Investigating population specific methods for Latin Americans: Sex estimation using the calcaneus in Chilean and Mexican populations.

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A Thesis Submitted to
Saint Mary's University, Halifax, Nova Scotia
In Partial Fulfillment of the Requirements for
the Degree of Master of Science in Applied Sciences

April 2019 Halifax, Nova Scotia

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Acknowledgements

Many thanks goes to the individuals and institutions who have supported the research and development of this thesis. First, a big thank you goes to members of my thesis committee for their patience and support throughout this (long) process. Dr. Tanya Peckmann who first agreed to take me on as a student and provided me with wisdom, insight and more opportunities than I could imagine. Thank you for taking the time and having the utmost of patience throughout this process. Dr. Susan Meek, who willingly decided to agree to be a part of the committee and who was a great help with not only statistical analyses but also in the writing process. Above all that, thank you for also being an incredibly warm and supportive person. Dr. Claudia Garrido-Varas who also willingly agreed to be a part of my committee, to you, I thank you immensely for your knowledge and insight into the field of human rights and for all of your help, directions and connections. Looking forward to having coffee with you one day ☺. Again to the three key women who helped me develop my research and writing skills, I cannot thank you enough.

To the individuals and institutions who helped me during my data collection. To the Universidad de Chile in Santiago, specifically Dr. Sebastian

Krapivka (Department of Anthropology) for allowing me access to the skeletal collections. To Carmina, Rocio and Mite thank you for your help during the data collection and thank you for showing me around during my stay in Santiago and becoming great friends. To Alejandra, thank you for housing me during my stay and for also being such a warm and welcoming individual. In Mexico, thank you to the Laboratorio de Antropología Física Departamento de Anatomía at the Universidad Nacional Autónoma de México (UNAM) and Guillermo Torres for assisting me in data collection and allowing access to the skeletal collection.

Thank you to the institutions that provided me with funding for this project. To the various funding programs at Saint Mary's University (The Vice-President Academic & Research International Mobility Award, The Faculty of Graduate Studies and Research and The SMUWorks Program) which provided funding to allow me to continue in the program and fostering additional research projects. A big thank you to MAGC Solutions and Lupus Canada for the scholarships and financial assistance.

Last but seriously not least, to my family and friends 'thank you' doesn't seem like enough. To my family in which the questions of "Is it done yet?" the answer is finally, yes, yes it is. To my parents and brothers, thank you for the care packages, ongoing encouragement and support throughout all

of this. My incredibly valued friends, Andrew, Christina, Kayla, Sabi and Natasha for your ever listening capabilities (whether you wanted to hear it or not) and allowing me to bounce a million and one ideas off of - usually at the weirdest hours - thank you. To my very dear friends, Bente, Kathryn, Lionel and Mary who provided unwavering support, encouragement and always willing to share a drink when needed, thank you. And to the best 'puppervisor', Olive, thanks for over-seeing my work.

Abstract

Investigating population specific methods for Latin Americans: Sex Estimation using the calcaneus in Chilean and Mexican populations.

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Latin American populations are often grouped together as one ancestry. Therefore, this research investigated population specificity for sex estimation using the calcaneus of contemporary adult Chilean and Mexican populations. The calcaneus was chosen as it is a bone with high resistance to taphonomic change. Ten variables were measured on Chilean (64 males and 66 females) and Mexican (92 males and 63 females) calcanei. After testing the two populations, no significant differences were found between the Chilean and Mexican samples so they were combined as the 'Combined CM' population to develop the discriminant functions for sex estimation. Sex estimation classification accuracy rates ranged from 70.5% (univariate) to 86.3% (multivariate). The 'Combined CM' population was compared to other populations and, overall, showed that significant differences existed between populations. This has been attributed to stature, nutrition, psychological stress, and research design.

Date: April 5th 2019

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Chapter 1: Introduction

1.1. Objectives

When unidentified human remains are recovered, the task of a forensic anthropologist is to analyze the remains and create a biological profile, providing the most accurate information possible in order to reduce the number of potential identities (Berg and Ta'ala, 2015). The biological profile includes estimating ancestry, sex, age and stature of the individual. Sex estimation is a crucial step in developing the biological profile of unknown human remains as stature and age estimations are dependent on the estimation of sex. Working groups and associations such as National Institute of Science and Technology's Scientific Working Group for Anthropology (SWGANTH) and the British Association for Biological Anthropology and Osteoarchaeology (BABAO) develop and disseminate best-practice guidelines for the field of forensic anthropology. SWGANTH and BABAO cites the importance of developing methods for sex estimation using various elements of the skeleton (BABAO, 2015; SWGANTH, 2013). They also encourage developing sex estimation methods for various population groups as methods of sex estimation have been shown to be population-specific (Bidmos and Asala, 2004; Bidmos and Dayal, 2004; Gualdi-Russo, 2007; Hudson et al., 2016; Patriquin, et al., 2003; Spradley et al., 2008; Spradley and Jantz, 2011; Sauer, 1992). Methods utilizing population specificity are important because populations have different morphologies that have been influenced by gene flow, environmental factors and life styles (Konigsberg et al., 2009, Spradley et al., 2011). There is limited research for the estimation of sex for Latin American populations (Spradley, 2012; Spradley and Anderson, 2015; Tise et al., 2013). This project aims to examine the estimation of sex for Chilean and Mexican populations using the calcaneus.

The goals of this project are to (1) estimate if sexual dimorphism is present in the calcaneus of contemporary Chilean and Mexican populations, (2) determine if there is a statistically significant difference in size between Chilean and Mexican calcanei and, if so, does this reflect a need for discriminant functions for each population, (3) determine if discriminant function equations developed on a contemporary White South African population will accurately estimate sex from the calcaneus of contemporary Chilean and Mexican populations and, (4) compare contemporary Chilean and Mexican population data to other population data.

1.2. Terminology Defined

1.2.1. Gender and Sex

The terms 'gender' and 'sex' are sometimes used interchangeably to describe whether an individual is male or female; however, the two terms are not synonymous. 'Gender' is a social-construct that refers to a characteristic of an individual's self-identity and may have multiple classification categories, e.g. man, woman, transgendered (Black and Ferguson, 2011; Walker and Cook, 1998). 'Gender' is also connected to socially accepted behaviours or roles that are not expressed in biological physiology (Armelagos 1998).

However, 'biological sex' is a dichotomous term to describe an individual as either male or female and is linked to external genitalia, internal reproductive structures, sex chromosomes, and sex hormones. 'Biological sex' refers to an individual's karyotype, whether they have XX chromosomes (female) or XY chromosomes (male) (Walker and Cook, 1998). Sex chromosomes are responsible for influencing the secretion of sex hormones during puberty, which influences the growth and development of bone structure and physical traits related to the form and function of each sex. Sex estimation of the human skeleton is possible as hormones, body mass, and activities influence skeletal allometry (Garcia-Martinez et al., 2016). The pelvis is an example of this concept as pelvic morphology differs between males and females in order to accommodate birthing. Sexual dimorphism can also be observed throughout the skeleton as males often have larger muscle attachment sites than females which leads to a more robust skeleton (Cabo et al., 2012). When forensic anthropologists construct the biological profile, it is the biological sex that is estimated, not the gender, of the individual. Therefore, throughout this research, the term 'sex' will be used and not 'gender' when referring to males and females.

1.2.2. Ethnicity, Race, and Ancestry

Human variation is the result of populations evolving in various geographical areas, and is influenced by genetic and environmental factors (AAPA, 1996). However, as there are no distinct geographical boundaries, and gene flow exists, there are no isolated homogenous populations and therefore human beings cannot be classified into specific biological groups or categories.

The terms 'ethnicity', 'race' and 'ancestry' are often used interchangeably when describing human variation between populations, however, these concepts are not tantamount.

The term ‘ethnicity’ refers to the self-identification into cultural groups. Ethnicity does not reflect on an individual’s phenotype or genotype, instead, it describes the individual’s or group’s socio-cultural practices, languages used and religious practice (Klimentidis et al., 2009). In a forensic context ethnicity is an important aspect of an individual’s identity and can assist with an identification. Ethnicity, however, cannot be ascertained by examining skeletal remains. If there are certain cultural modifications made to the skeleton, that can be attributed to a specific culture, or if the individual is buried with cultural relics, it may assist with the ethnic identification (Birkby et al., 2008). The term ‘ethnicity’ is an inappropriate term to use when describing human biological variation and therefore will not be used throughout this research.

‘Race’ is a social construct that has been used to describe population variation based on phenotypes and cultural practices (Cartmill, 1999; Konigsberg et al., 2009; Sauer 1992). The term ‘race’ follows the assumption that populations can be grouped together to form a limited number of static categories based on physical appearance, such as skin pigmentation, distinguishable facial features, and origin of geographical location (Ferguson et al., 2010; Sauer, 1992; Ta’ala, 2015). The ‘race concept’ was first developed by Johann Friedrich Blumenbach in the late 18th century. He classified human beings into five categories: Negroid, Mongoloid, Caucasoid, American Indian, and Malayan (Kelso, 1974). Blumenbach studied the relationship between cranial morphology and ‘racial’ background (Ta’ala, 2015). In the 1800s, Morton added to Blumenbach’s studies of cranial morphology and population variation and focused on the cranial capacity (cephalic index) of each ‘race’. Morton studied the cephalic index of five different ‘races’, Caucasian, Asian, Malay, Native American and African to support his theory of polygenism – that humans could be classified as separate species (Freeman, 1997; Lewis et al., 2011). From his studies, Morton concluded that Caucasians had the greatest cranial capacity and therefore were the most intelligent 'species', while African and Native Americans showed a much lesser cranial capacity and therefore had a much lower intelligence (Freeman, 1997; Lewis et al., 2011) Morton's research was used to infer intelligence for each population and provided the justification for discrimination, segregation, and slavery around the world (Blakey, 1987; Moses, 1999). The idea of racial superiority continued into the 1900s. In South Africa, the 1913 Land Act was the beginning of racial segregation. Racial segregation continued into the late 1990s as South Africa faced a form of government rule, Apartheid, that separated Whites and Non-Whites, with millions of people being forcibly removed from their homes and thousands imprisoned or killed. In the Americas and Europe, 'race' provided validation for targeting, and slaughtering, millions of Jewish peoples during the Second World War.

In the 1960's, the school of thought surrounding the term 'race' had started to change. Frank Livingstone created the "theory of clines". A cline is described as an observable gradient in characteristics such as allele frequencies, or phenotypes (Freeland, 2005). Livingstone's theory illustrated that 'races' do not exist, instead clines were a more appropriate explanation for human variation (Livingstone, 1962). The discovery of DNA and the advancements in examining the human genome and population genetics added a new dimension to the study of human variation (Caspari, 2003). Gene mutations, frequencies of inherited traits and genetic admixture as a result of population migration, and the accessibility of global travel resulted in a more complex population variation even within population groups that no longer fit the 'race' concept (AAPA, 1996; Ousley et al., 2009).

The word ‘race’ is a biologically loaded and socially constructed term. It is language intended to produce an emotional response in the mind of the audience in order to directly affect their views on a topic. ‘Race’ is a category assigned to an individual based on a perceived set of biological or physical traits (Cartmill, 1999; Konigsberg et al., 2009; Sauer 1992). Perceived ‘races’ are not reflections of biological reality. Therefore, the term ‘race’ will not be used in this thesis when defining population groups.

The term ‘ancestry’ encompasses the biological variation and genetic component of population diversity. Ancestry is the result of microevolutions of a population caused by genetic admixtures through gene flow and environmental factors (AAPA, 1996; Konigsberg, 2009). As a result, phenotypic traits can be measured and quantified through DNA analysis using techniques such as Single Nucleotide Polymorphisms (SNPs), Variable Number of Tandem Repeats (VNTRs), and Short Tandem Repeat Polymorphisms (STRPs) allowing the identification of geographical-based patterns to identify ancestor-descendent relationships. This biological variation is also reflected in human skeletal remains as studies suggest that population variation can be quantified in the human skeleton (Bidmos and Assala, 2004; Bidmos and Dayal, 2004; Gualdi-Russo, 2007; Hudson et al., 2015; Patriquin, 2003; Spradley et al., 2008; Spradley and Jantz, 2011; Sauer, 1992). The term ‘ancestry’ is a neutral and scientifically appropriate term and therefore ‘ancestry’ will be used in this research when referring to various populations.

1.3. Human Rights

The Universal Declaration of Human Rights was established in 1948 in Paris, France, by the United Nations General Assembly. It is an outline of human rights that are to be protected. People have the right to freedom, dignity, life, and safety regardless of their sex, religion, political opinions, ‘race’, colour or language (UN General Assembly, 1948). Slavery, wrongful and unjust imprisonment, extreme methods of interrogation, and execution are by-products of times of conflict and war and are all violations of human rights (UN General Assembly, 1948). In death, human rights continue to exist. In international armed conflicts, the 1949 Geneva Conventions has codified the obligation that the deceased be identified prior to their disposal and that the Central Tracing Agency and other organizations be notified of these deaths. In situations of non-international armed conflicts, there are no specific treaties regarding the methods and procedures to identify the dead prior to their burial (UN General Assembly, 1948). However, in 1974 the UN General Assembly requested that parties involved in armed conflicts cooperate in their efforts to provide information, to all parties involved, regarding the missing and deceased individuals. Case-laws have been established, in various countries, for the identification of deceased individuals in times of conflict. Argentina and Colombia have case-laws that require the deceased be examined prior to their burial in order to establish the circumstances surrounding their death and for individual identification (Rota, 2009). The European Court of Human Rights and the Inter-American Commission and Court of Human Rights were involved during the armed conflict in the former Yugoslavia. Once the conflict was deemed non-international, the parties involved agreed to the exchange of information regarding the identification of the deceased (Skåre and Burkey, 2008).

Israel's High Court of Justice ruled in the *Jenin (Mortal Remains)* case that the location, identification, and burial of the dead are important humanitarian acts (Barake v. Minister of Defense, 2002). Rule 116 of the International Commission of the Red Cross states that according to the collected practice, the means and records of identification, manner of the individual's death, as well as information regarding the burial (individualized marked burials and their location) are all part of the obligation to identify the dead of conflict. This Rule also allows for the exhumation and application of forensic methods in order to identify the dead after burial, if required (ICRC, 2016).

1.3.1. The Role of the Forensic Anthropologist in Human Rights Cases

In cases of human rights violations, where mass graves or unmarked graves are recovered, a multi-disciplinary team consisting of pathologists, odontologists, fingerprint experts, crime scene investigators, archaeologists, and anthropologists work together to identify the victims (Kahana and Hiss, 2009). Forensic anthropologists are uniquely positioned to assist with human rights cases as they have experience with the recovery of human remains, skeletal analysis, and working closely with diverse communities all over the globe. In human rights cases, mass graves often contain commingled human remains – the mixing of the bones of two of more individuals within an assemblage (Haglund et al., 2001; Skinner et al., 2003). The forensic anthropologist and/or archaeologist must follow the best practices set forth by the governing agency. Examples of this are the practices and models laid out by the Minnesota Protocol, which sets a common standard of practice for those investigating unlawful deaths and enforced disappearances (Minnesota Protocol, 2017). The excavation process allows for the recovery of human remains in the least destructive way possible, as well as the preservation of context and any evidence of the burial site (Conner and Scott, 2001).

Once the remains are recovered, the forensic anthropologist will assist in post-mortem identification by constructing the biological profile (i.e. estimation of sex, age at death, ancestry, and stature), providing details regarding the general health status as well as particular identification features, and interpreting the traumatic injuries and pathologies found on the skeletal remains. (Baraybar and Gasior, 2006; Blau and Briggs, 2009; Mundorff, 2012). Forensic anthropologists will also record testimonies from witnesses, families and friends of the deceased for antemortem data: clothing or pieces of jewelry last seen or most often worn, tattoos, recent injuries, anything that may assist in the identification of the remains (Kimmerle et al., 2009). The antemortem data would be compared against the postmortem data for identifications.

Identifying victims of mass atrocities can be lengthy and costly. DNA analysis, along with radiological and isotope analyses are expensive methods that may be unavailable or unaffordable in some situations (Garrido Varas, 2012b). International excavations and analyses are rarely state funded, especially if the conflict was an internal conflict, e.g. Argentina, Peru, Guatemala and Mexico (Heyden, 2015). Forensic anthropologists must use techniques that are less costly, easily accessible, efficient, and non-invasive (Blau and Briggs, 2009; Mundorff, 2012). Therefore, methodologies such as those described in this project are beneficial, advantageous, and necessary for the identification of human remains in cases of human rights atrocities and criminal cases. As well, having a narrowed subgroup of individuals for potential identification allows for a more manageable use of costly resources such as DNA analysis.

1.3.2. Human Rights Cases in Chile

On 11 September 1973, after the death of President Salvador Allende, the Chilean military staged a coup d'état. General Augusto Pinochet held presidency and military dictatorship from 11 September 1973 until 20 March 1990. After 17 years of authoritarian rule, President Pinochet was responsible for the deaths and disappearances of thousands of individuals (Garrido Varas and Leiva, 2012a; Ross and Manneschi, 2011). In 1991, various truth commissions and human rights groups began to investigate the human rights violations that occurred as a result of the Pinochet regime. Several reports were published listing the number of recorded individuals that were subjected to torture, missing and executed. A total of 31,831 cases of political imprisonment and torture were recognized and a total of 3,227 cases of political executions were recorded (CNRR, 2005; Rettig, 1993; Valech, 1996;). Execution victims were often buried in unmarked mass graves located in cemeteries. It was not uncommon to find additional remains in burial plots already assigned to a deceased individual.

To date, approximately 275 of the 3,227 fatal victims have been identified by the *Unidad Especial de Identificación Forense* (Garrido Varas, 2012a). The largest of the illegal burials uncovered in Chile is Patio 29, located in the capital city of Santiago. Patio 29, located within the Cemetario Generale de Santiago, held a total of 158 individuals, of which 69 individuals have since been identified. In Chile regarding human rights cases, DNA tests will be performed after strict considerations of the recovered remains when possible. However, it is not within Chile's policy to conduct DNA tests on all bone fragments recovered (Garrido Varas and Intriago Leiva, 2012). Therefore, it is important to create methods for the estimation of sex that utilize less expensive and more readily available technologies.

1.3.3. Human Rights Cases in Mexico

Human rights violations in Mexico are a common occurrence. Corruption within the government and the on-going drug-cartel wars have resulted in the deaths of thousands of individuals throughout the country (Malloy, 2013). Mexico's officials are unable to provide the appropriate resources dedicated to identifying those recovered from mass graves. Oftentimes it is the families of missing persons that come forward to various independent, non-profit human rights groups inquiring about the whereabouts of their loved ones.

An example of this in Mexico, are the 'maquiladora murders' or 'femicides' (Moore, 2012). A maquiladora is a factory, usually owned by a foreign county, that employs Mexican citizens (Pantaleo, 2010). Maquiladoras are known to have poor and inhumane working conditions. Since 1993, over 370 women and young girls who were employees of the maquiladoras, have been found dead and abandoned in either the deserts or other desolate locations in Mexico (Pantaleo, 2010). Investigations into these crimes are often minimal and negligent, or intentional manipulation of evidence hinders the progress of the cases (Pantaleo, 2010). As a result, not only do the found human remains go unidentified, but the families are left with no closure as to the whereabouts of their daughters.

In 2003, the National Commission for Human Rights in Mexico (CNDH) released a report that examined the forensic examination of 200 of the 'maquiladora murder' cases

(EAAF, 2007). The ‘Equipo Argentino de Antropologia Forense’(EAAF) reviewed 20 case files of unidentified female remains and three case files from families, who wanted confirmation that the remains that they received were actually those of their missing daughter. Throughout their research, EAAF discovered that Mexican officials had buried unidentified remains in mass graves, a practice that Mexico was supposed to have ceased in 1995. The initial 20 cases they received expanded to 55 cases. EAAF was able to identify 24 women and girls through genetic, anthropological, and odontological analyses (EEAF, 2007).

Mexico’s current state of gang violence, drug cartels, corruption and firearms trades have resulted in the deaths of thousands of people. Its citizens are fleeing to the United States in order to seek asylum (Moore, 2012). They pay a “Coyotaje” to smuggle them across the U.S.A.–Mexico border; which can take many days of walking through the desert before reaching their destination (Ledezma, 2013). As Arizona shares a portion of the U.S.A.–Mexico border, illegal border crossings are most apparent in this area. In the year 2004, the United States border patrol accounted for 43% of illegal border crossing apprehensions along the Arizona–Mexico border (Anderson 2008). A large number of asylum seekers die while crossing the U.S.A.–Mexico border (Birkby et al., 2008). Between 2001 and 2006, the Pima County Office of the Medical Examiner, located in Tucson, Arizona, recorded a total of 918 undocumented border crosser deaths. Fortunately, through various means (e.g. DNA, dental, radiography, circumstantial, visual), they have successfully identified 73% of the undocumented border crossers (i.e. 667 individuals). Of those 667 individuals, 611 of them were Mexican civilians. As of 2008, there were still 251 undocumented border crossers who have yet to be identified (Anderson 2008).

In 2011, 52 migrant deaths were recorded in Brooks County, Texas, and 126 migrant deaths were recorded in 2012 (Spradley, 2014). Unlike Arizona, Texas does not have a centralized medical examiner's office to receive deceased undocumented migrants and, therefore, the identification of undocumented border crossers is shared between various medical examiner's offices and Justice of the Peace jurisdictions (Anderson and Spradley, 2016). As a result, many of the migrant deaths are uncatalogued or uninvestigated. Fortunately, the Forensic Anthropology Center at Texas State University, Baylor University, and Sam Houston State University have volunteers who assist with the identification of deceased undocumented Mexican border crossers (Anderson and Spradley, 2016). The three educational institutions provide the required personnel and instrumentation to conduct analysis of the remains to work towards an identification.

It is a human right for any one deceased individual to be identified, and have his/her loved ones notified of his/her death. In cases where mass graves are uncovered and human rights violations are involved, the excavation and identification process can be lengthy and expensive. Therefore, it is important to develop methods, such as those used throughout this research, which are cost-effective, require little technical equipment, and have results that can be accurately reproduced by a trained forensic anthropologist. When identifying a set of remains, it is imperative that the scientist has the most accurate dataset to reference. It has been well documented that applying American White or American Black datasets to Latin American populations is not appropriate as the Latin American population is more gracile (Jantz, 2004; Spradley et al., 2008). This project aims to provide additional information to the biological profiles of both Chilean and Mexican populations that can be used to assist with identification of individuals in a number of forensic contexts, globally – especially when dealing with incomplete remains due to commingling and taphonomic changes.

Chapter 2: Background

2.1 The Admissibility of Forensic Evidence in Court

Prior to 1993, the admissibility of expert evidence in courtrooms in the United States was allowed on the basis that the *Frye* general acceptance criterion was met. The Frye test would be met if the technique or scientific method in question was widely accepted and valid within the scientific community (293 F. 1013 (D.C. (1923)). The current admissibility of expert evidence in courts in the United States, known as the Daubert ruling, was established from the 1993 case of *Daubert v. Merrell Dow Pharmaceuticals Inc.* (509 U.S. 579 (1993)). The Daubert and Schuller families sued Merrell Dow Pharmaceuticals, Inc., based on the belief that their children's birth defects were caused by the mothers' prenatal ingestion of the prescription drug Benedectin. Throughout the trial, testimony demonstrating the causal relationship for the prenatal ingestion of Benedectin and birth defects was thrown out for not meeting the general acceptance criterion. This led to a review of the Frye test and the creation of the Daubert ruling. The Daubert ruling states that in order for expert testimony (and their methods or theories) to be used, the methods must meet five criteria: (1) the method or theory must have been objectively tested; (2) the method has to have been subjected to peer review; (3) the method or theory must have known error rates; (4) the method or theory has controls; (5) the method must have general acceptance within the scientific community (509 U.S. 579 (1993)).

In Canada, the admissibility of forensic evidence in court, known as the Mohan ruling, was established from the 1994 Supreme Court of Canada decision in the *R. v.*

Mohan trial (2 S.C.R. 9, (1994)). The accused was charged with four counts of sexual assault on four underaged females during their medical examinations. The accused had appealed his case, based on the testimony of a psychiatrist who testified that his character traits do not fit the psychological profile of a serial rapist or pedophile. This testimony was brought into question as to whether or not it should be allowed into the courts and caused the review of the criteria of the admissibility of character evidence and expert evidence. The Mohan ruling states that in order for expert testimony to be used, the methods must meet four criteria: (1) the relevance of the expert evidence being given to the trial; (2) the necessity of the expert testimony in assisting the trier of fact (judge or jury); (3) the absence of any exclusionary rule; and (4) a properly qualified expert is providing the expert evidence to the trier of fact (2 S.C.R. 9, (1994)).

In order to satisfy both the Daubert and Mohan criterion, techniques employed by forensic anthropologists must be repeatable, reproducible, and reliable. The repeatability of a technique is described as having a consistent outcome given the consistent circumstances (Bartlett and Frost, 2008:467). Reproducibility of a technique is described as having a consistent outcome, given that one of the factors within the circumstance has changed (Bartlett and Frost, 2008:467). For example, in osteometric analyses, intra-observer tests are used to verify the repeatability of a technique when measured by one observer at different times and inter-observer tests are used to verify the reproducibility of the technique when measured by two observers at different times. The reliability of a technique includes its error rates and refers to its ability to classify the subjects with consistent results. In osteometric analyses, researchers test the reliability of a method by applying the method to a subsample of individuals who were excluded from the core sample. Ways to assess the reliability of a technique, are by running 'Leave-one-out' classifications, or cross-validation analyses. The field of forensic anthropology is a research driven field, where validation studies, and intra- and inter-observer tests are examined in order to ensure that the scientific method is upheld. Methods used for forensic anthropological analyses must have an accuracy rate greater than 80.0% and have less than 10.0% intra-class or inter-class error (Christensen and Crowder, 2004; Marlow and Pastor, 2011; Rogers et al., 1999; Williams and Rogers, 2006). Methods that show an accuracy rate of less than 80.0% should be used critically, and coupled with stronger methods of analysis.

2.2 Sex Estimation in Forensic Anthropology

Sex estimation is an important criterion when constructing a biological profile from unidentified human remains. It is important that sex is established, as standards for age and stature estimations are dependent on the sex of the individual (Kimmerle et al., 2008; Rosing et al., 2007; Peckmann et al., 2015). Once the sex of the individual have been estimated, it can reduce the number of potential candidates for identification by 50 percent (Dayal et al., 2008). Methods for estimating sex include morphological and metric assessment of the skeletal elements. Both morphological and metric methods been shown to be population-specific (Guaraldi-Russo et al., 2007; Patriquin et al., 2003; Rosing et al., 2007). Accuracy rates for both metric and morphological rates range from 61.8% to 100% depending on what skeletal element was used.

The morphological methods for sex estimation involve analyzing physical traits of skeletal elements to assess the overall size, shape and robusticity of the remains. Larger and more robust traits are more indicative of the male sex. Smaller more gracile traits are more indicative of the female sex. Morphological assessments are non-quantifiable, subjective and have a lesser accuracy rate than metric analyses (Spradley and Jantz 2011; Stewart, 1997).

Metric analyses of skeletal elements use a quantitative anthropometric technique. Anthropometry involves collecting measurement data from skeletal elements and examining the data using statistical analyses. The resulting value from the analyses indicates if the skeletal element is male, female, or if the sex is deemed indeterminate. Metric analyses are objective, quantifiable, and have a low-bias as the measurement points use defined skeletal markers or traits (Rogers, 2005).

2.3 Sex Estimation using the Pelvis

2.3.1. Morphological Sex Estimation Techniques

The pelvis is the most accurate method for estimating sex due to the morphological differences between men and women pertaining to childbirth (Krogman and Iscan, 1987, MacLaughlin and Bruce, 1986; Rogers and Saunders, 1994; Walker, 2005). Research using the os coxae as a sex estimator was first conducted by Phenice (Phenice, 1969). Phenice developed a three gradient morphological model involving the ventral arc, subpubic concavity, and the medial aspect of the ischio-pubic ramus as a means to establish sex. An average correct classification accuracy of 95.0% was obtained. Other researchers (Bruzek, 2002; Klales et al., 2012; Lovell, 1989; MacLaughling and Bruce, 1990; Rogers and Saunders 1994; Rosenberg, 1986; Sutherland and Suchey, 1991; Volk and Ubelaker, 2002) have conducted validation studies using Phenice’s methods and received varying results, between 59% accuracy (MacLaughling and Bruce, 1990) to 99.0% accuracy (Rosenberg, 1986).

