Estimating Sex from the Seven Cervical Vertebrae: An Analysis of White European Skeletal Populations

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I dedicate my dissertation to my parents, Genia and Ed, and my brothers, Peter and Alexander. Without your love, encouragement, and unwavering dedication I could not have persevered and learned to reach my greatest potential. I also dedicate this work to Katherine Drake who has lovingly supported me throughout this process.

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ABSTRACT

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The current study focused on the seven cervical vertebrae to establish an accurate sex estimation method for White European skeletal populations. The influences of stature and aging on the cervical vertebrae were also investigated to assess their effects on estimating sex from the cervical vertebrae.

Three characteristics from the seven cervical vertebrae were measured (CHT, maximum body height; CAP, vertebral foramen anterior-posterior diameter; and CTR, vertebral foramen transverse diameter). Two hundred and ninety five individuals (157 males, 138 females), ranging from 20 to 99 years old were studied from the contemporary University of Athens and the historic Luis Lopes Skeletal Collections. To date, no study has used the combination of cervical vertebral foramen measurements and the vertebral body height to estimate sex.

Intra- and inter-observer error rates were low, with the exception of C_1TR. The statistical analyses showed that only CHT and CTR measurements exhibited sexual dimorphism. Seven multivariate discriminant functions were developed that successfully estimated sex between 80.3% and 84.5% accuracy. A cross-validation study tested the reliability of estimating sex using the seven functions. Five of the seven functions exhibited strong statistical algorithms. No ancestral differences were exhibited between the contemporary Greek and historic Portuguese skeletal collections indicating that the discriminant functions are useful for estimating sex of White Europeans from different time periods. No relationship existed between stature and any of the three measurements. Adult females exhibited no age-related changes to the vertebral morphometrics whereas males exhibited age-related changes in only four of the seven CAP diameters. Further testing revealed that these diameters gradually decreased in size between 30 years and 90 years of age. However, the CAP diameter exhibited no significant dimorphic potential for estimating sex. Therefore, this study will assist in estimating sex of unknown White European individuals from the cervical vertebrae and will be useful in cases such as mass disasters when only fragmented remains are available for examination.

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TABLE OF CONTENTS

ACKNOWLEGMENTS ..... **iv**

LIST OF TABLES ..... **ix**

LIST OF FIGURES ..... **xiii**

1 CHAPTER 1: INTRODUCTION **1**

1.1 Research Objectives 1

1.2 Potential for Sex Estimation from the Cervical Vertebrae 2

1.3 Concepts of Identity in Forensic Anthropology 5

2 CHAPTER 2: BACKGROUND **11**

2.1 Evolution of the Vertebral Column and the Origins of Bipedalism 11

2.2 The Vertebral Column: Anatomy and Function 13

2.2.1 Vertebral Growth and Development 14

2.2.2 Vertebral Anatomy 18

2.2.3 The Function of the Vertebral Column 24

2.3 Skeletal Identification in Forensic Anthropology 25

2.4 Sex Estimation in Forensic Anthropology 26

2.4.1 Estimating Sex from the Pelvis 27

2.4.2 Estimating Sex from the Skull 31

2.4.3 Estimating Sex from the Long Bones 36

2.4.4 Estimating Sex from the Vertebrae 40

2.4.5 Estimating Sex from Other Post-cranial Skeletal Elements 43

2.5 The Admissibility of Forensic Anthropology Methods in Court 49

2.6 Osteological Collections used in this Research 53

2.6.1 University of Athens Human Skeletal Reference Collection 53

2.6.2 Luis Lopes Skeletal Reference Collection 55

3 CHAPTER 3: MATERIALS AND METHODS **57**

3.1 Research Objectives 57

3.2 Skeletal Materials Utilized for this Research 58

3.3 Methods 61

3.3.1 Demographic Data 61

3.3.2 Skeletal Measurements 63

3.4 Statistical Analyses 70

4 CHAPTER 4: RESULTS 77

4.1 Research Objectives 77

4.2 Descriptive Statistics 78

4.3 Normality 85

4.4 Inter- and Intra-observer Error 87

4.5 Sexual Dimorphism and Ancestral Variation in the Cervical Vertebrae 94

4.5.1 Vertebral Sexual Dimorphism 94

4.5.2 Vertebral Variation due to Ancestry 99

4.6 Correlations between Vertebral Morphometrics and Stature 101

4.6.1 The Effects of Stature on Vertebral Morphometrics 101

4.6.2 Relationships between CAP, CTR, and CHT measurements 104

4.7 Discriminant Functions 107

4.7.1 Estimating Sex from a Single Vertebra 107

4.7.2 Estimating Sex from all Cervical Vertebrae (C_1 - C_7) 114

4.7.3 Estimating Sex from Atypical Vertebrae (C_1 and C_2) 117

4.7.4 Estimating Sex from Typical Cervical Vertebrae (C_3 – C_6) and C_7 118

4.7.5 Estimating Sex from Four Typical Cervical Vertebrae (C_3-C_6) 121

4.7.6 Stepwise Discriminant Function Analysis to Estimate Sex from Cervical Vertebrae 124

4.8 Sex Estimation Accuracy 127

4.8.1 Cross Validating the Predicted Sex Estimating Potential of Function 1 129

4.8.2 Cross Validating the Predicted Sex Estimating Potential of Function 2 130

4.8.3 Cross Validating the Predicted Sex Estimating Potential of Function 3 130

4.8.4 Cross Validating the Predicted Sex Estimating Potential of Function 4 131

4.8.5 Cross Validating the Predicted Sex Estimating Potential of Function 5 132

4.8.6 Cross Validating the Predicted Sex Estimating Potential of Function 6 132

4.8.7 Cross Validating the Predicted Sex Estimating Potential of Function 7 133

4.9 The Effects of Age on Cervical Vertebrae 133

4.9.1 Age-Related Changes to the Cervical Vertebrae 133
4.9.2 Post-hoc Test of Age-Related Changes to Four CAP Diameters in the Males 137

5 CHAPTER 5: DISCUSSION 146
5.1 Context of the Current Research 146
5.2 The Relationship between Sex and Cervical Vertebral Morphometrics 147
5.2.1 Sexual Dimorphism in the Cervical CAP, CTR and CHT Morphometric 148
5.2.2 Sex estimation in the Cervical Vertebrae 160
5.3 The Relationship between Stature and Cervical Vertebrae 165
5.4 The Relationship between Age and the Cervical Vertebrae 168

6 CHAPTER 6: CONCLUSIONS 171

7 APPENDIX A: Cervical Vertebrae Skeletal Measurements 195

8 APPENDIX B: SPSS Discriminant Function Data for Functions 1 to 7 209
8.1 Appendix B1: SPSS Discriminant Function 1 Analysis Results 210
8.2 Appendix B2: SPSS Discriminant Function 2 Analysis Results 213
8.3 Appendix B3: SPSS Discriminant Function 3 Analysis Results 216
8.4 Appendix B4: SPSS Discriminant Function 4 Analysis Results 219
8.5 Appendix B5: SPSS Discriminant Function 5 Analysis Results 222
8.6 Appendix B6: SPSS Discriminant Function 6 Analysis Results 225
8.7 Appendix B7: SPSS Discriminant Function 7 Analysis Results 228

9 APPENDIX C: Raw Data 231
9.1 Appendix C1: Athens Collection Raw Data 232
9.2 Appendix C2: Lopes Collection Raw Data 238

LIST OF TABLES

Table 3.1 Description of measurements taken from each cervical vertebra. 64

Table 3.2 Designated age categories and their respective ages in years used to assess the age related changes between vertebral foramen measurements using ANOVA. 76

Table 4.1 Demographic information for all individuals in the Athens and Lopes Skeletal Collections. 78

Table 4.2 Demographic information for males and females in the Athens Skeletal Collection. 79

Table 4.3 Demographic information for males and females in the Lopes Skeletal Collection. 79

Table 4.4 Descriptive statistics for vertebral foramen anterior-posterior diameter (CAP), vertebral foramen transverse diameter (CTR), and maximum vertebral body height (CHT) for male individuals (N=70) in the Athens Collection. 81

Table 4.5 Descriptive statistics for vertebral foramen anterior-posterior diameter (CAP), vertebral foramen transverse diameter (CTR), and maximum vertebral body height (CHT) for female individuals (N=65) in the Athens Collection. 82

Table 4.6 Descriptive statistics for vertebral foramen anterior-posterior diameter (CAP), vertebral foramen transverse diameter (CTR), and maximum vertebral body height (CHT) for male individuals (N=87) in the Lopes Collection. 83

Table 4.7 Descriptive statistics for vertebral foramen anterior-posterior diameter (CAP), vertebral foramen transverse diameter (CTR), and maximum vertebral body height (CHT) for female individuals (N=73) in the Lopes Collection. 84

Table 4.8 Normality probability p-values assessed in males and females in the Athens and Lopes Collections evaluating the parametric distribution of the sampled data. 86

Table 4.9 Intra-observer error bias for the three morphometric traits in the Athens and Lopes Collections. 90

Table 4.10 Inter-observer error bias for the three morphometric traits in the Athens and Lopes Collections. 91

Table 4.11 Two-sample t-test evaluating the similarities between Athens males (N=70) and females (N=65) and between Lopes males (N=87) and females (N=73) at every cervical vertebral level. 95

Table 4.12 Two-sample t-test evaluating ancestry differences between males and females at every cervical vertebral level within the Athens Collection (N=135) and the Luis Lopes Collection (N=160). 101

Table 4.13 Correlations between stature and all three measurements (CAP, CTR and CHT) in males (N=55) and females (N=46) from a combined sample (Athens and Lopes Collections). 103

Table 4.14 CAP versus CTR correlation between males and females in the combined sample (Athens and Lopes Collections). 105

Table 4.15 CAP versus CHT correlation between males and females in the combined sample (Athens and Lopes Collections). 106

Table 4.16 CTR versus CHT correlation between males and females in the combined sample (Athens and Lopes Collections). 106

Table 4.17 Discriminant function, sectioning point, and overall accuracy rates using the C_1AP and C_1TR measurements from the first cervical vertebra (C_1). 108

Table 4.18 Discriminant functions, sectioning points, and accuracies using the different combinations of measurements from the second cervical vertebra (C_2). 108

Table 4.19 Discriminant functions, sectioning points, and accuracies using the different combinations of measurements from the third cervical vertebra (C_3). 109

Table 4.20 Discriminant functions, sectioning points, and accuracies using the different combinations of measurements from the fourth cervical vertebra (C_4). 110

Table 4.21 Discriminant functions, sectioning points, and accuracies using the different combinations of measurements from the fifth cervical vertebra (C_5). 111

Table 4.22 Discriminant functions, sectioning points, and accuracies using the different combinations of measurements from the sixth cervical vertebra (C_6). 112

Table 4.23 Discriminant functions, sectioning points, and accuracies using the different combinations of measurements from the seventh cervical vertebra (C_7). 113

Table 4.24 Discriminant functions, sectioning points, and accuracies using all three measurements from all seven cervical vertebrae (C_1-C_7). 114

Table 4.25 Discriminant functions, sectioning points, and accuracies using the two vertebral foramen measurements (CAP and CTR) from all seven cervical vertebrae (C_1-C_7)..... 115

Table 4.26 Discriminant functions, sectioning points, and accuracies using CTR and CHT measurements from all seven cervical vertebrae (C_2-C_7). 116

Table 4.27 Discriminant function, sectioning points, and accuracies using all measurements from the first and second cervical vertebrae (C_1-C_2). 117

Table 4.28 Discriminant function, sectioning point, and accuracies using all three measurements from typical cervical vertebrae (C_3-C_6) and C_7..... 118

Table 4.29 Discriminant function, sectioning point, and accuracies using vertebral foramen (CAP and CTR) measurements from typical cervical vertebrae (C_3-C_6) and C_7. 119

Table 4.30 Discriminant function, sectioning point, and accuracies using the most dimorphic measurements (CTR and CHT) from typical cervical vertebrae (C_3-C_6) and C_7..... 120

Table 4.31 Discriminant function, sectioning point, and accuracies using all three measurements from typical cervical vertebrae (C_3-C_6). 121

Table 4.32 Discriminant function, sectioning point, and accuracies using vertebral foramen measurements (CAP and CTR) from typical cervical vertebrae (C_3-C_6). 122

Table 4.33 Discriminant function, sectioning point, and accuracies using the most sexually dimorphic measurements (CTR and CHT) from typical cervical vertebrae (C_3-C_6)..... 123

Table 4.34 SPSS generated stepwise discriminant function, sectioning point, and accuracies. 125

Table 4.35 Discriminant function, sectioning point, and accuracies using the two most dimorphic measurements (CTR and CHT) from the two most dimorphic cervical vertebrae (C_2 and C_5). 126

Table 4.36 Discriminant function, sectioning point, and accuracies using all three measurements from the two most dimorphic cervical vertebrae (C_2 and C_5)..... 127

Table 4.37 Seven discriminant functions that successfully estimated sex using measurements of the cervical vertebrae. 128

Table 4.38 Cross-validation accuracies for the seven discriminant functions that achieved greater than 80% predicted accuracies by SPSS version 21.0. 129

Table 4.39 Age category sample sizes for males and females in the Athens and Lopes Collections. 134

Table 4.40 Results of ANOVA tests evaluating age-related dimensional changes to male and female cervical morphometrics in the combined sample (N=295). 136

Table 4.41 Results for male C_2AP measurement post-hoc test to assess age-related changes to the cervical vertebrae. 138

Table 4.42 Results for male C_3AP measurement post-hoc test to assess age-related changes to the cervical vertebrae. 140

Table 4.43 Results for male C_4AP measurement post-hoc test to assess age-related changes to the cervical vertebrae. 142

Table 4.44 Results for male C_6AP measurement post-hoc test to assess age-related changes to the cervical vertebrae. 144

LIST OF FIGURES

Figure 2.1 Comparing the position and angle of the vertebral column at the base of the skull between a) modern human skeleton and b) gorilla. The vertebral column extends downwards from the skull in humans and at an angle in primates. (Photos by Andrew S. Rozendaal) 12

Figure 2.2 Superior view of cervical vertebra from a) 3 year old female with unfused vertebral bodies; b) 3 year old female with fusing vertebral bodies; c) 6 year old male with fused arches and bodies creating the adult sized vertebral foramen. (Photos by Andrew S. Rozendaal) 17

Figure 2.3 Typical cervical vertebra a) anterior aspect and b) left lateral aspect. (Photos by Andrew S. Rozendaal) 19

Figure 2.4 Typical cervical vertebra a) superior aspect and b) posterior aspect. (Photos by Andrew S. Rozendaal) 20

Figure 2.5 Anterior, right lateral, and posterior aspects of the human vertebral column depicting the five vertebral sections. (Photos by Andrew S. Rozendaal) 21

Figure 3.1 The seven cervical vertebrae in anatomical articulation and identified as C_1 through C_7 from the anterior (left) and lateral (right) perspectives. (Photos by Andrew S. Rozendaal) 62

Figure 3.2 Anterior view of a typical cervical vertebra depicting the Maximum Vertebral Body Height ($C_{(n)}HT$) measurement. (Photo by Andrew S. Rozendaal) 65

Figure 3.3 Lateral view of a typical cervical vertebra. Vernier caliper placement measuring Maximum Vertebral Body Height ($C_{(n)}HT$) on the anterior margin of the vertebral body. (Photo by Andrew S. Rozendaal) 66

Figure 3.4 Superior view of a typical cervical vertebra depicting the anterior-posterior ($C_{(n)}AP$) and transverse ($C_{(n)}TR$) vertebral foramen diameters. (Photo by Andrew S. Rozendaal) 67

Figure 3.5 Superior lateral view of a typical cervical vertebra. Vernier caliper placement to measure Cervical Anterior-Posterior Diameter ($C_{(n)}AP$). (Photo by Andrew S. Rozendaal) 68

Figure 3.6 Superior view of a typical cervical vertebra. Vernier caliper placement to measure Cervical Transverse Diameter ($C_{(n)}TR$). (Photo by Andrew S. Rozendaal) 68

Figure 4.1 An example of a probability plot to visually assess the distribution of data for normality. 87

Figure 4.2 Interval plot showing means and the 95% confidence interval for CAP measurements between males (1) and females (2) in the Athens Collection. An asterisk (*) indicates the variables that are statistically significant. 96

Figure 4.3 Interval plot showing the means and the 95% confidence interval for CAP measurements between males (1) and females (2) in the Lopes Collection. An asterisk (*) indicates the variables that are statistically significant. 96

Figure 4.4 Interval plot showing means and the 95% confidence interval for CTR measurements between males (1) and females (2) in the Athens Collection. An asterisk (*) indicates the variables that are statistically significant. 97

Figure 4.5 Interval plot showing the means and the 95% confidence interval for CTR measurements between males (1) and females (2) in the Lopes Collection. An asterisk (*) indicates the variables that are statistically significant. 97

Figure 4.6 Interval plot showing means and the 95% confidence interval for CHT measurements between males (1) and females (2) in the Athens Collection. An asterisk (*) indicates the variables that are statistically significant. 98

Figure 4.7 Interval plot showing the means and the 95% confidence interval for CHT measurements between males (1) and females (2) in the Lopes Collection. An asterisk (*) indicates the variables that are statistically significant. 98

Figure 4.8 An example of an exploratory correlation scatter plot to visually asses the correlation between stature and C_1AP for males (sex = 1) and females (sex = 2). 104

Figure 4.9 An example of an exploratory interval plot to visually asses the age-related changes to male C_7AP diameter from age category 2 to 8. 137

Figure 4.10 The exploratory interval plot to visually asses the age-related changes to male C_2AP diameter from age category 2 to 8. 139

Figure 4.11 The exploratory interval plot to visually asses the age-related changes to male C_3AP diameter from age category 2 to 8. 141

Figure 4.12 The exploratory interval plot to visually asses the age-related changes to male C_4AP diameter from age category 2 to 8. 143

Figure 4.13 The exploratory interval plot to visually asses the age-related changes to male C_6AP diameter from age category 2 to 8. 145

CHAPTER 1: INTRODUCTION

1.1 Research Objectives

Creating new reliable methodologies for skeletal identification is an integral component of medico-legal investigations. The goal of forensic anthropology is to assist in the identification of unknown human skeletal remains by applying standard scientific techniques to create a biological profile, an osteological biography that involves analyses to estimate sex, age at death, stature, ancestry, skeletal traumas and pathologies. This profile will assist in the process of identifying the unknown individual.

The current study will focus on the seven cervical vertebrae to establish an accurate sex estimation method for a White European skeletal population. The objectives of this research are:

(1) To understand the relationship between sex and the measurements of the cervical vertebral foramen (anterior-posterior and transverse diameters) and the cervical vertebral body (maximum body height) in the contemporary Athens and the historic Lopes White European skeletal populations.

(2) To understand the relationship between stature and the measurements of the cervical vertebral foramen (anterior-posterior and transverse diameters) and cervical vertebral body (maximum body height) in the contemporary Athens and the historic Lopes White European skeletal populations.

(3) To evaluate the relationship between age and the measurements of the cervical vertebral foramen (anterior-posterior and transverse diameters) and the cervical

vertebral body (maximum body height) in the contemporary Athens and the historic Lopes White European skeletal populations.

1.2 Potential for Sex Estimation from the Cervical Vertebrae

When identifying human remains, sex estimation is a factor of primary significance because other elements within the biological profile (i.e. age at death, stature, and ancestry) are sex dependent (Komar and Buikstra 2008: 126; Spradley and Jantz, 2011; Tersigni-Tarrant and Shirley 2013: 139). Having methods for estimating sex from many skeletal elements is therefore vital for human identification.

Most bones in the human body have been assessed for their potential in estimating sex. The skull and the pelvic girdle are considered the most sexually dimorphic bones and consequently the more commonly analyzed for creating a biological profile (Komar and Buikstra 2008: 128; Spradley and Jantz 2011). The femora and the humeri have also been shown to exhibit a high degree of sexual dimorphism (Komar and Buikstra 2008: 128; Spradley and Jantz 2011). However, skeletal remains that are recovered from a deposition site are often poorly preserved and fragmentary making skeletal analyses complicated or impossible. The quality of biological profiling information anthropologists can derive from an assemblage of bones depends on the quantity of recovered elements and the degree of osteological preservation. Most profiling techniques require a nearly complete and undamaged set of remains (Tersigni-Tarrant and Shirley 2013: 381; Waldron 1987). Post-mortem changes to the body, also known as taphonomy, hinder the recovery of a complete skeleton due to destructive environmental factors (e.g. mechanical erosion, bleaching, warping, decalcification),

fracturing, disarticulation, and scattering due to animal scavenging (Tersigni-Tarrant and Shirley 2013: 351-352). Forensic anthropologists are therefore faced with many absent or badly preserved sexually diagnostic elements from which they must construct a biological profile (Spradley and Jantz 2011). In these instances, a large list of sex estimating methodologies from a variety of skeletal elements must be available to forensic anthropologists.

Recent research has cited sex estimation methods from less frequently analyzed skeletal elements such as: phalanges, scapulae, clavicles, ulnae, radii, tibiae, fibulae, and vertebrae (Bethard and Seet 2013; Marino 1995; Pearson 1915). Research has shown that metric analyses utilizing the scapulae, clavicles, radii, ulnae, and tibiae have produced greater sex estimating accuracy rates than metric analyses from the skull (Spradley and Jantz, 2011). Also, sex estimation studies that include analyses from multiple less-frequently studied bones have potential for greater sex estimating accuracy than studies using one of the more commonly analyzed bones (Byers 2008: 194; Spradley and Jantz 2011).

The seven cervical vertebrae (C_1-C_7) are sexually dimorphic bones that are useful for forensic sex estimation. Vertebrae exhibit morphological characteristics that individualize them from other bones of the human body making them easily identifiable if recovered from a crime scene (Voisin 2011). The cervical vertebrae are also easily distinguished from the thoracic and lumbar vertebrae due to their unique attributes: the cervical bones are the smallest vertebrae, all exhibit transverse foramina in the lateral vertebral arches, and the spinous processes are horizontally oriented with a bifurcated tip on most bones. The first (C_1), second (C_2) and seventh (C_7) cervical vertebrae also

present morphological characteristic that are not present in C_3-C_6 such as: the circular shape in C_1, the presence of an odontoid process in C_2, and a flat transitional inferior vertebral body surface in C_7. These unique skeletal attributes allow for rapid anatomical sequencing of the cervical vertebrae (White et al 2012: 131-136).

Unlike the fragile skull or the large exposed surface area of long bones and the pelvic girdle, vertebrae are more likely to be recovered from a deposition site (Dittrick and Suchey 1986; Marlow and Pastor 2011; Voisin 2011; Waldron 1987). Research has shown that the vertebral column, along with the proximal femora, is more likely to survive the post-depositional process than any other bone in the body including the most sexually dimorphic bones (skull and pelvic girdle). The scapulae, skull, phalanges, carpals, and tarsals are least likely to survive (Waldron 1987). The strong outer cortical bone layer and the small surface area of the cervical vertebrae expose less bone to the destructive taphonomic elements (Dittrick and Suchey 1986; Marlow and Pastor 2011; Waldron 1987). The dense cancellous (trabecular) bone within the internal marrow cavity is resilient to mechanical stresses and the circular vertebral shape increases the bone's architectural structural integrity (Hollis and Kolakanuru 2009; Marino 1995; Voisin 2011, Waldron 1987). If vertebral preservation is poor, the spinous process and superior articular facets are the most likely structures to be damaged however, the strong architectural construction increases the potential for recovery of the complete vertebral column (Bethard and Seet 2013; Dittrick and Suchey 1986; Marlow and Pastor 2011; Voisin 2011; Waldron 1987). These characteristics make vertebrae ideal for sex estimation.

