatively temperate North American climate. However, both the intralimb indices of American Whites and Blacks have shifted away from their respective ancestral populations and seem to be moving towards an intermediate position between European and West African intralimb proportions. The factors affecting this change in intralimb proportions for American Whites and Blacks can potentially include, genetic admixture, as well as environmental factors such as nutrition or climate. American Whites have significantly different crural indices than recent Europeans, while American Blacks have maintained similar crural indices to West Africans, potentially due to the secular trends seen in stature and lower limb length. Alternatively, upper limb bones maintained consistent proportion with stature, potentially explaining American Whites retention of similar brachial indices to recent Europeans.

However, there are certain limitations to this study, specifically the lack of

climate data. Given the nature of the data used in this study, collecting climate data for the birthplace or place of origin of each individual was unrealistic. Therefore, an actual assessment of the climatic influences on the brachial and crural indices of American Whites and Blacks was not possible for this study. Another potential limitation to this study involves sample sizes. Only 16 individuals were used to represent the brachial and crural indices of West Africa, which could have potentially affected the results obtained. As well as the fact that only male individuals were used to look at the differences between limb lengths and intralimb indices for American Whites and Blacks in this study. Females should also be studied, though it has been shown that they respond differently to environmental changes compared to males (Stinson 1985; Jantz and Jantz 1999).

This research is the stepping-stone for future studies into the body proportions/limb proportions of American Whites and Blacks. Though basic in its nature, it provides a preliminary understanding of the relationship of the intralimb proportions of American Whites and Blacks and their ancestral heritages. While the intralimb proportions of American Whites and Blacks are significantly different from each other, they are both shifting away from the intralimb proportions of their ancestral populations and the factors affecting this shift in intralimb proportions still need to be studied. Further research needs to be conducted assessing more specifically the association of intralimb proportions and climate for the recent admixed populations of North America. As well as research involving Hispanics, a population ripe with admixture of varying degree of indigenous, European, and even African genetics. Due to the limited skeletal samples of both recent Hispanics and pre-Hispanic populations, this research could not be conducted in this specific study. This research can also lead to a new ancestry estimation method to

contribute to a forensic anthropologists' tool kit. Both the brachial and crural indices of American Whites and Blacks were significantly different from each other and produced decent group allocation results. Therefore, they can be used as a potential ancestry estimation method if only the limb bones are recovered. As well as in conjunction with more accurate ancestry estimation methods for full skeleton recoveries.

## LITERATURE CITED

Allen, J.A.

1877 The influence of physical conditions on the genesis of species. *Rad Rev* 1:108-140.

Auerbach, Benjamin M.

2007 Human Skeletal Variation in the New World during the Holocene: Effects and Subsistence across Geography and Time. Ph.D. dissertation, Department of Anthropology, Johns Hopkins University.

2012 Skeletal Variation among Early Holocene North American Humans: Implications for Origins and Diversity in the Americas. *American Journal of Physical Anthropology* 149:525-536.

Auerbach, Benjamin M., and Adam D. Sylvester

2011 Allometry and Apparent Paradoxes in Human Limb Proportions: Implications for Scaling Factors. *American Journal of Physical Anthropology* 144:382-391.

Bergmann, Carl

1847 *Über die verhältnisse der warmökonomie der thiere zu ihrer grösse*. Göttingen Studien 1:595-708.

Bogin, Barry

1999 *Patterns of human growth*. Cambridge: Cambridge University Press.

Bogin, Barry, and Luis Rios

2003 Rapid morphological change in living humans: implications for modern human origins. *Comparative Biochemistry and Physiology Part A* 136:71-84.

Bogin, Barry, and Maria Inês Varela-Silva

2010 Leg Length, Body Proportion, and Health: A Review with a Note on Beauty. *International Journal of Environmental Research and Public Health* 7:1047-1075.

Bryc, Katarzyna, Adam Auton, Matthew R. Nelson, Jorge R. Oksenberg, Stephen L. Hauser, Scott Williams, Alain Froment, Jean-Marie Bodo, Charles Wambebe, Sarah A. Tishkoff, and Carlos D. Bustamante

2010 Genome-wide patterns of population structure and admixture in West Africans and African Americans. *PNAS* 107(2):786-791.

Bryc, Katarzyna, Eric Y. Durand, J. Michael Macpherson, David Reich, and Joanna L. Mountain

2015 The Genetic Ancestry of African Americans, Latinos, and European Americans across the United States. *The American Journal of Human Genetics* 96:37-53.