Lovell (1989) tested the accuracy rates of Phenice's morphological methods. Twelve researchers evaluated and scored 50 pubic bones from skeletal remains of males and females between the ages of 52 and 92 years old. When evaluating the data compiled by the 12 researchers, Lovell (1989) found that overall the correct classification accuracy was 83.0% and, although the osteological experience of the researcher was not a significant contributing factor, the age-at-death of the deceased individual was a contributing factor and influenced the results; the older the individual, the less accurate the sex estimation.

More recently, Klales et al. (2012) revised the Phenice method (Phenice, 1969) to address the issues of subjectivity and inconsistencies when assessing morphological traits of the pubis. They analyzed the range of expression for each of the three morphological traits (ventral arc, subpubic concavity and the medial aspect of the ischio-pubic ramus) in males and females. Their sample consisted of 170 individuals (Black and White males and females, evenly represented) from the Hamann-Todd Human Osteological Collection and 140 individuals (various ancestries, unevenly represented) from the W.M. Bass Donated Skeletal Collection. They developed a five-gradient method to better describe and characterize the range of expression for each trait. Klales et al. (2012) had four researchers of varying experience score the pelves and analyze the scores using ordinal logistic regression for calculating the posterior probabilities for classification. Overall, the more experienced researchers scored higher correct classification accuracies than the less experienced researchers. When analyzing the classification accuracies for each of the three traits independently, the ventral arc showed the highest classification accuracy of

88.5%. The subpubic concavity followed with an 86.6% classification accuracy, and the ischio-pubic ramus had a 75.8% correct classification. They also used logistic regression equations to combine all three traits with an overall correct classification of 94.5%; this was the highest overall correct classification.

Bruzek (2002) acknowledged the varying degrees of accuracy in Phenice's methods and assessed morphological traits from the pubis, the illium, and the ischium to estimate sex. This study utilized two distinct populations, French (Laboratoire d'Anthropologie de l'Universite Paris Skeletal Collection) and Portuguese (Museu Antropologico da Universidade de Coimbra Skeletal Collection), from a sample of 402 adults of known age and sex. Pelvic traits examined included the preauricular surface, greater sciatic notch, composite arch, inferior pelvis, and ischio-pubic proportion. When all five traits were combined, accuracy rates ranged between 93.0% and 98.0%.

Patriquin et al. (2003) assessed morphological variations of sex in the pelves of South African Blacks and South African Whites. The purpose of the study was to identify if population-specific research was required when using the pelvis as a sex estimator. Their research established that the overall shape of the pubic bone and the subpubic concavity were the most sexually dimorphic traits for the South African White population, with an overall average accuracy of 88.0% correct classification. In the South African Black population, the greater sciatic notch and the overall shape of the pubic bone were the most sexually dimorphic traits, with an overall correct classification average of 86.0%.

Wescott (2015) utilized the auricular surface and the postauricular sulcus of 181 males and 141 females of American White and Black ancestry. The auricular surface was scored as 'completely elevated', 'partially elevated' or 'nonelevated' and the postauricular sulcus was scored as either ‘present’ or ‘absent’. Wescott (2015) found ‘no elevation’ or only ‘partial elevation’ of the auricular surface in 99.4% of males and 33.3% of females. Complete elevation of the auricular surface was present in 0.6% of the male population and 66.7% of the female population. The preauricular sulcus was absent in 73.0% of the males while it was present in 85.0% of the females. The overall accuracy rate, using the preauricular sulcus as a means of estimating sex, was 79.2%.

2.3.2. Metric Sex Estimation Techniques

Murphy (2000) used the height and width measurements of the left and right acetabulum from a prehistoric New Zealand Polynesian population to create two discriminant function equations for sex estimation. The discriminant function equation of the left innominate had a correct classification of 85.2% and the discriminant function equation of the right innominate had a correct classification of 86.2%. The author emphasizes the limitations of the discriminant functions to Polynesian populations and highlights the need for research into developing population-specific data sets.

Steyn et al. (2004) used geometric morphometric analysis of the greater sciatic notch to discriminate sex between Black and White South African populations. Their findings concluded that this method was more accurate for the Black South African population, as the male sciatic notch was narrow and the female greater sciatic notch was wide. In the White South African population, Steyn et al. (2004) had lower accuracy rates, as both the males and the females displayed narrow greater sciatic notches.

Steyn and Iscan (2008) studied a contemporary Greek skeletal population and used 17 measurements to create seven discriminant function equations for estimating sex.

When using the sacrum alone, the average correct classification was 60.9%; however, accuracy rates increased to 77.8% when using the articulated pelvis. The discriminant function equation that yielded the best results (95.4%) used a single innominate bone (either the left or right).

Gonzalez et al. (2009) used a geometric morphometric approach to estimating sex using coordinates of landmarks from the ilium and ischiopubic region of a Portuguese population. Their sample consisted of 121 adult left innominates from the Museu Antropologico de Coimbra. The data generated from the measured variables were used to generate discriminant function equations. Classification accuracies ranged from 90.9% to 93.4% correct classification.

With the advancements of technology, researchers have been using three-dimensional multi-detector Computed Tomography (3D CT scans) to measure the skeleton. Karakas et al. (2013) utilized 3D CT scans of pelves to measure the subpubic angle to estimate sex within an Anatolian population. The sample consisted of 66 males and 43 females. The subpubic angle for males was determined to be between 48º and 81º. The subpubic angle for females was determined to be between 64º and 100º. Accuracy in estimating sex using the subpubic angle was 90.8%. Although this method has a high degree of accuracy, 3D CT scanners are not always available to forensic anthropologists, especially when working in remote areas.

Decker et al. (2011) utilized a random sample of 100 clinical CT scans of the pelvis at the University of South Florida College of Medicine. Ancestry was not recorded during data collection. A total of 35 landmarks were used to measure 20 variables. Logistic regression was used to create a four-variable equation using the most sexually dimorphic variables. One hundred percent accuracy rate for correct classification was obtained using the equation. The researchers also used FORDISC 3.0 to test sex estimation using the measured variables. The overall correct classification accuracy was 86.0%. The authors suggest that using the CT method would provide a more accurate means of collecting data and establishing discriminant functions for contemporary populations, providing that access to CT scanners is possible.

Franklin et al. (2014) used 3D CT scans from a sample of 200 males and 200 females from various Western Australian hospitals; specific information regarding the ethnicity of each individual was not recorded, but the sample is representative of a ‘typical’ Western Australian population (Franklin et al., 2014:158). They used 24 landmarks and 12 measurement variables to study sexual dimorphism. Out of the 12 measurement variables, 10 variables were found to be sexually dimorphic, while two variables were not sexually dimorphic and, therefore, excluded from the discriminant functions. The authors achieved 100.0% accuracy when using the 10-variable method. The least sexually dimorphic trait was the ischial length, which still had a correct classification of 81.2 % when used independently for sex estimation. Although using 3D CT scans result in high classification accuracies, forensic anthropologists may not have access to this technology and, therefore, will need to use more traditional methodologies for analyzing human remains.

2.4. Sex Estimation using the Skull

2.4.1. Morphological Sex Estimation Techniques

The skull has been extensively studied both morphologically and metrically and has been described as the second best method of estimating sex (Hrdlicka 1939; Krogman

1986; Rogers 2005; Walker 2008). Sex estimation of the skull using morphological techniques was developed by Acsadi and Nemeskeri (1970). A total of five morphological traits were observed to be the most sexually dimorphic: the nuchal crest, the mastoid process, the supra-orbital margin, the supra-orbital ridge, and the mental eminence. The morphological features were scored from +2 to -2, where +2 represents ‘hypermasculine’, +1 represents ‘masculine’, 0 represents ‘indifferent’, -1 represents ‘feminine’ and -2 represents ‘hyperfeminine’. This method is one of the standard methods for estimating sex used by forensic anthropology practitioners (Buisktra and Ubelaker, 1998).

Konigsberg and Hens (1998) examined sex estimation and utilized a sample of 138 skulls, of unknown ancestry, from an historical sample in Tennessee. Their research assessed the same five morphological traits as Acsadi and Nemeskeri (1970), scoring each trait as 1 (female), 2 (unknown), or 3 (male). Once scored, logistic regression analyses and multivariate cumulative probit models were used to analyze the data. The logistic regression analyses had an overall correct classification average of 81.0%. The multivariate cumulative probit models had an overall correct classification average of 83.0%.

Loth and Henneberg (1996) used a Black South African sample from the Raymond Dart skeletal collection to develop a method of sex estimation using the mandible. The authors used 116 males and 84 females to assess the presence or absence of flexure of the posterior border of the ramus at the level of the occlusal surface. They concluded that a straight posterior border of the ramus was indicative of a female trait and the presence of a flexure was indicative of a male trait. The classification accuracy for estimating sex using the posterior angle of the ramus was 99.0%. They tested the technique on a subsample of individuals from the Terry skeletal collection consisting of White Americans, Black Americans, and Native Americans and achieved an average accuracy rate of 91.5%.

Rogers (2005) studied 46 skulls from a White European 19th century Anglican Church collection. A total of 17 morphological traits were assessed on each of the skulls for sexual dimorphism. The overall classification accuracy was 89.1% when all 17 traits were used together. When using the traits individually, accuracy rates ranged from 10.3% (tooth size) to 76.6% (nasal aperture).

Walker (2008) used a ‘1 to 5’ scoring gradient of five-variables and discriminant analyses to estimate sex from the skull. The characteristics that were assessed were the nuchal crest, mastoid process, supra-orbital margin, supra-orbital ridge, mental eminence. The sample consisted of 304 skulls of contemporary African American, English, and European American ancestry, as well as 156 individuals from an ancient Native American sample where sex was determined from pelvic morphology. Walker (2008) applied linear, logistic, and quadratic discriminant function analyses, as well as *k*-nearest neighbour analysis to evaluate sex estimation accuracies. When using the contemporary sample and pooling the ancestry, the five-variable quadratic discriminant function equation had the highest classification accuracy (90.7%); however, this method also had a high sex bias (5.0%). The five-variable logistic discriminant function model scored 88% accuracy and had a sex bias of 0.1%. When applying the methods to the ancient Native American sample, the five-variable logistic regression model scored the highest accuracy at 78.0% and the lowest sex bias of 0.2%.

2.4.2. Metric Sex Estimation Techniques

Ramsthaler et al. (2007) examined 98 skulls from two contemporary forensic collections housed at the Centres of Forensic Medicine at Frankfurt and Mainz University, Germany. The purpose of this study was to assess the accuracy of the FORDISC 3.0 software for estimating sex on a White European population and also to test whether FORDISC 3.0 was more accurate in classifying sex than using morphological assessments. The overall average classification accuracy was 86.0% when using FORDISC 3.0 for sex estimation. When using the morphological method of sex estimation, 94.0% classification accuracy was achieved.

Ramamoorthy et al. (2016) assessed 26 craniometric parameters on a South Indian population. Their sample consisted of 43 males and 27 females. They developed multivariate, stepwise, and univariate discriminant functions that had overall classification accuracies of 85.7%, 77.1%, and 72.9% respectively.

Noren et al. (2005) utilized the angle of the internal acoustic canal of the petrous bone to estimate sex in a Southwestern German population. Their sample consisted of petrous bones from 48 females and 65 males from a forensic collection from the Institute of Forensic Medicine at the University of Tubingen, Germany. They used a cast of the internal acoustic canal to measure the angle. The range of degrees for females was between 25º and 60º and the range of degrees for males was between 35º and 60º. The overall accuracy rate for sex estimation using the cast of the internal acoustic canal was 83.2%.

Lynnerup et al. (2006) utilized the diameter of the petrous bone to estimate sex. Their sample consisted of 65 females and 48 males from the Institute of Forensic

Medicine at the University of Tubingen, Germany. The mean female diameter was 3.4 mm and the mean male diameter was 3.7 mm. Average classification accuracy using this method was 70.0%.

Steyn and Iscan (1998) used the skull to analyze 12 standard cranial measurements and five standard mandibular measurements on 44 males and 47 females of White South African ancestry from the Pretoria and Raymond Dart skeletal collections in South Africa. Discriminant function analyses were applied to estimate sex from the skull. They created five discriminant function equations and their average accuracy rates for correct classification ranged from 80.2% to 85.7%. Robinson and Bidmos (2009) used the five discriminant functions created by Steyn and Iscan (1998) and applied them to three White South African populations. Their sample consisted of 115 males and 115 females from three skeletal collections: Raymond Dart skeletal collection, the Pretoria skeletal collection, and the Cape Town skeletal collection. When applying the discriminant function equations of Steyn and Iscan (1998) to the Raymond Dart sample, accuracy rates ranged from 72.0% to 87.8%. Accuracy rates for the application of the discriminant functions to the Pretoria skeletal collection sample ranged from 66.3% to 84.7%. Finally, accuracy rates for the application of the discriminant functions to the Cape Town skeletal collection sample ranged from 72.1% to 95.2%. Although there was a greater range for accuracies on the three validated samples, each of the samples classified higher than the original dataset.

Franklin et al. (2005) used the Raymond Dart skeletal collection to study the use of 3D landmark coordinates on skulls as a basis for sex estimation. Their sample consisted of 182 males and 150 females from a pooled sample of four South African indigenous groups. A total of 97 variables were used in order to achieve the desired eight anthropometric measurements. The data were analyzed and multivariate, stepwise, and univariate discriminant function equations were created from the dataset. Accuracy rates using the discriminant functions ranged from 77.0% to 80.0% for correct classification.

Dayal et al. (2008) utilized the skull and mandible for estimating sex from a Black South African population. They used 14 cranial measurements and six mandibular measurements and created six discriminant function equations and demarking points for each measurement. Classification accuracies ranged from 80.0% to 85.0% for the discriminant function equations and ranged from 53.0% to 76.0% for the individualized demarking points for each of the measurements.

2.5 – Sex Estimation using other Post-Cranial Elements

Although the pelvis and the skull provide high accuracy rates for sex estimation, sometimes they are fragmented or missing at a forensic scene. There are only a few studies that use morphological methods for sex estimation using post-cranial elements other than the pelvis (Falys et al., 2005; Rogers, 1999; Rogers et al., 2000). This is because metric analyses provide for a more rigorous and scientific approach to sex estimation, allowing for higher accuracy rates, repeatability, and a decrease in observer bias (Bidmos and Asala, 2003; DiMichele, 2012)

Spradley and Jantz (2011) examined American Black and White individuals, from the Forensic Anthropology Data Bank, to establish accuracy rates for estimating sex from the skull and post-cranial elements. Their research concluded that for both populations (American Black and American White) the humerus, femur, clavicle, and scapula were better classifiers for sex than the skull (Spradley and Jantz 2011). The femur (91.6%), scapula (91.8%), clavicle (93.4%), and the humerus (93.8%) all scored higher overall correct classification accuracies than the skull (90.6%) for sex estimation of American Black populations. The tibia (91.6%), ulna (92.8%) scapula (93.0%), humerus (93.0%), femur (93.5%), clavicle (93.6%), and the radius (94.3%) all scored higher than the skull (90.0%) for sex estimation of American White populations. Based on their findings, Spradley and Jantz (2011) suggested that future research into post-cranial elements for sex estimation should be conducted.

The hyoid has been studied for the estimation of sex (Balseven-Odabasi et al., 2013; Kim et al., 2006; Kindshuh et al., 2010; Logar et al., 2016). Balseven-Odabasi et al. (2013) studied the sexual dimorphism of the hyoid in a Turkish population. They recorded 33 measurements from 85 individuals (32 females and 53 males). Out of the 33 measurements that were tested, only 18 proved to be sexually dimorphic. Using stepwise discriminant function analyses, the researchers achieved an average accuracy rate of 79.3%. Kim et al. (2006) utilized digital photographs of hyoids from 52 Korean males and 33 Korean females. Using V-Ceph Version 3.0, they generated a discriminant function equation with the three most sexually dimorphic features (body length, maximum width of the proximal end of the greater horn, and the length of the thinnest portion of the greater horn), which yielded a correct classification accuracy of 88.2%. Kindshuh et al. (2010) tested sexual dimorphism of the hyoid using an historical White American and Black American sample from the Robert J. Terry skeletal collection. Their study showed classification accuracies between 82.0% and 85.0%. Logar et al. (2016) tested the discriminant functions of Kindshuh et al. (2010) on a contemporary White American sample from the McCormick skeletal collection. Logar et al. (2016) showed that secular change was an impacting factor and resulted in poor classification of the contemporary skeletal collection when the historical discriminant functions were applied. The authors generated population-specific discriminant functions for the contemporary White American population group with accuracy rates ranging from 67.0% to 93.0%.

The sternum has been studied as a means of discriminating sex. Macaluso (2010) utilized the Raymond Dart skeletal collection and the Pretoria collection to analyze eight sternal variables from 123 males and 83 females of Black South African ancestry. The author generated univariate, stepwise, and multivariate discriminant function equations. Univariate discriminant functions had accuracy rates between 68.4% and 83.5%. The stepwise discriminant function, which utilized the corpus semi length and manubrium width, had an 86.4% correct classification accuracy. Finally, the multivariate discriminant functions showed accuracy rates between 80.6% and 84.5%. Franklin et al. (2012) utilized Multisclice Spiral Computed Tomography (MSCT) to analyze eight linear sternal measurements. Discriminant functions were generated from the eight variables and accuracy rates were between 72.2% and 84.5%.

Marino (1995) utilized eight measurements from the first cervical vertebra to test sexual dimorphism. This study examined 100 individuals of White European and Black African descent from the Terry collection and generated discriminant function equations that had accuracy rates between 77.0% and 85.0%. Wescott (2000) studied eight variables of the second cervical vertebra from 400 individuals. His five discriminant functions had correct classification accuracies from 81.7% to 83.4%. Marlow and Pastor (2011) and Bethard and Seet (2013) both conducted validation studies using the five discriminant functions created by Wescott (2000). Marlow and Pastor (2011) tested the Wescott (2000) discriminant functions on a skeletal sample of 18th and 19th century White Europeans (French Huguenots) from the Spitalfields skeletal collection, and attained an overall accuracy rate of 76.9%. Marlow and Pastor (2011) then created a population-specific discriminant function equation, using the individuals from the Spitafields collection, and attained an accuracy rate of 83.3%. Bethard and Seet (2013) applied the discriminant function equations from Westcott (2000) to a skeletal population of mixed ancestry (from the Hamilton County Forensic Centre and the Willian M. Bass Donated Skeletal Collection) and achieved overall accuracy rates from 83.3% to 86.7%. These studies demonstrate the importance of testing discriminant functions on other populations and the development of population-specific studies.

Skeletal elements of the arm have been studied for sex estimation. Frutos (2002), Dabbs and Moore- Jansen (2010), Bell (2013), and Hudson et al. (2016) studied the scapula to estimate sex in various populations. Dabbs and Moore-Jansen (2010) utilized the Hamann-Todd skeletal collection to create a new five-variable discriminant function equation for a White American population. The overall accuracy rate for this method was 95.7%. Bell (2013) applied a seven-variable model to test the hypothesis on Greek and White American populations. In addition to a high classification accuracy (between 87.6% to 94.6%), Bell's results also demonstrated that there were no significant differences between the size of the scapulae of the two populations. Frutos (2002) utilized the clavicle and the scapula for estimating sex in a Guatemalan sample of 35 females and 62 males. The author measured the maximum length and the midshaft circumference of the clavicle and the length and breadth of the glenoid cavity of the scapula. Using the 'leave-one-out' method, he created discriminant functions for the clavicle, the scapula, as well as an equation using both the scapula and clavicle. Accuracy rates for the clavicle ranged from 85.6% to 94.8% correct classification accuracy. The scapula had an overall classification accuracy of 91.0% to 91.2%. Hudson et al. (2016) utilized the scapula for sex estimation from a Mexican skeletal population. The authors tested the Frutos (2002) Guatemalan scapulae discriminant function equations on a Mexican population. Accuracy rates ranged from 48.7% to 100.0% for female and male correct classification, respectively. Hudson et al. (2016) then developed population-specific discriminant function equations for the Mexican population and achieved accuracy rates ranging from 83.6% to 89.3%.

Albanese (2013) used a White European population from the Robert J. Terry skeletal collection and a Portuguese population from the Coimbra skeletal collection to assess the accuracy rates for sex estimation using the clavicle, humerus, radius, and ulna. Based on the 16 equations developed from the measurements, average accuracies ranged from 89.2% (humerus) to 94.2% (clavicle, humerus, radius, and ulna combined). Albanese applied the discriminant function equations, developed from the Terry and the Coimbra skeletal collections, to a White European population from the Grant skeletal collection and to a Portuguese population from the Lisbon skeletal collection. Accuracy rates ranged from 87.8% (clavicle and ulna) to 97.6% (humerus and ulna combined; ulna only) for the White European population and between 77.8% (clavicle, humerus and radius combined; clavicle, ulna and radius combined) and 88.0% (clavicle and humerus combined) for the Portuguese population.

Barrier and L’Abbe (2008) examined estimating sex using the radius and ulna from a sample of 200 Black South African males and 200 Black South African females from the Pretoria and Raymond Dart skeletal collection in South Africa. Direct and stepwise discriminant functions were created using 16 standard anthropometric measurements from the radius and ulna. Accuracy rates ranged between 76.0% (maximum olcrenon breadth) and 89.0% (ulna, all variables).

Mastrangelo et al. (2011a) utilized the carpals for the estimation of sex. Their sample consisted of 50 males and 50 females from a Spanish population and used between four and nine measurements per carpal. A total of 37 univariate discriminant functions and eight multivariate discriminant functions were generated from their data. The lunate had the most accurate discriminant function with 98.5% correct classification accuracy. The least accurate discriminant functions were the univariate equations for the maximum length and maximum height of the triquetral bone, which had a correct classification accuracy of 80.0%. Mastrangelo et al. (2011b) then tested a contemporary Mexican population consisting of 78 males and 58 females from the Universidad Nacional Autonoma de Mexico (UNAM) skeletal collection. Accuracy rates ranged from 61.8% to 90.8% for the univariate discriminant functions and 81.3% to 92.3% when multivariate stepwise discriminant functions were used.

Ross and Manneschi (2009) developed methods for sex estimation from a Chilean population using the femur and the humerus. The maximum vertical head diameter of the humerus, the maximum head diameter of the femur, and the midshaft circumference of the femur were measured to derive linear discriminant function equations. Discriminant function equations were created for each of the three measurements and had accuracy rates of 87.0%, 86.0% and 82.0% respectively. Iscan and Steyn (1997) studied the femur and tibia in a White South African population for the estimation of sex. The data were derived from a sample of 56 males and 50 females from the Pretoria skeletal collection. A total of 13 measurements were subjected to discriminant function analysis. Average correct classification accuracies ranged from 86.0% to 91.0% with the distal breadths of the femur and the tibia being the most sexually dimorphic of the measurements.

The foot has been shown to be morphologically sexually dimorphic, and has demonstrated high accuracy rates for sex estimation (Hemy et al., 2013; Krauss et al. 2011; Case and Ross, 2007). Male feet are usually wider and overall larger than female feet, making the skeletal elements of the foot ideal to use in sex estimation studies (Krauss et al. 2011). Skeletal elements of the feet are often well preserved as they are protected by socks and shoes (Garrido-Varras, 2012a; Ross and Manneschi, 2011**)**. Robling and Ubelaker (1997) used 200 individuals of White European ancestry from the Terry skeletal collection to examine the potential for sex estimation using the metatarsals. They developed discriminant functions with classification accuracies ranging from 83.0% to 100.0%. Mountrakis et al (2010) analyzed metatarsals from a Greek population and derived discriminant functions that resulted in accuracy rates ranging from 80.7% to 90.1%. Lee et al. (2012) used a contemporary Korean population to study the sexual dimorphism of the talus. They collected nine measurements from 140 individuals to generate discriminant function equations with accuracy rates ranging from 67.1% to 87.1%. Peckmann et al. (2015) studied the talus in a contemporary Greek population. Nine measurements were recorded from 182 individuals to create univariate, direct, and stepwise discriminant function equations. Accuracy rates for correct classification ranged from 65.2% to 93.4% for the univariate discriminant functions, 90.5% to 96.5% for the direct discriminant functions, and 86.7% correct classification for the stepwise method.

2.6. The Calcaneus

The calcaneus, often referred to as the ‘heel bone’, is the largest of the tarsal bones and is composed of cancellous and trabecular bone (Gray, 1995; Saladin, 2007).

The calcaneus articulates with the inferior portion of the talus and anteriorly with the cuboid. The calcaneus is responsible for anchoring the calcaneal tendon (or Achille's tendon), which extends to the gastrocnemius and soleus calf muscles allowing for plantar flexion of the foot when the calf muscles are flexed. The calcaneus is also responsible for guiding the tendons for the flexor halluces longus (responsible for moving the first toe) and the fibularis longus, and brevis muscles, which are responsible for plantarflexion and eversion of the foot (Gray, 1995).

The calcaneus begins developing at 13 weeks in utero as a cartilaginous element (Scheuer and Black, 2004). The primary ossification centre appears between the fifth and sixth month in utero (Scheuer and Black, 2004). By the time the infant is born, the calcaneus can be easily identified. The calcaneus has one epiphysis that fuses between the ages of 14 years and 18 years of age, making the calcaneus a good indicator for subadult age estimation (Passalaqua, 2013).

As a major weight bearing bone, the calcaneus is composed of dense trabecular bone. Yattram (1984) established that the density of the calcaneus is directly correlated to the force applied to it, i.e. the more weight applied to the bone, the greater its density. In clinical settings, the calcaneus is an indicator of bone health so that if low bone mineralization is detected in the calcaneus at a young age, the individual may be at risk for osteo-degenerative or osteoporotic disease later in life (Hilderbrand et al., 1999). Also, if an individual is no longer applying weight to the bone, i.e. due to immobility, the calcaneus will lose density (Phan et al, 2006). The density of the calcaneus allows it to withstand high amounts of pressure and erosion (Follet et al, 2004). Due to its high density, the calcaneus is frequently found to be well preserved during excavations; also, it is often protected by socks and shoes, therefore making the calcaneus an invaluable bone in forensics research (Bidmos and Asala, 2003; Pickering, 1986).

2.6.1. Sex Estimation Using the Calcaneus

Steele (1976) was the first to use discriminant function equations to assess the sex of an individual based on measurements of the calcaneus. Steele (1976) used 30 American White males, 30 American White females, 30 American Black males, and 30 American Black males from the Terry skeletal collection. Initially, nine measurements were recorded from the calcaneus, but due to improper instruments and difficulty in accessing anthropometric points, only five of the measurements were used in the discriminant function equations. Correct sex classification accuracy ranged from 79.0% to 89.0%.

Introna et al. (1997) conducted a study using a Southern Italian population from the University of Bari. The study used 40 males and 40 females and recorded eight measurements following Steele's (1976) methodology. They performed univariate and multivariate discriminant function analyses with correct sex classification accuracy rates ranging from 83.5% to 87%. Gualdi-Russo (2007) recorded three measurements from 118 individuals from a contemporary Northern Italian skeletal population at the University of Balogna. Discriminant functions were generated and correct classification ranged between 87.9% and 95.7%. When testing the Northern Italian discriminant functions on the Southern Italian sample used by Introna (1997), the majority of the Southern Italian males were misclassified as females. Accuracy rates for the males were between 30.0%

and 64.0%, while females had correct classification accuracy rates between 96.0% and 99.1%.

Bidmos and Asala (2003) recorded nine calcaneal measurements from 53 White South African males and 60 White South African females from the Raymond Dart skeletal collection. They included a cross-validation sample of 20 males and 20 females from the Dart skeletal collection. Univariate, stepwise, and direct discriminant functions were generated from the data. Correct classification accuracy for the univariate method was between 73.0% and 86.0%. The stepwise method and the direct methods showed accuracy rates between 81.0% and 91.0% and 82.0% and 92.0%, respectively. Cross-validation accuracies ranged from 84.0% to 88.0%. Bidmos and Asala (2004) applied the same methods to a Black South African population of 58 males and 58 females. The overall correct classification accuracies scored lower than that of the South African White population. The length variables were the most sexually dimorphic. When multivariate discriminant functions were used, accuracy rates ranged from 79.0% to 86.0%. Univariate discriminant function accuracy rates ranged from 64.0% to 79.0% correct classification.