Vertebral morphology has also been shown to exhibit sexually dimorphic characteristics allowing for accurate and reliable sex estimation: Marino (1995) studied the first cervical vertebra, Wescott (2000), Marlow and Pastor (2011) and Bethard and Seet (2013) studied the second cervical vertebra, Kibbi and colleagues (2010) studied the seventh cervical vertebra, Tatarek (2005) studied the cervical neural foramen, Voison (2011) and Hou and colleagues (2012) studied the twelfth thoracic vertebra.

1.3 Concepts of Identity in Forensic Anthropology

In this thesis, the term *biological sex* (i.e. *sex*) refers to the physical and genetic differences between males and females as determined at the time of conception and the subsequent development of physical sexual traits (Armelagos 1998). Sexually dimorphic differences manifest in the skeleton allowing for estimations of biological sex by forensic anthropologists. The anatomical certainty of *biological sex*, rather than *gender*, makes it an ideal term to differentiate between the male and female body for this research.

An individual's DNA coded within chromosomes produces variations of hormonal levels, which form the physiological variations between the male and female body – males express one X and one Y chromosome (XY) and females express two X chromosomes (XX) (Armelagos 1998; Kottak 2011: 419). The etiologies of skeletal sexual differences arise primarily from the production of sexual hormones around the time of puberty and secondly from functional differences between males and females (Kottak 2011: 419; Tersigni-Tarrant and Shirley 2013: 140; Voison 2009). Adult males tend to be more robust with prominent muscle attachment sites resulting in larger bone structures compared to adult females, who tend to be more gracile with smaller bone

structures. Females also exhibit skeletal morphological differences to accommodate the function of giving birth, carrying the fetus, and passing the infant through the pelvic inlet at birth.

The term *gender* refers to the behavioural and attitudinal differences between males and females that are socially constructed and vary between cultures (Kottak 2011: 419). Socially accepted categories such as man/woman, boy/girl, masculine/feminine, or other gender classes refer to the gender role, behaviours and activities an individual self-identifies or is assigned during life, that are not expressed in the biological physiology (Armelagos 1998; Konigsberg and Hens 1998; Tersigni-Tarrant and Shirley 2013: 140). Therefore the term *gender* will not be used in this thesis.

This thesis will use the term *ancestry* to define the biological diversity expressed between human populations that are manifested in the skeletal anatomy (Byers 2008: 152; Harle 2010; Hemphill 1998; Komar and Buikstra 2008: 147; Schneider and Sciulli 1983). When a group of individuals originates from a specific geographic location they form a gene pool, i.e. shared similarities in physical characteristics that are expressed in the skeletal morphology due to genetic heredity and influenced by geographic environmental stresses (Ember and Ember 1988: 110). Closely affiliated populations share similarities in genetic alleles and gene frequencies that have been shaped through generations of microevolution to create groups of genealogical ancestors (Harrison 2010: 50-51; Konigsberg et al 1992). The geographical distributions and frequencies of morphological skeletal traits allow forensic anthropologists to use skeletal analyses to potentially assign an unknown individual into one of a limited number of continental

groups when creating a biological profile (Albanese and Saunders 2006; Sauer 1992; Smay and Armelagos 2000).

The concept of *ancestry* acknowledges that human variation is a continuous unit due to the boundless interaction (i.e. genetic and cultural) between population groups as opposed to a static unit, such as in 'racial' categorization (Albanese and Saunders 2006; Relethford 1990: 144-146; Smay and Armelagos 2000). 'Race' is defined as the division of a species into distinct population groups that are defined by shared observable characteristics among its members (Albanese and Saunders 2010; Ember and Ember 1988: 120; Harrison 2008: 36, 39; Konigsberg et al. 2009; Kottak 2011: 340; Relethford 1990: 144; Sauer 1992; Smay and Armelagos 2000; Winant 2000). It is a culturally constructed tool used to categorize individuals into perceived divisible groups by discriminating between racial typologies and traits that explain only the observable differences between human populations. Biological racial typologies are phenotypic characteristics such as skin colour, body build, facial features, and height – characteristics that are associated with appearances (Ember and Ember 1988: 110-116). The 'race' concept, although designed as a classification tool for defining biologically similar populations, created inequalities between geographically different populations through social, economic, educational, and political circumstances (Kottak 2011: 338-339; Relethford 1990: 144).

The concept of 'race' began with the ancient concepts of barbarity and citizenship that defined who belonged within a political or cultural group (Harrison 2010: 36; Morgan 2013; Winant 2000). The ancient Phoenician, Roman, and Greek civilizations compared the physical differences in human populations they encountered, such as the

people that inhabited central Africa, and judged them as "primitive" or "uncivilized" in comparison to their own cultural standards – an ideology termed ethnocentrism (Downs and Bleibtreu 1971: 5-11; Harrison 2010: 36, 170; Winant 2000).

Categorizing humans into racial groups was used by the Europeans for political, imperialistic and economic ambitions (Winant 2000). Between the sixteenth and eighteenth centuries, 'race' was synonymous with terms such as type, kind, sort, breed, and species. In colonial America, individuals and groups were placed into categories controlled by power, wealth, and dominance to support nationalistic views to justify social and economic inequality (Albanese and Saunders 2006; Möschel 2011; Price 2010). During this time, people were categorized into hierarchal 'racial' divisions based on human characteristic differences such as size, form, and colour. (Harrison 2010: 46).

The eighteenth century Swedish botanist Carl Linnaeus was the first scientist to organize humanity into different groups based on observable features. These groups included Africanus, Americanus, Asiaticus, Europeanus, and Monstrosus (Harrison 2010: 37). In 1779, Johan Blumenbach continued classifying human "varieties" to include *Caucasian* the 'white' race, *Mongoloid* the 'yellow' race, *Malayan* the 'brown' race, *Ethiopian* the 'black' race and *American* the 'red' race (Harrison 2010: 37). However, these early classifications categorized populations based on external phenotypic characteristics implying that 'racial' characteristics were static entities (Harrison 2010: 38).

In the mid nineteenth century, Samuel G. Morton examined racial typologies of human crania (Albanese and Saunders 2006; Smay and Armelagos 2000). The belief was that "negros" had smaller brains and therefore smaller crania than "whites" (Albanese

and Saunders 2006; Smay and Armelagos 2000). Morton's research in Craniometry, the study of the size and shape of the human skull, lead scientists to believe that 'races' that exhibit larger skulls have larger brains and therefore possess superior mental capabilities (Albanese and Saunders 2006; Harrison 2010: 38; Smay and Armelagos 2000).

In the early twentieth century, the scientific study of biological human variation was heavily influenced by the nineteenth century 'race' research (Albanese and Saunders 2006; Smay and Armelagos 2000). Anthropologists framed their osteological investigations to further identify racial traits expressed in the skeletal anatomy and published their findings in scientific journals such as *The American Journal of Physical Anthropology* (AJPA), founded in 1918 by Ales Hrdlička (Smay and Armelagos 2000). Hrdlička stated that the objective of the AJPA was for physical anthropologists to investigate and understand what is a biologically "normal white man" (Smay and Armelagos 2000: 20). However, in 1942 Ashley Montagu argued that external physical traits are not the cause of human variation. Racial typologies based on differences in external traits only narrow the definition of humanity and that all humans are one species (i.e. *Homo sapiens*) "characterized by an educability, a capacity for wisdom and intelligence approached by no other creature" (Montagu 1997: 48; Harrison 2008: 38). In 1950, Carleton Coon and colleagues reaffirmed Montagu's argument in *Races: A Study of the Problems of Race Formation in Man* which further inspired twentieth century anthropologists to reconsider the 'race theory' and abandon the term 'race' (Downs and Bleibtreu 1971: 137). Therefore the term 'race' will not be used in this thesis to define population variation.

‘Ethnicity’ is defined as the cultural distinctions between population groups that share a society or region that emerges from a social or political process (Kottak 2011: 337; Morning 2011: 75). Group membership is defined by similarities in cultural beliefs, language, customs, religion, historical experiences, geographic placement, kinship, and norms (Albanese and Saunders 2006; Harrison 2010: 36, 39; Konigsberg et al. 2009; Kottak 2011: 336-337; Sauer 1992; Smay and Armelagos 2000; Winant 2000). Individuals within an ethnic group identify themselves with others in that group through solidarity and a belief that they have common descendants that excludes them from belonging to another group (Kottak 2011: 337). ‘Ethnicity’ is a self-identifying cultural construct rather than a biological reality. Therefore the term ‘ethnicity’ will not be used in this thesis to define population variation.

CHAPTER 2: BACKGROUND

2.1 Evolution of the Vertebral Column and the Origins of Bipedalism

The modern human has evolved over thousands of years to differential environmental pressures and physiological stresses on the body. The greatest difference between modern humans and other primates is the vertebral column, which has adapted to a bipedal stance (Prost 1980; Sylvester 2006). The pivotal development from quadrepedalism, locomotion relying on four limbs, to bipedalism, locomotion relying on two limbs, required changes to the skeletal structure for support of the entire body. This biological advantage allocates the hind-limbs for locomotion and the forelimbs for other manipulations suggesting quadrupedalism is ancestral to the derived bipedal behaviour (Sylvester 2006). Bipedalism increased hominid biological fitness and created a different evolutionary path from other primates (Prost 1980; Sylvester 2006).

The positioning of the foramen magnum, the inlet at the base of the skull, through which the spinal cord travels from the brain to the vertebral column, and the base angle the foramen magnum creates with the first cervical vertebra are the unique features that distinguish modern humans from ancestral human paleospecies (Aiello and Dean 1999: 210; Willoughby 2007: 13). The foramen magnum of modern humans is anteriorly positioned (Figure 2.1a) compared to ancestral human paleospecies and primates (Figure 2.1b). This morphology results in the vertebral column extending downwards from the foramen magnum rather than posteriorly as observed in primates (Aiello and Dean 1999: 210-211). As a result of erect posture and the vertical spine, the human body exhibits a redistribution of body weight from a horizontal suspension structure to a vertical support

(Tatarek 2005). The spine compensates this shift by exhibiting a unique S-shaped curvature in the body's sagittal plane that is unique to modern humans. The cervical and lumbar portions of the spine are convex forward (lordotic) with the thoracic and sacral regions concave forward (kyphotic). The function of this curvature is to align the head and the heavy organs of the trunk over the body's center of gravity at the pelvis (Aiello and Dean 1999: 244; Tatarek 2005; Tersigni-Tarrant and Shirley 2013: 51).

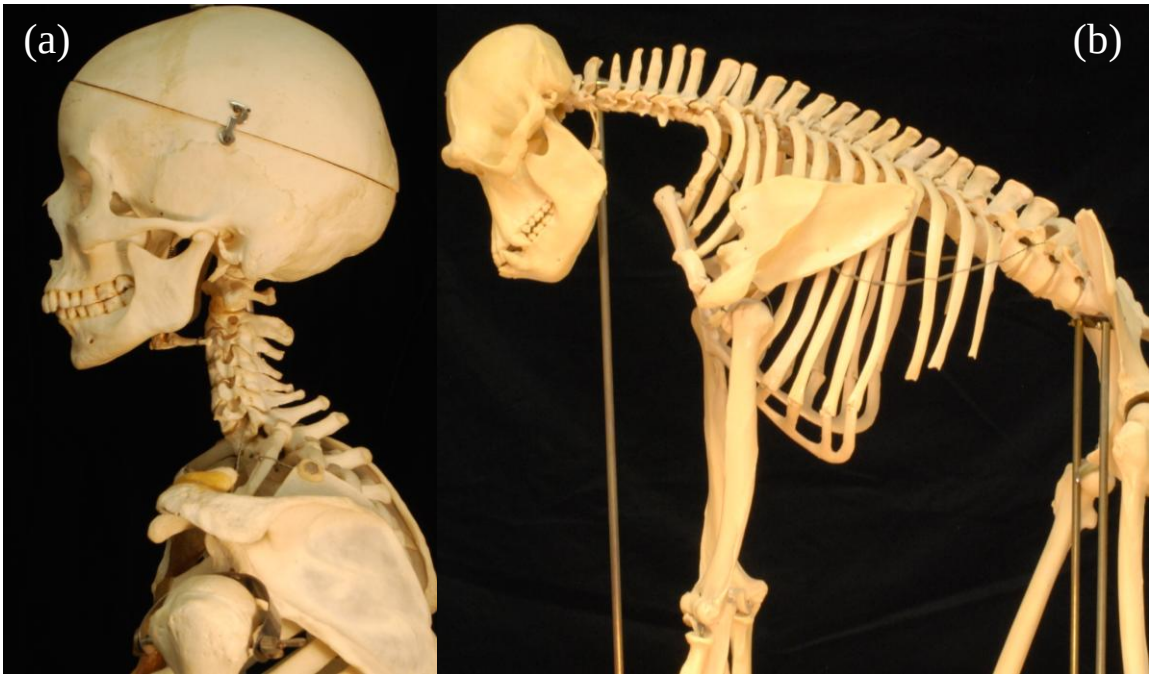

Figure 2.1 Comparing the position and angle of the vertebral column at the base of the skull between a) modern human skeleton and b) gorilla. The vertebral column extends downwards from the skull in humans and at an angle in primates. (Photos by Andrew S. Rozendaal)

Vertebrae are extremely sensitive to the consequences of upright posture and the increased weight-bearing role of the vertebral column. As a result, the morphology of each human vertebra has evolved in both size and shape to accommodate the new physiological stresses of bipedalism (Aiello and Dean 1999: 288; Clark 1985). The vertebrae gradually increase in size from the cervical to lumbar regions with a proportional increase in length and breadth of the vertebral bodies (Clark 1985). With the head evenly balanced above the center of gravity, the muscles used to maintain the head's position do not exert much effort resulting in reduced musculature of the neck compared to other primates, who have bigger and broader neck muscles (Aiello and Dean 1999: 224). The skeletal response to reduced musculature is smaller spinous processes in modern humans. A further adaptation is the bifid spinous process of the cervical vertebrae that no other primate exhibits (Aiello and Dean 1999: 218).

2.2 The Vertebral Column: Anatomy and Function

The skeletal system is a framework that supports and protects all the organs of the body. It also works with the muscular system to support the weight of the individual, provide locomotion through a lever system of movement, and maintain control and posture to carry out precise movements. The structure of bone consists of a dense, solid, external layer called compact or dense (cortical) bone and an internal marrow cavity comprised of spongy or cancellous (trabecular) bone resembling an open lattice structure (Martini and Nath 2009: 188). Bone is also the body's mineral reservoir where calcium and phosphates are stored as hydroxyapatite crystals (bone minerals) that can be metabolically broken down into calcium and phosphate ions. Bone is comprised of

approximately 75% inorganic compounds of calcium and phosphate minerals (hydroxyapatite salt) and 25% organic materials. Of the organic materials, 97% is collagen fibers and 3% is homogeneous ground substances (Clark 1985; Martini and Nath 2009: 185). Bone gets its strength and resiliency from a combination of strong hydroxyapatite crystals with flexible collagen fibers woven into the structural matrix. This provides both strength and flexibility when bone is subjected to torsional, tensional and compression forces through the pull of muscles and bodily movements. Fats are also stored within the structure of bone acting as energy reserves in the form of yellow marrow. Blood cell production is another function of the skeletal system. Red blood cells, white blood cells, and other blood components are produced within red marrow of the bone marrow (Martini and Nath 2009: 185).

2.2.1 *Vertebral Growth and Development*

The vertebral column is the most anatomically complex joint-linking system in the human body. Its development is equally complex requiring the organism to exert an exceptional expenditure of energy that will greatly impact the individual's growth. Growth is the generalized term referring to an increase in an organism's size whereas size refers to the rate and duration of growth. Development describes an increase in size and complexity that leads to an increase in functional range (Clark 1985).

In utero, the vertebral column develops from the mesoderm layer of the developing embryo. The mesoblast membrane forms into primordial membranous organs that will further become the base of the skull, vertebral column, neck ligaments, and the cerebro-spinal nervous system (the spine) (Gray 1995: 96). The vertebrae first appear in

the fetus as small cartilaginous masses at approximately the second month of fetal development. The masses surround the notochord, the primitive form of the developing spinal cord, by the third month of development with the cartilaginous dorsal arches closing around the notochord by the fourth month *in utero*. The cartilaginous masses morph into bone, the process of ossification, beginning in the fifth fetal month (Gray 1995: 148).

Each vertebra forms from four primary ossification centers, one for each arch (lamina) and two for the body (Gray 1995: 11). The two exceptions are the atlas and axis, the first (C_1) and second (C_2) cervical vertebrae, respectively. The number of primary ossification centers in the atlas varies from two to five with three being the most frequent configuration. The axis develops through seven ossification centers corresponding to the seven major parts of a typical vertebra (one body, two pedicles, two transverse processes and two laminae) (Gray 1995:12-13). The forming vertebral body of the atlas detaches around seven weeks and migrates to become the odontoid process of the axis (Grey 1995: 4; Scheuer and Black 2004:195). From the sixth to eighth week of fetal development the formation of bone begins strengthening all the vertebral bodies and laminae however, at birth, the laminae and vertebral body remain un-united (Gray 1995: 11).

Within the first year after birth, ossification further strengthens the developing vertebral column. At about six months after birth, a child will typically begin holding up their head requiring structural support from the spine, especially the cervical vertebrae. This erect posture develops the convex forward spinal curvature, the lordotic curve, in the cervical spine (Clark 1985). The laminae of the cervical vertebrae are the first vertebral elements to exhibit accelerated ossification to support the growing head. At this time the

dorsal aspect of the left and right laminae fuse creating the biologically primitive form of the spinous process and posterior aspect of the vertebral foramen (Figure 2.2a). Posterior laminar fusion then progresses through the thoracic and then the lumbar regions; concurrently with accelerated ossification of the vertebral bodies. It begins first in the thoracic region and extends superiorly and inferiorly to the cervical and lumbar regions respectively (Gray 1995: 13). Beginning around the third year since birth the vertebral bodies merge to the anterior aspects of both the left and right laminae creating the vertebral foramen and enclosing the spinal cord (Figure 2.2b). The merging regions form the pedicles from which the transverse processes develop (Gray 1995: 11). By age five, the skeletal structure that forms the vertebral canal is at its full adult size protecting the spinal cord within (Figure 2.2c) (Clark 1985). No further development occurs to the vertebrae before puberty however, males generally experience an additional two years of growth prior to puberty compared to females (Clark 1985). A continuous increase in size is the only change occurring with the growth of the primary ossification centers of the vertebral bodies, adding to vertebral body height and the ends of spinous and transverse processes (Clark 1985; Gray 1995: 11).

Figure 2.2 Superior view of cervical vertebra from a) 3 year old female with unfused vertebral bodies; b) 3 year old female with fusing vertebral bodies; c) 6 year old male with fused arches and bodies creating the adult sized vertebral foramen. (Photos by Andrew S. Rozendaal)

At the time of puberty, vertebrae experience a relatively intense adolescent growth spurt that does not subside until the individual is in their twenties. Puberty does not affect the size or shape of the vertebral foramen (Clark 1985). At around 16 years of age, three secondary ossification centers appear in the transverse processes and the dorsal aspect of the spinous processes. By 21 years of age, bone begins depositing between all

the vertebral bodies and their corresponding superior and inferior epiphyseal surfaces completing epiphyseal fusion between age 25 and 30 years old (Gray 1995: 12).

2.2.2 *Vertebral Anatomy*

The typical vertebra is comprised of three major structures: the body (centrum) and two arches (vertebral or neural arches). The body is circular in shape and comprises the anterior aspect of the vertebral structure (Figure 2.3). It is the largest part of the vertebral structure and bears the most weight of the entire bone. The superior and inferior surfaces (i.e. superior and inferior endplates) of the vertebral body are flattened (Figure 2.3a) and interconnect to adjacent vertebrae by ligaments and intervertebral discs, a gelatinous filled pad of fibrous cartilage (Gray 1995: 2; Martini and Nath 2009: 232). Intervertebral discs form gliding joints between vertebral bodies that permit small flexion and rotational movements of the vertebral column and provide shock absorption throughout the spine. An exception is between the first and second vertebrae where no intervertebral disc is present (Martini and Nath 2009: 277). The anterior surface of the vertebral body is perforated with a few small apertures to allow the passage of blood vessels while the posterior aspect has a single irregularly shaped aperture through which veins exit the bone (Gray 1995: 3).

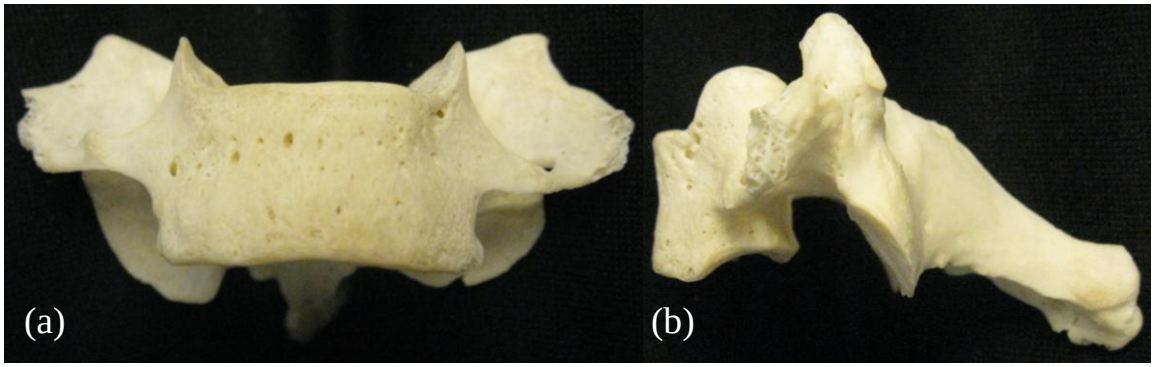

Figure 2.3 Typical cervical vertebra a) anterior aspect and b) left lateral aspect. (Photos by Andrew S. Rozendaal)

Two vertebral arches form the posterior aspect of the vertebral structure. Anteriorly, the left and right arches fuse with the left and right lateral sides of the vertebral body, respectively. Posteriorly, the left and right arches fuse together forming the spinous process which is a posteriorly projected bony mass that serves as a point of vertebral muscle and ligament attachment (Figure 2.4a). The fusion between the body and both arches creates a circular foramen, the vertebral foramen. The vertebral foramen of each vertebra are aligned with adjacent vertebrae creating the spinal canal through which the spinal cord travels from the brain and then branches into nerve roots, when exiting the vertebral canal, to communicate with the peripheral body (Martini and Nath 2009: 431-432).

The left and right vertebral arches are further broken into two parts, the pedicles and the laminae. The pedicles are short anterior-lateral segments of the arch that fuse with the vertebral body. The laminae are plate-like structures extending posteriorly from the pedicles and fusing together creating the spinous processes (Gray 1995: 3; Martini and Nath 2009: 232). At the point where the pedicles meet the laminae, six processes emerge, three on the left and three on the right lateral sides of the vertebra. Two project

superiorly (Figure 2.4b), two projects inferiorly, and two project laterally. The superior and inferior processes articulate with superior and inferior adjacent vertebrae by way of smooth concave articular facets. The laterally projected transverse processes, one on the left and another on the right side of the bone, serve as points of attachment for muscles and ligaments. In the thoracic region of the spine, transverse processes also articulate with the ribs (Gray 1995: 3; Martini and Nath 2009: 232-233; White et al 2012: 133).