- Buikstra, Jane E., and Douglas H. Ubelaker  
1994 Standards for Data Collection from Human Skeletal Remains. Arkansas Archaeological Survey Research Series No. 44.
- Campbell, Catarina D., Elizabeth L. Ogburn, Kathryn L. Lunetta, Helen N. Lyon, Matthew L. Freedman, Leif C. Groop, David Altshuler, Kristin G. Ardlie, and Joel N. Hirschhorn  
2005 Demonstrating stratification in a European American population. *Nature Genetics* 37(8):868-872.
- Campbell, Michael C., and Sarah A. Tishkoff  
2008 African Genetic Diversity: Implications for Human Demographic History, Modern Human Origins, and Complex Disease Mapping. *Annu Rev Genomics Hum Genet* 9:403-433.
- Chakraborty, Ranajit, Mohammad I. Kamboh, M. Nwankwo, and Robert E. Ferrell  
1992 Caucasian Genes in American Blacks: New Data. *American Journal of Human Genetics* 50:145-155.
- Cowgill, Libby W., Courtney D. Eleazer, Benjamin M. Auerbach, Daniel H. Temple, and Kenji Okazaki  
2012 Developmental Variation in Ecogeographic Body Proportions. *American Journal of Physical Anthropology* 148:557-579.
- Diegoli, Toni M., Jodi A. Irwin, Rebecca S. Just, Jessica L. Saunier, Jennifer E. O'Callaghan, and Thomas J. Parsons  
2009 Mitochondrial control region sequences from an African American population sample. *Forensic Science International: Genetics* 4:e45-e52.
- Edgar, Heather J.H.  
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.
- Eleazer, Courtney D., Libby W. Cowgill, and Benjamin M. Auerbach  
2010 Variation in human body proportions during ontogeny. *American Journal of Physical Anthropology* 50:100-101.
- Eltis, David, and David Richardson  
1997 West Africa and the transatlantic slave trade: New evidence of long-run trends. *Slavery and Abolition: A Journal of Slave and Post-Slave Studies* 18(1):16-35.
- Ely, Bert, Jamie Lee Wilson, Fatimah Jackson, and Bruce A. Jackson  
2006 African-American mitochondrial DNAs often match mtDNAs found in multiple African ethnic groups. *BMC Biology* 4(34).

Eveleth, PB, and TM Tanner

1976 Worldwide variation in human growth. New York: Cambridge University Press.

Fage, J.D.

1969 Slavery and the Slave Trade in the Context of West African History. *The Journal of African History* 10(3):393-404.

Frelat, Mélanie A., and Philipp Mitteroecker

2011 Postnatal Ontogeny of Tibia and Femur Form in Two Human Populations: A Multivariate Morphometric Analysis. *American Journal of Human Biology* 23:796-804.

Galanter, Joshua Mark, Juan Carlos Fernandez-Lopez, Christopher R. Gignoux, Jill Barnholtz-Sloan, Ceres Fernandez-Rozadilla, Marc Via, Alfredo Hidalgo-Miranda, Alejandra V. Contreras, Laura Uribe Figueroa, Paola Raska, Gerardo Jimenez-Sanchez, Irma Silva Zolezzi, Maria Torres, Clara Ruiz Ponte, Yarimar Ruiz, Antonio Salas, Elizabeth Nguyen, Celeste Eng, Lisbeth Borjas, William Zabala, Guillermo Barreto, Fernando Rondon Gonzalez, Adriana Ibarra, Patricia Taboada, Liliana Porras, Fabian Moreno, Abigail Bigham, Gerardo Gutierrez, Tom Brutsaert, Fabiola Leon-Velarde, Lorna G. Moore, Enrique Vargas, Miguel Cruz, Jorge Escobedo, Jose Rodriguez-Santana, William Rodriguez-Cintron, Rocio Chapela, Jean G. Ford, Carlos Bustamante, Daniela Seminara, Mark Shriver, Elad Ziv, Esteban Gonzalez Burchard, Robert Haile, Esteban Parra, and Angel Carracedo

2012 Development of a Panel of Genome-Wide Ancestry Informative Markers to Study Admixture throughout the Americas. *PLOS Genetics* 8(3):1-16.

Guo, Guang, Yilan Fu, Hedwig Lee, Tianji Cai, Kathleen Mullan Harris, and Yi Li

2014 Genetic Bio-Ancestry and Social Construction of Racial Classification in Social Surveys in the Contemporary United States. *Demography* 51:141-172.

Halder, Indrani, Bao-Zhu Yang, Henry R. Kranzler, Murray B. Stein, Mark D. Shriver, and Joel Gelernter

2009 Measurement of Admixture Proportions and Description of Admixture Structure in Different US Populations. *Human Mutation* 30(9):1299-1309.