DiMichele (2008) used 320 individuals from the William Bass skeletal collection and examined four measurements from the calcaneus. The sample consisted of contemporary individuals of mixed demographics, including American White, American Black, and Hispanic ancestries. The overall accuracy rate ranged from 48.0% to 73.0%. Therefore, DiMichele pooled the ancestry groups for sex estimation which produced an average accuracy rate of 88.6% for females and overall an average accuracy rate of 84.7% for males.

Peckmann et al. (2015) used a Greek population to study sexual dimorphism in the calcaneus. A total of nine measurements were used from 198 individuals. Discriminant function equations were generated and accuracy rates ranged from 70.0% to 90.0% for univariate discriminant functions, 82.9% to 87.5% for direct discriminant functions, and 86.2% for the stepwise method. Cross-validation classification accuracies ranged from 70.0% to 90.0%.

Kim et al. (2013) used 104 calcanei from a Korean sample. There were a total of 10 measurements used to generate discriminant function equations. Accuracy rates were between 65.4% and 89.4%. The authors also compared the mean values with other population groups and found significant differences between Koreans and other population groups demonstrating the need for population-specific discriminant functions.

Reipert et al. (1999) utilized ankle radiographs from 800 White Europeans to assess six variables (three linear measurements and three angles). Out of the six variables, the most sexually dimorphic was the calcaneal length. The calcaneal length showed an overall correct classification of 80.0%. Zhang et al. (2016) studied sexual dimorphism in the calcaneus using radiographs to measure eight variables (five linear measurements and three angles). Their sample consisted of radiographs from 293 Chinese individuals. Their discriminant function equations had accuracy rates ranging from 52.6% to 89.1%. The authors noted that there are limitations to using radiographs: the possibility that the technology may not always be available, and practitioners should be cautious when applying 2D methods derived from radiographs to the 3D skeletal element, as the radiograph may not reflect the accurate size of the skeletal element.

Hoover (1997) utilized the talus, calcaneus, navicular, and intermediate cuneiform from a prehistoric White American population. From a sample of 49 individuals, a total of 15 variables were recorded from the tarsals, and discriminant functions were generated with accuracy rates of 94.0%. Harris (2012) utilized a combination of tarsals (i.e. talus, calcaneus, navicular, intermediate and lateral cuneiform) to create discriminant functions for sex estimation from 18 variables. The author used 82 White European males and 78 White European females from the William Bass Skeletal Collection. Accuracy rates ranged from 74.2% to 93.5% correct classification.

Overall the calcaneus is an invaluable bone to the study of forensic osteology, due to its density, potential for preservation, and its success with high accuracy rates for sex estimation. There is, however, still a requirement to develop population-specific discriminant functions for the Latin American populations (Spradley et al., 2008). This research focuses on creating discriminant functions for sex estimation in two contemporary Latin American populations, Chilean and Mexican.

Chapter 3: Materials and Methods

The goals of this project are to (1) determine if the calcaneus exhibits sexual dimorphism in contemporary Chilean and Mexican populations, (2) determine if the calcaneus differs in size between Chilean and Mexican populations, (3) determine if discriminant function equations developed on a contemporary White South African population will accurately determine sex from the calcaneus in contemporary Chilean and Mexican populations and, (4) compare contemporary Chilean and Mexican population data to other population data.

3.1. Skeletal Collections used for this Research

This research utilized two contemporary skeletal collections: the Sub Actual de Santiago collection at the Universidad de Chile in Santiago and the Universidad Nacional Autónoma de México (UNAM) collection in Mexico City. These collections are considered contemporary because the selected individuals lived the majority of their lives in the mid-20th to 21st centuries.

When creating comparative data sets for forensic anthropological applications, it is important to develop the methods using contemporary samples and from the same skeletal populations to which the data will be applied. This is due to a concept called secular change. Secular change in biological anthropology refers to the allometric changes in body size and bone robusticity for a population over a period of time in response to environmental, genetic and social factors (Danubio and Sanna, 2008; Jantz and Jantz, 1999). From the 1940s onwards, records show that Latin American populations were living longer and healthier lives due to the vaccination and eradication of diseases (i.e. diphtheria, malaria, dengue fever) and increased sanitation regulations (Martinez-Palomo and Sepulveda, 1989).

3.1.1. Universidad de Chile – Sub Actual de Santiago Skeletal Collection

The Chilean collection is a mid to late 20th century skeletal collection housed at the Universidad de Chile, in Santiago, Chile. The skeletal remains that comprise the collection, were donated to the Universidad de Chile from the 'Cemetario Generale', located in Santiago, Chile, under the National Monument Law No. 17228. The individuals in the collection are well documented, with known sex, age-at-death and, in most cases, cause of death. The individuals in this collection were born between 1874 and 1969, with the majority of them birthed between 1920 and 1969. The individuals from this collection died between 1949 and 1986 and with an age at death between neonatal and 96 years of age. In order to achieve a contemporary test sample from the Chilean collection, individuals selected for this project were those that spent the majority of their life post 1940. Data from the Chilean collection used for this study were collected from 64 males and 66 females between 15 years and 90 years of age, with a mean age at death of 44 years.

3.1.2. Universidad Nacional Autonoma de Mexico Skeletal Collection

The Mexican collection is a late 20th to 21st century skeletal collection housed in the Laboratorio de Antropología Física Departamento de Anatomía at the Universidad Nacional Autónoma de México (UNAM) in Mexico City. The remains in this collection were donated to the university by either the deceased prior to their death or by family members. To date, there are 238 individuals registered in this collection. The individuals in the collection have a full documented history, including dates of birth, death, weight, height, age, sex and, when possible, medical history. Birth years for the individuals in this collection range from 1890 to 1987. The individuals in this collection died between 1990 and 2014. In order to achieve a contemporary test sample from the Mexican collection, individuals selected for this project were those that spent the majority of their life post 1940. Data from the Mexican collection were collected from 92 males and 63 females between 15 years and 99 years of age. The mean age at death of the individuals in this collection is 52 years old.

3.2 Methods

A total of 10 variables were measured for each calcaneus. These variables were categorized into length, breadth, and height measurements. Table 3.1 describes each variable measurement recorded from the calcanei, and Figures 3.1 to 3.4 illustrate the landmarks for the variable measurements. All measurements were recorded in millimetres (mm) to the nearest 0.01 mm using a sliding Vernier caliper. The variables were adapted from Martin and Knussmann (1988), Bidmos and Asala (2003) and Kim et al. (2013) (Table 3.1).

Following the protocol of Buikstra and Ubelaker (1998), the left calcaneus was measured unless it exhibited pathologies or damage or was absent, in which case the right calcaneus was used. Only morphologically mature calcanei were chosen. A mature calcaneus would be fully developed with the epiphysis fully fused (Scheuer and Black, 2004). Calcanei exhibiting changes to the bone but not inhibiting measurement recording were included in the study (Figure 3.5). Any calcanei exhibiting structural malformations, arthritic degradation, or severe cortical bone damage where the measurement variables could not be assessed (i.e. original healthy margins were no longer observable) were not selected (Figure 3.6).

Table 3.1 – Descriptions of calcaneal measurements and their respective definitions

Measurement	Abbreviation	Definition*	Reference
Calcaneal length measurements			
Maximum length	MAXL	Projection of the most posterior point of the tuberosity of the calcaneus to the most anterior/superior point of the cuboidal facet.	Martin and Knussman, 1988
Load arm length	LAL	The linear distance between the most posterior aspect on the posterior articular surface for the talus to the most anterior superior point of the cuboidal facet.	Steele, 1988
Dorsal articular facet length	DAFL	The linear distance between the most posterior and the most anterior points on the posterior articular facet of the calcaneus.	Martin and Knussman, 1988
Calcaneal breadth measurements			
Middle breadth	MIDB	The maximum breadth of the calcaneus measured linearly at the most medial edge of the sustenaculum tali to the most lateral edge of the dorsal articular facet.	Martin and Knussman, 1988
Minimum breadth	MINB	The distance between the medial and lateral surfaces of the superior part of the body of the calcaneus.	Bidmos and Asala, 2003
Dorsal articular facet breadth	DAFB	Measurements taken from the most medial to the most lateral points on the posterior articular facets.	Martin and Knussman, 1988
Calcaneal height measurements			
Maximum height	MAXH	Distance between the most superior and the most inferior points of the calcaneal tuberosity.	Bidmos and Asala, 2003
Minimum height	MINH	Straight distance from the concavity of the superior surface of the body of the calcaneus to the most concave point on the inferior surface of the calcaneal body.	Kim et al., 2013
Body height	BH	Distance between the superior and inferior surfaces of the body of the calcaneus taken in the coronal plane, midpoint between the most posterior point of the dorsal articular facet and the most anterior point of the calcaneal tuberosity.	Bidmos and Asala, 2003
Cuboidal facet height	CFH	The linear distance between the most superior and the most inferior points on the cuboidal articular facet.	Martin and Knussman, 1988

*Modified from Martin and Knussman, (1988), Bidmos and Asala, (2003), Kim et al., (2013)

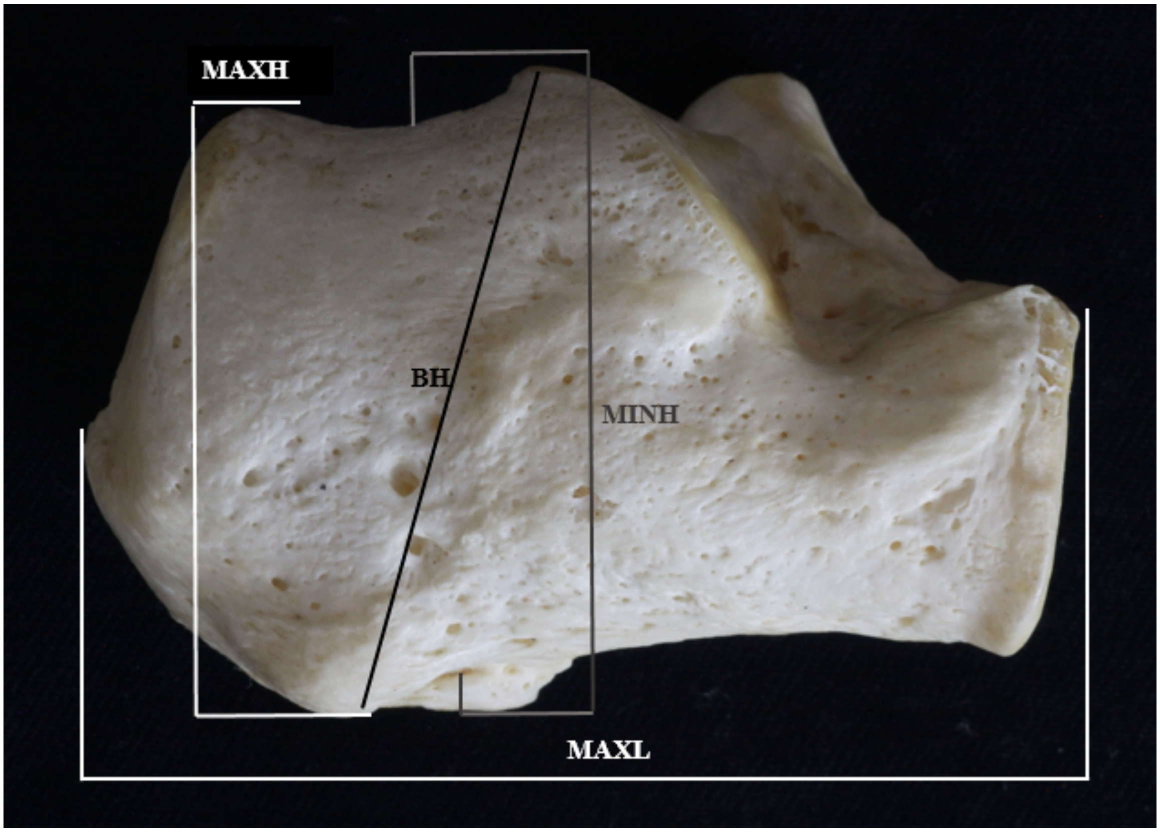

Figure 3.1 – Calcaneus, lateral view. Measurements of the calcaneus: maximum length (MAXL), maximum height (MAXH), body height (BH), and minimum height (MINH). Photo taken by: Natasha Dilkie, 2015

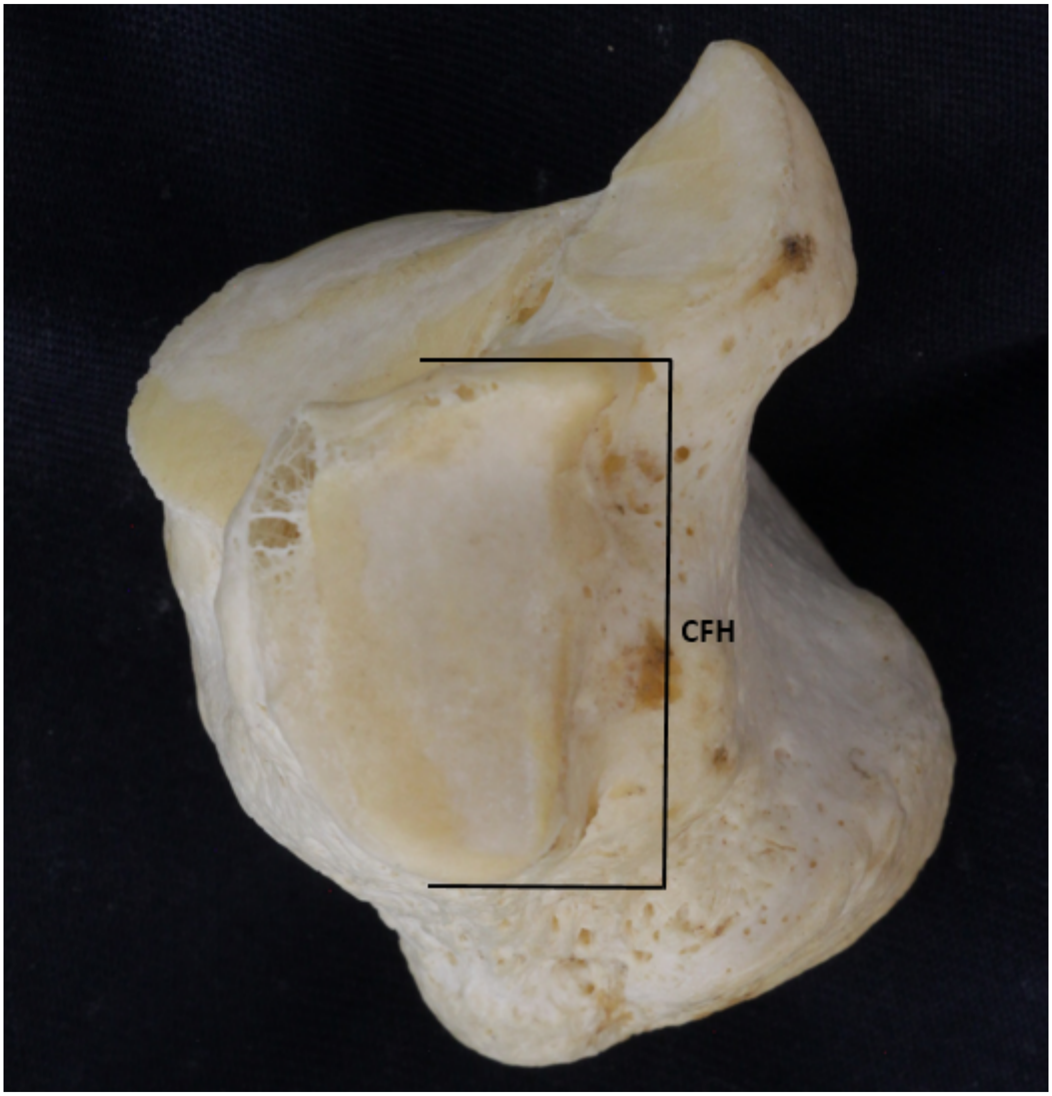

Figure 3.2 – Cuboidal articular facet, anterior view. Measurement of the cuboidal articular facet height (CFH). Photo taken by: Natasha Dilkie, 2015

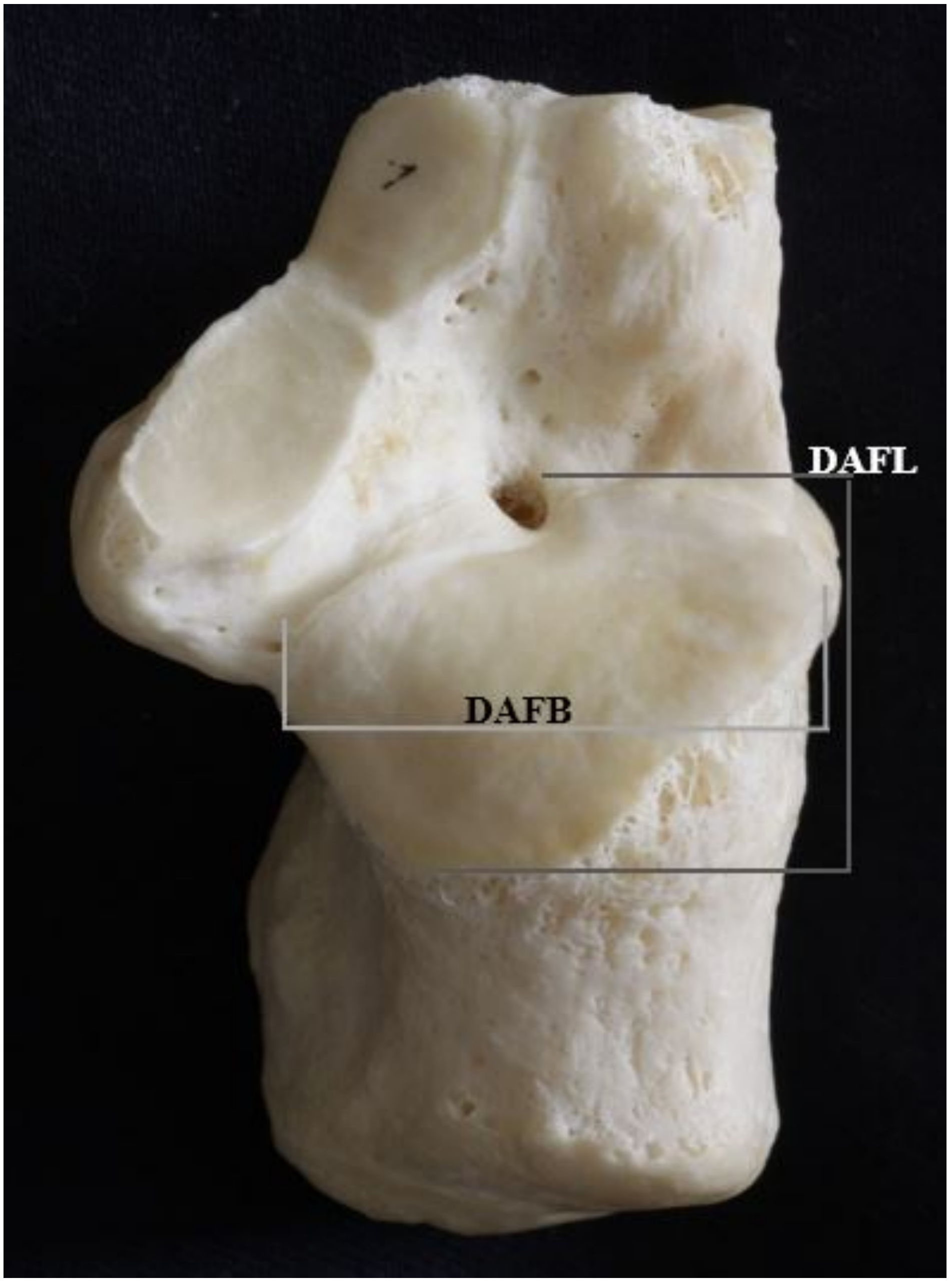

Figure 3.3 – Calcaneus, superior view. Measurements of the dorsal articular facet: dorsal articular facet length (DAFL) and dorsal articular facet breadth (DAFB): Photo taken by: Natasha Dilkie, 2015.

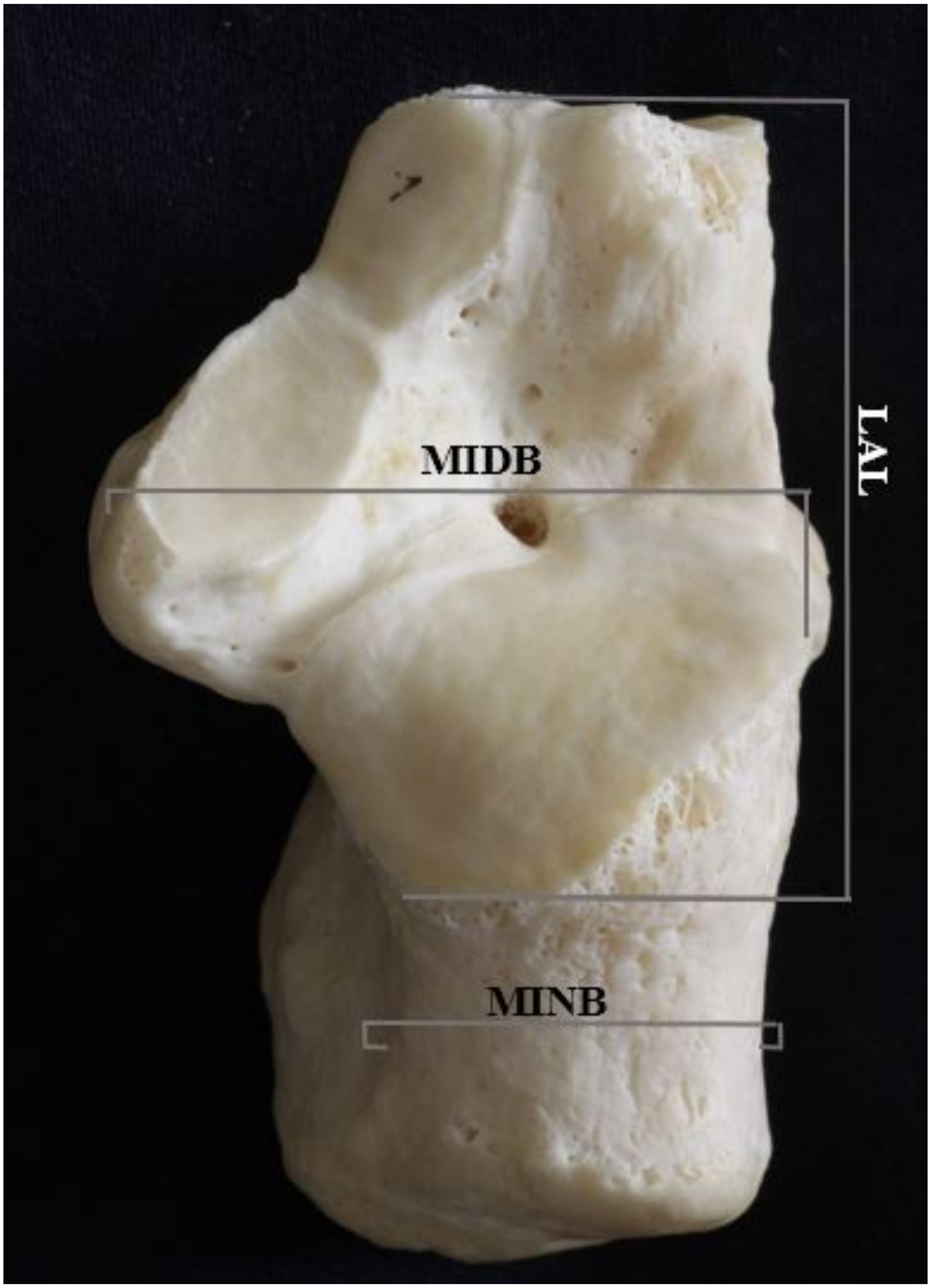

Figure 3.4 – Calcaneus, superior view. Measurements of the calcaneus: minimum breadth (MINB), middle breadth (MIDB) and load arm length (LAL). Photo taken by: Natasha Dilkie, 2015.

Figure 3.5 – Example of minor erosion and minor osteophytic growth on the posterior surface of the calcaneus. Measurements were not inhibited by the erosion or the osteophytic growth. Photo taken by: Ciara Logar, 2014

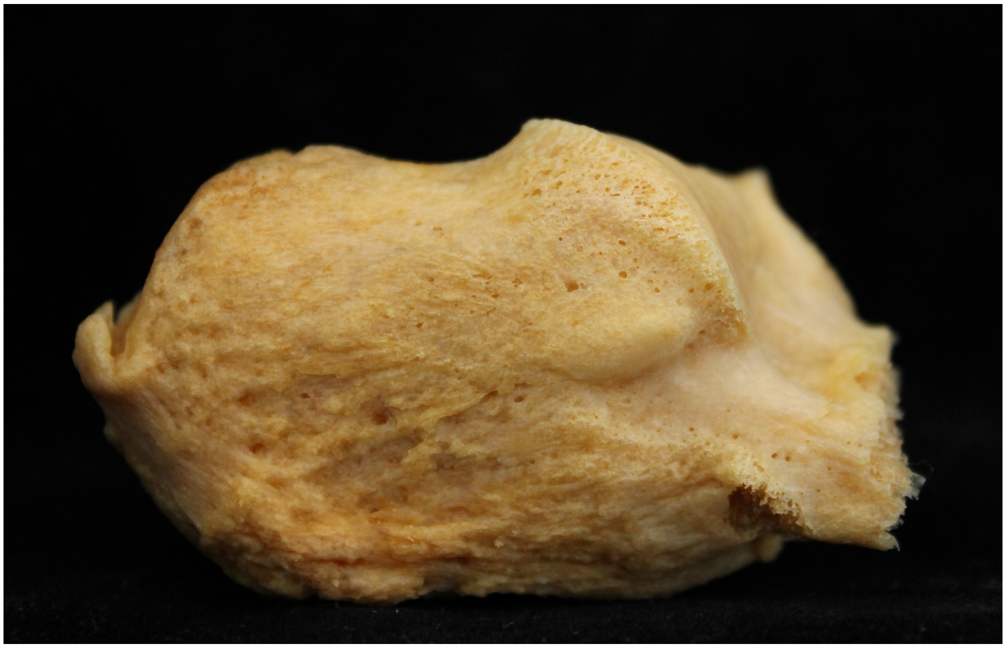

Figure 3.6 – Example of a highly degraded and osteophytic calcaneus that was not included for the data collection. The cuboidal facet has been obliterated during the maceration process. Osteophytic growth on the posterior surface of the body of the calcaneus prohibited recording measurements. Photo taken by: Ciara Logar, 2014

3.3 Statistical Methodologies

The following statistical methods were applied to both the Chilean and Mexican populations. Each of the populations was analyzed independently from one another unless otherwise specified. This study follows the protocol of the discriminant function approach that Bidmos and Asala (2003) outlined in their research using the calcaneus as a method for sex differentiation in a White South African population. Minitab version 17.0, Minitab Express version 1.5.0 were used to calculate the descriptive statistics, Anderson-Darling normality tests, two-sample t-tests, and independent sample t-tests. Statistical Package for Social Sciences 23.0 (SPSS) was used to calculate the discriminant function equations. Descriptive statistics (means and standard deviations) for males and females were calculated for both the Mexican and Chilean data sets to obtain means and standard deviations for each measurement.

3.3.1. Bilateral Asymmetry

Tests for bilateral asymmetry were conducted on 32 individuals from the Chilean population sample and 31 individuals from the Mexican population sample. Normality of differences between left and right calcanei were first tested. Parametric t-tests were applied to the normally distributed data in order to test for the presence or absence of bilateral asymmetry. If no significant differences were found between left and right calcanei; protocol developed by Buikstra and Ubelaker (1998) were followed. The left calcaneus was measured, unless it was unavailable or damaged so that the measurement points were inaccessible for use (Figure 3.6).

Bonferonni adjustment is applied to alpha values where multiple comparisons are used and a strong evidence for significance is required (i.e. a more conservative test) thereby reducing the rate of type I error (i.e. rejecting a true null hypothesis or false negative). A Bonferonni adjustment (*α / n comparisons*; where *α* is equal to 0.05 and *n* is equal to 10*)* was applied to alpha (α_{adjusted}= 0.005).