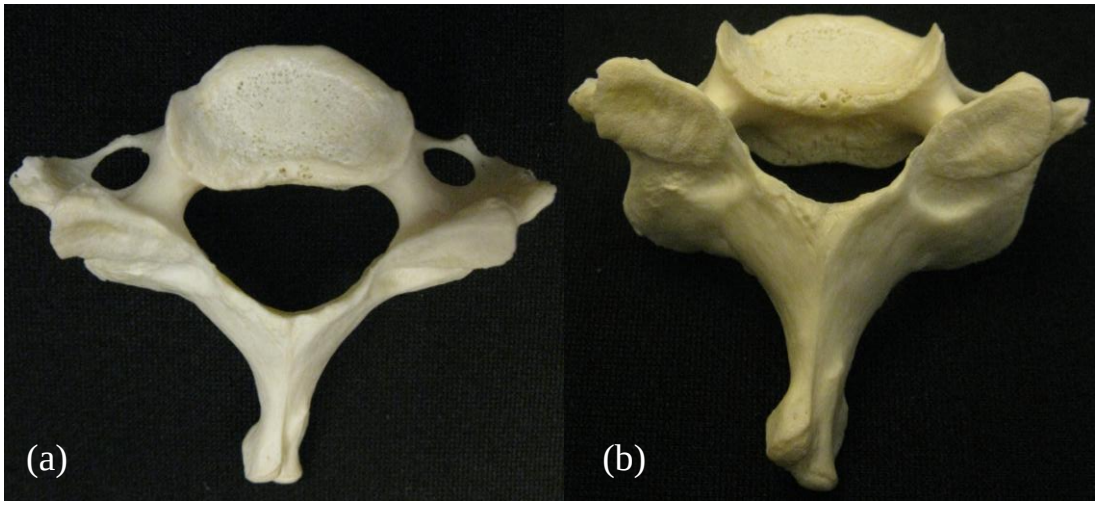

Figure 2.4 Typical cervical vertebra a) superior aspect and b) posterior aspect. (Photos by Andrew S. Rozendaal)

The vertebral column is comprised of 26 bones divided into five sections: cervical vertebrae, thoracic vertebrae, lumbar vertebrae, the sacrum, and the coccyx (Figure 2.5). The most superior section of the vertebral column is the cervical vertebrae which include seven bones (C_1-C_7). This section is the most mobile vertebral region. It constitutes the neck and articulates directly with the skull (Aiello and Dean 1999: 288). The first cervical vertebra (C_1) is commonly referred to as the atlas because it supports the head.

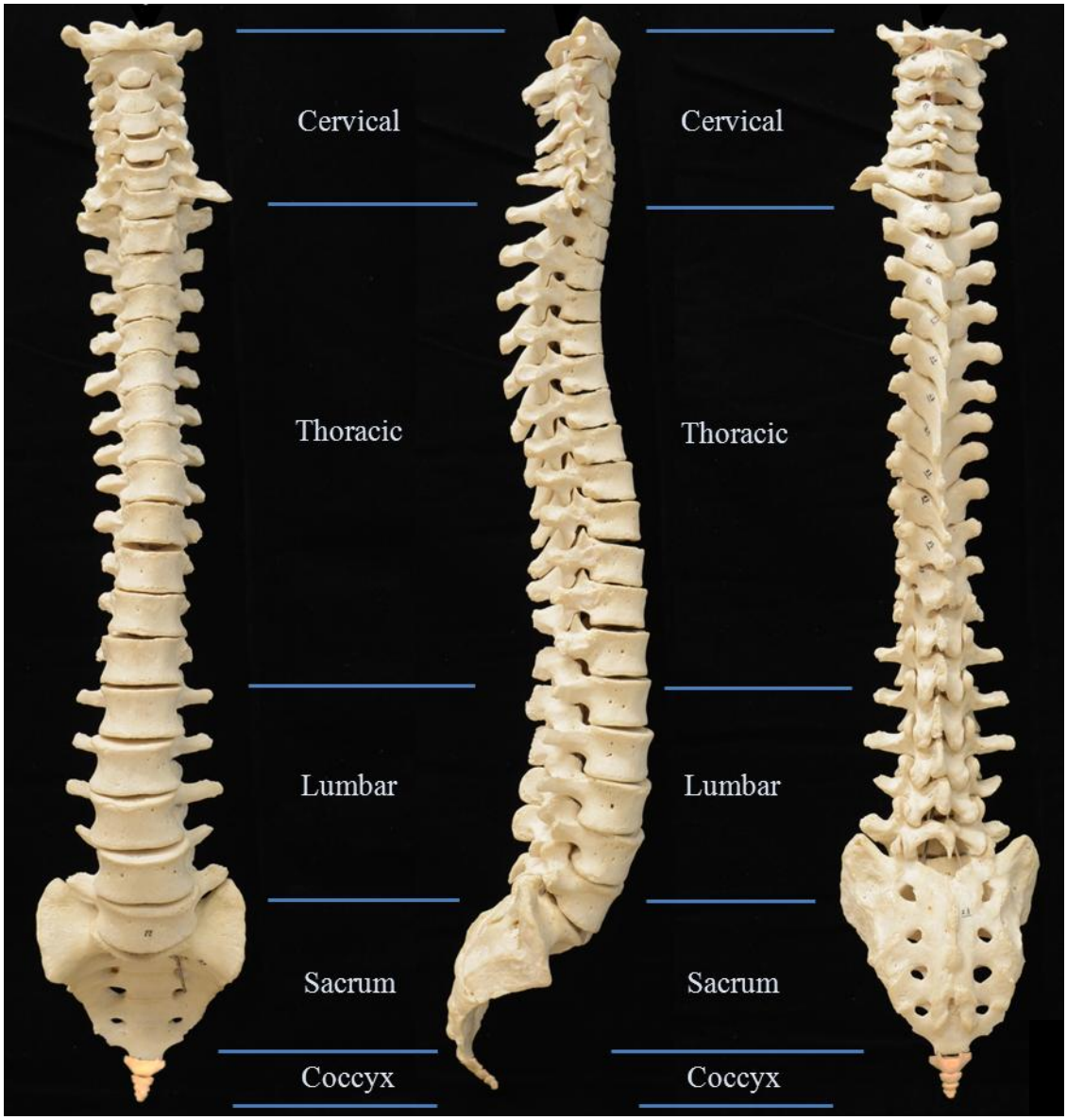

Figure 2.5 Anterior, right lateral, and posterior aspects of the human vertebral column depicting the five vertebral sections. (Photos by Andrew S. Rozendaal)

It derives its name from Atlas, a primordial Titan from Greek mythology who holds the globe on his shoulders (Grey 1995: 4; Martini and Nath 2009: 234). The atlas is roughly circular in shape and is the only vertebra that lacks a vertebral body and spinous process. Replacing the body and spinous process are anterior and posterior arches joined together by two lateral masses that form superior and inferior articular facets (Grey 1995: 4). The superior articular facets cradle the occipital condyles of the skull to permit flexion and extension (as in nodding "yes") and the inferior facets articulate with the axis, the second cervical vertebra (C_2). The axis is characterized by the large skeletal tubercle on the superior-anterior aspect called the dens (odontoid process). The dens articulates with the atlas through the atlanto-axial joint allowing a left and right pivoting motion, also known as an axis of rotation (as in shaking your head to indicate "no") (Martini and Nath 2009: 235). The rotation around a fixed axis, the dens, is where this bone derives its name. Both the atlas and the axis are considered atypical vertebrae because their individual morphologies are unique and do not resemble other vertebrae.

The third through sixth cervical vertebrae (C_3-C_6) are considered typical cervical vertebrae exhibiting similar characteristics of bifid spinous processes, although this is variable in C_6, vertebral bodies that are smaller than the vertebral foramen, and transverse foramina on the transverse processes (Martini and Nath 2009: 234). The seventh cervical vertebra (C_7) is a uniquely characterized transitional vertebra that is also considered an atypical vertebra due to its unique morphological structure. The most notable characteristic of C_7 is the long, slender, and sharp inferiorly angled spinous process. It also possesses a large transverse process that allows for added muscular support to

prevent the head and neck from falling forward (Gray 1995: 7; Martini and Nath 2009: 236).

The transition from one vertebral section to the next is not an abrupt change but rather a transition with the last vertebra in a region resembling the first vertebra in the next region (Martini and Nath 2009: 236). The second vertebral region is the thoracic encompassing 12 bones (T_1-T_{12}). The distinguishing feature of these bones is the costovertebral joints that articulate with the proximal ends of the ribs. This helps support the chest for breathing and the protective functions of the rib cage (Aiello and Dean 1999: 275; Martini and Nath 2009: 236). The first nine thoracic vertebrae (T_1 through T_9) contain a pair of demi-facets, where a facet is split between two adjacent vertebral bodies. Meanwhile, the first, tenth, eleventh, and twelfth (T_1, T_{10}, T_{11} and T_{12}) vertebrae all contain a pair of full facets on their vertebral bodies to support ribs. (Martini & Nath 2009: 236). The twelfth thoracic vertebra (T_{12}) is morphologically similar to T_{11}, however, it is a transitional vertebra with the lumbar vertebral section. The inferior vertebral body surface and general size of the vertebral body, spinous process and laminae closely resemble that of a typical lumbar vertebra. The lower back is the lumbar region, which consists of five lumbar vertebrae (L_1-L_5). These vertebrae are the largest and thickest because they bear the most body weight and require large surface areas for muscles that provide stability for the human body. The cervical, thoracic and lumber vertebrae are connected by ligaments yet separated between each vertebral body by intervertebral disks and fibrous cartilaginous pads that allow for a large range of motion (Gray 1995: 3; Martini and Nath 2009: 232)

The fourth region of the vertebral column is the sacrum consisting of five fused sacral vertebrae. The sacrum protects the reproductive, digestive and urinary organs through paired articulations with the left and right os coxae. The large surface area of the sacrum also provides articulation for many ligaments and muscles essential for moving the legs (Martini and Nath 2009: 238). The most caudal region of the vertebral column is the coccyx formed through fusion of three to five coccygeal vertebrae. This region provides attachment sites for ligaments that contribute to stability and muscles that constrict the opening of the anus (sphincter) (Martini and Nath 2009: 239).

2.2.3 *The Function of the Vertebral Column*

The vertebral column serves several specific purposes. Firstly, it provides the 'back bone' for the human body. It functions with the muscular system to support the weight of the individual, provides locomotion through a lever system of movement, and maintains control and posture to carry out precise movements (Martini and Nath 2009: 185; Voisin 2009). Secondly, the spine houses and protects the sensitive spinal cord from external injury, such as a high velocity sports impact (Sylvester 2006; Tatarek 2005). The spinal cord is the nervous system's communication channel that travels from the base of the brain, through the spinal canal (created by vertebral foramina) and branches off to the peripheral body. If the spinal cord is damaged, communication between the brain and portions of the peripheral nervous system is impaired leading to paraplegia or even tetraplegia, a loss of sensation and movement of the lower extremities (Tatarek 2005). Vertebrae consist of nearly 90% cancellous bone making them structurally resilient to many internal and external forces however, the cervical spine is more vulnerable to injury

from external forces due to decreased soft tissue protection. The thoracic and lumbar regions are surrounded by larger and stronger muscles and tissue masses which provide increased support (Clark 1985). Thirdly, vertebrae are the body's primary reservoir for calcium (Clark 1985). Calcium is the most abundant mineral in the human body and stored within bone to maintain proper physiological functions. Neurological and muscular activities require calcium and death may ensue if blood calcium concentrations drop below 50% of the normal levels (Martini and Nath 2009: 185).

2.3 Skeletal Identification in Forensic Anthropology

Biological sex can easily be established through observing soft tissue anatomy in a clinical setting. The presence of male or female genitalia is a clear indicator of the individual's sex. Sexually dimorphic differences also manifest in the skeleton allowing for estimations of biological sex by forensic anthropologists. Adult males tend to be larger and more robust with more prominent muscle attachment sites compared to adult females who tend to be smaller and more gracile. The etiologies of anatomical sexual differences influencing the overall size and robusticity of the skeletal structure arise primarily from the production of sexual hormones around the time of puberty and secondly from functional and behavioural differences between males and females (Kottak 2011: 419; Tersigni-Tarrant and Shirley 2013: 140; Voison 2009).

Skeletal sexual dimorphism is best defined in adults and late adolescents as puberty accelerates skeletal growth and morphologically changes to the skeletal structure. These changes are fully manifest in the skeleton after the age of 17 years old when the sexual hormones begin 'normalizing' (Tersigni-Tarrant and Shirley 2013: 140). The

female body size differs from the male body size by approximately 8% (females are 92% the size of males) (Byers 2008: 176). Females exhibit differential skeletal morphology to males to accommodate the function of giving birth, carrying the fetus and passing the infant through the pelvic inlet at birth. Since the female pelvis is structurally wider than the male pelvis there are consequential variations between other bones in the female body. For instance, the female elbow is more laterally angled compared to the male elbow, to prevent the arm from hitting the hip while walking (Rogers 1999). Also, the female femora have a greater medial angle from the hips so that the knees are under the torso to support the body's weight (Byers 2008: 176).

2.4 Sex Estimation in Forensic Anthropology

Most bones in the human body have been assessed for their potential in estimating sex. Forensic anthropologists examine sexually dimorphic differences by studying architecture and size variations through morphological or metric analyses. Morphological analyses focus on gross anatomical differences (architecture) observed between the male and female body and rely on observational comparisons (Tersigni-Tarrant and Shirley 2013: 143). Metric analyses use skeletal quantitative measurements (size) and mathematical equations paired with statistical probabilities to evaluate whether the bone falls within the average male or female dimensions (Tersigni-Tarrant and Shirley 2013: 152). Metric variables have some advantages over morphological methods such as simplicity and consistency in their recording due to the standardization of skeletal landmarks (Gonzalez et al 2009).

2.4.1 *Estimating Sex from the Pelvis*

2.4.1.1 Morphological Methods of Analyses

The human pelvis is the most accurate bone from which to estimate the sex of an individual (Spradley and Jantz 2011). One of the earliest descriptors between the male and female pelvis comes from a medical dissertation by Ackermann in 1788 who explains that the observable subpubic angle tends to be more V-shaped in males and U-shaped in females (Thiemann 2010; Ubelaker 1978).

Early methods by Phenice (1969), Feremback and colleagues (1980), and Işcan and Derrick (1984) have been considered the most accurate morphological methods for pelvic sex estimation due to their high accuracy rates (Bruzek 2002; Tersigni-Tarrant and Shirley 2013: 144). The Phenice (1969) method was developed from examining 275 individuals from the Terry Collection and visually comparing three traits of the pelvis: the subpubic concavity, medial aspect of the ischio-pubic ramus, and the ventral arc. The sex estimation method has an accuracy rate of 95%. The presence or absence of the ventral arc is considered the most sexually diagnostic feature and accurate sex estimation is attainable from assessing this one structure of a fragmentary pelvis. Ferembach and colleagues (1980) created a list of 11 morphological characteristics from the pubic bone for the estimation of sex. A validation study by Bruzek and Ferembach (1992) found that this method yielded an accuracy rate of 93% for sex classification. However, Bruzak (2002) cautions the use of this method because it requires a highly trained observer with experience in classifying characteristics using an ordinal scale of evaluation. The Işcan and Derrick (1984) method examined 17 males and 10 females representing contemporary Americans and Asiatic populations. The authors studied the post-auricular

area of the pelvis. The morphological shape and the presence of raised or flat contours of the post-auricular surface yielded a sex estimation accuracy rate of 90%.

Bruzek (2002) incorporated the studies by Phenice (1969), Feremback and colleagues (1980), and Işcan and Derrick (1984) to create a new sex estimation method using 402 individuals from French and Portuguese skeletal populations. Bruzek (2002) recorded five of the most accurate morphological characteristics including the pre-auricular surface, the greater sciatic notch, the form of the composite arch, the inferior margin of the os coxa, and the proportional length between the ishium and pubis. With a sex estimation accuracy rate of 95% this proved to be an effective method. Bruzek (2002) cautions the use of the original studies by Phenice (1969), Feremback and colleagues (1980), and Işcan and Derrick (1984) because validation testing has shown discrepancies in the accuracy rates claimed by the original authors. For instance, when the Phenice method was tested on populations from which the original data was not derived the accuracy rates ranged from 59% to 96%. These results may be due to the researchers' experience in morphological analyses, subjectivity of characterizing the morphological characteristics, population variation between skeletal collections, and even age-related factors between the specimens being tested in each study (Bruzek 2002; Komar and Buikstra 2008: 130; Lovell 1989).

Klales and colleagues (2012) revised the method of pubic non-metric sex estimation presented by Phenice (1969) from a sample of 310 Black and White American individuals. Using Phenice's (1969) original three characteristics (ventral arc, the subpubic concavity/contour, and the medial aspect of the ischio-pubic ramus) Klales and colleagues (2012) attempted to better understand the range of expression for each trait by

expanding from three grades of expression to five grades to better encompass a range of variation. The accuracy for estimating sex was 94.5% and 86.2% accurate when tested on a validation sample.

2.4.1.2 Metric Methods of Analyses

Letterman (1941) measured three pelvic traits from 426 White and Black American males and females: the maximum width and height of the greater sciatic notch, the distance between the posterior-inferior iliac spine, and the line between the point of greatest depth of the notch. Letterman's (1941) measurements revealed that females had wider sciatic notches and a larger distance in the posterior-inferior iliac spine compared to males. Males however, exhibited a deeper greater sciatic notch. Letterman (1941) concluded that the sciatic notch was the best discriminant measure of the pelvis.

Singh and Potturi (1978) validated the conclusions by Letterman (1941) that the sciatic notch was the best discriminant measurement of the pelvis. Singh and Potturi (1978) measured seven sciatic notch characteristics from 200 individuals from the Banaras Hindu University Skeletal Collection: maximal width, maximal depth, posterior segment of the width, posterior angle, total angle, and two indices (Index I and Index II). The posterior angle of the greater sciatic notch measurement, a new morphometric characteristic, was found to be the most useful parameter resulting in accuracy rates between 92% and 100% in females and 75% and 88% in males. Also, any single demarking point could identify the unknown sex with 100% accuracy.

The sacrum was studied by Flander (1978) who examined 15 morphometric dimensions and incorporated univariate and multivariate statistical analyses to create two

discriminant functions. Flander's (1978) study was very useful because the discriminant functions not only rendered sex estimation accuracy rates between 84% and 91% for American Whites and Blacks, respectively, but the functions were also able to estimate ancestry between American Blacks and Whites.

Arsuaga and Carretero (1994) recorded 34 morphometric variables from individuals housed in the Coimbra Collection in Portugal. The authors used multivariate statistical analyses and found that the female pelvic bones were larger at the pelvic inlet and broader at the sciatic notch when compared to males. Discriminant function analysis incorporating 14 of the 34 measurements yielded sex estimation accuracies of 98.6% for males and 100% for females.

The sacrum was studied by Patel and colleagues (2005) using two methods: the sacral index method (consisting of sacral breadth and length measurements) and the Kimura's base-wing index method (consisting of the transverse width of sacral base and transverse width of the wing measurements). However, low accuracy rates were achieved at 62.5% and 68.75% for males and females, respectively, for the sacral index method. Kimura's base-wing index method only achieved 18.75% accuracy. The findings indicate the sacrum does not exhibit sexual dimorphism in the traits measured by this study and not all developed methods of sex estimation are successful.

Albanese (2003) examined the os coxae of 324 individuals from the Terry Collection and 232 from the Coimbra Collection to create logistic regression statistical functions. Nine traits were measured: pelvic height, iliac breadth, pubis length, ischium length, maximum femoral length, maximum femoral head diameter, femoral epicondylar breadth, anterior-posterior femoral diameter at the mid-shaft, and transverse femoral

diameter at the mid-shaft. Two new measurements of the pelvis were also defined and collected (superior pubic ramus length, and acetabular-ischium length). The combination of pelvic and femoral measurements contributed to high accuracy rates of over 90% for all statistical models. The pelvic height, iliac breadth, superior pubis ramus length, maximum femur head diameter, and epicondylar breadth of the femur were the most dimorphic traits yielding a best-fit model accuracy of 98%.

Gonzalez and colleagues (2009) studied 121 os coxae from the Coimbra Collection using discriminate functions analyses. Photos of the greater sciatic notch and the ischiopubic complex were taken with landmarks placed along the edges of the images to quantify the measurable shape of these structures. The technique obtained high sex estimation accuracy rates between 90.1% and 93.4%.

Plochocki (2011) studied the curvature of the sacrum of 125 American Black and White individuals for their potential in estimating sex. Nine measurements describing the anterior sacral curvature only achieved accuracies between 66% and 72%. Although males exhibited a significantly greater curvature depth, the discriminant functions could not reliably assign sex. Therefore, Plochocki (2011) cautions using this method and suggests it only be utilized if other sex estimation techniques cannot be performed.

2.4.2 *Estimating Sex from the Skull*

2.4.2.1 Morphological Methods of Analyses

The skull is considered the second most sexually dimorphic skeletal element after the pelvis. Krogman (1955) studied 14 cranial morphological traits that exhibited sexual dimorphism: size of the skull, architecture of the skull, forehead shape, frontal

eminences, superciliary arches, orbital shape, piriform aperture, zygomatic bone, parietal eminences, mastoid process, occipital bone, occipital condyles, shape of the palate, general appearance of the mandible. In 1986, Krogman and Işcan added another four traits including: size and shape of the nasal opening, size of the nasal bone, zygomatic arch length, and shape of the chin. Using a combination of all 18 features, Krogman and Işcan (1986) achieved 92% accuracy rates for sex estimation. Five of the most dimorphic traits (nuchal crest, mastoid process, supraorbital margin, supraorbital ridge/glabella, and mental eminence) are often used by forensic anthropologists for the estimation of sex of unknown skeletal remains (Dirkmaat 2012: 243).

Ascádi and Nemeskeri (1970) examined five sexually dimorphic morphological characteristics of the skull that are not ancestrally specific: nuchal crest, mastoid process, supra-orbital margin, supra-orbital ridge at the anatomical point 'glabella', and the mental eminence of the mandible. Buikstra and Ubelaker (1994) presented the translated work by Acsádi and Nemeskeri (1970) in a manual on standardizing data collection from skeletal remains because of their simplicity in estimating sex. Ascádi and Nemeskeri's (1970) results were further validated by Krogman and Işcan (1986) who found the five traits to be the best morphological indicators of sex from the skull. Walker (2008) further examined the five characteristics proposed by Acsádi and Nemeskeri (1970) on 304 individuals of "European American", "African American", "ancient Native American", and "English" ancestry. An ordinal scoring system for each non-metric trait was used and the score inputted into statistical models to estimate the sex. Different statistical models (univariate analyses, k-nearest neighbor, and linear, logistic and quadratic regressions) were tested using a combination of traits with accuracy rates between 68.8% and 90.1%.

Rogers (2005) studied 17 sexually dimorphic cranial traits from an historical skeletal sample and achieved overall accuracy rates of 89.1%. When the method was tested on a modern skeletal population the result yielded an accuracy rate of 92%. Williams and Rogers (2006) examined 21 cranial characteristics that achieved the greatest accuracy rates for sex estimation by other researchers. The study was performed on a sample of 50 contemporary individuals of White European ancestry. The results indicate that a combination of the 20 traits achieved an accuracy rate of over 96% for sex classification. This study has become widely used in the event a fragmentary or damaged skull is recovered and few characteristics can be properly scored (Dirkmaat 2012: 242-244; Komar and Buikstra 2008: 129-131).

Suazo and colleagues (2009) examined 16 cranial characteristics that exhibited high levels of accuracy by other researchers. The study was performed on 284 skulls from Brazil. The results indicate accuracies between 72.89% and 84.75% with the greatest dimorphism found in features whose morphology is related to the insertion points of major muscle groups. These features include the mastoid process, zygomatic bone, ridges of the occipital bone, and general morphology of the mandible.

2.4.2.2 Metric Methods of Analyses

Metric analysis by Giles and Elliot (1963) used discriminant functions from eight cranial measurements of American Blacks and Whites. The method obtained an accuracy rate of 85% for identifying males and females. Snow and colleagues (1979) tested the Giles and Elliot (1963) method on 52 crania of American White, Black and American

Indian ancestry recovered from known forensic cases. An accuracy of 88% was achieved substantiating the effectiveness of the Giles and Elliot (1963) method.