Heirnaux, Jean, and Alain Froment

1976 The Correlations between Anthropobiological and Climatic Variables in Sub-Saharan Africa: Revised Estimates. *Human Biology* 48(4):757-767.

Holliday, Trenton W.

1995 Body size and proportions in the Late Pleistocene Western Old World and the origins of modern humans. Ph.D. Dissertation, University of New Mexico.

1997a Body Proportions in Late Pleistocene Europe and Modern Human Origins. *Journal of Human Evolution* 32:423-447.

1997b Postcranial evidence of cold adaptation in European Neanderthals. *American Journal of Physical Anthropology* 104:245-258.

- 1999 Brachial and Crural Indices of European Late Upper Paleolithic and Mesolithic Humans. *Journal of Human Evolution* 36:549-566.
- 2002 Body Size and Postcranial Robusticity of European Upper Paleolithic hominins. *Journal of Human Evolution* 43:513-528.
- Holliday, Trenton W., and Anthony B. Falsetti
- 1995 Lower limb length of European early modern humans in relation to mobility and climate. *Journal of Human Evolution* 29:141-153.
- 1999 A New Method for Discriminating African-American from European-American Skeletons Using Postcranial Osteometrics Reflective of Body Shape. *Journal of Forensic Sciences* 44(5):926-930.
- Holliday, Trenton W., and Christopher B. Ruff
- 2001 Relative Variation in Human Proximal and Distal Limb Segment Lengths. *American Journal of Physical Anthropology* 116:26-33.
- Holliday, Trenton W., and Erik Trinkaus
- 1991 Limb/trunk Proportions in Neandertals and Early Anatomically Modern Humans. *American Journal of Physical Anthropology* 12:93-94.
- Hulse, Frederick S.
- 1960 Adaptation, Selection, and Plasticity in Ongoing Human Evolution. *Human Biology* 32(1):63-79.
- Jantz, Lee Meadows, and Richard L. Jantz
- 1999 Secular Change in Long Bone Length and Proportion in the United States, 1800-1970. *American Journal of Physical Anthropology* 110:57-67.
- Katzmarzyk, Peter T., and William R. Leonard
- 1998 Climatic Influences on Human Body Size and Proportions: Ecological Adaptations and Secular Trends. *American Journal of Physical Anthropology* 106:483-503.
- King, Kathryn A.
- 2007 Climatic Adaptation and Postcranial Metric Variation in Precontact North America. Ph.D. dissertation, Department of Anthropology, University of Tennessee, Knoxville.
- Konigsberg, Lyle W., Samantha M. Hens, Lee Meadows Jantz, and William L. Jungers
- 1998 Stature Estimation and Calibration: Bayesian and Maximum Likelihood Perspectives in Physical Anthropology. *Yearbook of Physical Anthropology* 41:65-92.
- Krogman, Wilton Marion
- 1939 A Guide to the Identification of Human Skeletal Material. *FBI Law Enforcement Bulletin* 8:3-31.

Lao, Oscar, Peter M. Vallone, Michael D. Coble, Toni M. Diegoli, Mannis van Oven, Kristiaan J. van der Gaag, Jeroen Pijpe, Peter de Knijff, and Manfred Kayser  
2010 Evaluating Self-declared Ancestry of U.S. Americans with Autosomal, Y-Chromosomal and Mitochondrial DNA. *Human Mutation* 31:E1875-E1893.

Lind, Joanne M., Holli B. Hutcheson-Dilks, Scott M. Williams, Jason H. Moore, Myron Essex, Eduardo Ruiz-Pesini, Douglas C. Wallace, Sarah A. Tishkoff, Stephen J. O'Brien, and Michael W. Smith  
2007 Elevated male European and female African contributions to the genomes of African American individuals. *Human Genetics* 120:713-722.

Martorell, R., R.M. Malina, R.O. Castillo, F.S. Mendoza, and I.G. Pawson  
1988 Body Proportions in Three Ethnic Groups: Children and Youths 2-17 Years in NHANES II and HHANES. *Human Biology* 60(2):205-222.

Meadows, Lee, and Richard L. Jantz  
1995 Allometric Secular Change in the Long Bones from the 1800s to the Present. *Journal of Forensic Sciences* 40(5):762-767.

Moore-Jansen, P.M., S.D. Ousley, and R.L. Jantz  
1994 Data Collection Procedures for Forensic Skeletal Material. Report of Investigations No. 48. Department of Anthropology, University of Tennessee, Knoxville.