3.3.2. Intra-observer and Inter-observer Error

To ensure the methodology can be replicated and repeated by the researcher, a random sub-sample of the data set was selected for remeasurement. Intra-observer error analysis was conducted by the current researcher by remeasuring a subsample of 30 individuals total from the Chilean and Mexican collections with two weeks between measurements. The difference between the original 30 measurements and the 30 remeasurements were tested for normality using the Anderson-Darling normality test. As the measurements were repeated twice per individual, paired comparisons were used. Non-parametric paired Wilcoxon-Rank test was used for non-normally distributed variables, and parametric paired t-test was used for normally distributed variables. Bonferonni correction was applied to alpha ($\alpha = 0.005$) to avoid a type I error.

To assess for inter-observer error, a graduate student in each city (Santiago and Mexico City) remeasured the same subsample of 30 individuals as the current researcher, two weeks after the original measurements were recorded. The differences between the original 30 measurements and the 30 remeasurements were tested for normality using the Anderson-Darling normality test. In order to assess reproducibility, a non-parametric Wilcoxon-Rank Sign test was used for non-normally distributed variables and a parametric paired t-test was used for normally distributed variables. Bonferonni correction was applied to alpha (α = 0.005) to avoid a type I error.

Technical error of measurement (TEM) and relative technical error of measurement (rTEM) were also calculated for both intra- and inter-observer error to assess the reliability (Perini et al., 2005). Using the same sub-samples that were used in the previous tests, TEM for each variable was calculated using the following equation for the intra- and inter-observer sub-samples:

$$TEM = \sqrt{\frac{(\Sigma D^2)}{2N}}$$

Where *D* is the difference between the two measurements and *N* is the number of individuals used in the sample. When TEM is calculated it holds the same units as the variable measured. In order to reflect as a comparative value, TEM was converted to rTEM which is expressed as a percentage. Using the previously calculated TEM and the variable averages (VAV – average of the first and second measurement for each individual, and then overall average for all individuals per variable measured), the following equation was applied for each variable to assess the percentage difference between measurements for both intra- and inter-observer error:

$$rTEM = \frac{TEM}{VAV} * 100$$

3.3.3. Sexual Dimorphism Analysis

Testing for sexual dimorphism was performed on both the Chilean and Mexican populations independently. In order to test for sexual dimorphism in the Chilean data set, the measurement variables for both males and females were tested independently for normal distribution using the Anderson-Darling normality test. Bonferonni correction was applied to alpha (adjusted $\alpha = 0.005$) to avoid type I error. In order to determine if the Chilean calcanei were sexually dimorphic, independent two-sample t-tests were used to compare the means and standard deviations of the 10 measurement variables between males and females. The normality tests and the independent two-sample t-tests were repeated for the Mexican data set in order to establish if sexual dimorphism is present in this population.

3.3.4. Population Analysis

Two sample t-tests were used to calculate the differences between the calcaneal measurements between the Chilean and Mexican populations. If $p \leq 0.005$ (Bonferroni applied), then a significant difference between the two populations exists, and the two populations would not be combined for further data analysis. If $p \geq 0.005$ (Bonferroni applied) for all measurements, then a significant difference does not exist between the Chilean and Mexican populations and the data would be combined for further analysis and will be referred to as 'Combined CM'.

The discriminant functions developed by Bidmos and Asala (2003) from a White South African population were applied to the Chilean and Mexican populations to determine if the White South African discriminant functions would accurately determine sex from the calcaneus in contemporary Chilean and Mexican populations. Classification accuracies were calculated by dividing the total number of correctly classified males by the total number of individuals and dividing the total number of correctly classified females by the total number of individuals. The Chilean and Mexican data sets were analyzed independently from one another. Table 3.2 shows the equations that were developed by Bidmos and Asala (2003) from a White South African population.

Table 3.2 – Discriminant function (stepwise, multivariate and univariate) equations developed by Bidmos and Asala (2003) on a White South African population. *

Equation	Sectioning point
Stepwise discriminant function equations	
y = (DAFB x 0.314) + (MAXL x 0.081) + (MIDB x 0.159) + (-19.932)	- 0.042
y = (DAFB x 0.366) + (MIDB x 0.260) + (-18.421)	0.065
y = (MAXL x 0.163) + (MIDB x 0.180) + (-18.343)	0.010
y = (CFH x 0.341) + (BH x 0.223) + (-15.765)	0.009
Multivariate discriminant function equations	
y = (DAFB x 0.295) + (MAXL x 0.088) + (MIDB x 0.163) + (DAFL x 0.038) + (LAL x [- 0.036]) + (CFH x 0.103) + (MINB x 0.075) + (MAXH x [- 0.008]) + (BH x [- 0.266]) + (- 19.628)	- 0.045
Multivariate discriminant function equations	
y = (DAFB x 0.352) + (MIDB x 0.228) + (MINB x 0.063) + (- 18.333)	0.044
y = (MAXL x 0.154) + (DAFL x 0.170) + (LAL x 0.025) + (-18.478)	0.010
y = (CFH x 0.313) + (BH x 0.151) + (MAXH x 0.083) + (- 16.208)	0.001
Univariate discriminant function equations	
y = (DAFB x 0.552) + (- 12.150)	0.065
y = (MAXL x 0.227) + (- 18.210)	0.019
y = (MIDB x 0.476) + (- 18.960)	0.051
y = (DAFL x 0.448) + (- 13.080)	0.052
y = (MINB x 0.463) + (- 9.634)	0.031
y = (CFH x 0.479) + (- 10.350)	0.007
y = (BH x 0.360) + (- 13.566)	0.038
y = (MAXH x 0.291) + (- 13.220)	0.034
y = (LAL x 0.314) + (- 14.380)	0.007

*Maximum length (MAXL), load arm length (LAL), dorsal articular facet length (DAFL), dorsal articular facet breadth (DAFB), minimum breadth (MINB), middle breadth (MIDB) maximum height (MAXH), body height (BH), and cuboidal articular facet height (CFH)

3.3.5. Discriminant Function Analysis

Discriminant function analysis is commonly used in forensic anthropology to differentiate groups. For this study, discriminant functions were used to discriminate between sexes, i.e. males and females, by using IBM SPSS software. Discriminant function equations were created from the combined data from Chilean and Mexican populations, referred to as the 'Combined CM' data. Three types of discriminant functions (direct, stepwise and univariate) were developed in order to achieve the highest correct classification accuracy results for sex classification.

Direct discriminant function analysis was used to create multivariate discriminant function equations. The multivariate analysis produced an equation that utilized all 10 measurements. Additional multivariate discriminant function equations were produced that included all length measurements, all breadth measurements, and all height measurements independently. Standardized coefficients, structure matrices, eigenvalues and canonical correlations identified which of the measurements had the highest predictive capability for the Chilean and Mexican populations. Stepwise discriminant function analysis employed SPSS and was used to create clustered measurement discriminant functions. The selected combination of measurements was based on which of the highest classifying measurements yielded the highest accuracy of prediction (i.e. highest accuracy classification) variables. When fragmentary remains are recovered, it may not be possible to employ multivariate and stepwise discriminant functions as not all measured variables may be present; therefore, univariate functions may need to be used. Univariate discriminant functions were created from each of the 10 variables to assess the accuracy of each variable when used in individual equations. For each of the discriminant function equations, percent accuracy was calculated based on the number of correctly classified individuals divided by the total number of individuals (i.e. males or females), multiplied by 100.

In order to validate the newly created discriminant functions, the "leave-one-out" test was conducted using SPSS version 23. Although the Subactual de Santiago skeletal collection and the UNAM skeletal collections have an overall robust sample size, factors such as lack of proper storage facilities, poor preservation methods, and frequent handling of the remains resulted in a smaller sample size available for this project. For these reasons, there were an insufficient number of calcanei to set aside for an independent sample for validation without compromising sample size for the creation of robust discriminant functions. However, cross-validation could be conducted by using a “leave-one-out” test, which systematically classified the data by the functions derived from all cases minus the one case left out of the analysis. The outputs generated by SPSS provide a number and classification accuracy percentage to indicate how accurately the newly created discriminant functions would classify.

3.3.6. Population Comparison Tests

Independent two sample t-tests were used to calculate the differences between the calcaneal measurements between the Combined CM data set and other populations. Means and standard deviations from the Combined CM dataset were tested against the means and standard deviations of other calcanei population studies by applying the Independent Two Sample t-test to various populations : Greek (Peckmann et al., 2015), Korean (Kim et al., 2013), Historic White European and Black (Steele, 1976), White South African (Bidmos and Asala, 2003), Black South African (Bidmos and Asala, 2004), Northern Italian (Introna et al., 1997), Southern Italian (Gualdi-Russo, 2007), White European (DiMichele, 2008), Prehistoric New Zealand (Murphy, 2002), Hispanic (Tise et al., 2013). This test was calculated using Minitab Express version 1.5.0.

Chapter 4: Results

Data for the Chilean sample were collected from 64 males and 66 females between 15 years and 90 years of age, with a mean age at death of 44 years. Data for the Mexican sample were collected from 92 males and 63 females between 15 years and 99 years of age, with a mean age at death of 52 years old. A total of 10 variables were measured for each calcaneus: Maximum Length (MAXL), Maximum Height (MAXH), Body Height (BH), Minimum Height (MINH) Dorsal Articular Facet Length (DAFL), Dorsal Articular Facet Breadth (DAFB), Minimum Breadth (MINB), Middle Breadth (MIDB) Load Arm Length (LAL), and Cuboidal Articular Facet Height (CFH). These variables were categorized into length (MAXL, DAFL, LAL), breadth (DAFB, MINB, MIDB), and height (MAXH, BH, MINH, CFH) measurements.

4.1. Bilateral Asymmetry

4.1.1. Chilean Population

Table 4.1 shows the results from the paired t-test that was used to test for bilateral asymmetry for the Chilean population. A total of 32 individuals from the Chilean population sample were measured. The data were normally distributed for 9 variables (MAXL, MAXH, BH, MINH, DAFL, DAFB, MIDB, LAL, CFH) in the Chilean population. Therefore, a paired t-test was used to test for bilateral asymmetry for these nine variables. The MINB variable was not normally distributed and therefore a Wilcoxon Rank Sign Test was applied to the data to test for bilateral asymmetry. All variables, except DAFB ($p = .001$), showed P-values greater than α ($p = 0.005$) therefore, no bilateral asymmetry was present. The mean difference for DAFB was calculated to be 0.78 mm. According to Kindschuh et al. (2010) this difference is biologically irrelevant and the use of measurements within the discriminant functions is not unique to either the left or right calcaneus, therefore either bone can be used. According to methods established by Buikstra and Ubelaker (1998), the left calcaneus was measured for all variables unless it was damaged, pathological, or absent, in which case the right calcaneus was used.

Table 4.1 – Bilateral asymmetry between left and right calcanei of the Chilean population.

Measurement	n	Mean difference between left and right (mm)	Test	Test statistic	P-value
MAXL	32	0.21	T-test	T = - 1.35	0.19
LAL	32	0.06	T-test	T = 0.35	0.73
DAFL	32	0.26	T-test	T = -1.41	0.17
MIDB	32	0.20	T-test	T = -0.11	0.91
MINB	32	0.16	Wilcoxon Rank Sign Test	W = 221.00	0.11
DAFB	32	0.66	T-test	T = 3.01	0.001*
MAXH	32	0.59	T-test	T = - 1.92	0.06
BH	32	0.20	T-test	T = 1.60	0.12
MINH	32	0.23	T-test	T = -0.49	0.62
CFH	32	0.49	T-test	T = -1.88	0.07

*Significance p<0.005

4.1.2. Mexican Population

Table 4.2 lists the results from the bilateral asymmetry tests conducted on the 31 individuals from the Mexican population sample. The data for all 10 variables were normally distributed in the Mexican population. Therefore, a paired t-test was used to analyze the data, for all 10 variables. Since the P-values were greater than α (p = 0.005), no significant differences were observed between left and right calcanei. Therefore, bilateral asymmetry does not exist in the calcaneus. As per methods established by Buikstra and Ubelaker (1998), the left calcaneus was measured for all variables unless it was damaged, pathological, or absent, in which case the right calcaneus was used.

Table 4.2 – Bilateral asymmetry between left and right calcanei of the Mexican population.

Measurement	n	Mean difference between left and right (mm)	Test	Test statistic	P-value
MAXL	31	0.02	T-test	T = -0.10	0.92
LAL	31	0.34	T-test	T = 1.42	0.17
DAFL	31	0.49	T-test	T = -2.72	0.01
MIDB	31	0.01	T-test	T = -0.08	0.94
MINB	31	0.09	T-test	T = -0.82	0.42
DAFB	31	0.00	T-test	T = 0.00	0.99
MAXH	31	0.28	T-test	T = - 1.11	0.27
BH	31	0.52	T-test	T = 2.64	0.01
MINH	31	0.08	T-test	T = -0.37	0.71
CFH	31	0.03	T-test	T = 0.20	0.85

*Significance $p<0.005$

4.2. Intra-Observer and Inter-Observer Error

A non-parametric paired Wilcoxon-Rank test was used for non-normally distributed variables and a parametric paired t-test was used for normally distributed variables to test for intra- and inter-observer error. Table 4.3 demonstrates that there are no statistically significant differences between intra-observer measurements. This indicates that the measurements taken were consistent and can be reproduced accurately by one researcher.

Technical error of measurement (TEM) and relative technical error of measurement (rTEM) were calculated using the differences between variable measurements. Table 4.4 demonstrates the TEM values range from 0.32mm to 0.99mm and the rTEM values range from 0.81% to 3.33% difference for intra-observer error. Studies have cited that for intra-observer TEM, results that show less than a 2.0 mm difference are acceptable (Stull et al., 2014), and for rTEM, results that show less than 7.5% are acceptable (Perini et al., 2005). The TEM results of this study demonstrate that the measurements recorded were taken with precision and reliability.

Table 4.3 – Statistical analyses for intra-observer error.

Measurement	n	Test	Test statistic	P-value
MAXL	30	T-test	T = - 0.46	0.65
LAL	30	T-test	T = 0.83	0.41
DAFL	30	T-test	T = 1.43	0.16
MIDB	30	T-test	T = 1.01	0.32
MINB	30	Wilcoxon	W = 162.50	0.15
DAFB	30	T-test	T = 2.02	0.05
MAXH	30	Wilcoxon	W = 287	0.26
BH	30	T-test	T = - 2.53	0.02
MINH	30	T-test	T = 3.02	0.01
CFH	30	T-test	T = 1.94	0.06

*Significance $p<0.005$

Table 4.4 – Intra-observer Technical Error of Measurement.

Variables	MAXL	LAL	DAFL	MIDB	MINB	DAFB	MAXH	BH	MINH	CFH
Sum Deviations^2	24.58	16.08	23.64	6.21	12.27	23.26	41.86	58.48	7.55	38.00
TEM (mm)	0.64	0.52	0.63	0.32	0.45	0.62	0.84	0.99	0.35	0.80
Relative TEM (%)	0.85	1.08	2.22	0.81	1.82	2.16	1.94	2.27	0.99	3.33

Table 4.5 displays the inter-observer error rates. The only variable that showed a significant difference between the two observers was the BH measurement. This indicates that a clearer definition or marked landmarks are required when measuring the BH variable. The remaining nine measurements demonstrated no significant difference indicating that the measurements taken were consistent and can be reproduced accurately.

Technical error of measurement (TEM) and relative technical error of measurement (rTEM) were calculated using the differences between variable measurements. Table 4.6 demonstrates the inter-observer error TEM values range from 0.63 mm to 2.41 mm, and the rTEM values range from 1.27% to 5.57%. Studies have cited that for inter-observer TEM, results that show less than a 2.0 mm difference are acceptable (Stull, 2014), and for rTEM, results that show less than 10.0% are acceptable (Perini et al., 2005). Although the BH variable was within the rTEM limit, the TEM value was 2.41 mm. This discrepancy is consistent with the inter-observer error results and caution should be taken when using the BH variable. The remaining variables' TEM and rTEM values fall within the acceptable limits. Therefore, these measurements were taken accurately between researchers.

Table 4.5 – Statistical analyses for inter-observer error.

Measurement	n	Test	Test statistic	P-value
MAXL	30	T-test	T = - 0.77	0.45
LAL	30	T-test	T = 0.34	0.73
DAFL	30	T-test	T = 1.53	0.14
MIDB	30	T-test	T = -0.31	0.76
MINB	30	T-test	T = 0.00	0.99
DAFB	30	T-test	T = 3.01	0.01
MAXH	30	T-test	T = - 1.13	0.27
BH	30	T-test	T = - 4.26	0.00*
MINH	30	Wilcoxon Rank Test	T = 271.00	0.43
CFH	30	T-test	T = 0.759	0.76

*Significance p<0.005

Table 4.6 – Inter-observer Technical Error Measurement.

Variable	MAXL	LAL	DAFL	MIDB	MINB	DAFB	MAXH	BH	MINH	CFH
Sum Deviations^2	54.42	44.78	46.09	23.90	36.23	69.84	30.92	349.37	123.85	48.80
TEM (mm)	0.95	0.86	0.88	0.63	0.78	1.08	0.72	2.41	1.44	0.90
Relative TEM (%)	1.27	1.80	3.09	1.58	3.15	3.73	1.67	5.57	4.03	3.78

4.3. Descriptive Statistics and Sexual Dimorphism

4.3.1. Chilean Population

Table 4.7 shows the means, standard deviation, mean difference between sexes, and the independent t-test for both males and females for the Chilean population. Overall, the calcanei of Chilean males are larger than those of Chilean females. The p-values from the independent t-test confirm that there are significant differences between the males and females of the Chilean population for all variables measured. Therefore, the calcaneus can be used for the estimation of sex in the Chilean population.

Table 4.7 – Descriptive statistics and independent t-test for the Chilean population.

Variable	Sex	n	Mean (mm)	Standard Deviation (mm)	Mean difference in male and female measurement (mm)	P-value
MAXL	Male	64	78.02	3.85	6.39	0.00*
	Female	66	71.63	3.48		
LAL	Male	64	50.15	2.38	5.04	0.00*
	Female	66	45.11	2.24		
DAFL	Male	64	30.05	2.15	3.03	0.00*
	Female	66	27.02	1.91		
MIDB	Male	64	41.13	2.41	4.08	0.00*
	Female	66	37.05	2.20		
MINB	Male	64	25.75	2.66	2.27	0.00*
	Female	66	23.48	2.03		
DAFB	Male	64	29.51	2.70	3.16	0.00*
	Female	66	26.35	2.18		
MAXH	Male	64	44.10	3.77	3.78	0.00*
	Female	66	40.32	2.54		
BH	Male	64	44.00	3.54	3.69	0.00*
	Female	66	40.31	2.83		
MINH	Male	64	37.06	2.81	4.17	0.00*
	Female	66	32.89	2.36		
CFH	Male	64	25.16	2.18	2.40	0.00*
	Female	66	22.76	1.77		

*Significance $p<0.005$

4.3.2. Mexican population

Table 4.8 list the means, standard deviation, mean difference between sexes, and the independent t-test for both males and females for the Mexican population. Overall, the calcanei of Mexican males are larger than those of Mexican females. The p-values from the independent t-test confirm that there are significant differences between the males and females of the Mexican population for all variables measured. Therefore, the calcaneus can be used for the estimation of sex in the Mexican population.

Table 4.8 – Descriptive statistics and independent t-test for the Mexican population.

Variable	Sex	n	Mean (mm)	Standard Deviation (mm)	Mean difference in male and female measurement (mm)	P-value
MAXL	Male	92	77.45	4.99	7.02	0.00*
	Female	63	70.43	5.39		
LAL	Male	92	48.99	3.59	3.99	0.00*
	Female	63	44.34	3.02		
DAFL	Male	92	29.35	2.32	3.31	0.00*
	Female	63	26.04	2.29		
MIDB	Male	92	40.87	2.64	4.39	0.00*
	Female	63	36.48	2.86		
MINB	Male	92	26.02	2.25	3.10	0.00*
	Female	63	22.92	2.46		
DAFB	Male	92	29.87	2.51	3.25	0.00*
	Female	63	26.62	2.33		
MAXH	Male	92	43.95	3.68	4.02	0.00*
	Female	63	39.93	3.34		
BH	Male	92	45.35	3.45	3.64	0.00*
	Female	63	41.71	3.58		
MINH	Male	92	36.82	3.06	3.70	0.00*
	Female	63	33.12	2.90		
CFH	Male	92	36.82	3.06	13.98	0.00*
	Female	63	22.84	1.87		

*Significance $p<0.005$

4.4. Population dimorphism

4.4.1. Testing for Population Dimorphism Between Chilean and Mexican Populations

Table 4.9 shows the means, standard deviation, mean difference between sexes, and the independent t-tests for males of the Chilean and Mexican populations. The independent t-tests confirm that there are no significant differences between the males of the Chilean population and the males of the Mexican population. Table 4.10 shows the means, standard deviation, mean difference between sexes, and the independent t-tests for females of the Chilean population and the females of the Mexican population. The independent t-tests confirm that there are no significant differences between the females of the Chilean populations and females of the Mexican population. Since a significant difference does not exist for either sex, when comparing the Chilean and Mexican populations, the populations were therefore combined for further analyses and are referred to as the 'Combined CM' population.

Table 4.9 – Independent t-test results for testing population dimorphism between the Chilean and Mexican male population.

Variable	Ancestry	n	Mean (mm)	Mean difference between populations (mm)	95% Confidence interval Lower	95% Confidence interval Upper	P-value	T-value
MAXL	Chilean	64	78.02	0.57	0.83	1.97	0.42	-0.80
	Mexican	92	77.45					
LAL	Chilean	64	50.15	1.15	-0.21	2.10	0.02	-2.42
	Mexican	92	49.00					
DAFL	Chilean	64	30.05	0.70	0.02	1.42	0.06	-1.93
	Mexican	92	29.35					
MIDB	Chilean	64	41.13	0.26	0.55	1.07	0.53	-0.63
	Mexican	92	40.87					
MINB	Chilean	64	25.75	0.27	0.54	1.07	0.51	0.66
	Mexican	92	26.02					
DAFB	Chilean	64	29.51	0.36	0.48	1.21	0.40	0.85
	Mexican	92	29.87					
MAXH	Chilean	64	44.10	0.14	1.06	1.34	0.81	-0.23
	Mexican	92	43.96					
BH	Chilean	64	44.00	1.35	0.22	2.48	0.02	2.37
	Mexican	92	45.35					
MINH	Chilean	64	37.06	0.24	0.70	1.18	0.62	-0.50
	Mexican	92	36.82					
CFH	Chilean	64	25.17	0.03	0.68	0.73	0.94	-0.07
	Mexican	92	25.14					

*Significance $p<0.005$

Table 4.10 – Independent t-test results for testing population dimorphism between the Chilean and Mexican female population.

Variable	Ancestry	n	Mean (mm)	Mean difference between populations (mm)	95% Confidence interval Lower	95% Confidence interval Upper	P-value	T-value
MAXL	Chilean	66	70.43	1.20	0.39	2.80	0.14	-1.50
	Mexican	63	71.63					
LAL	Chilean	66	45.11	0.77	0.16	1.70	0.10	-1.64
	Mexican	63	44.34					
DAFL	Chilean	66	27.02	0.98	0.24	1.71	0.01	2.63
	Mexican	63	26.04					
MIDB	Chilean	66	37.05	0.57	0.33	1.46	0.21	-1.26
	Mexican	63	36.48					
MINB	Chilean	66	23.48	0.56	0.23	1.34	0.16	-1.40
	Mexican	63	22.92					
DAFB	Chilean	66	26.35	0.27	0.52	1.06	0.50	0.68
	Mexican	63	26.62					
MAXH	Chilean	66	40.32	0.38	0.65	-1.42	0.47	-0.73
	Mexican	63	39.93					
BH	Chilean	66	40.13	1.40	0.27	2.53	0.01	2.46
	Mexican	63	41.72					
MINH	Chilean	66	32.89	0.23	0.69	1.16	0.61	0.50
	Mexican	63	33.12					
CFH	Chilean	66	22.76	0.08	0.56	0.72	0.80	0.25
	Mexican	63	22.84					

*Significance $p<0.005$

4.4.2. Sexual Dimorphism in the ‘Combined CM’ Population

Table 4.11 shows the means, standard deviation, mean difference between sexes, and the independent t-tests for both males and females for the ‘Combined CM’ population. Overall, for the ‘Combined CM’ population, male calcanei were larger than female calcanei. The p-values from the independent t-tests confirm that there are significant differences between the males and females of the ‘Combined CM’ population. Therefore, the calcaneus can be used for the estimation of sex in the ‘Combined CM’ population.

Table 4.11 – 'Combined CM' population descriptive statistics.

Measurement	Sex	n	Mean (mm)	Standard Deviation (mm)	Mean difference in male and female measurement (mm)	P-value$^{\beta}$
MAXL	Male	156	77.68	4.55	6.64	0.00*
	Female	129	71.04	4.54		
LAL	Male	156	49.47	3.19	4.74	0.00*
	Female	129	44.73	2.67		
DAFL	Male	156	29.64	2.27	3.09	0.00*
	Female	129	26.54	2.15		
MIDB	Male	156	49.97	2.55	4.20	0.00*
	Female	129	36.77	2.55		
MINB	Male	156	25.91	2.42	2.70	0.00*
	Female	129	23.21	2.25		
DAFB	Male	156	29.72	2.59	3.24	0.00*
	Female	129	26.48	2.25		
MAXH	Male	156	44.01	3.70	3.88	0.00*
	Female	129	40.13	2.95		
BH	Male	156	44.79	3.53	3.80	0.00*
	Female	129	41.00	3.28		
MINH	Male	156	36.92	2.95	3.92	0.00*
	Female	129	33.00	2.63		
CFH	Male	156	25.15	2.18	2.35	0.00*
	Female	129	22.80	1.82		

* Significance $p<0.005$

$^{\beta}$ Minitab software used only displayed variables to two decimal places.

4.4.3. Testing White South African Discriminant Functions on the 'Combined CM' Population

Discriminant function equations generated using nine variables from the White South African population data were applied to the 'Combined CM' population dataset (Table 4.12). Overall, the discriminant functions derived from the White South African population dataset did not accurately classify the 'Combined CM' population. When the White South African discriminant function equations were applied to the 'Combined CM' population, the data showed greater male-bias than female-bias overall.

For the multivariate discriminant functions, overall correct classification accuracies ranged from 45.26% to 88.64%. When all nine variables were applied to the 'Combined CM' population dataset, they showed the lowest (45.26%) overall correct classification accuracy. Females (100%) were classified with greater accuracy than the males (0.00%). The height (MAXH, BH, CFH) variables showed the highest overall correct classification (69.47%). Males (96.15%) were classified with greater accuracy than the females (37.21%). The breadth (DAFB, MIDB, MINB) and length (MAXL, LAL, DAFL) variables both showed overall correct classification of 63.51%. For the breadth variables combined, males (99.36%) were classified with higher accuracy than the females (20.15%). However, for the length variables, females (96.12%) were classified with greater accuracy than the males (36.54%).

Table 4.12 – Testing the White South African discriminant functions on the 'Combined CM' population.

	Predicted group membership						
	Male		Female		Overall correct classification		Sex bias
	n	%	n	%	n	%	%
Testing White South African Multivariate Discriminant Functions							
All nine variables	0/156	0.00	129/129	100.00	129/285	45.26	-100.00
Breadth variables only (DAFB, MIDB,MINB)	155/156	99.36	26/129	20.15	181/285	63.51	79.21
Length variables only (MAXL, LAL, DAFL)	57/156	36.54	124/129	96.12	181/285	63.51	-59.58
Height variables only (MAXH, BH, CFH)	105/156	96.15	48/129	37.21	198/285	69.47	58.94
Testing White South African Stepwise Discriminant Functions							
Nine variables (DAFB, MAXL, MIDB)	149/156	95.50	66/129	51.10	215/285	75.40	44.40
Breadth variables only (DAFB, MIDB)	155/156	99.36	37/129	28.68	192/285	67.36	70.68
Length variables only (MAXL, DAFL)	51/156	32.69	124/129	96.12	175/285	61.40	-63.43
Height variables only (BH, CFH)	154/156	98.71	16/129	12.40	170/285	59.65	86.31
Testing White South African Univariate Discriminant Functions							
MAXL	41/156	26.28	123/129	95.34	164/285	88.64	-69.06
LAL	139/156	89.10	86/129	66.67	225/285	78.95	22.43
DAFL	89/156	57.05	115/129	89.15	204/285	71.58	-32.10
DAFB	156/156	100.00	2/129	1.55	158/285	55.44	98.45
MIDB	100/156	64.10	121/129	93.80	221/285	77.54	-29.70
MINB	155/156	99.36	19/129	14.73	174/285	61.05	84.63
MAXH	54/156	34.61	126/129	97.67	180/285	63.16	-63.06
BH	152/156	97.43	22/129	17.05	174/285	61.05	80.38
CFH	147/156	94.23	30/129	23.26	177/285	62.10	70.97

The stepwise discriminant function equations use the most discriminant variables to yield the highest accuracy rates. Overall classification accuracies ranged from 59.65% to 75.40%. When the most discriminant variables (DAFB, MAXL, MIDB) of all nine variables were applied to the 'Combined CM' population dataset, they showed the highest (75.40%) overall correct classification accuracy. Males (95.50%) were classified with greater accuracy than the females (51.10%). When the height (BH, CFH) stepwise discriminant function was applied to the 'Combined CM' population dataset, it yielded the lowest overall accuracy (59.65%). Males (98.71%) were classified with greater accuracy than females (12.40%). The stepwise discriminant functions using the most discriminant breadth (DAFB and MIDB) variables yielded an overall accuracy rate of 67.36% with males (99.36%) being classified more accurately than females (28.68%). The stepwise discriminant functions using the the most discriminant length variables (MAXL and DAFL) yielded an overall accuracy rate of 61.40% with females (96.12%) being classified more accurately than males (32.69%).