Konigsberg and Hens (1998) examined 138 crania from a Late Mississippian archaeological site in Tennessee. They used an ordinal categorization scale to estimate sex from five cranial traits: superciliary arch form, chin form, size of mastoid process, shape of the supraorbital margin, and nuchal cresting. Single and multivariate indicator models created logistic regressions with 81% accuracy rates for sex estimation. The cumulative probit model achieved 83% correct sex classification.

Walker (2008) re-analyzed the same five cranial traits as used by Konigsberg and Hens (1998) to create multivariate quadratic discriminant functions. The method was created using a sample of 304 individuals from "European American", "African American", and "English" ancestry. A logistic statistical model containing all five cranial characteristics yielded an accuracy rate of 88%. Any combination of less than five traits yielded sex estimation accuracy rates between 84% and 88%.

In some forensic cases damaged skulls are found and therefore methodologies based on fragmentary cranial elements are necessary. Norén and colleagues (2005) studied the petrous portion of the temporal bone, the densest section of the skull and most likely to be undamaged, to estimate the sex of an individual. Norén and colleagues (2005) measured the angle created between the lateral aspect of the internal auditory canal and the medial surface of the petrous portion of the temporal bone. The method produced an accuracy rate of 83.2% for sex classification.

Franklin and colleagues (2008) studied the mandible of 225 Black South African individuals to estimate sex. Nine measurements were examined and all exhibited sexual

dimorphism. Dimensions associated with the ramus and corpus lengths were found to exhibit the greatest dimorphism. Univariate discriminant function accuracies ranged between 70.7% and 77.3%. A step-wise discriminant function achieved 81.8% accuracy using only four measurements: coronoid height, bi-gonion breadth, maximum mandible length, and corpus length. Four other discriminant functions were created and achieved 84% accuracy using all nine variables, 79.6% accuracy using unilateral measurements, 75.1% accuracy using the five measurements of the ramus, and 63.6% accuracy using the two measurements of the symphysis.

Using radiographs from an Indian population, Indira and colleagues (2012) examined five measurements of the mandibular ramus: maximum ramus breadth, minimum ramus breadth, condylar height, projective height of ramus, and coronoid height. The results of the study indicated that males exhibited larger dimensions in all characteristics as compared to females. However, the discriminant function equation only achieved an accuracy of 76%. Giles (1964) performed a similar analysis by directly measuring dry bones from White and Black Americans and achieved an 85% accuracy rate. Similarly, Steyn and Işcan (1998) achieved an accuracy of 81.5% from a White South African population. Indira and colleagues (2012) attribute the low accuracy rates to population variability, which further highlights the need for population specific sex estimation studies.

2.4.3 *Estimating Sex from the Long Bones*

2.4.3.1 Morphological Methods of Analyses

Rogers (1999) used 20 (10 males and 10 females) individuals from the Grant Skeletal Collection and developed a method for estimating sex from the posterior distal aspect of the humerus. Four characteristics relating to shape of the olecranon fossa were assessed: trochlear constriction, trochlear symmetry, olecranon fossa shape, and angle of the medial epicondyle. This method was tested on 128 individuals from the University of New Mexico and the William Bass skeletal collections and achieved an accuracy rate of 92% for sex estimation. A validation study by Falys and colleagues (2005) revaluated the findings by Rogers (1999) by studying 351 humeri from a White European skeletal collection in England. Although the accuracy only achieved 79.1% accuracy, individual characteristics achieved similar sex discriminatory potential as reported by Rogers (1999).

2.4.3.2 Metric Methods of Analyses

Black (1978) and Spruiell (1984) used an archaeological population to study the circumference of the femoral diaphysis. Their methodologies achieved accuracy rates of 85% and 90% for sex estimation, respectively. Di Bennardo and Taylor (1979) used 115 Black Americans from a contemporary sample and re-examined Black's (1978) discriminant functions. The validation study showed accuracy rates of 82% for correct sex estimation.

Dittrick (1979) and Dittrick and Suchey (1986) used an archaeological population and created discriminate functions from nine measurements of the femur and humerus.

Three measurements from the femur (maximum diameter of the head, anterior-posterior mid-shaft width and mid-shaft circumference) and one from the humerus (humeral head transverse diameter) proved to be the most sexually dimorphic measurements with accuracy rates for estimation of sex ranging between 85% and 96%.

Işcan and Miller-Shaivitz (1984) measured four morphoscopic characteristics of the tibia: maximum length, anterior-posterior diameter at the nutrient foramen, medio-lateral diameter at the nutrient foramen and the circumference of tibial diaphysis at the level of nutrient foramen. The circumference measurement was found to be the most sexually dimorphic with accuracy rates of 77% and 80% in White and Black populations, respectively.

Berrizbeitia (1989) used 567 Black and White Americans to estimate sex from the head of the radius. Two measurements, the maximum and minimum head diameters, resulted in 96% accuracy during a cross validation study. Interestingly, the method was developed using a combination of two ancestries rather a single ancestral group which resulted in very accurate sex estimation regardless if ancestry is known. Also, when only using the left radius the bone achieved accuracy rates of 92% as compared to 94% accuracy using the right radius.

France (1998) measured various dimensions of the humerus and found the epicondylar breadth to be most sexually dimorphic. Discriminant formulas using the most dimorphic measurements of the bone (vertical and transverse diameters of the humeral head, epicondylar breadth, and distal articular width) yielded accuracy rates between 85.5% and 93.5% for sex classification.

Mall and colleagues (2001) examined the humerii, ulnae, and radii of 143 individuals from the Anatomical Institutes at the Universities Munich and Cologne to estimate sex from the arm bones. Maximum length, head diameters and epicondyle width characteristics from each bone were measured. Accuracies of 94.93%, 93.15%, and 90.58% were exhibited by the radius, humerus, and ulna, respectively. The humeral head diameter was the single most sexually dimorphic characteristic achieving 90.41% accuracy.

Albanese (2003) metrically examined the femora of 324 individuals from the Terry Collection and 232 from the Coimbra Collection. The traits measured included: maximum femur length, maximum femur head diameter, anterior-posterior diameter of the femur at mid-shaft, transverse diameter of the femur at mid-shaft, and epicondylar breadth of the femur. This methodology showed accuracy rates between 90% and 98.5% for sex classification. Inter- and intra-observer errors for most measurements were below 2% indicating a high level of reproducibility.

Barrier and L'Abbé (2008) studied 400 individuals from the Pretoria and Raymond Dart Collections in South Africa to develop an osteometric method of sex estimation from the radius and ulna. Nine measurements from the radius and seven from the ulna yielded accuracies between 80% and 89%. Barrier and L'Abbé (2008) have described the sex discriminating potential of the method as 'moderate' and should be used in conjunction with other methods to estimate sex especially if the method is performed on unknown individuals outside of the studied sample.

Soni and colleagues (2013) examined six measurements from 80 humeri of individuals from Indian ancestry. The single most dimorphic characteristic was the

epicondylar width that achieved an accuracy of 80% in males and 87.5% in females through discriminant function analyses. The second most dimorphic measurement was the vertical head diameter which achieved 87.5% and 70% accuracy in males and females, respectively. A discriminant function utilizing the epicondylar width and vertical head diameter achieved 85% and 90% accuracy in males and females, respectively.

Bhosale and Zambare (2013) studied 200 femora from the Maharashtraian population in India. Six traits were measured: maximum length, maximum diameter of the head, mid-shaft circumference, antero-posterior diameter, bicondylar width, antero-posterior epicondyle diameter (medial and lateral). The length, maximum diameter of head, mid-shaft circumference, maximum antero-posterior diameter of medial and lateral epicondyle and bicondylar width exhibited the greatest dimorphism with accuracy rates between 70.5% and 83.6% when used individually.

Albanese (2013) studied 370 individuals from the Terry, Grant, and Coimbra Collections to create a metric method of estimating sex from the humerus, radius, ulna and clavicle. Logistic regression statistical analyses were created for a combination of possible bone pairings and revealed an overall accuracy rate of 95.2% for sex estimation.

Kranioti and Apostol (2015) studied the tibia of 157 Greek, 190 Italian and 105 Spanish individuals to estimate sex. Three measurements included: maximum tibial length, upper epiphyseal breadth, and lower epiphyseal breadth. All three measurements expressed statistically significant differences in all three populations and resulted in 88% sex estimating accuracy from a pooled sample group. Sex estimation using univariate discriminant functions achieved between 71.5% and 94% accuracy and the most dimorphic trait between all three populations was the upper epiphyseal breadth.

2.4.4 *Estimating Sex from the Vertebrae*

2.4.4.1 Metric Methods of Analyses

Marino (1995) examined complete and fragmentary first cervical vertebrae of 100 individuals of Black and White ancestry. Eight measurements of the superior and inferior articular regions were studied: superior facet maximum length, superior facet maximum width, inferior facet maximum length, inferior facet maximum width, maximum distance between the lateral edges of the superior facets, maximum distance between the lateral edges of the inferior facets, maximum length of the vertebral foramen, and maximum width of fovea. Accuracy rates ranged between 60% and 85% for sex classification.

Wescott (2000) investigated eight dimensions of the second cervical vertebra to estimate sex: maximum sagittal length, maximum height of the dens, the sagittal diameter of the dens, transverse diameter of the dens, length of vertebral foramen, maximum breadth of the superior facets, superior facet sagittal diameter, and the superior facet transverse diameter. Four hundred vertebrae of White and Black ancestry were studied. An accuracy rate of 83% was achieved using discriminant functions that incorporated five measurements with the best sex estimation potential. The advantage of this method is the use of fragmentary vertebrae when ancestry is unknown.

Marlow and Pastor (2011) re-evaluated the sex estimating method developed by Wescott (2000) and included one additional measurement, the width of the vertebral foramen. An English historic skeletal sample consisting of 153 individuals was studied and showed an accuracy rate of 76.99% using Wescott's (2000) original discriminant functions. Four measurements (maximum sagittal length, dens sagittal diameter, width of

vertebral foramen, maximum breadth across superior facets) were found to achieve higher discriminatory potential with an accuracy rate of 83.3%.

Bethard and Seet (2013) also re-examined Wescott's (2000) study and used a sample of 300 individuals. Only five measurements, from Wescott's original eight, were examined: maximum sagittal length; superior facet sagittal diameter, superior facet transverse diameter, length of vertebral foramen, and maximum height of the dens. Five sex classification discriminant functions were created with all showing greater than 80% accuracy rates. One discriminant function achieved the highest accuracy rate of 86.7% with an inter-observer error rate of 1.89% and an intra-observer error rate of 1.39%, which suggests a high degree of replicability for each measurement.

Amores and colleagues (2014) studied the seventh cervical and twelfth thoracic vertebrae (transitional vertebrae) of 121 Spanish individuals for their potential in estimating sex. Four discriminant functions of the seventh cervical vertebra were created achieving an accuracy rate of 80%. One discriminant function was created for the twelfth thoracic vertebra achieving an accuracy rate of 80.2%.

Voison (2011) examined 575 Black South African and North American individuals. Twelve measurements of the twelfth thoracic vertebra were recorded. The author found that sex classification accuracy rates increased with the addition of variables to the discriminant functions. Accuracy rates reached as high as 82.46% in males and 92.86% female.

Hou and colleagues (2012) studied 141 3-D reconstructions of the twelfth thoracic vertebra from a contemporary Chinese population to estimate sex and observe whether the size or shape of T_{12} was the cause of sexual dimorphism. Thirty linear measurements

were made with 28 exhibiting sexual dimorphism. Univariate sex estimation resulted in accuracies between 56.4% and 90.1%. One hundred and twelve ratios were created from the 28 sexually dimorphic linear measurements. Only 62 ratios were sexually dimorphic and achieved accuracies between 56.7% and 73.8%. Stepwise discriminant function analysis selected three measurements (superior maximum sagittal diameter of vertebral body endplate, inferior length of the vertebra, distance between superior articular processes) and one ratio (ratio of anterior to posterior height of vertebral body) as the most sexually dimorphic and predicted sex with an accuracy rate of 94.2%. Size ratios accurately predicated sex at 73.8% indicating size and not shape is the best predictor of dimorphism between male and female thoracic vertebrae.

MacLaughlin and Oldale (1992) studied 205 individuals from the Spitalfields archaeological skeletal collection to estimate sex using the eleventh thoracic, twelfth thoracic and first lumbar vertebral bodies. Discriminant functions were created and achieved accuracy rates between 70% and 90%. The most sexual discriminant trait (anterior transverse diameter of the twelfth thoracic vertebra) achieved an accuracy rate of 87%.

Yu and colleagues (2008) examined 102 Korean individuals using 3-D morphometry software to evaluate the twelfth thoracic vertebra. Thirty-five measurements were recorded with 23 discriminant functions created with accuracy rates of 90% for sex classification.

Gama and colleagues (2015) studied 13 dimensions of the second cervical vertebra to estimate sex. Two hundred and thirty seven vertebrae from two Portuguese skeletal collections were studied and logistic regression models achieved 86.7% to 89.7%

accuracy. Four measurements achieved the highest discriminating power including: sagittal maximum body diameter, and the maximum width of the right superior facet maximum width of the axis, maximum length of the axis. However, the last two measurements were noted to be more frequently damaged in the skeletal collections than any other characteristic.

Ostrofsky and Churchill (2015) studied lumbar vertebrae from 98 Black South African individuals to estimate sex. Eleven variables from all five lumbar vertebral were tested using univariate and multivariate discriminant function analyses. Univariate equations achieved 57.7% to 83.5% accuracy. The highest accuracies were associated with dimensions of the vertebral body. Multivariate equations achieved between 75.9% and 88.7% accuracy. Ostrofsky and Churchill (2015) have identified two limitations of their method. First, the requirement of the analyst to identify the correct lumbar vertebral number. If all lumbar vertebrae are present then assigning the correct anatomical sequence will aid in identifying the lumbar level. However, if lumbar vertebrae are missing or fragmentary, then identifying the correct lumbar vertebral number becomes more difficult. Second, an individual who exhibits non-modal number of vertebrae (four or six lumbar vertebrae) cannot be tested for sex estimation using this method.

2.4.5 *Estimating Sex from Other Post-cranial Skeletal Elements*

2.4.5.1 Morphologic Methods of Analyses

Rogers and colleagues (2000) tested sexual dimorphism of the medial clavicle to determine whether the presence or absence of the rhomboid fossa can estimate for sex.

Using a derived grading scale, the accuracy rates achieved 92.2% from the left clavicle and 81.7% from the right.

2.4.5.2 Metric Methods of Analyses

Steele (1976) examined White and Black Americans to investigate dimorphism of the talus and calcaneus. Five characteristics were measured from the talus and five were measured from the calcaneus. Accuracies ranged from 79% to 89% with the talus exhibiting greater sex estimating accuracy than the calcaneus. Steele (1976) also tested the method on a population of North American Indians and achieved the same degree of accuracy as compared to the original ancestral groups of White and Black Americans.

Wiredu and Seshadri (1999) studied the right fourth rib's sternal end from 346 individuals in a West African cadaveric population. When previous methods of rib sex estimation were tested on the current population, males were misclassified as females resulting in a need for a population specific sex estimation method. The maximum superior-inferior height and the maximum antero-posterior thickness of the sternal end were measurements were recorded. Stepwise discriminant functions yielded 80% accuracy in young individuals (<30 years old) and 74% accuracy in the older individuals (> 30 years old) for an overall accuracy of 78%. Interestingly, the discriminant functions created on the fourth rib are also applicable to the third and fifth sternal rib ends without any significant loss of sex estimating accuracy.

Case and Ross (2007) studied carpals, metacarpals, tarsals and metatarsals of 342 White Americans to estimate sex. The results found that the bones of the hands are superior to those of the feet at estimating sex and phalanges are better than metacarpals or

metatarsals. Also, overall bone length measurements are more appropriate for sex estimation than measurements of robusticity. Discriminant function analyses of the left hand outperformed all other analyses by achieving greater than 80% accuracy for estimating sex.

Manolis and colleagues (2009) studied the biometric data from 993 metacarpals of 151 individuals in a contemporary Greek skeletal population. Seven variables were measured: maximum inter-articular physiological length, medio-lateral diameter of distal epiphysis, antero-posterior diameter of distal epiphysis, medio-lateral diameter at midshaft, antero-posterior diameter at midshaft, medio-lateral diameter of proximal epiphysis, and antero-posterior diameter of proximal epiphysis. Discriminant functions were created for each metacarpal from the left and ride side of the body. Accuracies ranged from 83.7% to 88.1% for left metacarpals and 83.8% to 89.7% for right metacarpals.

Akhlaghi and colleagues (2010) derived discriminant functions to estimate sex from the patella using 113 individuals of Iranian ancestry. The three measurements used were: the maximum height, maximum width, and maximum thickness. An accuracy of 92.9% was achieved using all three measurements. Maximum width and maximum height of the patella were the best indicators of sex achieving accuracies of 91.2% and 89.4%, respectively, when used independently.

Mountrakis and colleagues (2010) performed a similar sex estimation study on 1595 metatarsals from 186 individuals from a modern Greek skeletal collection. The used seven measurements from each metatarsal: maximum length, medio-lateral width of head, dorso-plantar width of head, medio-lateral width at mid-shaft, dorso-plantar width

at mid-shaft, medio-lateral width of base, and dorso-plantar width of base. The left and right side metatarsals did not exhibit bilateral symmetry most likely due to morphological changes related to activity. Therefore, the left and ride sides were studied separately. Discriminant functions were created resulting in accuracy rates between 80.7% and 90.1%. Inter- and intra-observer error rates were low indicating a high level of reproducibility. A cross-validation study found accuracy rates from 77.9% to 86.4% when tested on an independent data set.

DiMichele (2010) studied the calcaneus because it is most often found intact at a deposition site due to its high skeletal density. Four measurements were recorded using 320 American White, Black and 'Hispanic' individuals from the William Bass Skeletal Collection: maximum length, load-arm length, load arm width, and posterior circumference. Discriminant functions were created using all four measurements and yielded an overall sex estimating accuracy rate of 86.69%.

Dabbs and Moore-Jansen (2010) tested a sex estimating method from the scapula using 804 individuals from the Hamman-Todd and Wichita State University cadaver collections. Twenty three measurements were taken to create a five-variable discriminant function with an overall accuracy of 95.7%. The five variables included: maximum length of spine, maximum length of scapula, maximum breadth of scapula, height of glenoid prominence, lateral curvature, and the thickness of the lateral border. A two-variable model (maximum length and breadth of the scapula) was also developed in the event one of the five sexually dimorphic variables was missing. The two-variable model achieved an accuracy of 91.3%. A test of the 5-variable model on an independent sample

from the same collection yielded an accuracy of 92.5% and 84.4% on a separate collection. A cross-validation of the 2-variable model yielded an accuracy of 91.3%.

Khanpetch and colleagues (2012) used metacarpals from 249 Thai individuals to estimate sex. Six measurements from each metacarpal resulted in every bone achieving at least one binary logistic regression equation that estimated sex with greater than 80% accuracy. Sex estimations from the right hand ranged between 85.2% and 89.3% accuracy. The left hand ranged from 83.2% and 89.8% accuracy to estimate sex.

Balseven-Odabasi and colleagues (2013) examined the hyiod bone from a Turkish population and derived discriminant functions to estimate sex from 85 cadavers. Photographs were taken of each bone and 33 measurements were affixed to the image using computer software. Using all 33 measurements achieved sex estimating accuracies of 92.5% and 78.1% for males and females respectively. However, only 18 measurements were found to exhibit sexual dimorphism and only three were selected as the best indicators for sex: length between the distal ends of the right and left greater cornua, perpendicular length from the centre point of a line between the distal ends of the right and left greater cornua to the centre point of the anterior view of the hyoid body, and maximum length of the lesser cornua. A discriminant function using these three measurements achieved 77.4% and 81.3% accuracy for males and females, respectively.

Bongiovanni and Spradley (2012) used sterna from 410 White and Black Americans to estimate sex using four measurements: maximum length, mesostermal length, sternebra 1 width, and sternebra 3 width. An overall accuracy of 84.12% was achieved through a cross-validation study. Mesosternum length and total sternal length were selected as the best discriminatory measurements of the sternum. Franklin and

colleagues (2012) examined 187 sterna from a Western Australian population using Multi-slice Spiral Computed Tomography (MSCT) scans. Ten anatomical landmarks were affixed to the scan using computer software and eight linear measurements were created between these landmarks. The length of the manubrium and body, sternal body length, manubrium width, and corpus sterni width at the first sternebra yielded the greatest discriminatory potential. A cross-validation study achieved accuracies between 72.2% and 84.5% (Franklin et al 2012). Chandrakanth and colleagues (2014) also studied the sternum of 117 individuals from a South Indian population. Five measurements (length of the manubrium, mesosternum, manubrium and mesosternum together, and width at first and at third sternebra) along with three indices (manubrio-corpus index, ratio of the length of the mesosternum and manubrium, and sternubrial-width index) were examined. All five measurements exhibited statistically significant dimorphic variation however, the three indices did not. Univariate statistical models achieved between 67.5% and 74.4% accuracy. Multivariate accuracies achieved between 79.5% and 81.2% accuracy (Chandrakanth et al 2014).

Zorba and colleagues (2012) studied permanent molars of 107 modern Greek individuals using 24 linear measurements from crown and cervical diagonal diameters of maxillary and mandibular dentition. Teeth are commonly found intact at a deposition site due to the strong tissue structure making them ideal for sex estimation. Males exhibited larger molars than females with 19 dimensions exhibiting dimorphism. Discriminant function analysis rendered overall 93% accuracy, 77.4% using the maxillary dentition and 88.4% using the mandibular dentition.

Viciano and colleagues (2013) examined adult dentition to estimate sex from a sample of 269 Spanish individuals. Four dimensions were collected from incisors, canines, and premolars and eight dimensions were recorded for molars. A total of 56 measurements were recorded to measure the mesiodistal, buccolingual, and diagonal crown and cervical diameters of each tooth. The canine from the maxilla and mandible were found to exhibit the greatest sexual dimorphism. Sex estimation accuracies ranged between 78.9% and 93.3% in males and 78.6% to 100% for females.

Navega and colleagues (2015) studied 18 measurements of the tarsal bones using 300 individuals from a Portuguese population. Tarsal bones included the calcaneus, talus, navicular, first cuneiform, second cuneiform, third cuneiform, and the cuboid. Various learning algorithms were used to estimate sex including discriminant function analysis, logistic regression, classification trees, and artificial neural networks. The calcaneus and talus were found to exhibit the most sexual dimorphism. Cross-validation accuracy rates ranged between 88% and 90% to estimate sex.

2.5 The Admissibility of Forensic Anthropology Methods in Court

American and Canadian legislatures dictate that forensic analytic techniques must adhere to the Daubert and Mohan evidence admissibility criteria to ensure the reliability and relevance of scientific techniques before the results of the analyses are admitted as evidence in court (Christensen and Crowder 2009; Christensen et al. 2014; Lesciotto 2015; Williams and Rogers 2006). A critical assessment of scientific techniques ensures that forensic experts are proactive in adhering to professional standards of practice and

are transparent in disclosing error rates when developing new methodologies (Christensen and Crowder 2009; Lesciotto 2015).

The Daubert admissibility criteria evolved from the Frye ruling, the first standards of judging scientific evidence eligibility that was established after *Fryer v. United States* (293 F.2s 1013, 1923) U.S. federal appeals court case in 1923. The Frye ruling "required that the scientific knowledge or test upon which the testimony or evidence was based should be generally accepted within the field from which it was derived" (Holobinko 2012: 394.e3). Scientific evidence and expert testimony was subjected to this standard to restrict the use of pseudoscientific methods and principles as evidence. The shortcoming of the Frye standards was that newly developed and implemented techniques, such as the evolving analyses of DNA evidence, were excluded as evidence on the grounds that the procedure was not widely accepted by the scientific community (Christensen and Crowder 2009; Holobinko 2012).