National Oceanic and Atmospheric Administration  
N.d. National Climatic Data Center. Climate at a Glance. <http://gis.ncdc.noaa.gov/map/cag/#app=cdo>, accessed April 10, 2015.

Newman, Marshall T.  
1953 The Application of Ecological Rules to the Racial Anthropology of the Aboriginal New World. *American Anthropologist* 55(3):311-327.

Parra, Esteban J.  
2007 "Admixture in north America." *Pharmacogenomics in Admixture Populations* 28-46.

Parra, Esteban J., Amy Marcini, Joshua Akey, Jeremy Martinson, Mark A. Batzer, Richard Cooper, Terrence Forrester, David B. Allison, Ranjan Deka, Robert E. Ferrell, and Mark D. Shriver  
1998 Estimating African American Admixture Proportions by Use of Population-Specific Alleles. *American Journal of Human Genetics* 63:1839-1851.



Parra, EJ, RA Kittles, G Argyropoulos, CL Pfaff, K Hiester, C Bonilla, N Sylvester, D Parrish-Gause, WT Garvey, L Jin, PM McKeigue, MI Kamboh, RE Ferrell, WS Pollitzer, and MD Shriver

2001 Ancestral Proportions and Admixture Dynamics in Geographically Defined African Americans Living in South Carolina. *American Journal of Physical Anthropology* 114:18-29.

Parra, EJ, RA Kittles, and MD Shriver

2004 Implications of correlations between skin color and genetic ancestry for biomedical research. *Nature Genetics* 36:S55-S60.

Paschou, Peristera, Petros Drineas, Jamey Lewis, Caroline M. Nievergelt, Deborah A. Nickerson, Joshua D. Smith, Paul M. Ridker, Daniel I. Chasman, Ronald M. Krauss, and Elad Ziv

2008 Tracing Sub-Structure in the European American Population with PCA-Informative Markers. *PLoS Genetics* 4(7):1-13.

Pearson, Osbjorn M.

2000 Activity, Climate, and Postcranial Robusticity: Implications for Modern Human Origins and Scenarios of Adaptive Change. *Current Anthropology* 41(4):569-607.

Price, Alkes L., Johannah Butler, Nick Patterson, Cristian Capelli, Vincenzo L. Pascali, Francesca Scarnicci, Andres Ruiz-Linares, Leif Groop, Angelica A. Saetta, Penelope Korkolopoulou, Uri Seligsohn, Alicja Waliszewska, Christine Schirmer, Kristin Ardlie, Alexis Ramos, James Nemesh, Lori Arbeitman, David B. Goldstein, David Reich, and Joel N. Hirschhorn

2008 Discerning the Ancestry of European Americans in Genetic Association Studies. *PLoS Genetics* 4(1):9-17.

Raxter, Michelle H., Benjamin M. Auerbach, and Christopher B. Ruff

2006 Revision of the Fully Technique for Estimating Statures. *American Journal of Physical Anthropology* 130:374-384.

Reed, Floyd A., and Sarah A. Tishkoff

2006 African human diversity, origins and migrations. *Current Opinion in Genetics & Development* 16:597-605.

Roediger, David R.

2006 Working toward whiteness: How America's immigrants became white: The strange journey from Ellis Island to the suburbs. Basic Books.

Ruff, Christopher B.