Overall classification accuracies for the univariate discriminant function equations varied from 55.44% to 88.64%. The highest (88.64%) overall correct classification accuracy was when the univariate MAXL discriminant function was applied to the 'Combined CM' population. Females (95.34%) were classified with greater accuracy than the males (26.28%). The DAFB variable had the lowest overall correct classification of 55.44% with males (100%) being classified more accurately than females (1.55%). The LAL variable had an overall accuracy rate of 78.95% with males showing an accuracy rate of 89.10% and females 66.67%. The DAFL variable had an overall accuracy rate of 71.58% with females (89.15%) classified more accurately than males (57.05%). The MIDB variable had an overall correct classification of 77.54% accuracy with females

(93.80%) showing higher sex accuracy than males (64.10%). Both the MINB variable and BH variable univariate discriminant function equations had overall accuracy rates of 61.05%. For the MINB and BH variables, the males (99.36%, 97.43%, respectively) were classified more accurately than the females (14.73%, 17.05%, respectively). The MAXH variable had an overall correct classification of 63.16% with females (97.67%) showing higher sex accuracy than males (34.61%). The CFH variable had an overall correct classification accuracy of 62.10%. The males (94.23%) were classified more accurately than the females (23.26%).

4.5. Discriminant Function Analysis

4.5.1. Discriminant Functions of the 'Combined CM' Population

Discriminant function equations were generated from the 'Combined CM' population and are shown in Table 4.13. Overall classification accuracies ranged from 80.00% to 86.30%. The multivariate discriminant function using all 10 variables had the highest eigenvalue and canonical correlation, indicating that it has the highest discriminating factor and effect size. It also had the highest overall correct classification accuracy rate of 86.30%. The equation with the lowest overall classification was the multivariate discriminant function using the height variables only (80.00%). The discriminant function equation using only the length variables had an overall correct classification of 81.80%. The discriminant function equation using only the breadth variables had an overall correct classification of 83.20%. In all four multivariate discriminant function equations, females were classified with greater accuracy than the males.

Table 4.13 – Discriminant function statistics for the ‘Combined CM’ population.

Function	Variable(s) included	Discriminant function equation	Sectioning point	Eigenvalue	Canonical correlation	Wilk’s Lambda	Male correct classification		Female correct classification		Overall correct classification	
							n	%	n	%	n	%
Multivariate discriminant functions												
1 – All variables	MAXL, LAL DAFL MIDB MINB DAFB MAXH BH MINH CFH	[MAXL(0.002) + LAL(0.084) + DAFL (0.103) + MIDB(0.139) + MINB(0.047) + DAFB(0.069) + MAXH(-0.009) + BH (-0.010) + MINH (0.053) + CFH (0.060)] + (-18.061)	-0.09	0.94	0.70	0.52	134/156	85.90	112/129	86.80	246/285	86.30
2 – Length variables	MAXL LAL DAFL	[MAXL(0.072) + LAL(0.154) + DAFL(0.170)] + (-17.445)	-0.08	0.75	0.65	0.57	125/156	80.10	108/129	83.70	233/285	81.80
3 – Breadth variables	MIDB MINB DAFB	[MIDB(0.255) + MINB(0.106) + DAFB(0.129)] + (-16.218)	-0.09	0.79	0.66	0.56	128/256	82.10	109/129	84.50	237/285	83.20
4 – Height variables	MAXH BH MINH CFH	[MAXH(0.051) + BH(0.009) + MINH(0.205) + CFH(0.223)] + (-15.121)	-0.07	0.61	0.61	0.62	120/156	76.90	108/129	83.70	228/285	80.00
Stepwise discriminant functions												
5 –Most discriminant variables	LAL DAFL MIDB DAFB	[LAL(0.109) + DAFL(0.119) + MIDB(0.175) + DAFB(0.088)] + (-17.832)	-0.09	0.90	0.69	0.52	135/159	86.50	112/129	86.80	247/285	86.00

Table 4.13 – Discriminant function statistics for the 'Combined CM' population (continued).

Function	Variable(s) included	Discriminant function equation	Sectioning point	Eigenvalue	Canonical correlation	Wilk's Lambda	Male correct classification		Female correct classification		Overall correct classification	
							n	%	n	%	n	%
Univariate discriminant functions												
6 – Maximum length	MAXL	MAXL (0.220) + (-16.429)	-0.11	0.53	0.59	0.65	120/158	76.90	99/129	76.70	219/285	76.80
7 – Load arm length	LAL	LAL (0.337) + (-15.937)	-0.08	0.63	0.62	0.61	120/158	76.90	104/129	80.60	224/285	78.60
8 – Dorsal articular facet length	DAFL	DAFL (0.45) + (-12.718)	-0.07	0.48	0.57	0.67	119/158	76.30	97/129	75.20	216/285	75.80
9 – Middle breadth	MIDB	MIDB (0.392) + (-15.326)	-0.08	0.68	0.64	0.56	128/156	82.10	101/129	78.30	229/285	80.40
10 – Minimum breadth	MINB	MINB (0.426) + (-10.523)	-0.05	0.33	0.50	0.75	111/156	71.20	96/129	74.40	207/285	72.60
11 – Dorsal articulate facet breadth	DAFB	DAFB (0.410) + (-11.577)	-0.06	0.44	0.55	0.69	113/156	72.40	96/129	74.40	209/285	73.30
12 – Maximum height	MAXH	MAXH (0.295) + (-12.485)	-0.05	0.33	0.50	0.75	109/156	69.90	92/129	71.30	201/285	70.50
13 – Body height	BH	BH (0.292) + (-12.583)	-0.05	0.31	0.48	0.76	113/156	72.4	91/129	70.50	204/285	71.60
14 – Minimum height	MINH	MINH (0.356) + (-12.503)	-0.07	0.48	0.57	0.67	117/156	75.00	106/129	82.20	223/285	78.20
15 – Cuboidal articular facet height	CFH	CFH (0.494) + (-11.899)	-0.05	0.34	0.50	0.75	111/158	71.20	97/129	75.20	208/258	73.00

n = *n* correctly classified individuals / *n* total individuals

The stepwise discriminant function uses the most discriminating variables, in order to derive the equation. The variables, from the ‘Combined CM’ population, that are the most discriminating are: LAL, DAFL, MIDB, and DAFB. This stepwise discriminant function equation (Equation 5) had the second highest overall classification accuracy (86.00%) when compared to all of the other generated discriminate function equations. The females (86.80%) were classified with a slightly higher degree of accuracy than the males (86.50%).

Overall, the univariate equations from the ‘Combined CM’ population showed the lowest accuracy rates for sex classification, with accuracy rates ranging from 70.50% to 80.40%. The MIDB (80.40%) displayed the highest overall correct classification accuracy and the MAXH (70.50%) showed the lowest overall correct classification accuracy. Females had greater classification accuracies in six (LAL, MINB, DAFB, MAXH, MINH and CFH) out of the 10 variables that were tested. Males had greater classification accuracy in four (MAXL, DAFL, MIDB, BH) of the 10 variables that were tested.

4.5.2. Cross-Validation for the ‘Combined CM’ Population

Cross-validation was completed using a “leave-one-out” systematically classified the data by the discriminant functions generated from all cases minus the one case left out of the analysis by the SPSS statistical software. The outputs generated by SPSS provided a number and classification accuracy percentage to indicate how accurately the ‘Combined CM’ discriminant functions would classify (Table 4.14). Equation 5 (the stepwise discriminant function) was the highest (86.00%) correctly classified discriminant function. The discriminant function equation with the lowest overall correct classification was univariate Function 12 (70.50%) which used the maximum height variable. The cross-validation data confirm that functions 1, 2, 3, and 5 are the most discriminatory, have the highest overall classification accuracies, and that the univariate discriminant functions show lower classification accuracies than the multivariate or stepwise equations.

Table 4.14 – Leave-one-out statistics for ‘Combined CM’ population.

Function	Variable(s) included	Discriminant function equation	Male correct classification		Female correct classification		Overall correct classification	
			n	%	n	%	n	%
Multivariate discriminant functions								
1 – All variables	MAXL, LAL DAFL, MIDB, MINB, DAFB MAXH, BH MINH, CFH	[MAXL(0.002) + LAL(0.084) + DAFL (0.103) + MIDB(0.139) + MINB(0.047) + DAFB(0.069) + MAXH(-0.009) + BH (-0.010) + MINH (0.053) + CFH (0.060)] + (-18.061)	130/156	83.30	111/129	86.00	241/285	84.60
2 – Length variables	MAXL, LAL, DAFL	[MAXL(0.072) + LAL(0.154) + DAFL(0.170)] + (-17.445)	125/156	80.10	106/129	82.20	231/285	81.10
3 – Breadth variables	MIDB, MINB, DAFB	[MIDB(0.255) + MINB(0.106) + DAFB(0.129)] + (-16.218)	127/156	81.40	109/129	84.50	236/285	82.80
4 – Height variables	MAXH, BH, MINH, CFH	[MAXH(0.051) + BH(0.009) + MINH(0.205) + CFH(0.223)] + (-15.121)	118/156	75.60	106/129	82.20	224/285	78.60
Stepwise discriminant functions								
5 –Most discriminant variables	LAL DAFL MIDB DAFB	[LAL(0.109) + DAFL(0.119) + MIDB(0.175) + DAFB(0.088)] + (-17.832)	135/156	86.50	110/129	85.30	245/285	86.00
Univariate discriminant functions								
6 – Maximum length	MAXL	MAXL(0.220) + (-16.429)	120/156	76.90	99/129	76.70	219/285	76.80
7 – Load arm length	LAL	LAL(0.337) + (-15.937)	120/156	76.90	104/129	80.60	224/285	78.60
8 – Dorsal articular facet length	DAFL	DAFL(0.45) + (-12.718)	119/156	76.30	97/129	75.20	216/285	75.80
9 – Middle breadth	MIDB	MIDB(0.392) + (-15.326)	128/156	82.10	101/129	78.30	229/285	80.40
10 – Minimum breadth	MINB	MINB(0.426) + (-10.523)	111/156	71.60	96/129	74.40	207/285	72.60
11 – Dorsal articulate facet breadth	DAFB	DAFB(0.410) + (-11.577)	113/156	72.40	96/129	74.40	209/285	73.30
12 – Maximum height	MAXH	MAXH(0.295) + (-12.485)	109/156	69.90	92/129	71.30	201/285	70.50
13 – Body height	BH	BH(0.292) + (-12.583)	113/156	72.40	91/129	70.50	204/285	71.60
14 – Minimum height	MINH	MINH(0.356) + (-12.503)	117/156	75.00	106/129	82.20	223/285	78.20
15 – Cuboidal articular facet height	CFH	CFH(0.494) + (-11.899)	111/156	71.20	97/129	75.20	208/285	73.00

n = *n* correctly classified individuals / *n* total individual

4.6. Population Comparison

4.6.1. Comparison between 'Combined CM' Population and Other Populations

Table 4.15 lists the means, standard deviation, mean difference between sexes, and the independent t-test for males and females, between the 'Combined CM' population group and the following population groups: Greek (Peckmann et al., 2015), Korean (Kim et al., 2013), White American (Steele, 1976), Black American (Steele, 1976), White South African (Bidmos and Asala, 2003), Black South African (Bidmos and Asala, 2004), Northern Italian (Introna et al., 1997), Southern Italian (Gualdi-Russo, 2007), North American (DiMichele, 2008), New Zealand (Murphy, 2002), and Hispanic (Tise, 2010). The p-values show that there are significant differences between the males and females from the 'Combined CM' population and those of the other population groups.

When comparing the 'Combined CM' population to the Greek population, there is a significant difference in seven of the eight variables for both the males and the females. When comparing the 'Combined CM' population to the Korean population, there is a significant difference in eight of the ten variables for males and eight of the ten variables for females. When comparing the 'Combined CM' population to the White American population, there is a significant difference in three out of the five variables for both males and females and a significant difference in four of the five variables for both the males and females in the Black American population. For both males and females, when comparing the 'Combined CM' population to the Black South African population, there is a significant difference in seven of the nine variables and a significant difference in eight of the nine variables for the White South African population. When comparing the

‘Combined CM’ population to the Northern Italians, there is a significant difference in the two variables examined for both males and females. When comparing the ‘Combined CM’ population to the Southern Italians, there is a significant difference in four of the six variables for males and three of the six variables for females. When comparing the ‘Combined CM’ population to the North American sample, there is a significant difference in the two variables examined for both males and females. When comparing the ‘Combined CM’ population to the New Zealand Polynesian sample, there is a significant difference in three of the five variables for males and two of the five variables for females. When comparing the ‘Combined CM’ population to the Hispanic population, there was a significant difference in one of the two variables examined for males; however, no significant difference was found between the ‘Combined CM’ population and the female Hispanic sample.

Table 4.15 – Population comparisons with the ‘Combined CM’ population dataset.

	Authors	Present Study			Peckmann et al. (2016)			Kim et al. (2012)			Steele (1976)			Steele (1976)		
	Population	Combined CM			Greek			Korean			White American			Black American		
Sex	Variables	n	Mean (mm)	SD	n	Mean (mm)	SD	n	Mean (mm)	SD	n	Mean (mm)	SD	n	Mean (mm)	SD
Male	MAXL	156	77.68	4.55	88	83.41*	4.35	50	80.50*	3.80	30	81.10*	5.60	30	82.70*	4.90
	LAL	156	49.47	3.19	88	51.93*	3.18	50	46.80*	4.20	30	50.80	3.90	30	50.40	3.20
	DAFL	156	29.64	2.27	88	30.53*	2.31	50	26.30*	2.40	-	-	-	-	-	-
	MINB	156	25.91	2.42	88	23.98*	2.65	50	26.10	2.90	30	27.90*	2.40	30	28.40*	3.70
	DAFB	156	29.72	2.59	88	32.08*	2.31	50	28.50*	2.60	-	-	-	-	-	-
	MAXH	156	44.01	3.70	88	48.28*	3.68	50	46.80*	3.90	-	-	-	-	-	-
	BH	156	44.79	3.53	88	47.73*	3.26	50	41.40*	2.80	30	44.80	2.80	30	42.40*	2.90
	MINH	156	36.92	2.95	-	-	-	50	39.60*	3.80	-	-	-	-	-	-
	CFH	156	25.15	2.18	88	25.58	1.85	50	26.00	2.40	-	-	-	-	-	-
	MIDB	156	49.97	2.55	-	-	-	50	43.10*	2.50	30	41.60*	2.70	30	43.70*	3.30
Female	MAXL	129	71.04	4.54	80	75.14*	3.56	54	73.80*	4.30	29	75.50*	3.90	30	75.80*	4.00
	LAL	129	44.73	2.67	80	46.76*	2.69	54	42.40*	4.00	29	46.90*	2.40	30	46.10	2.30
	DAFL	129	26.54	2.15	80	26.96	2.04	54	23.90*	2.40	-	-	-	-	-	-
	MINB	129	23.21	2.25	80	21.22*	1.86	54	24.40*	2.40	29	25.00*	2.30	30	25.80*	2.70
	DAFB	129	26.48	2.25	80	28.29*	2.23	54	27.20	2.30	-	-	-	-	-	-
	MAXH	129	40.13	2.95	80	42.80*	3.01	54	44.60*	3.30	-	-	-	-	-	-
	BH	129	41.00	3.28	80	42.28*	2.59	54	37.10*	2.50	29	39.90	3.40	30	39.20*	2.90
	MINH	129	33.00	2.63	-	-	-	54	35.5	2.50	-	-	-	-	-	-
	CFH	129	22.80	1.82	80	22.97	1.81	54	24.90*	2.30	-	-	-	-	-	-
	MIDB	129	36.77	2.55	-	-	-	54	39.60*	2.40	29	38.30	2.70	30	39.00*	2.50

*Significance $p<0.005$

Table 4.15 – Population comparisons with the Combined CM population dataset (continued).

	Authors	Present Study			Bidmos (2004)			Bidmos and Asala (2003)			Gualdi-Russo (2007)			Introna et al. (2004)		
Sex	Population	Combined CM			Black South African			White South African			Northern Italian			Southern Italian		
	Variables	*n*	Mean (mm)	SD	*n*	Mean (mm)	SD	*n*	Mean (mm)	SD	*n*	Mean (mm)	SD	*n*	Mean (mm)	SD
Male	MAXL	156	77.68	4.55	58	79.82*	3.77	52	84.78*	4.73	61	81.60*	4.40	40	83.41*	3.70
	LAL	156	49.47	3.19	58	44.15*	2.58	53	48.19	3.41	-	-	-	-	-	-
	DAFL	156	29.64	2.27	58	30.32	1.94	53	31.18*	2.09	-	-	-	-	-	-
	MINB	156	25.91	2.42	58	27.58*	2.47	53	22.34*	2.09	-	-	-	40	28.40*	3.00
	DAFB	156	29.72	2.59	58	22.85*	1.70	53	24.02*	2.01	-	-	-	40	26.00*	2.20
	MAXH	156	44.01	3.70	58	43.11	3.45	53	47.72*	3.55	-	-	-	40	45.20	3.30
	BH	156	44.79	3.53	58	36.31*	2.75	53	39.44*	2.76	60	43.00*	2.90	40	46.80*	3.40
	MINH	156	36.92	2.95	-	-	-	-	-	-	-	-	-	-	-	-
	CFH	156	25.15	2.18	58	23.97*	1.89	47	22.98*	2.16	-	-	-	40	24.50	2.40
	MIDB	156	49.97	2.55	58	42.54*	2.66	53	41.96*	2.07	-	-	-	-	-	-
Female	MAXL	129	71.04	4.54	58	73.68*	4.83	54	75.87*	4.07	50	73.50*	3.20	40	72.50	5.30
	LAL	129	44.73	2.67	58	41.04*	2.86	54	43.32	2.94	-	-	-	-	-	-
	DAFL	129	26.54	2.15	58	27.17	2.16	60	27.49*	1.86	-	-	-	-	-	-
	MINB	129	23.21	2.25	58	25.56*	2.52	58	19.43*	2.22	-	-	-	40	25.30*	2.60
	DAFB	129	26.48	2.25	58	20.63*	1.90	60	20.21*	1.58	-	-	-	40	23.20*	2.30
	MAXH	129	40.13	2.95	58	40.05	3.20	59	43.39*	3.33	-	-	-	40	40.00	3.20
	BH	129	41.00	3.28	58	33.83*	2.86	60	36.03*	2.79	50	38.30*	2.60	40	41.90*	3.50
	MINH	129	33.00	2.63	-	-	-	-	-	-	-	-	-	-	-	-
	CFH	129	22.80	1.82	58	20.97*	1.83	48	20.22*	2.02	-	-	-	40	22.40	2.40
	MIDB	129	36.77	2.55	58	39.20*	2.76	59	37.94*	2.13	-	-	-	-	-	-

Table 4.15 – Population comparisons with the Combined CM population dataset (continued).

Sex	Authors	Present Study			DiMichele (2008)			Murphy (2002)			Tise (2010)		
	Population	Combined CM			North American			NZ Polynesian			Hispanic		
	Variables	*n*	Mean (mm)	SD	*n*	Mean (mm)	SD	*n*	Mean (mm)	SD	*n*	Mean (mm)	SD
Male	MAXL	156	77.68	4.55	182	87.81*	5.09	25	80.33*	3.07	35	79.40	6.54
	LAL	156	49.47	3.19	184	54.40*	3.44	25	49.67	2.62	-	-	-
	DAFL	156	29.64	2.27	-	-	-				-	-	-
	MINB	156	25.91	2.42	-	-	-	26	25.32	1.82	-	-	-
	DAFB	156	29.72	2.59	-	-	-				-	-	-
	MAXH	156	44.01	3.70	-	-	-				-	-	-
	BH	156	44.79	3.53	-	-	-	24	39.75*	2.38	-	-	-
	MINH	156											
	CFH	156	25.15	2.18	-	-	-						
	MIDB	156	49.97	2.55	-	-	-	26	44.21*	1.88	34	42.00*	2.13
Female	MAXL	129	71.04	4.54	133	79.79*	4.17	21	71.34	4.24	6	74.43	7.50
	LAL	129	44.73	2.67	131	48.82*	2.84	22	46.17	2.34	-	-	-
	DAFL	129	26.54	2.15	-	-	-	-	-	-	-	-	-
	MINB	129	23.21	2.25	-	-	-	20	22.43	2.19	-	-	-
	DAFB	129	26.48	2.25	-	-	-	-	-	-	-	-	-
	MAXH	129	40.13	2.95	-	-	-	-	-	-	-	-	-
	BH	129	41.00	3.28	-	-	-	20	34.60*	2.78	-	-	-
	MINH	129	33.00	2.63	-	-	-	-	-	-	-	-	-
	CFH	129	22.80	1.82	-	-	-	-	-	-	-	-	-
	MIDB	129	36.77	2.55	-	-	-	22	40.58*	1.86	7	38.00	2.60

*Significance $p<0.005$

Chapter 5: Discussion

5.1. Context of the Current Study

Chile and Mexico are scattered with the bones of civil conflict. In Mexico alone, since 2006, the United Nations estimates that there are at least 26,000 cases of enforced disappearance with thousands of more individuals who remain unidentified in mass graves (UN, 2015). It is necessary to apply accurate population-specific sex estimation techniques for human skeletal remains to aid in the identification of these missing individuals. However, many of the sex estimation techniques utilized by forensic anthropologists were developed using non-Latin American populations. This project examines the estimation of sex from the calcaneus in two Latin American populations, Chile and Mexico.

On 11 of September 1973, the Chilean government experienced a military coup after the death of President Salvador Allende and Augusto Pinochet became dictator of Chile from 1973 to 1990. During that time, those that opposed Augusto Pinochet were tortured, imprisoned, and killed. Approximately 3,227 individuals were killed, of which 364 were documented to be executed without the repatriation of remains (Comision de Veridad y Reconciliacion, 1991; Garrido Varas, 2013). Burials for execution victims were sometimes marked; however, it was not uncommon to find additional human remains in burial plots already assigned to a deceased individual or in unmarked graves (Quinn, 2014). With human rights cases when possible, DNA tests will be performed after strict considerations of the recovered remains. However, it is not within Chile's policy to conduct DNA tests on all bone fragments recovered (Garrido Varas and Intriago Leiva, 2012a). Therefore, identification of unknown human remains has focused on utilizing a multidisciplinary approach for human identification, including forensic anthropological analyses (Garrido Varas and Intriago Leiva, 2012a).

The ongoing state of corruption, gang violence, war, and drug cartels in Mexico has resulted in the deaths of thousands of people (Molloy, 2013). In addition to the estimated hundreds of mass graves that have yet to be exhumed, many people are fleeing the country in attempts to seek asylum elsewhere. The number of deceased unidentified migrant crossers has increased in the past decade as many individuals die *en route* due to the poor and dangerous living conditions. The Mexican government is doing very little to mitigate this situation, and oftentimes it is non-governmental, not-for-profit organizations that assist in the recovery and identification of the deceased individuals (Pantaleo, 2010). Using DNA analyses for all unidentified human remains that are recovered is not an option, as the monetary resources for these organizations are limited and dependent on donations or fund raising. Therefore, these organizations also utilize less expensive forensic anthropological methods for the identification of unknown human remains (Pantaleo, 2010).

The calcaneus was chosen for this project as it is the largest foot bone in the human body. It has been shown to be useful for identification as it is often well preserved during excavations. The increased preservation is related to the increased strength and density of the bone's trabeculae and because it is often encased in socks and/or shoes (Peckmann et al., 2015). Footwear serves as protective “armor” and storage containers for feet that would otherwise be exposed to taphonomic events (Saul and Saul, 2005, p. 360). Research has shown high accuracy rates for sex determination from the calcaneus (Bidmos and Asala, 2003; Bidmos and Asala, 2004; Gualdi-Russo, 2007; Introna et al., 1997; Murphy, 2002; Pickering, 1986); however, these studies have cited the methods to be population specific.

The current project examined the calcaneus as a means to estimate sex in contemporary Chilean and Mexican populations. The goals of this project are to (1) determine if sexual dimorphism is present in the calcaneus of contemporary Chilean and Mexican populations, (2) determine if there is a statistically significant difference in size between Chilean and Mexican calcanei and, if so, does this reflect a need for different ancestral discriminant function equations for each population, (3) determine if discriminant function equations developed on a contemporary White South African population will accurately estimate sex from the calcaneus of contemporary Chilean and Mexican populations and, (4) compare contemporary Chilean and Mexican population data to other population data. The contemporary White South African population was chosen for comparison because, at the time the current project began, it was the only published article that used the same variables as the current research. Also, because of the lack of population-specific data for Latin American populations, traditionally, White European discriminant functions were often applied to skeletal remains from Latin America.

5.2 Bilateral Asymmetry in the Calcaneus

When using paired skeletal elements for developing new sex estimation methods, it is important to test for bilateral asymmetry. In the current research study, paired t-tests were conducted on both the Chilean and Mexican populations (combined male and female samples, randomly selected) to test for bilateral asymmetry. In the Chilean population, a statistically significant difference was only present in the DAFB variable (0.66 mm difference between left and right measurements). However, the numerical difference (0.66 mm) between the left and right calcanei was small and was only present in this one measurement (DAFB). Therefore, this difference is considered to be biologically irrelevant (i.e. 2%) and in accordance with Kindschuh et al. (2010), who state that if differences between sides are relatively small, left and right sides can be averaged. The Mexican population showed no statistically significant difference in bilateral asymmetry for any of the calcanei measurements. These findings, of the Chilean and Mexican samples, are in agreement with other sex estimation studies utilizing the calcaneus, which have found no significant difference in bilateral asymmetry in the calcaneus (Scott et al., 2017; Peckmann et al., 2015; Gualdi-Russo, 2007). However, a study conducted by Harris and Case (2012) using the calcaneus of a European-American population did find significant asymmetry in both male and female populations. This shows the importance of testing for bilateral asymmetry for every new population sample that is studied.

5.3 Intra- and inter-observer Error

Reliability and repeatability of measurements are of paramount importance in forensic anthropology. Measurements must be well defined so that researchers examining those variables are able to understand the definition and reproduce the measurement. The results of the intra-observer and error analyses showed that none of the variables were statistically significant therefore there were no differences within observers. The results of the inter-observer error analyses showed that one of the variables (BH) was statistically significant. Therefore, aside from the BH variable, there were no differences within observers. Statistically acceptable coefficients of reproducibility were obtained.

Technical error of measurement (TEM) and relative technical error of measurement (rTEM) were calculated using the differences between variable measurements. Tables 4.3

and 4.4 demonstrate that there are no statistically significant differences between intra-observer measurements. This indicates that the measurements taken were consistent and can be reproduced accurately.

Tables 4.5 and 4.6 display the inter-observer error rates. Nine measurements demonstrated no statistically significant difference indicating that the measurements taken were consistent and can be reproduced accurately. The only variable that showed a statistically significant difference between the two observers was the BH measurement. It must be noted however, that the significant difference between the BH measurement was small (TEM = 2.41 mm and rTEM at 5.57% difference). The BH measurement is defined as: Distance between the superior and inferior surfaces of the body of the calcaneus taken in the coronal plane, midpoint between the most posterior point of the dorsal articular facet and the most anterior point of the calcaneal tuberosity. The significant difference could be a result of subjectivity between observers in locating the exact point of the measurement or possibly caliper placement. It is possible that more training to enhance familiarity with the measurement may lead to better accuracy with repeating this measurement between observers. Another reason for the statistically significant difference could be due to a language barrier between the researcher and assistant when describing the methodology for measurements; English was not the first language of the research assistant who helped with re-measuring the variables to test for inter-observer error.