The 1993 *Daubert v. Merrell Dow Pharmaceuticals* (No. 92–102 509 US 579,1993) trial greatly impacted the admissibility of forensic evidence and scientific testimony. Due to the ambiguity associated with the Frye standards, epidemiological evidence presented during the Daubert trial was ruled inadmissible because the methodology used to test for a prohibited substance implemented by the drug company had not been subjected to rigorous review from the scientific community (Christensen and Crowder 2009; Holobinko 2012). The Daubert admissibility criteria were therefore created to clarify the requirements that scientific evidence meets reliability and relevance standards when presented during expert testimony. The reliability standards state that: 1) the scientific methodology is testable or replicable; 2) the methodology is peer reviewed;

3) the error rates for each method are known; and 4) the method is accepted by the scientific community. The relevance standard requires that the expert testimony provides evidentiary clarification for the case in which it is being given (Christensen and Crowder 2009; Dirkmaat et al 2008; Holobinko 2012). The Daubert criteria also prohibits the admission of evidence if it is potentially prejudicial, confusing, or misleading thereby outweighing its probative value (Dirkmaat et al 2008; Holobinko 2012).

The Mohan admissibility criteria was created after the 1994 Canadian Supreme Court trial *Regina v. Mohan* (2 S.C.R. 9 File No. 23063) to identify the legal requirements for experts who provide testimony in court (Holobinko 2012). Four female patients accused their pediatrician of sexual assault however, the defenses psychology expert presented evidence that was lacking scientific standardization resulting in the Court's decision to render the evidence inadmissible (Holobinko 2012). The judge therefore characterized four governing factors, known as the Mohan criteria, which provide Canadian trial judges the legal obligation to decide on the admissibility of expert testimony: 1) it is necessary that an expert testifies about the evidence due to its technical nature; 2) the evidence must be relevant to the case; 3) the evidence was not obtained illegally or inappropriately (exclusionary rule); and 4) the expert witness presenting the evidence is qualified with proper training and certification in the scientific principles related to the evidence being presented (Holobinko 2012). Using these criteria, the evidence is tested for essentialism, ensuring the potential for prejudicial bias does not outweigh the evidences probative value in providing necessary and reliable information to the Court (Holobinko 2012).

Forensic anthropological scientific research and courtroom testimony must meet the Daubert and Mohan requirements to ensure valid, reliable and relevant methodological standards when creating new methods, such as those used for the estimation of sex. Lesciotto (2015) examined the judicial treatment of forensic anthropological evidence and courtroom testimony. He compared cases prior to the Daubert ruling to post-Daubert cases to observe whether the new admissibility criteria had influenced the exclusion of expert testimony. Considerable admissibility challenges were made against various forensic fields after Daubert, however, the results of this study indicate that forensic anthropology has become more widely accepted after the inclusion of Daubert admissibility criteria. Lesciotto (2015) attributes this acceptance to a proactive approach by forensic anthropologists towards more objective and quantifiable medico-legal research techniques. The field has shifted focus to refine prior methodologies, evaluate error rates, and refine statistical analyses to meet the legal requirements in response to Daubert (Lesciotto 2015).

Researchers who create methods must prove high levels of reliability, accuracy, and precision to meet the admissibility criteria (Christensen and Crowder 2009; Lesciotto 2015). Reliability refers to the stability of reproducibility for testing and retesting a given method. Accuracy assesses the degree of correctness that a method can estimate the true representation. Precision is the ability for a method to consistently produce repeatable results, regardless whether it is correct (Christensen and Crowder 2009; Dirkmaat et al 2008; Komar and Buikstra 2008: 120). Accuracy rates and precision levels determine the reliability of the method (Christensen and Crowder 2009). Osteological methods utilized for the determination of sex are generally considered reliable if they produce accuracies

of at least 80% (Gama et al 2015; Marlow and Pastor 2011: 168; Molto 1979; Nichol and Turner 1986; Novotny and Işcan 1993; Rogers 1999; Rogers and Saunders 1994; Williams and Rogers 2006). Evaluating the precision of a methodology is done by measuring the degree of observer subjectivity or human error through intra- and inter-observer error rates. Intra-observer error refers to the precision of recording the same data by the same observer on different occasions whereas inter-observer error measures the variation of data recording accuracy by other observers (White et al. 2012: 584). Intra- and inter-observer error rates must be less than or equal to 10% (≤10%) (Gama et al 2015; Marlow and Pastor 2011; Molto 1979; Nichol and Turner 1986; Novotny et al 1993; Rogers 1999; Rogers 2005; Rogers and Saunders 1994; Williams and Rogers 2006). To maintain quality assurances in forensic anthropological research, accuracy and precision error rates must be presented to establish transparency of a newly developed method and demonstrate that techniques used for sex estimation are created using scientifically accepted principles that produce results that are statistically greater than chance (Christensen and Crowder 2009; Williams and Rogers 2006).

2.6 Osteological Collections used in this Research

2.6.1 *University of Athens Human Skeletal Reference Collection*

The University of Athens Human Skeletal Reference Collection, known as the Athens Collection, is housed in the Department of Animal and Human Physiology, University of Athens, Greece. It is an example of a growing contemporary reference skeletal collection housing an estimated 225 skeletal individuals that are available for study with known age at death, sex, occupation, place of birth, and cause of death

documented from death certificates. The University of Athens has been accepting skeletal remains since 1996 from cemeteries in the Athens area. Comprised of individuals who lived in the latter half of the twentieth and early twenty-first centuries, the Collection keeps growing due to the funerary customs in Greece (Eliopoulos et al 2007). After a period of three to five years since burial, the remains are exhumed and housed in the cemetery's ossuary. Unless living members of the deceased individual can afford to keep the body in the ossuary by paying the 'rental fee', the remains are deposited into a large underground pit on the cemetery grounds (Eliopoulos et al 2007). This practice produces large numbers of unclaimed bodies that are donated to the University of Athens, through legal authorization from the municipalities, for anthropological research.

The Athens Collection provides the most accurate data available for sex estimation in a contemporary White European population (Eliopoulos et al 2007; Mountrakis, personal communication February 2013). This collection is considered a contemporary, or modern, collection as a result of exposure to positive secular changes with the majority of individuals being born or living the majority of their lives after 1900. Researchers have observed overall increases in skeletal size beginning around 1900 (Albanese 2010). Secular changes, or secular trends, are non-genetic changes occurring over multiple generations that are not the result of evolution because there are no observed changes to allele frequencies within a population. Increases in skeletal size, or positive secular trends, can be attributed to better population health associated with advancements in medical technology for disease diagnosis, the creation and distribution of modern medication, increases in quality of living conditions, and better nutritional standards (Albanese 2010; Chan 2011). Populations that have benefited from improved

health exhibit better growth and development resulting in measurable increases in skeletal morphometrics.

2.6.2 *Luis Lopes Skeletal Reference Collection*

The Luis Lopes skeletal collection housed at the Bocage Museum, National Museum of Natural History, Lisbon, Portugal, is comprised of 1692 individuals with 1552 available for study (Cardoso 2006). Individuals in this collection lived in the nineteenth and early twentieth centuries with the majority of the individuals acquired from three major cemeteries within the city of Lisbon. Individuals are identified through coffin plates, grave numbers and cemetery registration allowing for a large range of biographic data including the place of death, the parish the funeral took place, the name of the individual's parents, place of birth, marital status, occupation, address, cause of death, date and hour of death, secondary deposition site, and sometimes the hospital from which the body came. The available demographics for individuals include sex, age-at-death, place of birth, occupation, place of residence, date and cause of death obtained from death certificates (Cardoso 2006).

The Lopes collection has been acquiring human remains since 1981, when the Bocage Museum asked the Lisbon City Hall for permission to collect human remains for research purposes (Cardoso 2006). The funerary practices in Portugal allow cemeteries to exhume remains from temporary graves after five years if the body has fully skeletonized and the living relatives or legal representatives of the deceased stop paying the 'rental fee' for the plot of land or urn. If the deceased becomes unclaimed the remains are exhumed and held for a few years until a rightful claimant collects them (Cardoso 2006).

If the individual is unclaimed the Museum may request the skeletal materials before they are incinerated or reburied in a communal grave.

The Luis Lopes collection was chosen for this project because the individuals represent an historic population (Cardoso 2006). Forensic anthropologists often create methodologies from historic populations although they may no longer represent a living population (Jantz and Moore-Jansen 1988). Komar and Gravis (2008) have found that a decedent population with ancestral roots to a living population does not accurately reflect the skeletal characteristics of the living population warranting the creation of contemporary skeletal reference samples. The Lopes historic collection will be tested against the contemporary Athens collection to observe whether secular changes have affected the cervical vertebrae. This will ensure the current method for estimating sex from the cervical vertebrae is transposable to both contemporary and historic skeletal samples.

CHAPTER 3: MATERIALS AND METHODS

3.1 Research Objectives

The current study focuses on three measurements (Maximum Cervical Vertebral Body Height, Cervical Foramen Anterior-Posterior Diameter, Cervical Foramen Transverse Diameter) of the seven cervical vertebrae to establish an accurate sex estimation method for a White European skeletal population. The objectives of this research are:

(1) To understand the relationship between sex and the measurements of the cervical vertebral foramen (anterior-posterior and transverse diameters) and the cervical vertebral body (maximum body height) in the contemporary Athens and the historic Lopes White European skeletal populations.

(2) To understand the relationship between stature and the measurements of the cervical vertebral foramen (anterior-posterior and transverse diameters) and cervical vertebral body (maximum body height) in the contemporary Athens and the historic Lopes White European skeletal populations.

(3) To evaluate the relationship between age and the measurements of the cervical vertebral foramen (anterior-posterior and transverse diameters) and the cervical vertebral body (maximum body height) in the contemporary Athens and the historic Lopes White European skeletal populations.

3.2 Skeletal Materials Utilized for this Research

This study examined 1020 vertebrae utilizing 295 skeletal cadaveric individuals of White European ancestry from two European skeletal reference collections, the University of Athens Human Skeletal Reference Collection (Athens Collection) and the Luis Lopes Skeletal Collection (Lopes Collection). Individuals were selected at random with priority given to approximate equal numbers of males and females (157 males and 138 females) to provide a statistically comparable sample from both sexes. The sample consists of adult individuals between 20 and 99 years of age. Sub-adult individuals (< 20 years of age) have been excluded from this study because they are not developmentally mature, i.e. the vertebrae have not reached their full adult size.

Individuals were excluded from the research if more than two vertebrae were missing from the cervical region of the spinal column. A minimum of five of the seven cervical vertebrae are needed to identify and seriate the vertebral bones in the correct anatomical position. If one or two vertebrae were missing, sequential ordering and numerically identifying the cervical bones was possible through anatomical articulation. However, if more than two vertebrae were missing the sequence could not be established and the individual was not included in the independent sample.

Vertebrae exhibiting taphonomic damage, including fracturing or the loss of bone, to the vertebral body or within the vertebral foramen were excluded from this study. Vertebrae exhibiting extreme pathologic remodeling to the morphometric characteristics were also excluded from this study. Extreme pathologies included severe osteoarthritis, diffuse idiopathic skeletal hyperostosis (DISH), tuberculosis, vertebral fusion, collapsed vertebrae, among other vertebral pathologies. These afflictions remodel the vertebrae

obscuring the morphometric characteristics and subsequently affecting the integrity and reliability of measurements for sex estimation.

Following the inclusionary criteria of previous researchers, vertebrae exhibiting mild osteoarthritis were included in this study (Eisenstein 1983; Jones and Thomson 1968; Tatarek 2005; Voisin 2011). Osteoarthritis is a skeletally manifested pathological condition characterized by increased bone density, osteophytic bony growth (spurs), and articular cartilage degeneration. Degenerative change to the vertebral column is a common age-related body alteration caused by the bipedal weight bearing responsibilities of the spine. Around 25 years of age, components of the spinal column complete their development and thereafter the spine begins the process of progressive degeneration that accelerates around 50 years of age (Soren 1993: 213; Steele and Bramblett 1988: 132-133). These changes generally manifest in the middle and lower cervical, upper thoracic and middle thoracic vertebrae (Shimoda et al 2012; Resnick 1995: 1396). Natural mechanical stresses to the skeleton caused by physical activity, muscular strain, and older age paired with constant metabolic skeletal reconfiguring and regeneration results in the appearance of osteophytic bony growths, marginal lipping of the vertebral bodies and facets, and macroporosity (Resnick 1995: 1396; Shimoda et al 2012; Steele and Bramblett 1988: 133). All persons over the age of 50 years, and possibly younger individuals, will exhibit osteoarthritic pathology and therefore excluding these individuals biases the independent sample from accurately representing the population (Resnick 1995 1396; Soren 1993: 213; Voisin 2011). Vertebrae exhibiting mild cases of osteoarthritis were included in this research only if the three morphometric traits (i.e. Maximum Cervical Vertebral Body Height, Cervical Foramen Anterior-Posterior

Diameter, and Cervical Foramen Transverse Diameter) were not afflicted and osteophytic manifestations did not interfere with caliper placement for measuring (Taitz 1996).

One hundred and thirty-five individuals (N=135) were examined from the Athens collection including 70 males and 65 females. This collection is a contemporary population as the individuals all lived in the second half of the twentieth century and have been exposed to positive secular changes. These individuals have spent the majority of their life post 1950 and therefore had access to contemporary diets and medical treatments that have greatly influenced bone growth and formation (Garmendia et al 2014; Velemínská et al 2013). The contemporary nature of this collection allows for a more accurate comparison to a modern White European population. One hundred and sixty individuals (N=160) were studied from the Lopes Collection including 87 males and 73 females. This collection is an historic population as the individuals lived during the nineteenth and early twentieth centuries with restricted diets and limited medical treatment.

An independent test sample consisting of 32 individuals (N=32) was isolated and three morphometric characteristics (Maximum Cervical Vertebral Body Height, Cervical Anterior-Posterior Diameter, Cervical Transverse Diameter) were measured from each skeletal collection (Athens N=6; Lopes N=26). These individuals were not included in the statistical analyses. This independent test sample was used to test the accuracy of the discriminant function equations that were derived using the original sample (i.e. cross-validation).

3.3 Methods

The seven cervical vertebrae were isolated from the 12 thoracic and five lumbar vertebrae of the human vertebral column. Cervical vertebrae were numerically identified as C_1 through C_7 according to their anatomical location (Figure 3.1). The C_1, C_2, and C_7 vertebrae were easily identified due to distinguishing anatomical characteristics. The C_1 vertebra is roughly circular in shape and lacks a vertebral body and spinous process. The C_2 vertebra is characteristically defined by the odontoid process. The C_7 vertebra is usually the largest cervical vertebra with a large, non-bifid, spinous process sharply projected inferiorly. The third through sixth cervical vertebrae (C_3-C_6) were physically sequenced by fitting them together according to anatomical articulations (Byers 2008: 143; White et al 2012: 131).

3.3.1 *Demographic Data*

The same demographic data for each individual were collected from the two skeletal collections. These data included: biological sex (male or female), ancestry (only White Europeans were selected), year-of-death, and age-at-death. The year-of-birth for each individual was not documented in the records and instead it was calculated by subtracting the age-at-death from the year-of-death. Individuals were further classified into age categories of 10 year increments (20-29.99, 30-39.99, 40-49.99. 50-59.99, 60-69.99, 70-79.99, 80-89.99, 90-99.99 years of age). Ten-year increments were selected because greater numbers of individuals in each age category will strengthen the statistical testing (Clark 1985; Taitz 1996; Tatarek 1999).

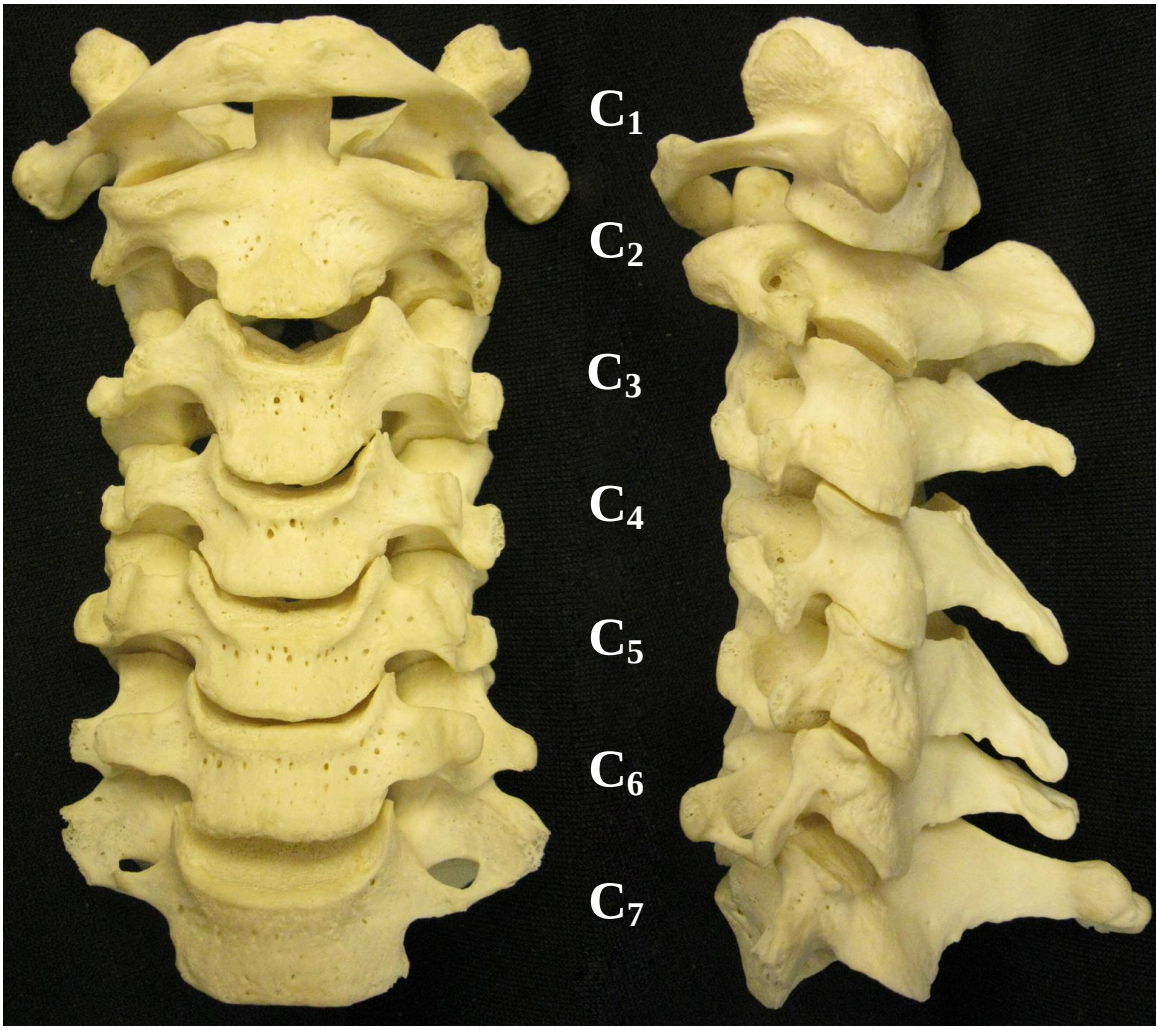

Figure 3.1 The seven cervical vertebrae in anatomical articulation and identified as C_1 through C_7 from the anterior (left) and lateral (right) perspectives. (Photos by Andrew S. Rozendaal)

3.3.2 *Skeletal Measurements*

Following the protocol of Clark (1985), Eisentstein (1983), Kibii and colleagues (2010), Taitz (1996), Tatarek (2005), and Verbiest (1955), three morphometric traits were measured from each cervical vertebra for the estimation of sex: Maximum Cervical Vertebral Body Height, Cervical Anterior-Posterior Diameter, Cervical Transverse Diameter (Table 3.1). These are standard vertebral measurements widely accepted by many researchers (Clark 1985; Eisentstein 1983; Jones and Thomson 1968; Kibii et al 2010; Taitz 1996; Tatarek 1999, 2005; Verbiest 1955). For detailed explanations of the vertebral measurements and the specific landmarks measured for this project, refer to Appendix A. Measurements were recorded using Vernier calipers rounding to the nearest 0.01 millimeter and then entered into a Microsoft Excel spread sheet.

Table 3.1 Description of measurements taken from each cervical vertebra.

Measurements	Code	Description	References
Maximum Cervical Vertebral Body Height	$C_{(n)}HT$	The maximum superior to inferior vertebral body height along the anterior border of each vertebra with the exception of C_1. C_2HT includes the odontoid process.	Fully 1956; Kibii et al 2010; Tatarek 1999; Raxter et al 2006; Wescott 2000.
Cervical Anterior-Posterior Diameter	$C_{(n)}AP$	The maximum mid-sagittal diameter from the anterior to posterior aspects of the vertebral foramen.	Clark 1985; Eisentstein 1983; Kibii et al 2010; Taitz 1996; Tatarek 1999, 2005; Wescott 2000; White et al 2012: 146.
Cervical Transverse Diameter	$C_{(n)}TR$	The maximum medio-lateral diameter measured from the left to the right pedicles within the vertebral foramen.	Clark 1985; Eisentstein 1983; Kibii et al 2010; Taitz 1996; Tatarek 1999, 2005; Wescott 2000; White et al 2012: 146.

n= the chronological vertebral identification number

The maximum cervical vertebral body height ($C_{(n)}HT$) measurement is defined as the maximum superior to inferior height of the vertebral body centrum (Figure 3.2) (Fully 1956 in Raxter et al 2006). The outside Vernier caliper arms measure from the superior to inferior vertebral body rims across the anterior one-third area (Figure 3.3). This measurement is taken perpendicular to the vertebral body's superior and inferior intervertebral surfaces and avoids any osteophytic growth or bone spurs that are present (Fully 1956 in Raxter et al 2006; Tatarek 1999, 2005). The CHT measurement was not recorded from the first cervical vertebra (C_1) because this bone lacks a vertebral body. Maximum body height recorded for the second cervical vertebra (C_2) included the odontoid process (Raxter et al 2006; Tatarek, Personal Communication, March 21, 2013).