1991 Climate and Body Shape in Hominid Evolution. *Journal of Human Evolution* 21:81-1055.

1993 Climatic Adaptation and Hominid Evolution: The Thermoregulatory Imperative. *Evolutionary Anthropology* 2(2):53-60.

- 1994 Morphological Adaptation to Climate in Modern and Fossil Hominids. *Yearbook of Physical Anthropology* 37:65-107.
- 2002 Variation in Human Body Size and Shape. *Annual Review of Anthropology* 31:211-232.
- Ruff, Christopher B., and Alan Walker  
 1993 Body Shape and Body Size. In Alan Walker and Richard Leakey (Eds.), *The Nariokotome Homo Erectus Skeleton* (1<sup>st</sup> ed., 234-265). Cambridge, Massachusetts: Harvard University Press.
- Salas, Antonio, Martin Richards, María-Victoria Lareu, Rosaria Scozzari, Alfredo Coppa, Antonio Torroni, Vincent Macaulay, and Ángel Carracedo  
 2004 The African Diaspora: Mitochondrial DNA and the Atlantic Slave Trade. *American Journal of Human Genetics* 74:454-465.
- Salas, Antonio, Ángel Carracedo, Martin Richards, and Vincent Macaulay  
 2005 Charting the Ancestry of African Americans. *American Journal of Human Genetics* 77:676-680.
- Schultz, Adolph H.  
 1926 Fetal Growth of Man and Other Primates. *The Quarterly Review of Biology* 1(4):465-521.
- Serrat, Maria A., Donna King, and C. Owen Lovejoy  
 2008 Temperature Regulates Limb Length in Homeotherms by Directly Modulating Cartilage Growth. *PNAS* 105(49):19348-19353.
- Shriver, Mark D., and Rick A. Kittles  
 2004 Genetic Ancestry and the Search for Personalized Genetic Histories. *Nature Reviews: Genetics* 5:611-618.
- Smitherman, Geneva  
 1991 "What is Africa to Me?" Language, Ideology, and African American. *American Speech* 66(2):115-132.
- Stegmann, Jr., A. Theodore  
 2005 Climate, Racial Category, and Body Proportions in the U.S. *American Journal of Human Biology* 17:393-402.
- Stefflova, Klara, Matthew C. Dulik, Jill S. Barnholtz-Sloan, Athma A. Pai, Amy H. Walker, and Timothy R. Rebbeck  
 2011 Dissecting the Within-Africa Ancestry of Populations of African Descent in the Americas. *PLoS ONE* 6(1):1-10.

Stinson, Sara

1985 Sex Differences in Environmental Sensitivity during Growth and Development. *Yearbook of Physical Anthropology* 28:123-147.

Sudarkasa, Nlara

1988 Interpreting the African Heritage in Afro-American Family Organization. In H. P. McAdoo (Ed.), *Black families* (2nd ed., 27-43). Newbury Park, California: Sage.

Temple, Daniel H., and Hirofumi Matsumura

2011 Do Body Proportions among Jomon Foragers from Hokkaido Conform to Ecogeographic Expectations? Evolutionary Implications of Body Size and Shape Among Northerly Hunter-Gatherers. *International Journal of Osteoarchaeology* 21:268-282.

Temple, DH, BM Auerbach, M Nakatsukasa, PW Sciulli, and CS Larsen

2008 Variation in Limb Proportions between Jomon Foragers and Yayoi Agriculturalists from Prehistoric Japan. *American Journal of Physical Anthropology* 137:164-174.

Temple, Daniel H., Kenji Okazaki, and Libby W. Cowgill

2011 Ontogeny of Limb Proportions in Late Through Final Jomon Period Foragers. *American Journal of Physical Anthropology* 145:415-425.

Thomas, Hugh

1999 *The Slave Trade: The Story of the Atlantic Slave Trade: 1440-1870*. New York City: Touchstone.

Tishkoff, Sarah A., Floyd A. Reed, Francoise R. Friedlaender, Christopher Ehret, Alessia Ranciaro, Alain Froment, Jibril B. Hirbo, Agnes A. Awomoyi, Jean-Marie Bodo, Ogobara Doumbo, Muntaser Ibrahim, Abdalla T. Juma, Maritha J. Kotze, Godfrey Lema, Jason H. Moore, Holly Mortensen, Thomas B. Nyambo, Sabah A. Omar, Kweli Powell, Gideon S. Preorius, Michael W. Smith, Mahamadou A. Thera, Charles Wambebe, James L. Weber, and Scott M. Williams

2009 The Genetic Structure and History of Africans and African Americans. *Science* 324:1035-1044.

Trotter, Mildred, and Goldine C. Gleser

1952 Estimation of Stature from Long Bones of American Whites and Negroes. *American Journal of Physical Anthropology* 10:463-514.

1958 A Re-Evaluation of Estimation of Stature Based on Measurements of Stature Taken During Life and of Long Bones after Death. *American Journal of Physical Anthropology* 16:79-123.

Warren, Jonathan W., and France Winddance Twine

1997 White Americans, the new minority?: Non-Blacks and the ever-expanding boundaries of Whiteness. *Journal of Black Studies* 28(2):200-218.

Weinstein, Karen J.

2005 Body Proportions in Ancient Andeans from High and Low Altitudes. *American Journal of Physical Anthropology* 128:569-585.

Yaeger, Rona, Alexa Avila-Bront, Kazeem Abdul, Patricia C. Nolan, Victor R. Grann, Mark G. Birchette, Shweta Choudhry, Esteban G. Burchard, Kenneth B. Beckman, Prakash Gorroochurn, Elad Ziv, Nathan S. Consedine, and Andrew K. Joe

2008 Comparing Genetic Ancestry and Self-Described Race in African Americans Born in the United States and in Africa. *Cancer Epidemiol Biomarkers Prev* 17:1329-1338.