5.4 Sexual Dimorphism in the Chilean, Mexican, and ‘Combined CM’ Populations

The results of this study demonstrate that sexual dimorphism is present in all of the variables of the Chilean population, the Mexican population, and when both populations were combined (i.e. the ‘Combined CM’ population). All measurement variables (MAXL, LAL, DAFL, MAXB, MINB, DAFB, MAXH, BH, MINH, CFH) were larger males than females for all three populations (Chilean, Mexican and ‘Combined CM’). These results concur with previous sex estimation studies that examine the calcaneus in other populations: Cretan (Nathena et al., 2017), Greek (Peckmann et al., 2015), Korean (Kim et al., 2013), Thai (Scott et al., 2017) White American (Steele, 1976), Black American (Steele, 1976), White North American (DiMichele, 2008), White South African (Bidmos and Asala, 2003), Black South African (Bidmos and Asala, 2004), Northern Italian (Introna et al., 1997), Southern Italian (Gualdi-Russo, 2007), New Zealand (Murphy, 2002), German (Reipert et al.,1996), Portuguese (Silva 1995), Columbian (Moore et al., 2016).

For the Chilean, Mexican, and the ‘Combined CM’ population, the most sexually dimorphic measurement variable was the MAXL variable. Table 5.1 shows the comparison of the mean difference between the male and female MAXL variables for various populations. The published literature shows the range for the mean difference between males and females is from 5.60 mm to 10.69 mm. For the Chilean population, there was a difference of 6.39 mm between the male and female MAXL variables. The Mexican population showed a greater difference, 7.02 mm, between the male and female MAXL variables. The ‘Combined CM’ population had a 6.64 mm difference between the male and female MAXL variables. With the exception of the research conducted by DiMichele (2008) using an American European population, which showed that the Posterior

Circumference variable was more sexually dimorphic than the MAXL variable, all other published research demonstrates that the MAXL variable has greater dimorphism than other measurements when estimating sex from the calcaneus (Bidmos and Asala 2003, 2004; Ekizoglu et al., 2017; Gualdi-Russo, 2007; Holland, 1995; Introna et al., 1997; Kim et al., 2013; Moore et al., 2016; Murphy, 2002a; Nathena et al., 2017; Peckmann et al., 2015a; Riepert et al., 1996; Scott et al., 2017; Silva, 1995; Steele, 1976; Wilbur, 1998; Zakaria et al., 2010; Zhang et al., 2016).

Table 5.1 – Comparison of the mean difference between the male and female maximum length (MAXL) of the calcaneus measurement variable between different populations.

Investigator	**Population**	**Mean difference (mm)**	**Percent difference (%)***
Zakarai et al. (2010)	Egyptian	10.67	13.5
Ekizoglu et al. (2017)	Turkish	9.79	12.1
Murphy (2002a)	Prehistoric New Zealand Polynesian	8.99	11.9
Bidmos and Asala (2003)	White South African	8.91	11.1
Peckmann et al. (2015a)	Greek	8.27	10.7
Wilbur (1998)	Prehistoric West-Central Illinois	7.90	10.6
Gualdi-Russo (2007)	Northern Italian	8.25	10.4
Zhang et al. (2016)	Chinese	6.78	9.9
DiMichele and Spradley (2012)	North American	8.02	9.6
Current study	**Mexican**	**7.02**	**9.5**
Moore et al. (2016)	Columbian	6.78	9.4
Harris and Case (2012)	European-American	7.74	9.3
Silva (1995)	Portuguese	6.95	9.2
Riepert et al. (1996)	German	7.80	9.1
Kim et al. (2013)	Korean	6.70	8.9
Current study	**‘Combined CM’****	**6.64**	**8.9**
Steele (1976)	Black American	6.90	8.7
Introna et al. (1997)	Southern Italian	6.60	8.7
Current Study	**Chilean**	**6.39**	**8.5**
Scott et al. (2017)	Thai	6.47	8.4
Bidmos and Asala (2004)	Black South African	6.14	8.0
Nathena et al. (2017)	Cretan	6.05	7.8
Steele (1976)	White American	5.60	7.2

*The mean difference in relation to the size of the calcaneus.

** ‘Combined CM’ = Combined Chilean and Mexican population

The percent difference was also calculated for each of the populations, which provides the mean difference in relation to the size of the calcaneus. The percent difference between sexes in relation to the size of the calcaneus is between 7.2% and 13.5%. In all populations, the maximum length of the male calcaneus is larger than the maximum length of the female calcaneus. In the current study, the percent difference between sexes in relation to the size of the calcaneus for the Chilean and Mexican population was 8.5% and 9.5%, respectfully, and the percent difference between sexes for the 'Combined CM' population was 8.9%.

Males tend to have more robust skeletons than females due to the influence of hormones and a greater body mass. This leads to greater muscle attachment sites, increasing the robusticity and size of the bone (Cabo et al. 2012; Garcia-Martinez et al., 2016). Hormonal influences on bone growth are dependent on two factors: (1) the amount of time in which hormones are being secreted and (2) the rate in which the individual's metabolism progresses (Humphrey, 1998; Willner and Martin, 1985). Overall, females start puberty earlier than males (approximately 2 years earlier) and have a shorter growth period than males (Riggs et al., 2002; Seeman, 2001; Wells, 2007). In females, estrogen inhibits periosteal apposition and stimulates endocortical bone formation, which results in an increased cortical thickness, a decrease in medullary thickness, and very little increase in periosteal diameter (Riggs et al., 2002; Seeman, 2001; Wells, 2007). Males, on average, have an additional year of pubertal growth that extends the periosteal apposition, leading to an increase in periosteal diameter, cortical thickness, and medullary diameter (Riggs et al., 2002; Seeman, 2001; Wells, 2007; Laurent et al., 2014). Therefore, hormonal influences during puberty influence sexual dimorphism in the human skeleton.

As a result of the hormonal influences on the musculoskeletal system, males have an overall greater body mass than females. This has an effect on the appendicular skeleton, particularly on the deposition of bone on weight bearing bones (Laurent et al., 2012). As the calcaneus is a major weight bearing bone, its size is influenced by the weight placed upon it. Yattram (1984) established that the density of the calcaneus is directly correlated to the force applied to it, i.e. the more weight applied to the bone, the greater its density. Therefore, body mass also has an impact on the sexual dimorphism of the calcaneus. As there was no statistically significant difference in sexual dimorphism between Chilean and Mexican populations, for the remainder of this thesis, only the 'Combined CM' (i.e. Combined Chilean and Mexican) population will be discussed.

5.5 Assessing Accuracy Rates of the White South African Discriminant Function Equations when Applied to the 'Combined CM' Population

The third goal of this project was to determine if discriminant function equations developed on a contemporary White South African population will accurately estimate sex from the calcaneus of contemporary Chilean and Mexican populations. As there was no statistically significant difference in sexual dimorphism between Chilean and Mexican populations, for the remainder of this thesis, only the 'Combined CM' (i.e. Combined Chilean and Mexican) population will be discussed. Previous studies have shown that, traditionally, discriminant functions developed on White European populations were often applied to Latin American populations because of the lack of population-specific data (France, 1998; Spradley and Jantz, 2003; Spradley et al., 2008). One publication examined the need for population-specific methodologies for ancestral groups that are considered Latin American. O'Bright et. al (2018) studied sex estimation from the tibia in a Chilean population. They applied discriminant functions created from the tibia of a Mexican population to Chilean tibiae and found that the Mexican discriminant functions produced low accuracy rates for estimating sex for the Chilean sample. They then compared mean tibial size to Croatian and White South African populations and found significant differences between populations. The study concluded a need for population-specific and temporally-specific discriminant functions for estimation of sex from the tibia of Chilean populations. O'Bright et al.'s study (2018) highlights that further assessment is required when applying methods and functions developed from other populations.

Bidmos and Asala (2003) used a total of nine measurement variables to estimate sex using the calcaneus in a White South African population. The variables they studied were the MAXL, LAL, DAFL, MINB, MIDB, DAFB, BH, MAXH and CFH. They created multivariate, stepwise, and univariate discriminant function equations to assess sexual dimorphism of the calcaneus in the White South African population. Their direct multivariate discriminant functions yielded an accuracy rate between 81.7% and 92.1%. Their accuracy rates for their stepwise discriminant function equations were between 80.9% and 91.1%. Finally, their univariate discriminant function equations produced accuracy rates between 72.9% and 85.8% (Bidmos and Asala, 2003).

The discriminant function equations from the White South African population were applied to the 'Combined CM' population data set to test for sex classification accuracy rates. The accuracy rates were as follows: the direct multivariate discriminant function equations between 45.26% and 69.47%, the stepwise discriminant function equations between 59.65% and 75.40%, and the univariate discriminant function equations between 55.44% and 88.64%.

The data were further analyzed and the sexual bias percentage was calculated for each of the discriminant function equations. Sex bias for the multivariate discriminant function equations ranged from -100% (female bias) to 79.21% (male bias). For the stepwise discriminant function equations, sex bias tended towards male bias for three of the equations and ranged from 44.4% to 86.31%. The stepwise discriminant function for the length variables (MAXL, DAFL) demonstrated female bias (-63.43%). Applying the White South African univariate discriminant function equations to the ‘Combined CM’ population data set resulted in a sex bias range from -69.06% to 98.45%. The decreased accuracy rate of the White South African discriminant functions when applied to the ‘Combined CM’ population shows that forensic anthropologists should limit the application of sex discriminant function equations to the population from which they were derived.

5.6 Assessing Accuracy Rates of the Newly Created Discriminant Functions for the ‘Combined CM’ population.

As the discriminant functions developed by Bidmos and Asala (2003) did not accurately classify sex in the ‘Combined CM’ population, population-specific discriminant functions were created for the ‘Combined CM’ sample. The calcaneus for the ‘Combined CM’ population showed overall sex estimation accuracy rates from 80.00% to 86.30% for multivariate discriminant function equations, 86.00% for the stepwise discriminant function equation, and 70.50% to 80.40% accuracy for the univariate discriminant function equations. Past studies have shown that the calcaneus displayed higher metric sex estimation accuracy rates than the skull, vertebrae, hyoid, clavicle, sternum, humerus, radius, ulna, pelvis, femur, tibia and carpals (see Table 5.2). However, the ‘‘Combined CM’’ calcaneus only showed higher overall classification accuracy rates for estimation of sex than the skull, vertebrae, and sternum. Table 5.3 shows studies that have been conducted using various skeletal elements in the Chilean and Mexican populations only. The 'Combined CM' population had overall greater classification accuracy rates than the Chilean scapula, femur and teeth. In the 'Combined CM' population, the calcaneus should only be used when other skeletal elements (with proven higher accuracy rates for this population) are not available for analyses.

Table 5.2 – Comparison of overall metric sex estimation accuracy rates for individual skeletal elements.

Skeletal Element	Overall Accuracy Rate (%)	References
Calcaneus	48.0 to 95.7	Bidmos and Asala, 2003; Bidmos and Asala, 2004; DiMichele, 2008; Gualdi-Russo, 2007; Introna et al., 1997; Kim et al., 2013; Moore et al., 2016; Murphy, 2002; Nathena et al., 2017; Peckmann et al., 2015; Scott et al., 2017; Silva 1995; Steele, 1976
Radius	76.0 to 94.3	Barrier and L'Abbe, 2008; Spradley and Jantz, 2011
Humerus	87.0 to 93.8	Ross and Manneschi, 2011; Spradley and Jantz, 2011
Clavicle	87.9 to 93.6	Papaioannou et al., 2012; Spradley and Jantz, 2011
Hyoid	79.3 to 93.0	Balseven-Odabasi et al., 2013; Kim et al., 2006; Kindshuh et al., 2010; Logar et al., 2016
Ulna	89.0 to 92.8	Barrier and L'Abbe, 2008; Spradley and Jantz, 2011
Femur	82.0 to 91.6	Ross and Manneschi, 2011; Spradley and Jantz, 2011
Tibia	86.2 to 91.6	Ekizoglu et al., 2016; Spradley and Jantz, 2011; Spradley, Anderson and Tise, 2015
Carpals	61.8 to 90.8	Mastrangelo et al., 2011a
'Combined CM' calcaneus	**71.6 to 86.3**	**Current study**
Skull	70.0 to 86.0	Dayal, 2007; Franklin et al., 2005; Noren, 2005; Robinson and Bidmos, 2009; Ramamoorthy, 2016; Ramsthaler, 2006
Vertebrae	76.9 to 85.0	Marino, 1995; Marlow and Pastor, 2011; Rozendaal, 2016; Wescott, 2000
Sternum	80.6 to 84.5	Franklin et al., 2011; Macaluso, 2010

Table 5.3 – Comparison of overall metric sex estimation accuracy rates for individual skeletal elements in Chilean and Mexican populations.

Skeletal Element	**Overall Accuracy Rate (%)**	**References**
'Combined CM' Population		
Calcaneus	**71.6 to 86.3**	**Current Study**
Chilean Population		
Scapula	80.7 to 86.0	Peckmann et al., 2016
Humerus	87.0	Ross and Manneschi, 2011
Femur	82.0 and 86.0	Ross and Manneschi, 2011
Tibia	79.4 to 89.2	O'Bright et al., 2018
Teeth	54.4 to 66.7	Peckmann et al., 2015
Mexican Population		
Carpels	81.3 to 92.3	Mastrangelo et al., 2011b
Scapula	83.6 to 89.3	Hudson et al., 2016
Clavicle	90.0	Spradley et al., 2015
Humerus	82.8 to 88.2	Spradley et al., 2015
Ulna	89.3	Spradley et al., 2015
Pelvic girdle	87.0 and 99.0	Gómez-Valdés et al., 2011
Femur	90.6	Spradley et al., 2015
Tibia	83.5 to 90.7	Spradley et al., 2015

The field of forensic anthropology is a research driven field, where validation studies are examined in order to ensure that the scientific method is upheld. Methods used for forensic anthropological analyses must have an accuracy rate greater than 80.0% (Scheuer, 2002; Marlow and Pastor, 2011; Rogers et al., 1999; Williams and Rogers, 2006). Methods that show an accuracy rate of less than 80.0% should be used critically and coupled with stronger methods of analysis. A Leave-One-Out validation test was completed using the 'Combined CM' sample. For the 'Combined CM' calcaneus, overall, the multivariate and stepwise discriminant function equations would meet the 80% minimum requirement; the overall correct classification rates ranged from 80% to 86.3%, and the validation test re-classified the calcanei with accuracy rates between 78.60% and 86.0%.

For the univariate discriminant function equations, only the maximum breadth meets the 80% minimum requirement with an overall correct classification rate and a re-classification of 80.4%. Therefore, for the 'Combined CM' population, only the multivariate, stepwise, and maximum breadth discriminant function equations should be used when estimating sex from the calcaneus.

The 'Combined CM' sample was not compared to either Reipert's study (1996) that used radiographs or Ekizoglu et al.'s research (2017) that used CT scans as methods of data collection. Although these studies showed high overall sex estimation accuracy rates (80.0% to 92.0%), comparing data collected from two-dimensional or three-dimensional images to dry bone (as used in the current research) is problematic. Studies have shown that data collected from two-dimensional radiographs may experience measurement depth and dimension loss, as well as image distortion (Berg et al., 2007; Krishan et al., 2016). Therefore, these studies cannot be compared to the current research. Ekizoglu et al. (2017) cite that there is no published study that investigates the validation or error comparison between measurements collected from dry bone and measurements collected from radiographs or CT scans, therefore, comparing the results from the 'Combined CM' sample to either study was not completed.

Finally, it is important to note that discriminant function equations created utilizing skeletal collections are a representative sample of the living population, and may not wholly reflect the entire living population. However, as concluded by Steele (1976), until more contemporary and more diverse (i.e. range of ages and socio-economic classes) collections become available, the methods developed should be effective for sex estimation. The discriminant functions created in this study are applicable to the victims of the Chilean and Mexican human right violations as this study used the skeletal remains of individuals whose birth and death dates would have reflected those that would have lived through the atrocities in each country.

5.7. Comparing Populations

5.7.1. Comparing Chilean and Mexican Populations

Chilean and Mexican populations were compared through statistical analyses. Means and standard deviations from the Chilean males were compared to the Mexican males and no statistically significant difference was found between the two populations. The same analyses were repeated for the Chilean and Mexican females and, again, no statistically significant differences were found. The results from the current study contradict other published studies using the calcaneus for sex estimation, which show that the estimation of sex from the calcaneus is population-specific (Bidmos and Asala, 2003; Bidmos and Asala, 2004; Bidmos, 2006; DiMichele, 2008; Gualdi-Russo, 2007; Kim et al., 2013; Nathena et al., 2017; Peckmann et al., 2015; Scott et al., 2017; Steele, 1976; Tise et al., 2013). However, the current study agrees with Spradley and Jantz's research (2011) which found that sex estimation from the calcaneus was not dependent on ancestry. In the current research, the similarities between the Chilean and Mexican populations may be attributed to stature, socio-economic and socio-cultural lifestyles.

5.7.1.1. Biological and Nutritional Influences Affecting Growth and Development

As the calcaneus is a weight bearing bone, its growth and development are influenced by stature (Yattram, 1984). It has been shown that the average height and weight of Chilean and Mexican populations are very similar. For a contemporary Chilean male, the average height is 1.71 m and average weight is 81 kg with a BMI of 27.8 kg/m^2 (Nation Master, 2018). Contemporary Mexican males have an average height of 1.69 m and an average weight of 78 kg with a BMI of 27.5 kg/m^2 (Nation Master, 2018). The average height and weight for contemporary Chilean females is 1.59 m and 71 kg and a BMI of 28.2 kg/m^2 (Nation Master, 2018). The average height and weight for contemporary Mexican females is 1.56 m and 69 kg and a BMI of 28.5 kg/m^2. It has also been shown that stature and weight influence the size and robusticity of the calcaneus (Lundeen et al., 1984; Harris and Case, 2012). As no statistically significant differences were found between the Chilean and Mexican calcanei, this may be related to similarities in their height and weight.

Nutritional intake has an effect on the growth and development of the human body. Chile and Mexico exhibit similar contemporary patterns in dietary in-take, particularly in the urban areas (Bermudez and Tucker, 2003; Muzza, 2002; Rivera et al, 2004; Rosen, 1999; Uauy, Albala and Kain, 2001). Overall, during the 1970s, Chileans and Mexicans were under-nourished, consuming high quantities of cereals, fruits and vegetables, and low quantities of proteins. Due to the lack of protein in their diet, they experienced stunted growth (Bermudez and Tucker, 2003; Muzza, 2002). However, in the 1980s and 1990s, in both populations, there was a shift from a plant-based diet to an in increase in the consumption of proteins, fats, and refined carbohydrates and sugars (Albala, Uauy, and Kain, 2001; Bermudez and Tucker, 2003; Muzzo, 2002; Rivera et al, 2004; Rosen, 1999). This change in diet had an effect on the health demographics of both the Chilean and Mexican populations. Health studies have reported the transition of body morphology in both populations from being under-nourished with stunted growth (in the 1960s to the 1980s), to overweight and obese (from the 1990s onwards) (Albala, Uauy, and Kain, 2001; Bermudez and Tucker, 2003; Muzzo, 2002; Rivera et al, 2004). As the calcaneus is a weight bearing bone, and its growth and development can be impacted by weight, it is possible that the similarities in dietary trends and, therefore, the similarities in body size and morphology, could be another reason why there were no statistically significant differences for the calcaneus between the Chilean and Mexican populations (Muzzo, 2002; O'Bright et. al., 2018; Yattram, 1984).

5.7.1.2. Socio-Economic Influences Affecting Body Morphology

That lack of statistically significant differences for the calcaneus between the Chilean and Mexican populations may also be attributed to similar socio-economic factors. Both countries fell into an economic deficit between the 1970s and 1990s, facing large debts and a weakness in the banking sector (Bergoeing et al., 2002). In Chile, this was a result of the Pinochet dictatorship. This led to a drastic overhaul of Chile's economy, forcing it into trade, financial liberalization, and privatization of most industries – allowing for competition in the private sector that resulted in driving the cost of living upwards without having an increase in income (Ffrench-Davis, 2010; Silva, 2009; Santarcangelo, Schteingart and Porta, 2018). In addition to the economic reform, interest rates were increased and a decrease in benefits to the working class were observed (Ffrench-Davis, 2010; Silva, 2010; Santarcangelo, Schteingart and Porta, 2018). All of this led to a social collapse in 1982 that included a significant difference in income distribution within the population, an increase in poverty, unemployment rates reaching beyond 30%, and a Gross National Income (GNI) per capita of $4,160 USD (Santarcangelo, Schteingart and Porta, 2018; World Bank 2016). The increase in privatization and private liberalization of industries caused extreme social inequality, an increase in poverty, and a reduction in available healthcare and adequate nutrition for the Chilean peoples (Bergoeing et al., 2002; Santarcangelo, Schteingart and Porta, 2018).

Mexico's economic downturn was as a result of public deficits, lack of competitiveness in the trade sector, and poor agricultural yields (Campos-Vazquez et al., 2017). Their dependency on petroleum exportation for financial stabilization added to the country's economic downfall when the Producer Price index (PPI) fell by over 20% in two years (Bergoeing et al., 2012). In only a few years, Mexico's external debt increased by 140% (Bergoeing et al., 2012). Following the economic downturn, Mexico had a GNI per capita of $5,800 USD (World Bank, 2016). This debt and financial collapse had a direct effect on people's lifestyles, which was reflected in increases in poverty and lack of access to resources, such as adequate healthcare and nutrition (de la Jara and Bossert, 1995; Woolcock, 2005).

5.7.2. Comparing the 'Combined CM' Population to the White South African Population.

As previously discussed, the third goal of this project was to determine if discriminant function equations developed on a contemporary White South African population (Bidmos and Aasala 2003) will accurately estimate sex from the calcaneus of contemporary Chilean and Mexican populations. The results showed that the White South African discriminant function did not accurately classify sex of the Chilean calcanei. A comparison of the descriptive statistics between the males and females of the 'Combined CM' population and the White South African population was completed. The study by Bidmos and Asala (2003) measured nine (MAXL, LAL, DAFL, MINB, DAFB, MAXH, MINH, BH, CFH) of the 10 variables used by the current study. All nine variables, except the LAL variable, showed significant differences between both populations for males and females. The significant differences between the two populations may be attributed to biological and socio-economic factors.

5.7.2.1. Biological Influences Affecting Growth and Development

The average height and weight of a White South African male is 1.73 m and 78.2 kg. The average height and weight of a White South African female is 1.62 m and 65.7 kg (O'Bright, 2016). For a Chilean male, the average height is 1.71 m and average weight is 81 kg and the average height and weight for Chilean females is 1.59 m and 71 kg (Nation Master, 2018; World Data, 2018). Mexican males have an average height of 1.69 m and an average weight of 78 kg (Nation Master, 2018; World Data, 2018). The average height and weight for Mexican females is 1.56 m and 69 kg. The significant differences in calcanei size between the 'Combined CM' population and the White South African population may be attributed to population differences in living weight and stature. As the calcaneus is a major weight bearing bone, its size is influenced by the weight placed upon it (Laurent et al., 2012; Yattram 1984).

5.7.2.2. Socio-Economic and Nutritional Influences Affecting Body Morphology

Calcaneal growth and development may also be affected by socio-economic conditions (Bogin et al., 2002; Dangour, 2001; Inwood and Roberts, 2010; Nyati et al., 2006). The differences in socio-economic conditions between the White South African and the 'Combined CM' population may account for the overall larger size the of the White South African calcanei. Bidmos and Asala (2003) used the Raymond Dart Skeletal Collection, housed in the University of Witwatersrand, Johannesburg. Their sample represented individuals who lived between the late 20th century and early 21st century in South Africa (Bidmos and Asala, 2003). The White South African individuals would have lived during the apartheid era (1948 to 1994); during apartheid, White South Africans held a higher socio-economic status and had greater access to life-improving resources than the non-White (i.e. Black, 'Coloured' (mixed-'race'), Asian) South African populations. White South Africans occupied the highest socio-economic status during apartheid (70.6% of Whites belonged to the highest income bracket and only 7.9% of Whites were living in the lowest income bracket) and mostly held upper-level non-labour jobs (e.g. managerial and office jobs) (Kon and Lachman, 2008; Treiman et al., 1996). Greater socio-economic status allowed White South Africans to gain access to better nutrition and health care compared to the non-White South Africans populations.

The individuals in both the Chilean and Mexican populations experienced economic collapse and restricted access to resources. As previously discussed, between 1970 and 1990 Chileans experienced the high unemployment (30%) and poverty rates. Therefore, individuals were not able to afford adequate nutrition and healthcare. Mexico's economic downturn was as a result of public deficits, high external debt, a lack of competitiveness in the trade sector, and poor agricultural yields (Campos-Vazquez et al., 2017). This debt and financial collapse had a direct effect on people's lifestyles, which resulted in increases in poverty and lack of access to adequate nutrition and healthcare (de la Jara and Bossert, 1995; Woolcock, 2005).

Nutritional deficiencies may comprise bone growth and development (Babaroutsi et al., 2005; Nathena et al., 2017; Naude et al., 2012; Stini, 1969). Overall, Chileans and Mexicans were under-nourished, consuming primarily a plant-based diet with very little protein. Due to the lack of protein in their diet, they experienced stunted growth (Bermudez and Tucker, 2003; Muzza, 2002). However, in the 1980s and 1990s, a shift from a plant-based diet to an in increase in the consumption of proteins, fats, and refined carbohydrates and sugars was observed in both Chilean and Mexican populations (Albala, Uauy, and Kain, 2001; Bermudez and Tucker, 2003; Muzzo, 2002; Rivera et al, 2004; Rosen, 1999). This change in diet had an effect on the health demographics of both the Chilean and Mexican populations. Health studies have reported the transition of body morphology in both populations from being under-nourished and stunted growth (in the 1960s to the 1980s) to overweight and obese (from the 1990s onwards) (Albala, Uauy, and Kain, 2001; Bermudez and Tucker, 2003; Muzzo, 2002; Rivera et al, 2004).

In comparison, the White South African population had sufficient access to food sources throughout apartheid and therefore did not experience nutritional deficiencies (Stupar, 2007; Turton and Chalmers, 1990; van der Berg et al., 2006). They could afford a broad spectrum of nutritional intake (e.g. grains, protein, fruits, and vegetables) and, therefore, did not experience growth impairments that would be attributed to malnourishment (Stupar, 2007; Turton and Chalmers, 1990; van der Berg et al., 2006). Hence, the nutritional deficiencies in the Combined CM population may have caused impaired bone growth and development, which may explain the larger calcaneal dimensions observed in the White South African (Bidmos, 2006) population when compared to the Combined CM population

Being of higher socio-economic status provided the White South African population greater access to healthcare. The most significant change with apartheid was the deregulation of the previous public health care system. By removing public health care, the private sector expanded, which made health care more expensive and prevented the non-White lower socio-economic classes from being able to afford such care (Kautzky and

Tollman, 2008). Kon and Lachman (2008) found that White South Africans had greater access to health care than other populations during apartheid. The patient to doctor ratio, for White South Africans, was 1:300 in comparison to the 1:91 000 for Black South Africans. Government health expenditure was five times greater for White South Africans than Black South Africans, allowing for a healthier population (Cameron, 2003; Malina et al., 2004; O'Bright, 2016; Stinson et al., 2012).

During the militarian rule in Chile, the medical and primary care shifted from the public (National Health Service) to the private sector. This resulted in the population having to pay for even basic medical treatment that, previously, would have been available without cost (Sidel and Sidel, 1977). The result of this was an increase in malnourishment and morbidity rates (especially, in what would otherwise be 'treatable' illnesses) and a decrease in services to treat illness (Sidel and Sidel, 1977). Mexico's health care system was also privatized and favoured the minority wealthy individuals while the majority of the population was unable to afford health care. In addition, the physician-patient ratio in a high-income class was 20: 100,000 and for the lowest income class it was 5: 100,000 (Barraza-Llorens et al., 2002). Therefore, the difference in access to medical care between the White South African and the "Combined CM" populations may have attributed to the calcaneal size differences displayed between these two samples.