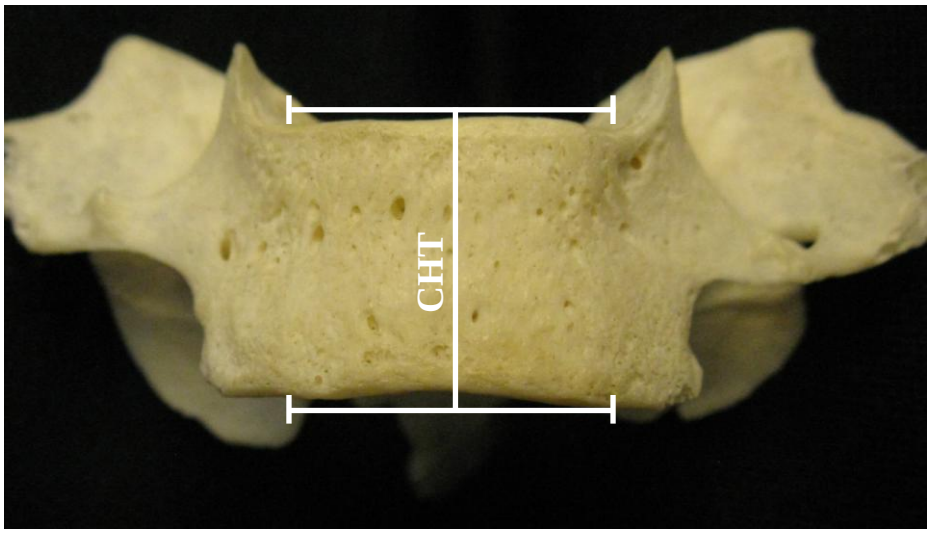

Figure 3.2 Anterior view of a typical cervical vertebra depicting the Maximum Vertebral Body Height ($C_{(n)}HT$) measurement. (Photo by Andrew S. Rozendaal)

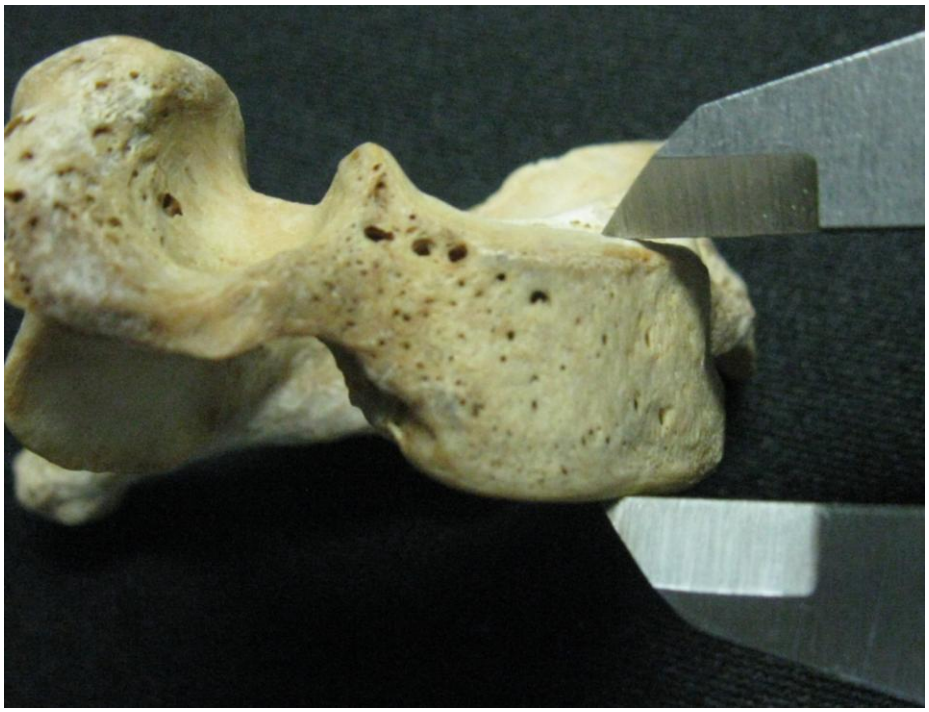

Figure 3.3 Lateral view of a typical cervical vertebra. Vernier caliper placement measuring Maximum Vertebral Body Height ($C_{(n)}$HT) on the anterior margin of the vertebral body. (Photo by Andrew S. Rozendaal)

The cervical anterior-posterior vertebral foramen diameter ($C_{(n)}$AP), also known as the sagittal canal, is the maximum mid-sagittal diameter from the anterior to posterior aspects of the vertebral foramen (Figure 3.4) (Clark 1985; Taitz 1996; Tatarek 1999, 2005; White et al 2012: 146). It is obtained from the superior aspect of the canal opening using the inside Vernier caliper arms (Figure 3.5). This measure is the maximum diameter from the midline of the posterior vertebral body to the point where the left and right laminae fuse creating the spinous process (Clark 1985). If osteophytic growth inhibits caliper placement for measuring $C_{(n)}$AP, modify by measuring from the middle of the posterior vertebral body, half way between the superior and inferior body rims, thereby avoiding osteophytes along the rims (Eisentstein 1983: 189). The cervical transverse vertebral foramen diameter ($C_{(n)}$TR), also known as the transverse canal, is the

maximum medio-lateral diameter measured from the left to the right pedicles within the vertebral foramen (Figure 3.4) (Clark 1985; Taitz 1996; Tatarek 1999, 2005; White et al 2012: 146). The $C_{(n)}$TR measurement is obtained from the superior aspect of the canal opening. The inside arms of the Vernier calipers measure from the left to the right pedicles perpendicular to the transverse plane (Figure 3.6) (Clark 1985; Eisentstein 1983; Kibii et al 2010; Taitz 1996; Tatarek 1999, 2005; Tatarek, Personal Communication, March 21, 2013; Wescott 2000; White et al 2012: 146.).

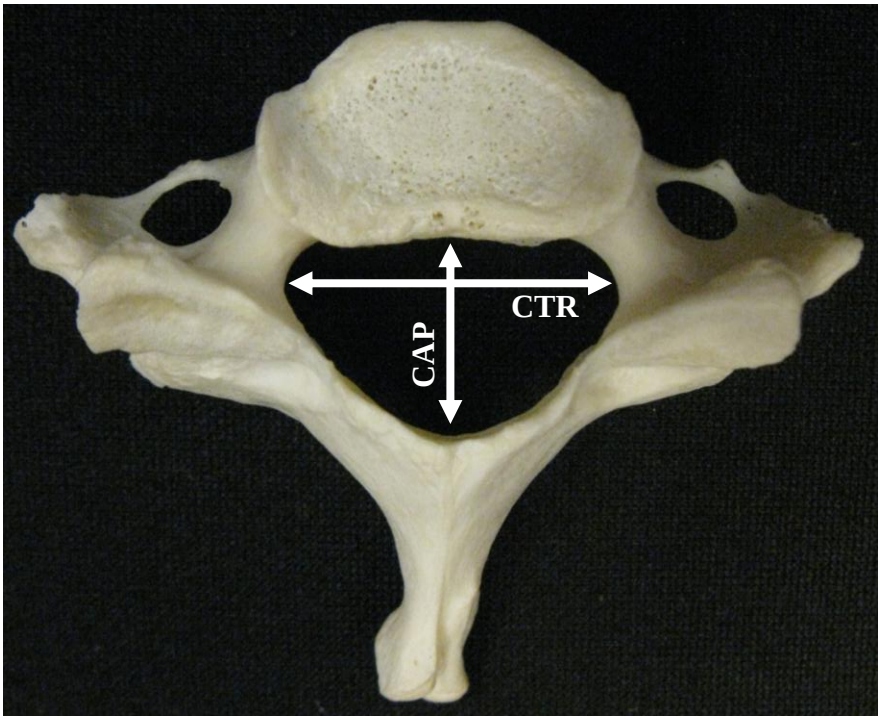

Figure 3.4 Superior view of a typical cervical vertebra depicting the anterior-posterior ($C_{(n)}$AP) and transverse ($C_{(n)}$TR) vertebral foramen diameters. (Photo by Andrew S. Rozendaal)

Figure 3.5 Superior lateral view of a typical cervical vertebra. Vernier caliper placement to measure Cervical Anterior-Posterior Diameter ($C_{(n)}$AP). (Photo by Andrew S. Rozendaal)

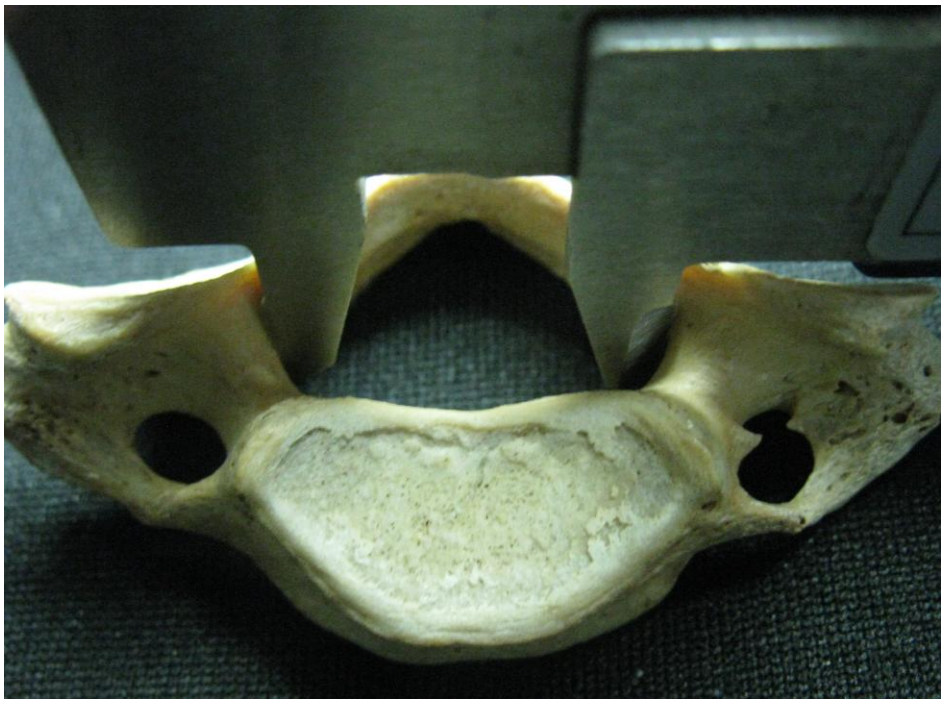

Figure 3.6 Superior view of a typical cervical vertebra. Vernier caliper placement to measure Cervical Transverse Diameter ($C_{(n)}$TR). (Photo by Andrew S. Rozendaal)

Skeletal stature estimates were obtained for each individual from both independent samples (N=101). Stature was correlated with each vertebral measurement to examine whether the three vertebral measurements were influenced by stature or the result of sexual dimorphism (Tatarek 1999, 2005). Skeletal stature estimates were provided by Dr. Sotiris Manolis for the Athens collection (N=51, 29 males and 22 females) as calculated using the revised Fully method by Raxter and colleagues (2006) (Manolis, Personal Communication, May 22, 2013). This anatomical method is considered to be the most reliable way of estimating stature from skeletal remains (Mays 2010: 127-134). Stature from the Lopes Collection (N=50, 26 males and 24 females) was recorded by the author. Methods by Trotter and Gleser (1952, 1958) utilizing an osteometric board were used to measure long bone lengths for the estimation of skeletal stature in this population. The use of the revised Fully method by Raxter and colleagues (2006) was not possible in the Lopes Collection due to poor preservation of all the requisite bones needed to carry out the stature estimation. Instead, mathematical stature formulae developed by Trotter and Gleser (1952, 1958) for White European males and females were used to estimate skeletal stature. These methods are considered accurate for the estimation of stature for incomplete human remains (May 2010). Maximum left and right femora, humerii, and tibii lengths were recorded (Trotter and Gleser 1952, 1958). Tibial length measurement revisions proposed by Jantz and colleagues (1995) for the Trotter and Gleser formulae were used; the biomechanical length was used rather than the maximal tibial length because the former estimates stature 2.5 cm to 3 cm too great. Individuals were selected at random and bones displaying pathologies or trauma were not measured. Left and right bone lengths were averaged to obtain one maximum length

value to accommodate for variation between the left and right sides of the body. This value was then used with long bone stature reconstruction formulae specific for White European males and females (Trotter and Gleser 1952, 1958). The values obtained from regression formulae for the femur, humerus and tibia were then averaged to obtain one estimated skeletal stature for each individual.

3.4 Statistical Analyses

The current study followed the statistical protocols of Tatarek (1999, 2005). Statistical analyses were performed using the MiniTab 17.0 statistical software package and discriminant functions were created using SPSS version 21.0 statistical software. The raw data were first separated into two populations: the Athens Collection (contemporary) and the Lopes Collection (historic). Descriptive statistics were calculated for each of the Athens and Lopes Collection including age ranges, means and medians, year-of-birth ranges and averages, and year-of-death ranges and averages. These descriptive statistics were also calculated between males and females of each population. Descriptive statistics were then calculated between the CHT, CAP and CTR measurements of males and females from both collections to examine the variation in these three morphometric characteristics. This included means, medians, standard deviations, and ranges.

A test for univariate normality was performed for each of the three variables (Maximum Cervical Vertebral Body Height, Cervical Anterior-Posterior Diameter, Cervical Transverse Diameter) for males and females within the Athens and Lopez populations. Normality probability plots were created to examine the data distribution and to highlight potential outliers. A normal distribution occurs when plotted

measurement points exhibit a linear distribution indicating that the measurements are not the result of chance outcomes. Distinct outliers were examined for accuracy and removed from the data set if found to be inputted incorrectly. A p-value significance level of 5% (p-value = 0.05) to measure normally distributed data was adjusted using a Bonferroni p-value correction of $\alpha = 0.0006$. If the p-value is greater than 0.0006 (p-value > 0.0006) this indicates the distribution is normally distributed and analyses may proceed.

A Bonferroni correction value is used in statistical significance calculations to reduce the chance that errors associated with multiple comparisons having affected the data being compared for analysis. A statistical significance value of 5% error rate ($\alpha = 0.05$) is used in this research and adjusted using Bonferroni corrections according to the number of testable variables (n) in the testing hypotheses. As the number of testable variables increases, there is a greater likelihood that an error appears in the statistical outcome. Therefore a variable may appear statistically significant, meaning the result is unlikely to have occurred by chance, due to procedural multiplicity error rather than a quantitative error resulting in the misclassification of a relationship between variables when one does not appear (type-1 error) (Meek, Personal Communication, December 10, 2014). Within the current research, large quantities of measurements were statistically compared increasing the probability of type-1 error. A Bonferroni correction was calculated (Bonferroni = α/n) adjusting the p-value for each statistical test accounting for the number of variables being tested.

Any method used for the estimation of sex of unknown human remains must have a high accuracy rate and replicability to be considered reliable. Accuracy refers to the degree of closeness the sex estimate is to being ‘true’ whereas replicability refers to the

degree of reproducibility or repeatability of the method by other researchers (Christensen and Crowder 2009; Dirkmaat et al 2008; Komar and Buikstra 2008: 120). To ensure high accuracy rates and replicability, the measurement must be free from researcher bias, measuring error, and must give a similar result, i.e. not statistically different, every time.

The three morphometric characteristics (Maximum Cervical Vertebral Body Height, Cervical Anterior-Posterior Diameter, Cervical Transverse Diameter) of the cervical vertebrae were tested for intra- and inter-observer measurement errors using paired t-tests to evaluate measurement reliability. To test for intra-observer error, thirty individuals from each of the Athens and Lopes Collections (N=60) were randomly selected and re-measured by the current author at least one week after the initial measurements were recorded. To test for inter-observe error, the three morphometric traits were measured by a research assistant at each collection location (Athens N=35; Lopes N=29). Written descriptions and visual demonstrations were provided for each assistant and they were instructed to record the measurements from individuals who fit the inclusion criteria.

The first goal of this research was to understand the relationship between sex and the measurements of the cervical vertebral foramen (anterior-posterior and transverse diameters) and the cervical vertebral body (maximum body height) in the contemporary Athens and the historic Lopes White European skeletal populations. Two-sample t-tests were used to determine whether statistically significant differences existed between male and female vertebral measurement means as a result of sexual dimorphism. Two-sample t-tests were also used to examine whether the males and females between the two skeletal collections exhibited statistically significant differences in vertebral measurements due to

ancestral variation. If the sexes from both populations did not exhibit significant differences (p-value > 0.002) between CHT, CAP and CTR then the two populations, i.e. Athens and Lopes, could be grouped together into one large independent population of "White Europeans" for all further statistical analyses.

Multivariate discriminant functions were created using canonical discriminant function coefficients for the purpose of estimating sex from the vertebrae. Discriminant functions were first created for each independent cervical vertebra, C_1 through C_7, using a combination of traits: 1) all three measurements (CAP, CTR, CHT); 2) vertebral foramen measurements only (CAP and CTR); and 3) the two most dimorphic measurements (CTR and CHT). Second, a discriminant function was created using all seven vertebrae and all 21 vertebral measurements. Third, C_1 and C_2 vertebrae were used to create discriminant functions, using all three measurements (CAP, CTR, CHT); C_1 and C_2 vertebrae were examined independently due to their irregular shape as compared to the typical cervical vertebrae C_3 through C_6 and the transitional C_7. Fourth, typical cervical vertebrae, C_3 through C_6, and the transitional C_7 vertebra were selected to create discriminant functions using a combination of traits: 1) all three measurements (CAP, CTR, CHT); 2) vertebral foramen measurements only (CAP and CTR); and 3) the two most dimorphic measurements (CTR and CHT). Fifth, the transitional C_7 vertebra was excluded and only typical cervical vertebrae C_3 through C_6 were assessed using a combination of traits: 1) all three measurements (CAP, CTR, CHT); 2) vertebral foramen measurements only (CAP and CTR); and 3) the two most dimorphic measurements (CTR and CHT). Sixth, all 21 measurements were entered into the stepwise discriminant function analysis. The stepwise method selected the most sexually dimorphic variables from the seven bones

and created one discriminant function. Lastly, discriminant functions were created from the two most dimorphic vertebrae (C_2 and C_5) using a combination of traits: 1) all three measurements (CAP, CTR, CHT); 2) vertebral foramen measurements only (CAP and CTR); and 3) the two most dimorphic measurements (CTR and CHT).

The discriminant functions that achieved overall predicted accuracies above 80% were further tested using an independent cross-validation sample from the Athens and Lopes Collections. A cross-validation test is a statistical comparison that assesses the reproducibility of the discriminant function and how the results of that function will estimate sex from an independent data set. Thirty-two (N=32) individuals of known sex represent the independent sample. The sex estimating cross-validation results were compared to the documented biological sex of each individual to test the accuracy of the discriminate functions.

The second goal of this research was to understand the relationship between stature and the measurements of the cervical vertebral foramen (anterior-posterior and transverse diameters) and cervical vertebral body (maximum body height) in two White European skeletal populations. Pearson's correlation coefficients were calculated between stature and the three morphometric traits (CHT, CAP, and CTR) to identify any morphometric relationships (Tatarek 2005). A correlation would indicate that an individual's height predetermines the size of the vertebral foramen rather than being influenced by other variables such as age, sex, or ancestry (Tatarek 2005). A Bonferroni adjusted p-value less than or equal to 0.002 (p-value ≤ 0.002) indicates significant correlation between the tested trait and stature. Exploratory correlation plots were then created for stature and the diameters of all three traits to visually display whether a linear

relationship existed between them. If a linear relationship existed then CHT, CAP, CTR and stature were size-related measurements, i.e. the size of one measurement influenced the size of the other. Pearson's correlation was also used to determine the relationship between the CHT, CAP and CTR morphometric characteristics. Exploratory correlation plots were also created to visually display whether a linear relationship existed between CHT, CAP and CTR diameters.

The third goal of this research was to evaluate the relationship between age and the measurements of the cervical vertebral foramen (anterior-posterior and transverse diameters) and the cervical vertebral body (maximum body height) in the contemporary Athens and the historic Lopes White European skeletal populations. Research suggests that the size of the vertebral foramen remains constant throughout life (Clark 1985). Eight age categories were created (Table 3.2) and one-way ANOVA statistical correlations (f-value) were calculated to understand the effects of aging on the Maximum Cervical Vertebral Body Height, Cervical Anterior-Posterior Diameter, Cervical Transverse Diameter. Exploratory plots were generated to visually compare age-related changes. Further testing was performed on vertebrae that exhibited statistically significant differences between age categories using a post-hoc test to understand which age category expressed the morphometric changes. To visually assess the differences between age categories exploratory interval plots were generated to visually compare age-related changes at each cervical bone.

Table 3.2 Designated age categories and their respective ages in years used to assess the age related changes between vertebral foramen measurements using ANOVA.

Age Category	Years of Age
2	20-29.99
3	30-39.99
4	40-49.99
5	50-59.99
6	60-69.99
7	70-79.99
8	80-89.99
9	90-99.99

CHAPTER 4: RESULTS

4.1 Research Objectives

The current study focuses on three measurements of the seven cervical vertebrae to establish an accurate sex estimation method for a White European skeletal population: vertebral foramen anterior-posterior diameter (CAP), vertebral foramen transverse diameter (CTR), and maximum vertebral body height (CHT). The objectives of this research are:

(1) To understand the relationship between sex and the measurements of the cervical vertebral foramen (anterior-posterior and transverse diameters) and the cervical vertebral body (maximum body height) in the contemporary Athens and the historic Lopes White European skeletal populations.

(2) To understand the relationship between stature and the measurements of the cervical vertebral foramen (anterior-posterior and transverse diameters) and cervical vertebral body (maximum body height) in the contemporary Athens and the historic Lopes White European skeletal populations.

(3) To evaluate the relationship between age and the measurements of the cervical vertebral foramen (anterior-posterior and transverse diameters) and cervical vertebral body (maximum body height) in the contemporary Athens and the historic Lopes White European skeletal populations.

4.2 Descriptive Statistics

The seven cervical vertebrae from 295 individuals (157 males and 138 females) of White European ancestry were examined for their potential in estimating sex. One thousand and twenty (N=1020) individual vertebrae were studied from two White European skeletal collections, the Athens Collection and the Luis Lopes Collection. These Collections were chosen because they represent contemporary and historic White European populations. The Athens Collection represents contemporary individuals who lived the majority of their lives in the second half of the twentieth century. The Lopes Collection represents historic individuals who lived in the nineteenth and early twentieth centuries. Table 4.1 shows the overall demographic information for both Collections. Tables 4.2 and 4.3 show the demographic profiles for males and females in the Athens and Lopes Collections, respectively.

Table 4.1 Demographic information for all individuals in the Athens and Lopes Skeletal Collections.

	Athens Skeletal Collection	**Luis Lopes Skeletal Collection**
N	135	160
Age Range (years)	23 - 99	20 - 94
Average Age (years)	58	57
Median Age (years)	60	58
Year of Birth	1879 - 1965	1826 - 1932
Birth Mean	1923	1879
Birth Median	1921	1877
Year of Death	1960 - 1995	1891 - 1968
Death Mean	1981	1936
Death Median	1984	1938

Table 4.2 Demographic information for males and females in the Athens Skeletal Collection.

	Athens Skeletal Collection (N=135)	
	Males	**Females**
N	70	65
Age Range (years)	23 - 87	24 - 99
Average Age (years)	56.43	60.62
Median Age (years)	58.5	62
Year of birth	1879 - 1965	1880 - 1964
Birth Mean	1923	1922
Birth Median	1921	1920
Year of Death	1960 - 1995	1965 - 1993
Death Mean	1980	1983
Death Median	1983	1984

Table 4.3 Demographic information for males and females in the Lopes Skeletal Collection.

	Luis Lopes Skeletal Collection (N=160)	
	Males	**Females**
N	87	73
Age Range (years)	20 - 88	20 - 94
Average Age (years)	54	61
Median Age (years)	54	65
Year of birth	1839 - 1932	1826 - 1927
Birth Mean	1881	1876
Birth Median	1880	1875
Year of Death	1891 - 1968	1898 - 1963
Death Mean	1935	1937
Death Median	1937	1940

Three characteristics of the cervical vertebrae were measured: the Vertebral Foramen Anterior-posterior Diameter (CAP), Vertebral Foramen Transverse Diameter (CTR), and the Maximum Vertebral Body Height (CHT). This method followed the morphometric protocols of Clark (1985), Kibii and colleagues (2010), Taitz (1996), Tatarek (1995, 2005) and Verbiest (1955). The measurements were recorded in millimeters (mm). Three measurements for seven bones resulted in recording 21 measurements for each individual however, if the characteristic was damaged it was not recorded resulting in fewer vertebrae measured at each cervical level. Tables 4.4 and 4.5 show the descriptive statistics for males and females in the Athens Collection. Tables 4.6 and 4.7 show the descriptive statistics for males and females in the Lopes Collection. The tables illustrate the number of vertebrae assessed (N), minimum measurement length (Minimum), maximum measurement length (Maximum), mean, median, and standard deviation (SD).

Table 4.4 Descriptive statistics for vertebral foramen anterior-posterior diameter (CAP), vertebral foramen transverse diameter (CTR), and maximum vertebral body height (CHT) for male individuals (N=70) in the Athens Collection.