When an economic crisis occurs, there is an increase in psychological and behavioural disorders, specifically stress (Catalano et al., 2011). Long term exposure to stress can impact the growth and development of the body, due to the over-production and/or under-production of hormones. This hormonal imbalance affects proper growth during puberty and influences bone structure (Kajantie and Phillips, 2006; Ranabir and Reetu, 2011). The decrease in secretion of the growth hormone can result in stunted growth, which has been referred to as 'psychosocial short stature' (Gilmore and Skuse, 1999). As previously discussed, the individuals from the Chilean skeletal collection would have endured psychological stresses living during the Pinochet regime. Combined with the hyperinflation of the economy and social unrest, there was the added stress of the fear of being killed, tortured, imprisoned, or 'disappeared' (Johnson, 2014). The individuals from the Mexican sample would have also experienced psychological stress, as they lived through an economic decline and financial collapse, which could have impacted their growth and development. Due to their higher socio-economic status, the White South African population would not have experienced the same psychological stress and related growth deficiencies that the Chilean and Mexican populations would have faced during the depression eras. Therefore, the differences in socio-economic status between the White South African and the "Combined CM" populations may have attributed to the calcaneal size differences displayed between these two samples.

5.7.3. Comparison of the 'Combined CM' Population to Other Populations

Overall, the discriminant functions created from the 'Combined CM' population performed well (71.6% to 86.3% overall classification accuracy). However, when looking at the classification accuracy rates from previous studies (Table 5.4) the 'Combined CM' population only outperformed the American (Dimichele and Spradley, 2012) and Black South African populations (Bidmos and Asala, 2003). Table 5.5 shows the mean difference between male and female calcanei for each study that conducted sex estimation tests using the MAXL variable only. As the raw data from each study was not available for analysis, percent difference between male and female calcanei were calculated for the MAXL variable. The reason why this measurement was analyzed specifically, is due to the fact that it is one of the most consistently studied variables for sex estimation of the calcaneus in the literature. This table supports that one of the reasons why there is a lower classification accuracy rate in the 'Combined CM' population is due to the decreased amount of sexual dimorphism between males and females of the 'Combined CM' population. Overall, populations with greater sexual dimorphism (as overserved by the percent difference measured) had higher overall classification accuracy rates, and those with a lower percent difference exhibited a lower overall classification rate. This highlights the need for population specific analyses.

Table 5.4 – Overall accuracy rates of previous studies using discriminant function analysis for sex estimation using the calcaneus.

Study	**Population**	**Accuracy rate (%)**
Steele, 1976	White & Black American	79 - 89
Introna, 1997	Southern Italian	83 - 87
Murphy, 2002	Pre-Historic New Zeland Polynesian	88 – 93
Bidmos and Asala, 2003	White South African	73 - 92
Bidmos and Asala, 2004	Black South African	64 - 86
Gualdi-Russo, 2007	Northern Italian	88 - 96
DiMichele, 2008	American (not pop specific)	48 - 89
Peckmann et al., 2015	Greek	70 - 90
Kim et al., 2016	Korean	65 - 89
Spradley, 2013	Hispanic	63 - 72

Table 5.5 – Percent difference of sexual dimorphism in the MAXL variable and corresponding univariate discriminant function accuracy rate in varying populations.

Investigator	**Population**	**Mean difference (mm)**	**Percent difference (%)***	**Univariate overall classification rate (%)**
Murphy (2002a)	Prehistoric New Zealand Polynesian	8.99	11.9	93.5
Bidmos and Asala (2003)	White South African	8.91	11.1	84.9
Peckmann et al. (2015a)	Greek	8.27	10.7	83.5
DiMichele and Spradley (2012)	North American	8.02	9.6	80.8
Kim et al. (2013)	Korean	6.70	8.9	81.7
Current study	**'Combined CM'****	**6.64**	**8.9**	**76.8**
Introna et al. (1997)	Southern Italian	6.60	8.7	83.7
Scott et al. (2017)	Thai	6.47	8.4	74.7
Bidmos and Asala (2004)	Black South African	6.14	8.0	75.8

Further population analysis was completed. Table 4.15 shows the means and standard deviations of the 'Combined CM' data compared to the means and standard deviations of the following populations: Greek (Peckmann et al., 2015), Korean (Kim et al., 2013), White American (Steele, 1976), Black American (Steele, 1976), Black South African (Bidmos and Asala, 2004), White South African (Bidmos and Asala, 2003), Northern Italian (Introna et al., 1997), Southern Italian (Gualdi-Russo, 2007), White North American (DiMichele, 2008), New Zealand Polynesian (Murphy, 2002), and Hispanic (Tise, 2010). Overall, there were statistically significant differences found between the 'Combined CM' population and all other populations. These results emphasize the need for population-specific and temporally-specific discriminant function equations. The reasons for these differences may be related to stature, nutrition, psychological stressors, and research design. Section 5.7.2 describes the reasons for the significant differences between the 'Combined CM' population and White South African sample, therefore, this comparison will not be repeated in this section.

5.7.3.1. Biological Influences on Population Variation

Overall, there are significant differences observed between the 'Combined CM' population and the Greek (Peckmann et al., 2015), White American (Steele, 1976), Black American (Steele, 1976), and Southern Italian samples (Gualdi-Russo, 2007), which may be related to differences in stature – the 'Combined CM' population is shorter in stature than these other comparative populations. For a Chilean male, the average height is 1.71 m and the average height for Chilean females is 1.59 m (Nation Master, 2018; World Data, 2018). Mexican males have an average height of 1.69 m and an average height for Mexican females is 1.56 m (Nation Master, 2018; World Data, 2018). The average height of an urban Greek male is 1.77 m and average height of an urban Greek female 1.62 m (Hatton and Bray, 2010; Manolis et al., 1995). For the White American sample, the average height of a male is 1.77 m and the average height of a female is 1.63 m (Komlos and Baur, 2000; Kuczmarski et al., 1994; NHANES III). The average height of a Black American male is 1.76 m and the average height of a Black American female is 1.63 mm (Komlos and Baur, 2000; NHANES III). For the Southern Italian population, the average height for males is 1.72 m and the average height for females is 1.57 m (Krul et al., 2010; Sanna, 2002). As the calcaneus is a weight bearing bone, its growth and development are influenced by stature (Yattram, 1984).

5.7.3.2. Nutritional Intake Influencing Population Variation

The significant differences between the 'Combined CM' calcanei measurements and the Korean calcanei measurements could be related to daily protein intakes. Protein is an essential macronutrient for the growth and development of the skeletal system (Muzzo 2002). Although neither the Chilean or Mexican populations were deficient in their caloric intake, they lacked sufficient amounts of protein in their diet (Bermudez and Tucker, 2003; Muzzo, 2002). The Chilean population averaged 37 g/capita/day of animal protein and Mexico's protein intake was similar with of 36 g/capita/day, however, South Koreans consume significantly larger amounts of animal protein (59.5 g/cap/day) (FAO, 2018). Therefore, the larger South Korean calcaneal measurements could be related to their increased consumption of protein as compared to the 'Combined CM' population.

5.7.3.3. Stress Influencing Population Variation

Overall, the calcaneal means for the Black South African population were smaller than the calcaneal means for the 'Combined CM' population. This could be attributed to long-term stress influencing the growth and development of the calcaneus. A population's stature and development is also a cumulative result of lifestyle, nutritional intake, and stress endured during childhood and throughout adulthood. Long-term exposure to stress can impact the growth and development of the body, due to the over-production and/or under-production of hormones (Cameron, 2002; Kruger, 2015). Hormonal imbalances influence glucocorticoids and catecholamines (weight influencing hormones) production as well as the secretion of the growth hormone, which is responsible for proper growth during puberty and influences bone structure (Kajantie and Phillips, 2006; Ranabir and Reetu, 2011). The decrease in secretion of the growth hormone can result in stunted growth and development of the skeletal system (Gilmore and Skuse, 1999). If the conditions leading to the initial stunted growth are reversed, a period of rapid growth may occur allowing for optimal stature (Cameron, 2002). As the calcaneus is completely formed by 14 to 18 years of age, stresses experienced throughout childhood would have a greater impact on the growth and development of the calcaneus bone than stresses experienced only throughout adulthood (Bergoeing et al., 2002; Campos-Vazquez et al., 2017; Scheuer and Black, 2004). In South Africa, segregation and marginalization of the Black South African population began in 1910. Apartheid was established in 1948 and existed until 1994; Apartheid was a system of institutionalised racial segregation which encouraged state repression of Black African, Coloured, and Asian South Africans for the benefit of the nation's minority white population (Thompson, 2001). The individuals from Bidmos and Asala (2004) study consisted of Black South Africans that experienced apartheid during their childhood and adult years. They endured harsh living conditions, poor nutrition, and psychological stresses from childhood (i.e. the formative years of development) throughout their adulthood (Dearden et al., 2017; Checkley et al., 2004; Haque, 2007; Merchant et al., 2003). In contrast, the Chilean and Mexican populations that were used in the current study experienced an economic depression followed by an economic growth period during their adolescent years which would have allowed for a 'catch-up' growth period, unlike the Black South African population (Cameron, 2002; Thorp, 1998). As a result, experiencing long-term stress as a child and throughout adulthood could have had an impact on the initial growth and limited the development of the calcaneus in the Black South African population. Therefore, this may be the reason for the overall smaller calcaneal measurements displayed in the Black South African population as compared to the 'Combined CM' population.

5.7.3.4. Effects of Research Design

When comparing results between populations, it is important to look at the research designs of the studies that are being compared. Factors such as sample size, ancestral make-up of the comparative population, socio-cultural practices, and secular change can contribute to the 'appearance' of significant differences between populations. These factors could have influenced the significant differences displayed between the 'Combined CM' sample and the Northern Italian, North American, Prehistoric New Zealand Polynesian, Hispanic samples.

Although, the Northern Italian sample showed statistically significant differences when compared to the 'Combined CM' sample, it must be noted that there were only two calcaneal variables (MAXL and BH) used for comparison and this may have affected the results; the 'Combined CM' population measured 10 variables, whereas, the Northern Italian study only measured two variables on the calcaneus. The limited variables for comparison could introduce sample bias, as only comparing two variables against 10 would not provide a representative sample to demonstrate that significant differences exist (McClave and Sinich 2013; Watt and van den Berg 1995). Therefore, a population comparison would not be possible. The significant differences displayed between the Northern Italian and 'Combined CM' populations could be as a result of differences in the number of variables being compared.

The DiMichele (2008) study used a North American sample that was created from Black American, White American, and Hispanic individuals. The study combined all three ancestral groups when analyzing the data. Although the current study combined two groups, i.e. Chilean and Mexican populations, these are both Latin American populations and, in forensic anthropology, are normally lumped together as one ancestral population.

However, the DiMichele (2008) study combined three groups that are considered, in forensic anthropology, as different ancestral populations, i.e. Black, White, and Hispanic. Previous research (Steele, 1976; Spradley and Jantz, 2013) has cited that when samples consist of combined ancestral groups the ability to compare these samples to other data becomes limited. Therefore, the significant differences displayed between the 'Combined CM' population and the North American population may be related to ancestral differences of the skeletal samples.

The significant differences illustrated between the 'Combined CM' population and the New Zealand Polynesian population may be related to secular change and lifestyle. The 'Combined CM' sample is a contemporary population whereas the New Zealand Polynesian sample is a pre-historic population. Secular change is a non-genetic response to sociocultural and environmental pressures that causes an increase or decrease in overall body dimensions over successive generations (Danubio and Sanna 2008: 91; Steen 2009: 62). Steele (1976) cites that when developing sex estimating discriminant function equations it is important to compare populations of similar time periods due to the influence of secular change on the skeleton. It has been shown that lifestyle factors (i.e. hunter gatherer vs sedentary) will have an impact on a population's growth and development (Danubio and Sanna 2008: 91; Steen 2009: 62). The Prehistoric Polynesian population would have led a more active hunter-gatherer lifestyle, whereas the 'Combined CM' population lived an urban sedentary lifestyle. Therefore, although significant differences exist between the 'Combined CM' population and the New Zealand Polynesian population, the differences may be attributed to secular change and the lifestyle factors as well as a difference in ancestral population.

The significant differences observed between the ‘Combined CM’ population and the Hispanic population may be due to sampling bias. A sample is used to estimate population parameters and is considered to be representative of said population. A sample bias or ‘sampling error’ (resulting in an unrepresentative sample), however, can lead to inaccuracies in the establishment of population parameters. Small sample sizes are associated with increased sampling error; as your sample size increases, the sampling error decreases (McClave and Sinich 2013; Watt and van den Berg 1995). Such a bias in sampling can result in inaccurate estimates for population parameters. In sex estimation studies, it is important to have a large sample size and an approximate equal representation of both sexes to provide an accurate and unbiased representation of the population for comparison. The Hispanic population displays low sample sizes (n males = 35; n females = 7) and the female population is greatly under-represented in the analyses. Therefore, the significant differences displayed between these two populations could be as a result of sample bias.

Chapter 6: Conclusion

The current study focused on 10 measurements of the calcaneus to establish a method for sex estimation in Latin American populations. The goals of this project were to: (1) to estimate if sexual dimorphism is present in the calcaneus of contemporary Chilean and Mexican populations, (2) determine if there is a statistically significant difference in size between Chilean and Mexican calcanei and, if so, does this reflect a need for different ancestral discriminant function equations for each population, (3) determine if discriminant function equations developed on a contemporary White South African population will accurately estimate sex from the calcaneus of contemporary Chilean and Mexican populations and, (4) compare contemporary Chilean and Mexican population data to other population data.

Two 20th century contemporary Latin American skeletal populations (from Chile and Mexico) were used in this study. Data for the Chilean sample (Sub Actual de Santiago Skeletal Collection) were collected from 64 males and 66 females between 15 years and 90 years of age, with a mean age at death of 44 years. Data from the Universidad Nacional Autonoma de Mexico Skeletal Collection were collected from 92 males and 63 females between 15 years and 99 years of age, with a mean age at death of 52 years old. Only morphologically mature calcanei were chosen (i.e. fully developed calcanei with the epiphysis fully fused). Calcanei exhibiting changes to the bone, but not inhibiting measurement recording, were included in the current study. Any calcanei exhibiting structural malformations, arthritic degradation or severe cortical bone damage, where the measurement variables could not be assessed (i.e. original healthy margins were no longer observable), were not selected.

A total of 10 variables were measured for each calcaneus: Maximum Length (MAXL), Maximum Height (MAXH), Body Height (BH), Minimum Height (MINH) Dorsal Articular Facet Length (DAFL), Dorsal Articular Facet Breadth (DAFB), Minimum Breadth (MINB), Middle Breadth (MIDB) and Load Arm Length (LAL), Cuboidal Articular Facet Height (CFH). These variables were categorized and analysed into length (MAXL, DAFL, LAL), breadth (DAFB, MINB, MIDB), and height (MAXH, BH, MINH) measurements. After testing for bilateral asymmetry (and finding no statistically significant differences between left and right calcanei), as per methods established by Buikstra and Ubelaker (1998), the left calcaneus was measured for all variables unless it was damaged, pathological, or absent, in which case the right calcaneus was used.

Reliability and repeatability of measurements is of paramount importance in forensic anthropology. Measurements must be well defined so that researchers examining those variables are able to understand the definition and reproduce the measurement. The results of the intra-observer and TEM error analyses showed that none of the variables were statistically significant; therefore, there were no differences within observers. The results of the inter-observer error and TEM error analyses showed that only one of the variables (BH) was statistically significant. It was suggested that caution should be taken when taking the BH measurement. Therefore, overall, there were no differences between observers.

The results of this study demonstrated that sexual dimorphism was present in all of the 10 variables measured in the Chilean population and the Mexican population. Once sexual dimorphism was established in both populations, statistical tests were applied to see if there were significant differences between the Chilean and Mexican populations. The independent t-tests confirmed that there were no significant differences between the Chilean and Mexican populations. Since a significant difference did not exist for either sex, the Chilean and Mexican populations were combined for further analyses and were referred to as the 'Combined CM' population.

Further tests were conducted to investigate population variation of the calcaneus. First, the discriminant function equations developed on a contemporary White South African population were applied to the 'Combined CM' population to test if the White South African discriminant functions would accurately estimate sex for the 'Combined CM' dataset (Table 4.10). The results showed greater male-bias than female-bias, overall. The sex estimation accuracy rates were as follows: the direct multivariate discriminant function equations between 45.26% and 69.47%, the stepwise discriminant function equations between 59.65% and 75.40%, and the univariate discriminant function equations between 55.44% and 88.64%. Possible reasons for the differences in size of the calcanei between the 'Combined CM' population and the White South African population include differences in socioeconomic status, psychological stress and in living weight and stature. As the calcaneus is a major weight bearing bone, its size is influenced by the weight placed upon it (Laurent et al., 2012; Yattram 1984). The White South African population was more affluent. Therefore, had greater access to healthcare and nutrition than either the Chilean and Mexican populations, which resulted in a healthier population allowing for optimal growth and development. Finally, the White South African population did not have to go through the psychosocial stresses of a depression or a dictatorship as the marginalized demographic and, therefore, would not have experienced the same psychological stress and related growth deficiencies that the Chilean and Mexican populations would have faced during the depression eras.

As a result of the White South African population discriminant functions not accurately classifying the ‘Combined CM’ population, discriminant functions were created specific to the ‘Combined CM’ population. Methods used for forensic anthropological analyses must have an accuracy rate greater than 80.0% (Christensen Scheuer, 2002; Marlow and Pastor, 2011; Rogers et al., 1999; Williams and Rogers, 2006). Methods that show an accuracy rate of less than 80.0% should be used critically and coupled with stronger methods of analysis. Overall, accuracy rates for the multivariate discriminant function were between 80.00% to 86.30%. The stepwise discriminant function yielded an accuracy rate of 86.00% and the univariate discriminant functions had accuracy rates between 71.60 and 80.40%. A Leave-One-Out validation test was completed using the ‘Combined CM’ sample. Overall, for the ‘Combined CM’ calcaneus, the multivariate and stepwise discriminant function equations meet the 80% minimum requirement; the overall correct classification rates ranged from 80% to 86.3%, and the validation test re-classified the calcanei with accuracy rates between 78.60% and 86.0%. For the univariate discriminant function equations, only the maximum breadth meets the 80% minimum requirement with an overall correct classification rate and a re-classification of 80.4%. Therefore, for the ‘Combined CM’ population, only the multivariate, stepwise, and maximum breadth discriminant function equations should be used when estimating sex from the calcaneus.

The means and standard deviations of the ‘Combined CM’ data were compared to the means and standard deviations of the following populations: Greek (Peckmann et al., 2015), Korean (Kim et al., 2013), White American (Steele, 1976), Black American (Steele, 1976), Black South African (Bidmos and Asala, 2004), White South African (Bidmos and Asala, 2003), Northern Italian (Introna et al., 1997), Southern Italian (Gualdi-Russo, 2007), White North American (DiMichele, 2008), New Zealand Polynesian (Murphy, 2002), and Hispanic (Tise, 2010). Overall, there were statistically significant differences found between the ‘Combined CM’ population and all other populations. These results emphasize the need for population-specific and temporally-specific discriminant function equations. The reasons for these differences may be related to stature, nutrition, psychological stressors, and research design. The results from this study highlight the importance of testing population-specific discriminant function equations and developing population-specific discriminant functions when required.

The calcaneus has proven to be a useful bone for sex estimation in Chilean and Mexican populations. Further research should be in testing population variation in Latin American populations not only for the calcaneus, but other skeletal elements as well. Should population variation exist, population-specific discriminant functions should be derived. Due to the amount of civil conflict in Latin America (past and present) it is imperative that their biological profiles be developed extensively, as they differ significantly from American, European and African populations.

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Appendix A – Raw data collected from the Subactual de Santiago Collection. (Sex 1- male; Sex 2 – female)

				Variables (mm)									
Subactual ID#	**Age (yrs)**	**Sex**	**Side**	**MAXL**	**LAL**	**DAFL**	**MIDB**	**MINB**	**DAFB**	**MAXH**	**BH**	**MINH**	**CFH**
B0252	15	2	L	67.91	42.83	25.81	35.58	21.22	25.72	35.66	37.21	32.35	21.74
B0380	16	1	R	82.94	50.72	29.77	42.85	26.79	31.62	48.18	45.93	40.4	25.99
B0357	18	1	L	74.62	48.91	30.10	40.42	25.38	25.94	43.12	33.31	30.87	23.12
B0381	18	1	R	78.89	49.18	28.94	38.44	23.7	27.06	42.4	41.95	35.33	23.11
B0236	18	2	R	71.34	46.24	26.79	36.37	22.36	25.32	41.80	38.74	32.96	22.15
B0204	19	2	L	75.59	46.09	27.28	37.26	24	25.11	38.03	38.47	33.39	22.45
B0072	20	1	L	71.03	50.25	29.44	38.79	24.57	25.69	41.64	44.09	32.75	23.25
B0048	20	1	L	76.71	51.94	29.37	39.89	23.73	23.33	44.68	43.96	35.32	28.96
B0083	21	1	R	74.22	47.71	29.93	37.74	26.37	25.54	42.55	41.94	34.2	23.84
B0333	22	1	L	77.34	47.6	29.05	41.34	27.58	28.13	38.83	40.45	32.58	27
B0354	22	1	L	77.39	50.38	27.99	41.89	25.26	31.76	43.12	45.87	36.5	24.05
B0352	23	1	L	75.66	50.01	29.67	41.53	21.43	32.13	45.86	44.13	35.00	23.63
B0238	23	2	L	67.05	41.13	24.56	37.53	25.76	26.29	37.55	37.83	33.27	22.32
B0376	23	2	R	73.76	46.00	24.88	35.67	20.81	23.41	40.31	41.75	30.76	20.17
B0128	24	1	L	76.87	50.97	30.63	39.67	22.36	31.88	39.80	39.68	33.88	25.27
B0145	24	1	L	81.65	54.68	30.21	45.59	28.13	37.25	42.75	45.69	39.40	25.09
B0092	24	2	L	67.38	46.15	28.69	39.22	21.42	28.83	36.28	37.74	33.88	22.34
B0305	24	2	R	72	47.07	25.64	39.00	25.14	25.57	38.72	41.21	34.84	22.16
B0153	25	1	L	77.04	49.26	30.05	42.13	26.57	31.8	46.6	44.96	35.12	26.99
B0028	25	1	L	81.11	50.48	30.70	39.15	22.42	29.23	37.25	40.77	33.18	26.36
B0382	26	1	L	80.04	52.86	33.23	40.63	25.96	30.15	43.47	45.97	40.01	30.54
B0318	27	1	L	80.69	49.94	24.32	42.03	26.65	29.86	44.64	46.16	35.51	24.93
B0150	27	2	R	74.24	45.59	25.82	37.25	23.65	26.02	42.19	37.95	33.14	23.24
B0088	28	1	L	73.32	44.87	25.62	36.82	21.01	31.26	41.93	43.33	34.29	21.08

				Variables (mm)									
Subactual ID#	**Age (yrs)**	**Sex**	**Side**	**MAXL**	**LAL**	**DAFL**	**MIDB**	**MINB**	**DAFB**	**MAXH**	**BH**	**MINH**	**CFH**
B0232	28	2	R	70.78	42.8	22.79	36.43	20.51	23.91	35.04	35.09	27.27	21.86
B0390	30	1	L	75.27	49.23	31.97	41.26	27.16	33.03	45.84	44.18	37.4	24.68
B0385	31	1	R	78.83	52.57	29.81	39.73	24.56	30.34	41.91	44.65	37.74	24.76
B0233	31	2	R	68.28	40.59	26.35	34.42	20.64	22.02	39.98	34.69	31.68	20.28
B0095	31	2	L	71.08	43.46	29.26	34.87	22.59	27.53	37.94	38.07	31.73	23
B0193	33	1	L	77.06	50.25	29.68	38.49	26.01	30.03	48.88	49.37	39.46	21.28
B0317	33	1	L	77.57	48.82	29.49	40.2	26.17	27.85	46.6	44.14	36.96	22.89
B0366	33	1	L	81.38	52.83	33.89	42.89	25.40	27.07	30.51	44.53	40.10	24.09
B0379	34	1	R	74.78	49.85	29.87	36.61	21.48	28.02	41.10	37.95	33.20	27.05
B0070	35	1	L	80.11	49.24	30.18	38.53	28.04	29.14	41.3	44.9	35.53	25.66
B0343	37	1	L	72.81	50.83	31.99	42.65	30.33	29.99	37.98	30.93	33.01	25.79
B0368	37	1	R	82.66	52.74	29.96	41.86	24.95	28.79	46.26	44.17	38.88	25.15
B0257	37	2	L	65.32	42.81	24.7	36.18	20.55	24.23	37.56	38.24	30.15	21.49
B0074	37	2	L	74.64	46.42	28.09	37.57	25.52	23.74	40.18	41.03	34.20	25.67
B0206	37	2	L	76.43	46.16	26.56	36.61	24.12	29.72	44.86	44.07	32.67	24.06
B0050	39	1	L	79.86	51.17	32.53	40.58	26.57	29.82	44.00	42.85	38.03	24.30
B0349	39	1	L	83.74	52.63	26.30	43.48	24.80	32.58	46.57	46.10	39.35	24.55
B0069	40	1	L	82.76	53.97	30.35	40.96	24.41	32.00	48.61	46.54	36.29	24.69
B0237	40	2	L	69.60	44.09	24.84	35.38	23.88	27.78	42.51	43.53	35.46	24.17
B0331	42	1	L	78.51	47.28	30.2	41.61	25.8	28.76	45.74	45.36	38.75	25.19
B0210	42	2	L	68.15	43.50	27.74	38.14	24.00	25.82	37.38	37.5	31.8	23.91
B00146	42	2	L	68.49	45.83	27.25	36.32	19.82	25.37	37.98	41.16	31.61	21.72
B0182	43	2	L	72.09	45.81	27.37	39.52	22.32	26.68	39.96	40.43	33.79	23.64
B0332	44	1	R	78.75	51.17	27.12	44.05	24.14	32.55	44.77	42.07	34.43	26.49
B0191	45	2	L	73.28	44.89	23.65	35.96	26.74	26.17	44.77	44.44	35.39	24.61

				Variables (mm)									
Subactual ID#	**Age (yrs)**	**Sex**	**Side**	**MAXL**	**LAL**	**DAFL**	**MIDB**	**MINB**	**DAFB**	**MAXH**	**BH**	**MINH**	**CFH**
B0015	46	1	L	73.81	45.75	29.4	43.07	24.26	29.5	37.88	40.76	33.44	26.55
B0152	46	1	R	76.66	50.03	31.3	43.24	27.87	31.82	45.66	46.17	39.92	26.76
B0073	46	2	R	69.9	44.24	27.87	37.1	22.94	28.13	39.61	41.79	34.94	21.9
B0021	48	1	L	78.22	49.02	31.16	38.43	22.44	26.68	40.39	39.1	34.3	26.47
B0026	48	2	L	72.29	44.38	26.95	36.49	22.13	28.9	41.04	39.84	32.25	22.28
B0079	49	2	L	73.6	46.03	30.23	37.01	20.93	26.24	36.79	40.09	31	22.47
B0013	51	1	R	71.57	46.49	28.18	37.75	26.69	26.61	43.73	41.75	36.64	23.54
B0195	52	2	R	68.41	44.66	23.08	36.03	22.01	28.16	41.1	36.06	31.83	25.11
B0325	53	1	R	74.87	51.39	27.57	41.65	26	32.6	46.03	44.94	40.41	25.06
B0302	54	2	R	64.88	40.36	24.97	33.57	22.2	26.12	40.3	37.2	33.78	22.83
B0322	55	1	R	77.58	46.54	26.77	40.47	21.18	23.94	36.54	43.08	36.06	24.78
B0344	55	1	R	81.7	51.47	30.96	44.48	24.58	30.43	49.58	50.39	38.48	24.93
B0076	56	1	L	73.56	51.41	30.24	37.9	26.88	28.57	40.31	47.35	38.1	24.23
B0168	56	1	L	75.36	47.48	28.15	39.58	21.83	26.68	42.94	43.36	34.21	24.95
B0181	56	2	L	70.18	44.51	24.54	35.56	23	23.9	39.37	37.98	32.36	22.72
B0209	56	2	L	70.4	42.33	25.3	32.99	20.28	28.19	36.64	38.83	28.38	21.19
B0025	57	1	R	80.86	51.63	31.3	42.7	24.43	29.12	44.41	40.89	35.92	29.36
B0001	58	1	L	79.04	46.67	27.43	38.75	25.48	25.71	44.25	44.07	38.38	21.56
B0249	58	2	R	70.87	40.32	24.19	36.71	21.75	25.29	37.21	37.78	29.52	20.68
B0199	58	2	R	73.78	43.98	29.58	36.98	21.9	27.82	40.43	42.01	30.09	20.78
B0215	59	1	R	83.41	53.78	33.75	45.97	28.58	32.21	49.44	44.29	40.1	26.24
B0308	59	2	L	71.38	47.95	28.52	41.28	23.81	28.72	37.95	43.95	34.77	20.53
B0189	59	2	R	77.14	46.95	25.37	38.98	25.11	26.31	42.93	42.66	33.24	24.68
B0377	63	2	L	75.58	50.88	31.36	39.08	24.05	28.35	43.88	42.72	35.59	23.67
B0218	64	2	R	69.89	43.87	25.96	38.11	21.96	27.17	39.35	39.81	32.36	26.31

				Variables (mm)									
Subactual ID#	**Age (yrs)**	**Sex**	**Side**	**MAXL**	**LAL**	**DAFL**	**MIDB**	**MINB**	**DAFB**	**MAXH**	**BH**	**MINH**	**CFH**
B0187	71	2	L	67.92	42.83	27.58	36.35	23.77	25.49	42.52	42.49	33.38	23.7
B0245	71	2	L	76.71	44.33	28.32	39.21	25.62	28.97	38.51	39.68	33.91	24.92
B0205	74	2	R	73.79	46.76	28.27	38.98	25.72	26.86	41.17	38.48	34.54	22.77
B0060	74	2	L	74.97	47.88	27.04	37.03	25.6	32.05	39.93	43.68	33.23	25.99
B0186	74	2	R	76.64	48.64	26.5	39.85	27.75	28.05	44.12	45.93	36.47	26.14
B0363	76	1	R	80.77	49.77	31.6	45.93	25.46	33.13	49.42	48.18	39.92	29.67
B0223	77	2	R	71.91	45.5	26.72	39.3	21.54	28.36	40.71	41.62	34.82	24.87
B0389	78	1	L	75.05	48.29	29.22	39.42	26.19	30.42	42.79	45.75	36.26	24.31
B0023	78	2	L	75.1	46.65	26.56	36.85	23.49	24.85	40.72	41.06	32.71	25.05
B0194	79	2	R	66.8	44.52	26.07	39	21.53	26.53	40.23	39.3	31.88	21.03
B0084	80	1	R	85.23	49.29	31.79	40.56	26.93	28.08	48.04	49.43	39.78	27.2
B0090	80	1	R	85.78	52.37	27.35	43.74	27.52	31.58	49.2	45.78	38.43	30.59
B0133	80	2	R	77.38	47.38	28.85	39	25.97	26.87	42.84	44.73	35.2	20.88
B0226	82	2	R	70.42	44.7	28.39	28.15	22.5	27.53	43.08	42.29	34.79	21.71
B0222	83	2	L	76.39	46.28	28.99	39.45	25.38	29.19	41.89	40	31.8	22.92
B0216	85	2	L	72.08	43.81	25.91	37.27	22.02	26.09	42.33	41.56	33.33	23.13
B0058	86	1	R	82.01	52.18	31.2	45.85	27.69	33.56	47.15	48.04	41.12	28
B0268	90	2	L	76.12	47.37	25.67	38.82	24.18	24.09	41.24	44.61	34.39	23.75
B0769	15-17	1	L	72.54	51.26	28.66	37.14	23.59	27.29	43.14	41.38	32.31	23.35
B0759	15-18	2	L	69.85	44.54	26.43	36.47	23.7	28.84	42.05	39.00	34.06	22.08
B0097	15-19	1	L	76.57	50.43	28.92	37.44	26.12	27.36	43.04	44.39	37.33	24.32
B0757	17-19	2	L	67.20	47.15	31.88	34.80	24.39	25.21	42.68	37.65	32.71	21.86
B0369	18-19	2	R	68.52	42.41	25.11	35.01	30.27	25.28	41.65	37.21	23	20.48
B0118	20-24	2	L	65.96	40.87	26.59	33.4	21.20	23.20	37.34	40.17	30.35	20.46
B0314	25-29	2	L	63.31	43.40	24.95	35.45	20.58	23.28	36.54	36.56	30.53	19.22

				Variables (mm)									
Subactual ID#	Age (yrs)	Sex	Side	MAXL	LAL	DAFL	MAXB	MINB	DAFB	MAXH	BH	MINH	CFH
B0099	25-30	1	L	77.45	51.22	32.68	40.76	23.92	27.05	41.11	44.61	37.33	24.75
B0104	30-34	1	L	79.56	55.02	28.87	43.61	30.90	31.22	48.62	47.16	43.50	18.99
B0014	30-34	2	L	67.13	42.92	27.96	33.91	22.51	19.31	37.79	36.54	30.68	21.86
B0109	35-39	1	R	75.83	51.87	30.89	40.43	23.94	30.79	46.04	47.18	40.49	25.98
B0114	35-39	1	L	77.58	49.14	28.86	41.61	24.26	29.07	43.28	46.95	37.44	26.59
B0096	35-39	1	R	87.47	55.39	36.48	45.71	31.36	33.03	49.8	45.14	42.28	26.39
B0139	35-39	2	L	70.19	45.70	28.75	37.60	23.78	28.60	39.42	40.16	33.31	22.47
B0020	35-39	2	L	75.17	47.38	27.8	36.49	23.61	24.33	40.22	42.13	33.73	22.56
B0132	40-44	1	R	68.57	43.22	27.01	39.96	24.76	25.69	41.2	41.74	35.69	23.19
B0256	40-44	1	L	75.16	48.79	29.18	40.78	24.97	30.53	48.62	47.80	35.09	22.48
B0110	40-44	1	L	76.06	50.1	31.32	43.22	28.42	28.11	44.1	44.83	38.83	25.95
B0112	40-44	2	L	69.14	45.00	26.31	37.65	22.52	25.19	38.5	40.78	33.49	23.54
B0094	40-44	2	R	69.7	46.93	30.14	37.08	24.35	28.04	37.01	39.7	34.27	20.45
B0173	40-44	2	R	72.57	48.35	29.89	39.11	26.76	26.61	44.85	45.64	37.16	22.49
B0082	40-44	2	L	75.36	48.48	27.79	39.80	23.83	29.68	41.12	45.26	35.15	23.38
B0297	40-49	2	R	75.62	47.77	27.93	40.58	25.42	28.48	42.65	44.25	34.33	27.35
B0131	45-49	1	L	75.25	48.72	31.15	41.05	25.46	26.36	45.73	48.56	39.75	21.98
B0125	45-49	1	L	78.56	50.82	34.21	41.56	24.09	29.35	44.5	44.21	38.58	26.23
B0106	45-49	1	L	84.73	49.93	30.74	44.74	30.11	32.81	49.33	46.28	39.53	27.71
B0283	45-49	2	R	68.49	43.04	29.79	34.7	26.07	23.36	44.33	38.42	34.41	23.55
B0307	45-49	2	R	73.64	43.3	25.52	37.23	23.69	25.35	42.74	42.47	37.07	23.87
B0122	50-54	1	L	72.7	48.12	30.52	42.05	24.74	29.67	41.42	39.75	34.86	23.31
B0059	50-54	1	R	78.39	51.66	34.09	43.29	28.925	33.02	49.71	48.35	42.67	25.82
B0316	50-54	2	L	70.8	44.46	29.61	35.68	22.19	24.52	38.82	34.58	29.26	18.72
B0315	50-54	2	L	72.41	44.20	26.11	35.28	23.97	24.6	38.22	37.29	32.85	23.6

				Variables (mm)									
Subactual ID#	Age (yrs)	Sex	Side	MAXL	LAL	DAFL	MAXB	MINB	DAFB	MAXH	BH	MINH	CFH
B0091	65-69	2	R	73.5	46.6	28.18	36.66	25.54	24.44	40.17	38.98	32.54	24.72
B0266	75-79	2	R	75.27	45.22	26.89	39.51	25.3	29.45	45.66	44.43	32.88	20.89

Appendix B – Raw data collected from the UNAM Skeletal Collection (Sex 1- male; Sex 2 – female)

				Variables (mm)									
UNAM ID#	**Age**	**Sex**	**Side**	**MAXL**	**LAL**	**DAFL**	**MAXB**	**MINB**	**DAFB**	**MAXH**	**BH**	**MINH**	**CFH**
199	27	1	L	78.07	50.95	28.81	40.83	22.01	30.72	41.46	42.54	35.52	24.09
190	27	2	L	62.55	45.44	24.01	39	21.51	29.55	40.44	40.76	35.6	24.55
70	30	1	L	72.35	48.81	28.46	41.05	25.15	29.12	41.79	42.7	34.95	23.48
208	31	2	L	71.02	50.32	28.69	38.92	22.89	30.27	39.95	41.14	34.35	19.54
94	32	1	L	70.12	47.51	28.77	40	24.85	29.37	39.24	37.49	33.29	21.9
213	37	2	L	76.91	47.63	26.37	37.88	26.7	28.56	44.59	42.68	34.7	22.54
65	40	1	L	80.21	49.1	28.49	40.34	27.37	31.04	46.66	45.63	38.33	25.47
67	40	1	L	71.39	45.81	28.71	38.97	25.77	29.23	43.98	42.46	35.79	23.71
84	42	1	L	77.71	47.9	29.96	38.35	24.22	29.02	41.88	42.22	33.94	23.78
140	50	1	L	74.36	47.3	27.66	38.92	25.69	28.71	42.77	43.73	35.44	23.87
86	50	1	L	79.98	48.32	27.95	39.26	26.21	30.16	43.01	45.8	37.46	27.7
69	50	2	R	69.73	45.61	28.78	38.57	24.55	28.35	42.76	41.39	32.78	24.08
221	52	1	L	71.74	42.7	30.22	38.53	23.76	29.79	40.54	42.65	33.03	21.95
224	52	1	L	66.65	45.69	27.14	39.77	23.94	27.88	40.6	39.07	31.89	21.61
205	55	2	L	68.4	45.93	27.09	35.5	21.07	27.71	35.66	39.47	32.64	21.1
195	56	2	L	72.73	42.39	28.36	38.35	23.98	28.96	42.08	40.56	34.5	19.88
234	57	1	L	81.42	53.21	30.57	41.77	28.78	31.87	48.1	49.56	38.12	25.43
222	60	1	L	77.5	45.2	25.1	39.32	24.67	26.77	42.89	43.01	32.48	24.23
240	63	1	L	85.11	56.05	32.56	41.56	26.25	29.52	42.79	48.27	38.4	25.75
210	64	2	L	65.6	44.67	24.91	37.76	21.08	24.81	37.34	40.34	29.06	22.33
233	67	1	R	81.63	49.47	30.5	39.51	26.93	29.08	46.82	47.42	37.73	26.24
216	68	1	L	87.59	51.68	31.01	45.62	25.88	33.28	50.4	53.25	39.91	24.85
201	72	1	L	70.64	40.65	26.76	38.97	25.76	28.15	39.05	41.05	31.99	23.69
212	72	1	L	75.69	47.66	24.77	42.01	27	26.85	43.06	45.48	36.04	26.67

				Variables (mm)									
UNAM ID#	**Age**	**Sex**	**Side**	**MAXL**	**LAL**	**DAFL**	**MAXB**	**MINB**	**DAFB**	**MAXH**	**BH**	**MINH**	**CFH**
230	73	1	L	88.84	54.61	28.44	42.03	24.16	28.78	38.74	48.88	38.06	26.14
198	74	1	L	75.58	45.5	28.87	40.43	26.64	27.9	39.06	43.51	34.15	22.74
241	75	1	R	67.66	43.97	26.87	36.71	21.86	27.08	43.28	41.45	35.79	20.7
237 aka 219	78	1	L	94.81	56.96	31.88	48.29	31.57	32.85	49.26	51.52	44.53	29.57
179	79	1	R	75.66	47.55	29.94	40.32	25.94	31.14	43.11	47.22	38.07	27.24
196	80	1	L	78.39	46.96	27.2	39.51	27.66	30.01	43.14	43.93	36.86	25.57
209	81	1	L	72.69	46.34	26.2	41.84	24.71	28.02	43.41	44.61	36.23	22.44
88	81	2	L	63.21	40.58	24.26	33.64	21.77	24.78	38.34	40.78	32.07	19.11
203	83	1	L	75.88	51.26	28.4	41.12	23.73	29.94	40.2	43.16	37.19	25.91
223	83	1	R	80.96	50.82	31.16	44.63	24.32	31.59	45.5	42.18	37.35	25.11
228	84	2	L	67.79	44.53	27.18	39.54	20.9	28.07	37.86	41.1	33.49	24.43
235	85	1	L	82.86	54.9	29.89	41.71	24.02	33.24	48.04	48.05	42.35	26.47
184	88	2	L	64.7	44.77	26.6	37.68	19.82	25.95	36.79	37.44	30.26	22.44
197	89	1	L	78.16	54.99	31.02	42.54	26.82	31.57	51.05	50.33	39.59	26.31
236	99	1	L	80.69	53.41	31.58	41.08	28.52	32.27	48.81	49.64	38.55	25.88
62	15-19	2	R	63.86	40.14	22.9	33.11	18.62	23.05	31.13	33.15	27.58	23.96
95	15-19	2	L	71.75	45.59	27.06	35.32	25.74	29.01	39.46	40.69	33.23	21.73
160	20-24	1	L	76.9	48.58	31.93	42.01	28.64	32.05	45.66	47.07	38.55	25.86
156	20-24	1	R	77.57	47.82	33.36	43.15	30.03	31.96	51.39	51.1	41.44	27.83
98	25-29	1	R	73.95	47.01	29.85	41.37	23.76	26.37	41.76	44.04	35.19	26.94
107	25-29	1	L	79.68	52.63	29.48	41.76	27.09	26.59	43.35	46.39	38.17	25.23
163	25-29	1	L	74.97	47.1	28.12	37.52	23.06	27.68	39.48	42.87	29.2	22.54
108	25-29	1	L	72.66	46.08	27.56	38.97	29.43	27.21	39.17	40.28	35.26	22.81
85	25-29	2	L	68.43	41.52	23.25	34.7	21.43	24.63	38.25	40.35	32.61	22.84
19	25-29	2	L	65.01	41.53	24.07	33.41	21.51	27.64	43.9	44.03	37.76	20.79

				Variables (mm)									
UNAM ID#	**Age**	**Sex**	**Side**	**MAXL**	**LAL**	**DAFL**	**MAXB**	**MINB**	**DAFB**	**MAXH**	**BH**	**MINH**	**CFH**
57	25-29	2	L	68.29	40.99	25.82	35.18	23.02	24.72	39.22	40.87	32.62	23.84
101	30-34	1	L	74.73	46.38	30.77	39.02	24.02	30.4	43.68	44.13	39.26	29.28
100	30-34	1	L	78.96	51.27	29.52	42.35	27.43	29.93	47.54	50.69	38.39	24.91
99	30-34	1	R	75.52	46.17	30	41.7	25.93	30.79	43.35	46.39	38.17	25.23
32	30-34	2	L	69.77	44.84	26.91	24.61	22.79	24.78	35.75	37.67	30.17	20
60	30-34	2	L	72.4	43.34	24.63	35.52	26.8	24.68	39.67	43.54	34.64	22.35
171	30-34	2	L	70.65	41.72	27.42	33.97	20.41	26.04	37.21	42.99	30.03	20.75
136	35-36	1	L	78.5	52.34	28.4	43.18	29.12	33.01	47.43	44.44	37.01	26.36
47	35-39	1	L	85.73	57.96	36.61	47.97	29.4	34.58	48.8	50.51	42.79	28.88
49	35-39	1	L	81.48	51.38	28	42.96	28.1	32.46	55.75	52.66	41.72	26.43
50	35-39	1	R	77.1	49	30.56	42.82	27.51	27.01	43.42	42.66	34.79	27.65
129	35-39	1	R	86.86	46.65	32.6	46.3	32.29	34.45	52.62	50.7	44.95	27.03
80	35-39	1	L	86.08	55.96	31.36	43.87	28.7	35.01	46.15	47.21	38.65	28.48
111	35-39	1	L	69.86	46.14	26.18	37.33	23.12	25.94	39.06	40.48	33.86	23.74
148	35-39	1	R	81.24	47.92	27.34	41.07	23.64	30.6	44.63	44.62	37.8	25.31
11	35-39	2	R	66.62	43.06	26.66	35.51	19.98	26.05	36.89	39.29	33.77	20.75
6	35-39	2	L	60.6	39.31	24.71	34.05	19.79	22.87	36.83	34.03	28.45	20.86
7	35-39	2	L	71.26	42.32	24.32	35.18	22.06	25.22	38.95	37.36	29.88	22.23
34	35-39	2	L	78.74	48.47	28.95	40.69	24.95	27.68	44.76	47.48	35.8	25.93
102	35-39	2	L	64.59	42.54	26.94	33.27	18.97	24.13	38.37	38.41	32.02	22.59
112	35-39	2	L	63.45	43.86	23.86	33.83	18.22	27.03	40.36	41.43	34.52	21.68
8	40-44	1	R	77.85	48.33	27.97	38.89	22.54	27.83	41.87	40.54	34.65	26.71
161	40-44	1	L	75.88	47.63	26.96	39.66	24.88	30.12	43.59	45.73	37.32	23.61
155	40-44	1	R	75.96	48.21	28.78	39.09	26.32	28.23	44.26	45.09	34.19	25.18
61	40-44	1	R	71.54	42.28	28.02	35.68	27.99	35.25	49.73	49.76	40.96	24.71

				Variables (mm)									
UNAM ID#	**Age**	**Sex**	**Side**	**MAXL**	**LAL**	**DAFL**	**MAXB**	**MINB**	**DAFB**	**MAXH**	**BH**	**MINH**	**CFH**
76	40-44	1	L	77.62	49.42	30.32	44.36	26.88	28.26	43.86	46.17	36.93	24
146	40-44	1	L	78.52	51.22	32.84	40.64	29.72	22.46	45.45	43.61	36.88	20.91
150	40-44	1	L	72.28	42.78	25.84	36.57	23.27	26.17	41.56	41.14	32.23	20.76
44	40-44	2	R	74.58	47.97	29.12	35.59	23.5	29.02	42.6	44.17	34.37	25.38
92	40-44	2	R	71.43	45.92	29.25	37.17	20.96	28.4	42.12	41.96	34.01	24.13
139	40-45	1	L	76.76	51.54	37.39	40.96	25.28	32.26	45.9	47.14	40.15	28.47
13	45-49	1	L	82.68	54.8	31.94	46.37	24.8	31.63	50.22	53.63	41.85	23.89
141	45-49	1	L	73.62	46.21	29.02	40.35	26.14	27.42	45.13	46.16	35.57	24.17
79	45-49	1	R	81.63	51.41	30.85	43.22	24.77	28.81	46.55	44.87	35.2	28.49
96	45-49	1	L	81.82	52.3	31.54	38.84	27.15	30.82	43.9	47.91	37.3	26.84
90	45-49	1	L	80.65	51.8	30.03	43.16	27.31	32.76	44.42	49.99	39.61	26.47
153	50-54	1	L	79.89	49.97	27.78	40.53	27.34	29.09	40.3	42.86	33.96	27.36
58	50-54	1	L	82.07	48.68	28.82	41.25	29	31.27	45.78	50.76	39.15	28.11
143	50-54	1	R	71.3	42.33	25.53	38.48	23.77	25.79	37.57	44.05	33.16	21.95
68	50-54	2	L	69.82	44.18	24.81	37.04	23.47	26.68	40.96	42.99	35.64	22.64
133	50-54	2	L	67.22	43.8	24.8	37.03	25.14	28.21	42.56	43.62	38.43	24.52
97	50-54	2	L	81.06	50.79	30.58	42.98	25.6	30.49	45.03	46.03	36.94	22.13
159	50-59	2	L	67.84	40.31	24.82	37.88	22.3	26.38	39.43	40.35	30.33	22.02
41	55-59	1	R	78.46	49.39	30.22	42.71	28.47	30.77	44.58	45.28	38.43	26.71
75	55-59	1	L	73.03	48.03	27.59	40.91	24.68	28.34	40.44	40.81	35.24	27.1
77	55-59	1	L	76.22	48.73	29.07	39.34	24.56	27.38	44.11	47.25	35.54	25.61
93	55-59	2	L	81.66	52.77	29.63	44.93	29.14	35.31	48.83	50.62	42.36	28.89
4	55-59	2	L	63.53	39.3	25.31	35.04	22.01	22.79	35.06	38.44	29.38	24.52
3	55-59	2	R	74.02	47.46	23.72	35.37	26.88	23.87	39.63	38.51	34.74	23.82
12	55-59	2	L	73.64	43.72	25.55	35.87	21.43	26.32	41.31	43.67	33.18	23.71

				Variables (mm)									
UNAM ID#	**Age**	**Sex**	**Side**	**MAXL**	**LAL**	**DAFL**	**MAXB**	**MINB**	**DAFB**	**MAXH**	**BH**	**MINH**	**CFH**
14	55-59	2	L	74.24	44.11	27.34	37	23.5	27.6	46.92	47.91	36.93	22.45
5	60-64	1	L	78.04	48.58	29.69	40.58	24.05	29.05	45.06	46.99	37.33	22.32
103	60-64	1	L	79.04	50.63	31.53	46.23	29	34.03	47.25	47.73	38.12	25.64
52	60-64	2	L	71.09	44.79	26.3	33.25	21.99	25.23	36.33	38.84	31.3	20.01
15	65-69	2	L	76.19	44.19	23.67	37	20.67	25.92	39.17	44.23	31.78	23.9
16	65-69	2	L	72.79	47.38	27.15	36.43	23.67	23.82	43.73	43.13	33.05	23.99
23	65-69	2	L	72.56	46.85	27.02	37.91	24.67	28.43	42.41	46.77	33.48	23.56
40	70-74	1	R	78.23	48.51	29.53	41.77	26.06	28.72	42.38	45.72	37.52	28.21
78	70-74	1	L	73.86	47.63	28.91	39.74	28.81	30.73	44.29	44.76	39.31	24.2
118	70-74	2	L	80.64	49.11	25.87	37.7	24.28	25.98	40.21	45.88	34.63	24.36
189	ADULT	1	L	81.23	53.02	32.53	42.19	24.78	32.83	41.52	44.25	33.91	25.83
181	ADULT	2	R	62	41.76	25.3	31.81	18.12	24.35	34.71	35.42	29.08	21
162	ADULT	1	L	75.52	48.44	27.37	39.37	26.79	29.89	42.58	43.44	37.87	24.71
66	ADULT	1	L	76.9	48.55	29.81	39.11	26.7	33.57	47.03	44.59	35.52	26
113	ADULT	1	L	67.99	43.27	25.22	34.44	21.39	25.25	38.48	37.78	30.34	21.86
122	ADULT	1	R	87.2	56.16	32.73	46.34	28.25	30.21	46.67	47.02	39.58	28.93
124	ADULT	1	L	76.33	46.3	29.77	40.66	25.86	29.37	40.93	43.13	35.7	24.47
130	ADULT	1	L	76.27	45.95	26.8	36.4	25.03	28.18	36.72	42.67	33.36	22.15
134	ADULT	1	L	76.73	49.5	29.85	41.28	27.35	29.18	43.23	43.87	36.08	25.94
167	ADULT	1	L	73.97	47.43	31.14	40.36	25.13	25.3	41.18	45.48	38.72	21.58
169	ADULT	1	L	78.49	50.7	32.07	41.5	27.4	30.72	46.05	45.57	39.24	25.75
170	ADULT	1	L	78.57	50.24	30.52	43	27.3	30.02	47.61	47.89	39.64	23.93
178	ADULT	1	L	80	49.2	29.05	39.53	28.54	28.4	46.73	47.62	39.55	24.47
183	ADULT	1	L	75.81	49.8	28.58	37.34	23.94	31.27	41.97	44.92	36.7	22.3
185	ADULT	1	L	83.32	51.66	30.27	43.25	25.46	35.93	42.18	44.9	35.94	27.38

				Variables (mm)									
UNAM ID#	**Age**	**Sex**	**Side**	**MAXL**	**LAL**	**DAFL**	**MAXB**	**MINB**	**DAFB**	**MAXH**	**BH**	**MINH**	**CFH**
186	ADULT	1	L	73.58	46.74	29.54	42.92	25.51	31.76	40.16	45.72	32.59	22.89
191	ADULT	1	L	73.5	44.88	27.68	40.67	20.04	28.66	43.06	42.19	35.41	22.45
192	ADULT	1	L	84.18	56.02	32.17	41.97	25.99	33.04	50.56	51.69	42.87	29.65
45	ADULT	1	R	72.55	46.5	28.14	39.75	24.47	28	44.58	43.04	35.24	26.23
38	ADULT	1	R	71.92	45.02	26.88	38.96	23.36	28.34	42.76	41.6	34.76	22.94
56	ADULT	1	L	69.48	46.58	25	34.27	22.91	27.46	39.63	42.41	31.05	24.01
72	ADULT	1	L	73.31	47.75	28.67	39.19	26.02	29.88	42.84	45.3	37.81	26.95
81	ADULT	1	L	79.12	53.22	30.4	38.47	26.56	31.25	37.35	40.12	31.48	25.76
82	ADULT	1	L	76.66	44.56	25.18	41.25	27.05	31.48	39.98	45.74	35.5	22.33
133	ADULT	2	L	67.22	43.8	24.8	37.03	25.14	28.21	42.56	43.62	38.43	24.52
174	ADULT	2	L	72.01	42.24	23.32	36.99	20.31	26.82	38.61	45.32	30.86	23.08
115	ADULT	2	L	71.65	43.97	26	36.15	24.04	29.17	41.09	45.78	35.61	22.91
120	ADULT	2	L	81.27	48.57	30.96	39.23	24.62	27.76	44.07	46.55	35.61	24.99
123	ADULT	2	L	66.69	43.43	23.06	33.68	20.51	25.03	36.86	39.77	32.06	22.5
128	ADULT	2	L	73.65	45.68	26.36	37.28	25.14	24.97	42.73	44.48	35.22	23.12
151	ADULT	2	R	67.34	41.34	23.39	38.29	26.17	26.22	35.88	35.84	32.79	22.87
165	ADULT	2	L	75.17	45.09	28.57	39.28	26.14	27.2	45.19	43.99	37.38	24.49
9	ADULT	2	L	65.09	39.55	23.26	35.4	22.59	22.75	37.81	39.01	29.85	22.64
2	ADULT	2	L	69.56	41.39	25.52	35.69	23.24	24.01	34.8	38.63	30.61	20.36
1	ADULT	2	L	72.66	44.87	23.85	37.88	24.08	27.65	38.71	41.96	32.25	24.17
25	ADULT	2	L	75.17	44.05	26.98	37.28	24.36	27.38	41.46	43.38	30.09	21.88
26	ADULT	2	L	80.43	48.92	29.44	40.07	24.37	24.66	40.94	46.45	34.47	25.72
18	ADULT	2	L	66.32	41.28	24.46	35.74	24.44	27.67	39.14	37.6	30.9	22.6
17	ADULT	2	L	66.83	41.78	23.7	35.47	20.94	26.5	36.51	39.18	29.81	22.06
36	ADULT	2	L	67.3	42.66	22.28	34.11	20.34	26.35	40.68	42.21	32.88	22.21

				Variables (mm)									
UNAM ID#	**Age**	**Sex**	**Side**	**MAXL**	**LAL**	**DAFL**	**MAXB**	**MINB**	**DAFB**	**MAXH**	**BH**	**MINH**	**CFH**
35	ADULT	2	R	69.64	42.52	26.96	36.72	23.58	27.5	36.85	37.36	27.88	23.15
28	ADULT	2	L	71.43	43.66	23.72	35.91	22.92	25.04	41.16	45.87	33.17	22.43
27	ADULT	2	L	73.42	47.15	29.35	37.36	22.97	28.79	43.76	45.09	33.83	20.78
55	ADULT	2	L	70.9	44.76	24.6	37.33	21.14	24.86	39.77	41.7	34.56	23.44
53	ADULT	2	L	81.53	50.17	32.59	41.88	29.22	31.63	43.37	46.64	36.48	27.57
64	ADULT	2	L	59.22	40.8	23.36	34.26	22.04	23.66	36.37	38.15	29.95	20.16