Measurement	N	Minimum (mm)	Maximum (mm)	Mean (mm)	Median (mm)	SD (mm)
C_1AP	59	25.73	37.15	31.47	31.21	2.02
C_2AP	64	12.94	19.86	16.22	16.15	1.45
C_3AP	59	11.95	18.11	14.13	13.96	1.23
C_4AP	69	10.69	17.43	13.54	13.63	1.36
C_5AP	63	10.30	17.47	13.63	13.70	1.52
C_6AP	62	10.30	16.72	13.49	13.64	1.41
C_7AP	65	10.22	16.67	13.97	14.06	1.48
C_1TR	59	25.99	34.47	29.24	29.51	2.03
C_2TR	64	21.41	28.47	24.53	24.71	1.56
C_3TR	59	21.72	27.38	23.82	23.97	1.28
C_4TR	69	22.23	27.69	24.68	24.48	1.28
C_5TR	63	22.98	28.55	25.50	25.53	1.39
C_6TR	62	21.79	28.28	25.81	26.04	1.29
C_7TR	65	21.56	28.96	25.01	24.88	1.45
C_2HT	65	32.57	47.16	39.65	39.08	3.01
C_3HT	59	11.32	17.69	13.86	13.87	1.38
C_4HT	69	11.34	17.51	13.80	13.67	1.16
C_5HT	62	10.03	15.86	13.09	13.04	1.20
C_6HT	63	11.56	16.46	13.69	13.59	1.11
C_7HT	65	11.13	18.14	15.43	15.41	1.40

Minimum measurement length (Minimum)
Maximum measurement length (Maximum)
Standard deviation (SD)

Table 4.5 Descriptive statistics for vertebral foramen anterior-posterior diameter (CAP), vertebral foramen transverse diameter (CTR), and maximum vertebral body height (CHT) for female individuals (N=65) in the Athens Collection.

Measurement	N	Minimum (mm)	Maximum (mm)	Mean (mm)	Median (mm)	SD (mm)
C_1AP	57	25.88	33.8	29.28	29.36	1.97
C_2AP	62	12.34	19.12	15.95	15.81	1.50
C_3AP	56	10.94	16.52	13.86	13.84	1.234
C_4AP	61	9.78	16.40	13.45	13.41	1.28
C_5AP	61	9.94	16.15	13.25	13.27	1.41
C_6AP	59	10.53	16.18	13.06	13.11	1.27
C_7AP	61	10.23	15.81	13.47	13.53	1.34
C_1TR	58	23.28	32.67	27.81	27.65	1.82
C_2TR	62	19.93	26.61	23.19	23.16	1.57
C_3TR	56	19.41	25.98	22.93	22.91	1.46
C_4TR	61	20.23	27.14	23.92	23.94	1.42
C_5TR	61	21.72	28.43	24.55	24.72	1.45
C_6TR	59	21.33	29.32	24.79	24.71	1.64
C_7TR	61	19.81	28.20	23.93	24.09	1.72
C_2HT	62	31.96	40.52	35.73	35.62	1.77
C_3HT	56	10.39	14.67	12.58	12.66	0.96
C_4HT	59	10.16	14.71	12.11	12.18	0.94
C_5HT	60	9.88	13.80	11.75	11.68	0.91
C_6HT	57	10.64	15.28	12.40	12.41	0.92
C_7HT	61	11.09	16.21	14.01	14.13	1.08

Minimum measurement length (Minimum)
Maximum measurement length (Maximum)
Standard deviation (SD)

Table 4.6 Descriptive statistics for vertebral foramen anterior-posterior diameter (CAP), vertebral foramen transverse diameter (CTR), and maximum vertebral body height (CHT) for male individuals (N=87) in the Lopes Collection.

Measurement	N	Minimum (mm)	Maximum (mm)	Mean (mm)	Median (mm)	SD (mm)
C_1AP	77	25.97	35.09	30.61	30.43	1.99
C_2AP	82	12.58	20.10	16.00	16.01	1.34
C_3AP	81	11.14	16.83	13.79	13.78	1.23
C_4AP	83	10.51	16.08	13.26	13.35	1.21
C_5AP	80	10.59	16.52	13.53	13.57	1.26
C_6AP	84	10.71	16.99	13.47	13.45	1.33
C_7AP	81	11.01	17.20	13.74	13.66	1.33
C_1TR	77	24.02	36.21	28.74	28.85	2.27
C_2TR	84	19.94	27.50	23.23	23.46	1.68
C_3TR	80	19.61	27.02	23.17	23.20	1.48
C_4TR	83	20.56	27.99	24.25	24.41	1.60
C_5TR	80	20.28	28.71	25.04	24.94	1.69
C_6TR	84	21.24	28.87	25.18	25.17	1.57
C_7TR	81	21.03	28.30	24.55	24.73	1.69
C_2HT	84	33.93	43.76	37.73	37.62	2.22
C_3HT	80	10.64	15.94	13.56	13.59	1.06
C_4HT	81	9.86	15.54	13.17	13.37	1.13
C_5HT	79	10.32	15.07	12.76	12.85	1.17
C_6HT	83	10.47	15.52	13.05	13.09	1.16
C_7HT	81	11.96	17.32	14.80	14.92	1.16

Minimum measurement length (Minimum)
Maximum measurement length (Maximum)
Standard deviation (SD)

Table 4.7 Descriptive statistics for vertebral foramen anterior-posterior diameter (CAP), vertebral foramen transverse diameter (CTR), and maximum vertebral body height (CHT) for female individuals (N=73) in the Lopes Collection.

Measurement	N	Minimum (mm)	Maximum (mm)	Mean (mm)	Median (mm)	SD (mm)
C_1AP	70	24.73	33.61	28.92	28.77	1.93
C_2AP	66	12.88	18.40	15.52	15.51	1.21
C_3AP	70	10.67	16.22	13.44	13.40	1.10
C_4AP	73	10.45	16.68	13.06	13.02	1.26
C_5AP	72	10.26	16.51	13.02	13.00	1.31
C_6AP	70	9.67	16.09	12.99	12.99	1.23
C_7AP	64	10.06	15.73	13.12	13.23	1.28
C_1TR	70	24.04	32.67	27.75	27.84	1.89
C_2TR	69	18.75	25.18	22.70	22.63	1.46
C_3TR	71	18.81	25.09	22.37	22.65	1.28
C_4TR	73	20.18	27.33	23.31	23.46	1.36
C_5TR	72	20.56	27.65	24.05	24.22	1.31
C_6TR	70	20.48	27.69	24.14	24.33	1.39
C_7TR	64	10.06	15.73	23.12	13.23	1.28
C_2HT	68	31.59	39.04	35.63	35.84	1.78
C_3HT	69	10.32	14.19	12.33	12.36	1.02
C_4HT	71	10.18	14.40	11.98	11.98	1.00
C_5HT	70	9.49	13.51	11.66	11.70	0.94
C_6HT	68	9.84	14.98	12.06	12.20	1.03
C_7HT	63	11.35	16.23	13.79	13.68	1.02

Minimum measurement length (Minimum)
Maximum measurement length (Maximum)
Standard deviation (SD)

4.3 Normality

Normality was assessed for males and females in both populations at every cervical vertebral level for each measurement using Minitab version 17.0. Males and females from the Athens and Lopes Collections were independently assessed resulting in a total of 80 variables. Table 4.8 shows the results of the calculated normality probability. Due to the large number of variables being assessed, a statistical significance level of 5% (p-value ≤ 0.05) is adjusted using a Bonferroni correction of $\alpha = 0.0006$ ($\alpha = 0.05/80$) to account for the possibility of a type-1 error. If the p-value is equal to or greater than the Bonferroni significance level of $\alpha = 0.0006$ ($\alpha \geq 0.0006$) then the data are normally distributed. The results show that the data for males and females in both the Athens and Lopes Collections are normally distributed for all 80 variables. Therefore, with normally distributed data, further statistical analyses were conducted using parametric tests, i.e. tests for normally distributed data. Normality probability plots for males and females in the Athens and Lopes Collections were also created for each measurement to visually observe the distribution of data and to identify measurement outliers. Figure 4.1 is an example of a probability plot for the C_5AP diameter. If the data exhibit a linear distribution in the probability plot then the data are normally distributed. All the normality probability plots indicate normally distributed data with no significant outliers in any of the variables.

Table 4.8 Normality probability p-values assessed in males and females in the Athens and Lopes Collections evaluating the parametric distribution of the sampled data.

Measurement	Athens Collection		Lopes Collection	
	Males p-value	**Females p-value**	**Males p-value**	**Females p-value**
C_1AP	0.030	0.720	0.875	0.695
C_2AP	0.321	0.777	0.838	0.772
C_3AP	0.207	0.914	0.717	0.576
C_4AP	0.893	0.937	0.837	0.538
C_5AP	0.850	0.721	0.712	0.517
C_6AP	0.335	0.964	0.884	0.813
C_7AP	0.852	0.250	0.456	0.220
C_1TR	0.145	0.525	0.693	0.526
C_2TR	0.248	0.946	0.230	0.354
C_3TR	0.276	0.677	0.974	0.039
C_4TR	0.492	0.916	0.303	0.216
C_5TR	0.574	0.922	0.879	0.204
C_6TR	0.101	0.623	0.723	0.358
C_7TR	0.507	0.540	0.412	0.673
C_2HT	0.083	0.542	0.059	0.556
C_3HT	0.314	0.521	0.402	0.538
C_4HT	0.780	0.218	0.184	0.609
C_5HT	0.562	0.673	0.086	0.644
C_6HT	0.561	0.282	0.572	0.315
C_7HT	0.318	0.231	0.980	0.118

*Significant difference at p-value $\leq$ 0.0006

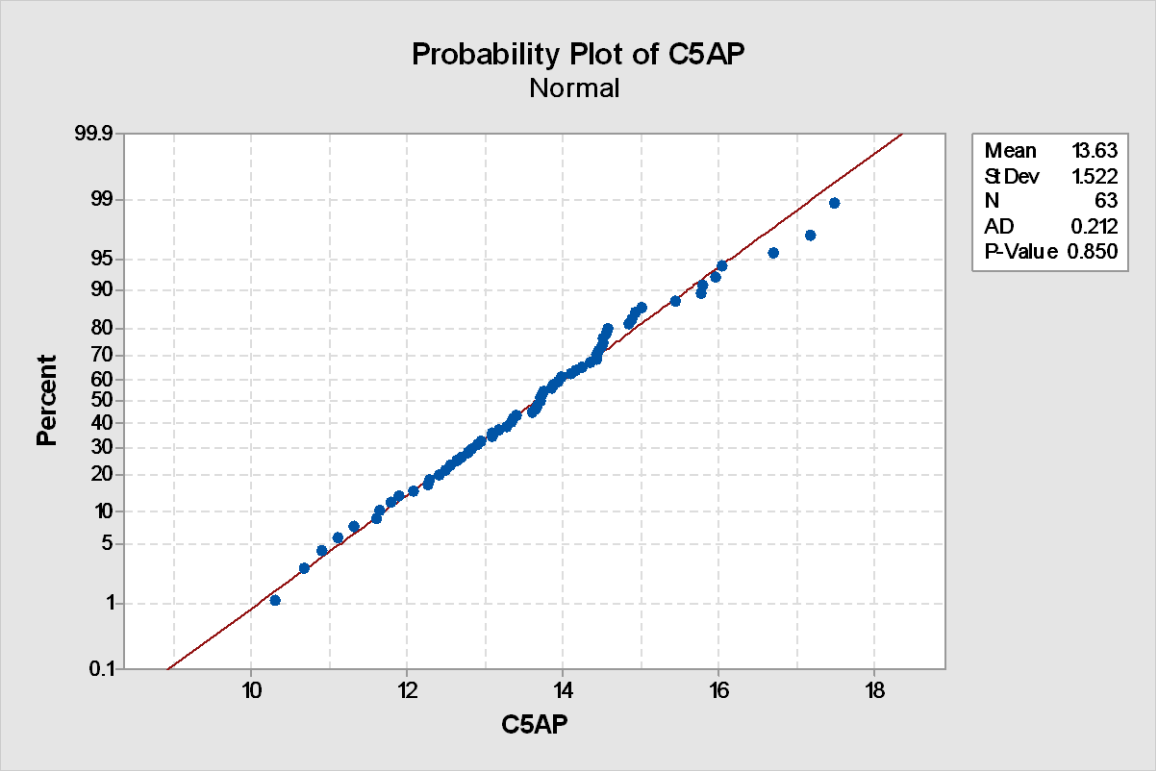

Figure 4.1 An example of a probability plot to visually assess the distribution of data for normality.

4.4 Inter- and Intra-observer Error

Morphometric replicability is essential to avoid bias and inaccuracies in methods for the estimation of sex. A method is considered unreliable if the measured characteristics are not repeatable. Intra- and inter-observer errors were evaluated using paired t-tests to measure the precision and reliability of attaining accurate cervical vertebral measurements. Intra-observer error, the difference between one observer re-evaluating the same phenomenon, was assessed by re-measuring a randomly selected sub-sample of 30 individuals from the Athens Collection and 30 individuals from the Lopes Collection (N=60). The data were normally distributed and therefore a paired t-test

was used to measure the paired statistical differences between the original data and the re-measured data (Table 4.9). Twenty-one variables were assessed for each individual from the Athens and Lopes Collections. Due to the large number of variables assessed, a statistical significance level of 5% (p-value ≤ 0.05) was adjusted using a Bonferroni correction of $\alpha = 0.002$ ($\alpha = 0.05/21$) to account for the possibility of a type-1 error in the calculations. In the Athens Collection, the resulting p-values showed no significant intra-observer differences between CAP and CHT measurements. Two CTR measurements (C_4TR and C_6TR) were less than or equal to the Bonferroni statistical significance level (p-value ≤ 0.002). This indicates that the values of these measurements are statistically different from the original data set and the reliability of obtaining those measurements is not consistent. However, the C_4TR diameter exhibited a difference of 0.0517 mm or a 0.21% error between the means of the two measurements (24.937 and 24.885) with a difference of 0.0645 mm between the standard deviations (1.548 and 1.546). The C_6TR diameter exhibited a difference of 0.0641 mm or a 0.25% error between the means of the two measurements (25.544 and 25.480) with a difference of 0.0920 mm between the standard deviations (1.666 and 1.677). Both characteristics exhibited differences that were less than 0.1 mm between the means and standard deviations of the two measurements. Also, intra-observer error rates are less than 10%, which is the precision standard for measurable characteristics to meet the Mohan and Daubert evidence admissibility criteria (Gama et al 2015; Marlow and Pastor 2011; Molto 1979; Nichol and Turner 1986; Novotny and Işcan 1993; Rogers 1999; Rogers and Saunders 1994; Williams and Rogers 2006). In the Lopes Collection, four measurements (C_3TR, C_5TR, C_6TR, and C_4HT) were statistically significant falling below the Bonferroni adjustment

(p-value ≤ 0.002). The C_3TR diameter exhibited a difference of 0.0833 mm or a 0.37% error between the means of the two measurements (22.616 mm and 22.532 mm) with a difference of 0.1001 mm between the standard deviations (1.316 mm and 1.352 mm). The C_5TR diameter exhibited a difference of 0.0473 mm or a 0.19% error between the means of the two measurements (24.451 mm and 24.404 mm) with a difference of 0.0680 mm between the standard deviations (1.568 mm and 1.585 mm). The C_6TR diameter exhibited a difference of 0.0323 mm or a 0.13% error between the means of the two measurements (24.481 mm and 24.449 mm) with a difference of 0.0463 mm between the standard deviations (1.486 mm and 1.494 mm). The C_4HT trait exhibited a difference of 0.210 mm or a 1.70% error between the means of the two measurements (12.349 mm and 12.559 mm) with a difference of 0.2886 mm between the standard deviations (1.305 mm and 1.308 mm). These four characteristics exhibited differences that were less than 0.3 mm between the means and standard deviations of the two measurements. Also, intra-observer error rates are less than 10%, which is the precision standard for measurable characteristics to meet the Mohan and Daubert evidence admissibility criteria (Gama et al 2015; Marlow and Pastor 2011: 168; Molto 1979; Nichol and Turner 1986; Novotny and Işcan 1993; Rogers 1999; Rogers and Saunders 1994; Williams and Rogers 2006). Therefore, the CTR diameter appears to be the least consistent measurement as compared to CAP and CHT, however, the differences in the CTR means are less than 0.1 mm and below 10% error. The other nine CTR measurements obtained from other vertebrae do not exhibit statistical differences. Extra care must be taken when measuring CTR.

Table 4.9 Intra-observer error bias for the three morphometric traits in the Athens and Lopes Collections.

	Athens Collection		Lopes Collection	
Measurement	**t-value**	**p-value**	**t-value**	**p-value**
C_1AP	1.24	0.225	0.53	0.598
C_2AP	1.46	0.156	0.27	0.789
C_3AP	-0.16	0.876	0.91	0.368
C_4AP	1.75	0.091	0.64	0.528
C_5AP	0.27	0.790	1.64	0.111
C_6AP	0.96	0.344	0.84	0.407
C_7AP	-0.27	0.789	2.99	0.006
C_1TR	0.93	0.359	1.01	0.321
C_2TR	-0.51	0.611	0.35	0.731
C_3TR	1.52	0.139	4.56	0.000*
C_4TR	4.32	0.000*	2.20	0.036
C_5TR	1.46	0.156	3.81	0.001*
C_6TR	3.75	0.001*	3.83	0.001*
C_7TR	1.73	0.094	2.39	0.024
C_2HT	-1.30	0.205	0.77	0.448
C_3HT	0.61	0.549	2.30	0.029
C_4HT	0.79	0.435	3.98	0.000*
C_5HT	0.71	0.482	1.58	0.126
C_6HT	1.37	0.183	-2.16	0.039
C_7HT	0.53	0.602	-1.47	0.151

*Significant difference at p-value $\leq$ 0.002

Inter-observer error, the variation between different individuals evaluating the same observed phenomenon, was assessed by the aid of one research assistant from each skeletal collection. These assistants re-measured and recorded the three morphometric characteristics of the cervical vertebrae. A randomly selected sub-sample was used including 35 individuals from the Athens Collection and 29 individuals from the Lopes Collection (N=64). Paired t-tests examine the paired statistical differences between the

original data collected by the author to the data re-measured by the assistants (Table 4.10).

Table 4.10 Inter-observer error bias for the three morphometric traits in the Athens and Lopes Collections.

	Athens Collection		Lopes Collection	
Measurement	**t-value**	**p-value**	**t-value**	**p-value**
C_1AP	-0.09	0.932	1.01	0.320
C_2AP	0.89	0.379	1.37	0.180
C_3AP	4.62	0.000*	1.14	0.263
C_4AP	1.94	0.061	2.14	0.042
C_5AP	0.19	0.853	0.55	0.586
C_6AP	1.26	0.219	1.23	0.227
C_7AP	0.06	0.950	1.51	0.142
C_1TR	-5.53	0.000*	16.33	0.000*
C_2TR	-2.54	0.016	0.89	0.382
C_3TR	-3.38	0.002*	0.35	0.729
C_4TR	-2.83	0.008	1.29	0.209
C_5TR	-4.79	0.000*	1.74	0.092
C_6TR	-4.44	0.000*	2.02	0.053
C_7TR	2.17	0.037	0.52	0.608
C_2HT	-0.77	0.445	-1.90	0.068
C_3HT	-0.99	0.329	3.73	0.001*
C_4HT	-0.62	0.541	2.62	0.015
C_5HT	-0.01	0.989	1.25	0.224
C_6HT	0.61	0.545	0.73	0.473
C_7HT	-0.12	0.905	1.41	0.170

*Significant difference at p-value $\leq$ 0.002

In the Athens group, the resulting p-values show no significant differences in the CHT measurement. One CAP measurement (C_3AP) and four CTR measurements (C_1TR, C_3TR, C_5TR and C_6TR) were less than or equal to the Bonferroni statistical significance

level of $\alpha = 0.002$ (p-value ≤ 0.002). This indicates that the values of those measurements are statistically different from the original data set collected by the author. The C_3AP diameter exhibited a difference of 0.0994 mm or a 0.70% error between the means of the two measurements (14.235 mm and 14.136 mm) with a difference of 0.1236 mm between the standard deviations (1.264 mm and 1.266 mm). The C_1TR diameter exhibited a difference of 0.1037 mm or a 0.37% error between the means of the two measurements (28.275 mm and 28.379 mm) with a difference of 0.0975 mm between the standard deviations (1.604 mm and 1.629 mm). The C_3TR diameter exhibited a difference of 0.0748 mm or a 0.32% error between the means of the two measurements (23.416 mm and 23.491 mm) with a difference of 0.1270 mm between the standard deviations (1.481 mm and 1.534 mm). The C_5TR diameter exhibited a difference of 0.1144 mm or a 0.45% error between the means of the two measurements (25.196 mm and 25.310 mm) with a difference of 0.1393 mm between the standard deviations (1.551 mm and 1.592 mm). The C_6TR diameter exhibited a difference of 0.1113 mm or a 0.43% error between the means of the two measurements (25.523 mm and 25.634 mm) with a difference of 0.1417 mm between the standard deviations (1.827 mm and 1.768 mm). These five characteristics exhibited differences that were less than 0.2 mm between the means and standard deviations of the two measurements. Also, inter-observer error rates were less than 10%, which is the precision standard for measurable characteristics to meet the Mohan and Daubert evidence admissibility criteria (Gama et al 2015; Marlow and Pastor 2011; Molto 1979; Nichol and Turner 1986; Novotny and Işcan 1993; Rogers 1999; Rogers and Saunders 1994; Williams and Rogers 2006). In the Lopes group, two measurements (C_1TR and C_3HT) are statistically significant as they were less than or

equal to the Bonferroni adjusted significance level of $\alpha = 0.002$ (p-value ≤ 0.002). The C_1TR diameter exhibited a difference of 5.738 mm or a 25.18% error between the means of the two measurements (28.527 mm and 22.789 mm) with a difference of 1.892 mm between the standard deviations (2.146 mm and 1.364 mm). The C_3HT characteristic exhibited a difference of 0.520 mm or a 4.17% error between the means of the two measurements (12.993 mm and 12.473 mm) with a difference of 0.710 mm between the standard deviations (1.481 mm and 1.394 mm). These two characteristics exhibited differences that were greater than 0.5 mm between the means and standard deviations of the two measurements. However, C_3HT exhibited less than 10% inter-observer error, which is the precision standard for measurable characteristics to meet the Mohan and Daubert evidence admissibility criteria (Gama et al 2015; Marlow and Pastor 2011; Molto 1979; Nichol and Turner 1986; Novotny and Işcan 1993; Rogers 1999; Rogers and Saunders 1994; Williams and Rogers 2006).

Cervical Transverse Diameters (CTR) in the Athens Collection exhibit a large quantity of inter-observer error indicating variation in measurement reliability. However, in the Lopes Collection the CTR measurements exhibit very low inter-observer error and are more consistent with the author's data set. The discrepancy in observer errors between the two Collections may have resulted from a misinterpretation of the definition of the CTR diameter by the Athens research assistant. The same may have occurred for the Lopes research assistant misinterpreting the C_1TR diameter. Therefore, extra care must be taken when measuring and explaining the variable CTR. With the exception of C_1TR measured in the Lopes Collection, all error rates are less than 10%, which is the precision standard of measurable characteristics to meet the Mohan and Daubert evidence

admissibility criteria (Gama et al 2015; Marlow and Pastor 2011; Molto 1979; Nichol and Turner 1986; Novotny and Işcan 1993; Rogers 1999; Rogers and Saunders 1994; Williams and Rogers 2006).

4.5 Sexual Dimorphism and Ancestral Variation in the Cervical Vertebrae

4.5.1 *Vertebral Sexual Dimorphism*

The first goal of this research was to understand the relationship between sex and the cervical vertebral morphometric characteristics (CAP, CTR and CHT) in two White European skeletal populations. The CAP, CTR, and CHT measurements were tested to assess whether statistically significant sexually dimorphic differences existed between males and females within each collection. The data were normally distributed allowing for the use of two-sample t-tests. A Bonferroni correction of $\alpha = 0.002$ ($\alpha = 0.05/21$) was used to account for the possibility of type-1 error. If the p-value for any measurement was less than or equal to $\alpha = 0.002$ ($\alpha \leq 0.002$) then males and females showed sexual dimorphism (Table 4.11). The results indicate that within the Athens and Lopes Collections most CTR and all the CHT measurements were sexually dimorphic (p-value ≤ 0.002). Therefore, these measurements are the most sexually dimorphic and have good predictive value for estimating males and females. Only one CAP diameter (C_1AP) in the Athens and Lopes Collections exhibits statistical differences related to sexual dimorphism. Therefore, the CAP measurement has no predictive value in estimating males and females in all cervical vertebrae. The distribution of all data points for each measurement (CAP, CTR and CHT) between males and females from the Athens and Lopes Collections is shown in Figures 4.2 to 4.7.

Table 4.11 Two-sample t-test evaluating the similarities between Athens males (N=70) and females (N=65) and between Lopes males (N=87) and females (N=73) at every cervical vertebral level.

Measurement	Athens Collection (N=135)				Lopes Collection (N=160)			
	Male N	Female N	t-value	p-value	Male N	Female N	t-value	p-value
C_1AP	59	57	5.91	0.000*	77	70	5.22	0.000*
C_2AP	64	62	1.02	0.310	82	66	2.33	0.021
C_3AP	59	56	1.15	0.251	81	70	1.86	0.065
C_4AP	69	61	0.39	0.701	83	73	1.03	0.306
C_5AP	63	61	1.46	0.147	80	72	2.45	0.015
C_6AP	62	59	1.75	0.083	84	70	2.36	0.020
C_7AP	65	61	2.00	0.048	81	64	2.85	0.005
C_1TR	59	58	4.01	0.000*	77	70	2.87	0.005
C_2TR	64	62	4.82	0.000*	84	69	2.07	0.040
C_3TR	59	56	3.48	0.001*	80	71	3.55	0.001*
C_4TR	69	61	3.17	0.002*	83	73	3.95	0.000*
C_5TR	63	61	3.73	0.000*	80	72	4.06	0.000*
C_6TR	62	59	3.80	0.000*	84	70	4.34	0.000*
C_7TR	65	61	3.80	0.000*	81	64	4.72	0.000*
C_2HT	65	62	9.00	0.000*	84	68	6.47	0.000*
C_3HT	59	56	5.83	0.000*	80	69	7.29	0.000*
C_4HT	69	59	9.11	0.000*	81	71	6.87	0.000*
C_5HT	62	60	6.97	0.000*	79	70	6.36	0.000*
C_6HT	63	57	6.94	0.000*	83	68	5.56	0.000*
C_7HT	65	61	6.41	0.000*	81	63	5.56	0.000*

*Significant difference at p-value ≤ 0.002

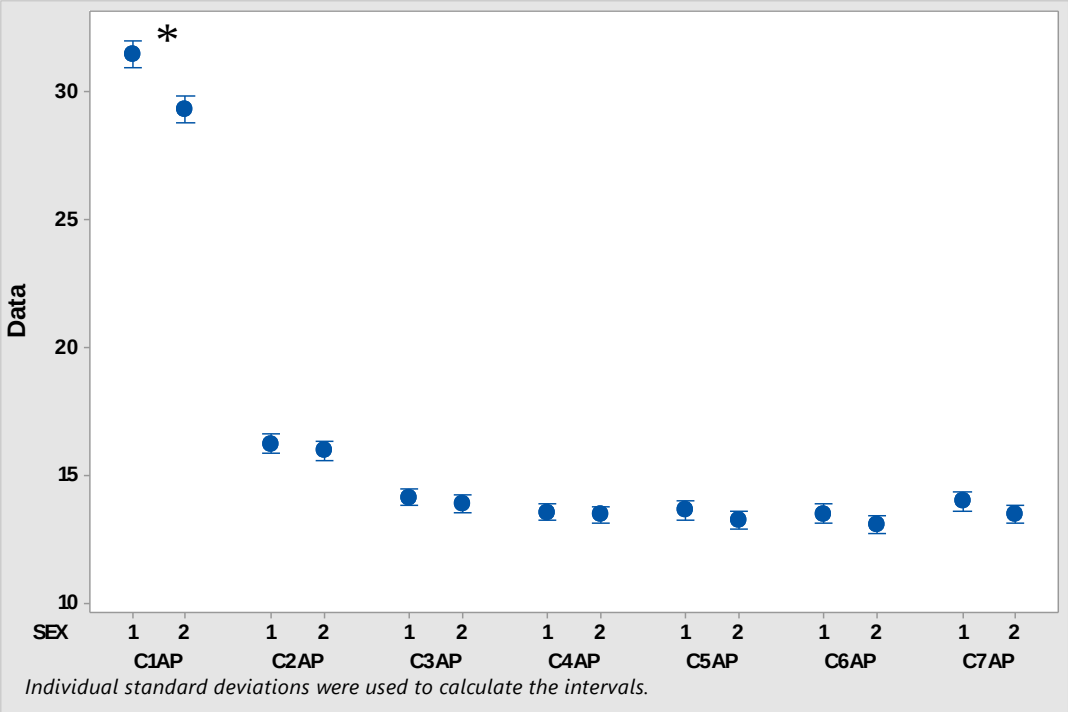

Figure 4.2 Interval plot showing means and the 95% confidence interval for CAP measurements between males (1) and females (2) in the Athens Collection. An asterisk (*) indicates the variables that are statistically significant.

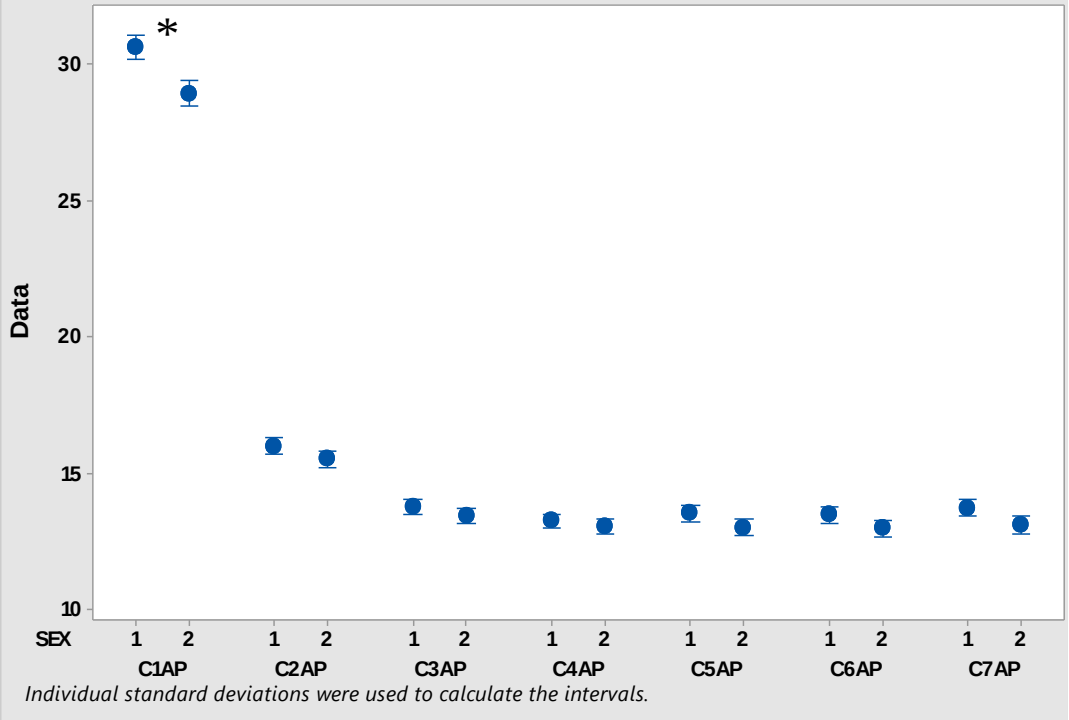

Figure 4.3 Interval plot showing the means and the 95% confidence interval for CAP measurements between males (1) and females (2) in the Lopes Collection. An asterisk (*) indicates the variables that are statistically significant.

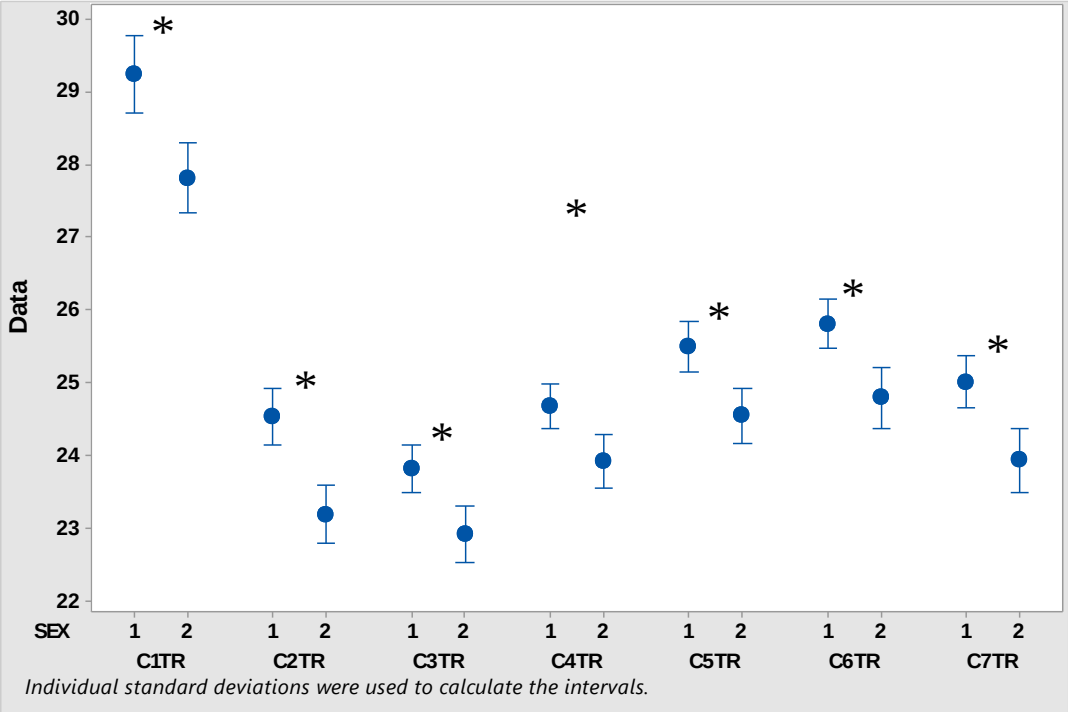

Figure 4.4 Interval plot showing means and the 95% confidence interval for CTR measurements between males (1) and females (2) in the Athens Collection. An asterisk (*) indicates the variables that are statistically significant.

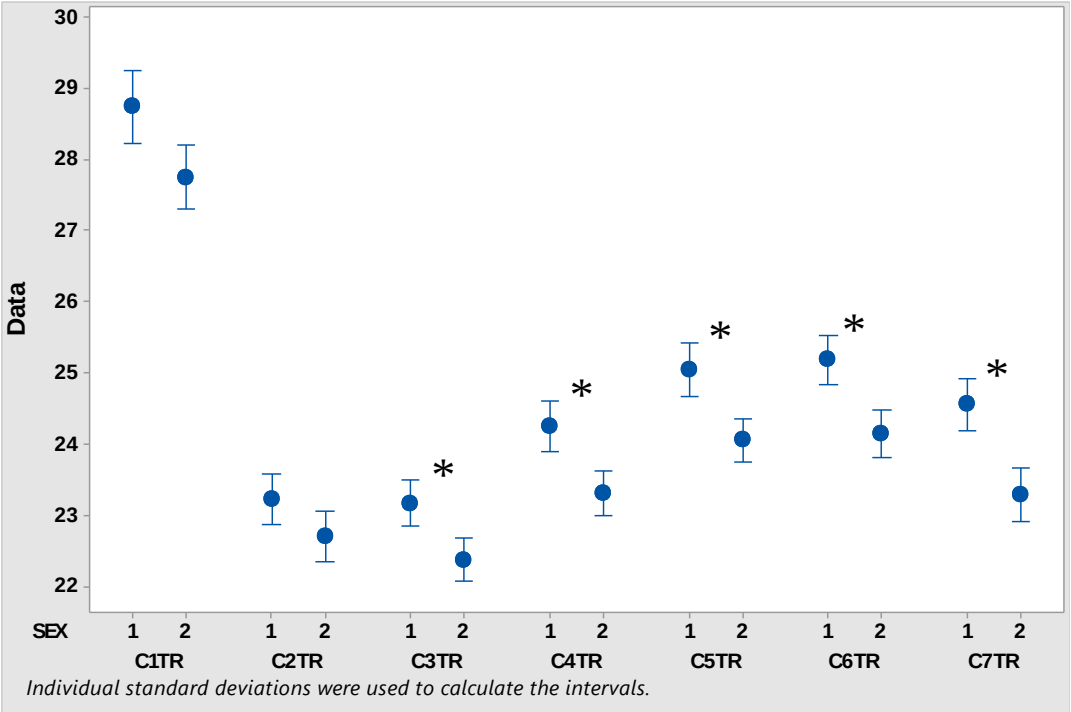

Figure 4.5 Interval plot showing the means and the 95% confidence interval for CTR measurements between males (1) and females (2) in the Lopes Collection. An asterisk (*) indicates the variables that are statistically significant.

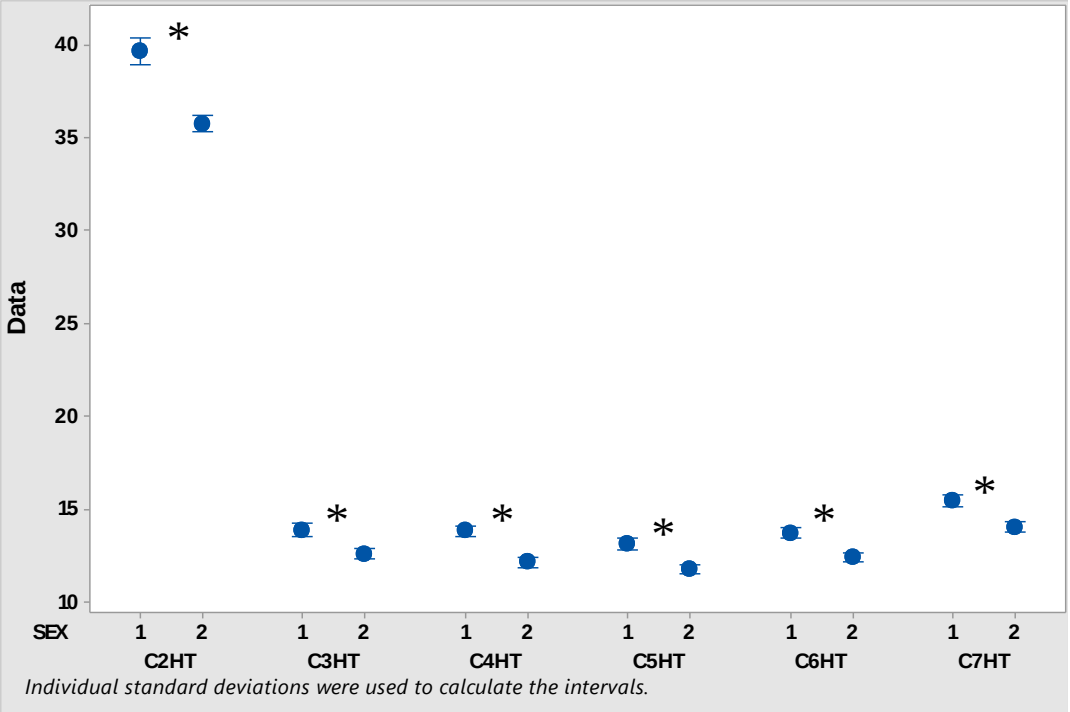

Figure 4.6 Interval plot showing means and the 95% confidence interval for CHT measurements between males (1) and females (2) in the Athens Collection. An asterisk (*) indicates the variables that are statistically significant.

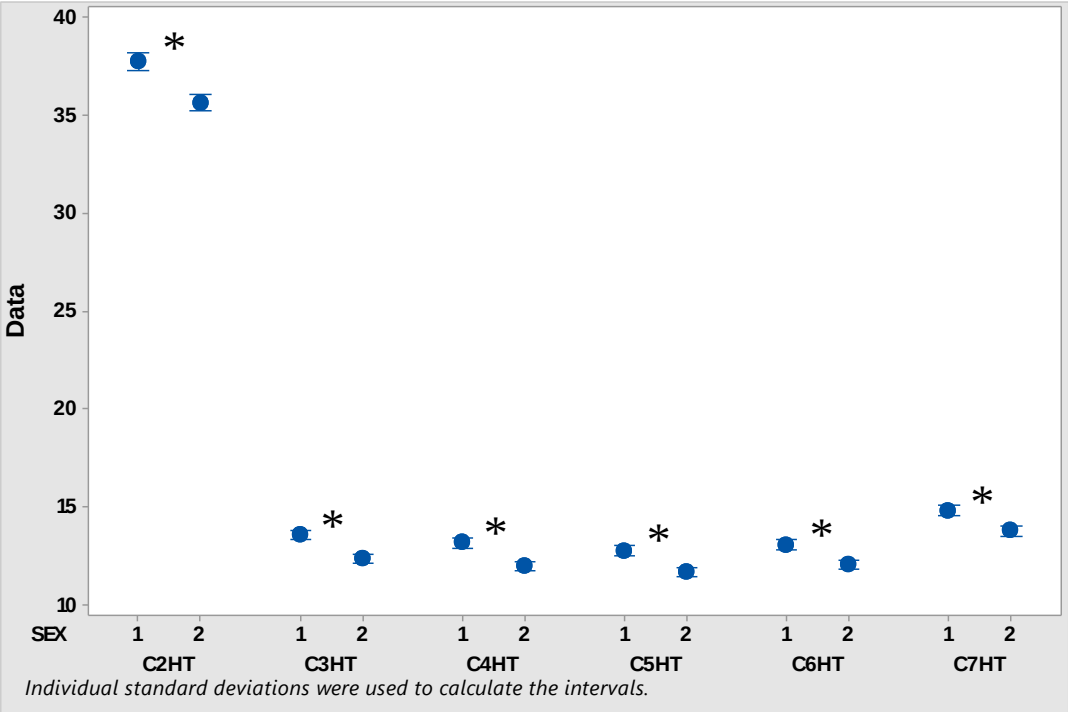

Figure 4.7 Interval plot showing the means and the 95% confidence interval for CHT measurements between males (1) and females (2) in the Lopes Collection. An asterisk (*) indicates the variables that are statistically significant.

4.5.2 *Vertebral Variation due to Ancestry*

The CAP, CTR, and CHT measurements were tested using two-sample t-tests to assess whether the mean vertebral measurements for males and females between the Athens and Lopes independent sample groups exhibited statistical differences due to ancestry. If the two collections do not exhibit ancestral differences then males and females may be grouped into one large combined sample group, i.e. White Europeans, for all further statistical analyses. A Bonferroni correction of $\alpha = 0.002$ ($\alpha = 0.05/21$) was used to account for the possibility of type-1 error. If the calculated p-values are less than or equal to the Bonferroni significance level of $\alpha = 0.002$ ($\alpha \leq 0.002$) then the Athens and Lopes Collections exhibit differences due to ancestry. Table 4.12 shows the results of the two-sample t-test performed on the CAP, CTR and CHT measurements at each vertebral level between males and females. The results show that males exhibit statistically significant differences (p-value ≤ 0.002) in only four of the 21 characteristics (C_2TR, C_2HT, C_4HT, and C_6HT) between the two populations. The C_2TR diameter exhibited a difference of 1.31 mm between the two means from the Athens and Lopez Collections (24.53 mm and 23.22 mm) with a difference of 0.66 mm between the standard deviations (1.56 mm and 1.67 mm). The C_2HT characteristic exhibited a difference of 1.92 mm between the two means from the Athens and Lopez Collections (39.65 mm and 37.73 mm) with a difference of 0.80 mm between the standard deviations (3.01 mm and 2.22 mm). The C_4HT diameter exhibited a difference of 0.63 mm between the two means from the Athens and Lopez Collections (13.80 mm and 13.17 mm) with a difference of 0.03 mm between the standard deviations (1.16 mm and 1.13 mm). The C_6HT characteristic exhibited a difference of 0.64 mm between the two means from the Athens and Lopez

Collections (13.69 mm and 13.05 mm) with a difference of 0.05 mm between the standard deviations (1.11 mm and 1.16 mm). These four male characteristics exhibited differences that were less than 2 mm between the Athens and Lopes Collections means and standard deviations. Females exhibit no statistically significant differences between the two populations. Therefore, males and females from both Collections do not exhibit significant ancestral differences in the cervical vertebral mean measurements and may be grouped into one large combined sample group of White Europeans.

Table 4.12 Two-sample t-test evaluating ancestry differences between males and females at every cervical vertebral level within the Athens Collection (N=135) and the Luis Lopes Collection (N=160).

Measurement	Males (N=157)				Females (N=138)			
	Athens N	Lopes N	t-value	p-value	Athens N	Lopes N	t-value	p-value
C_1AP	59	77	2.47	0.015	57	70	1.03	0.305
C_2AP	64	82	0.94	0.349	62	66	1.82	0.071
C_3AP	59	81	1.59	0.115	56	70	2.00	0.048
C_4AP	69	83	1.30	0.194	61	73	1.76	0.080
C_5AP	63	80	0.41	0.682	61	72	0.95	0.342
C_6AP	62	84	0.07	0.944	59	70	0.34	0.734
C_7AP	65	81	0.97	0.336	61	64	1.47	0.144
C_1TR	59	77	1.35	0.180	58	70	0.19	0.852
C_2TR	64	84	4.90	0.000*	62	69	1.84	0.068
C_3TR	59	80	2.78	0.006	56	71	2.25	0.026
C_4TR	69	83	1.85	0.067	61	73	2.53	0.013
C_5TR	63	80	1.76	0.080	61	72	2.04	0.043
C_6TR	62	84	2.67	0.008	59	70	2.39	0.018
C_7TR	65	81	1.77	0.079	61	64	2.22	0.029
C_2HT	65	84	4.32	0.000*	62	68	0.32	0.746
C_3HT	59	80	1.33	0.188	56	69	1.38	0.171
C_4HT	69	81	3.39	0.001*	59	71	0.79	0.431
C_5HT	62	79	1.65	0.100	60	70	0.56	0.578
C_6HT	63	83	3.36	0.001*	57	68	1.94	0.055
C_7HT	65	81	2.92	0.004	61	63	1.16	0.247

*Significant difference at p-value $\leq$ 0.002

4.6 Correlations between Vertebral Morphometrics and Stature

4.6.1 *The Effects of Stature on Vertebral Morphometrics*

The second goal of this research was to understand the relationship between stature and the cervical vertebral morphometric characteristics (CAP, CTR and CHT) in two White European skeletal populations. Pearson's correlation coefficients (r-value)

were calculated on a sub-sample of 55 males and 46 females (N=101) to examine whether correlations existed between stature and all three vertebral measurements at all vertebral levels. The individuals from the Athens and Lopes Collections were grouped into one combined sample group of White Europeans because there was minimal ancestral variation between the two Collections. A set of 42 variables were assessed for correlation (i.e. six correlation tests for seven bones) using a Bonferroni correction of $\alpha = 0.001$ ($\alpha = 0.05/42$) to account for possible type-1 error. If the p-value is less than or equal to the Bonferroni significance level of $\alpha = 0.001$ ($\alpha \leq 0.001$) then the vertebral measurements (CAP, CTR and CHT) are related to stature rather than being influenced by other variables such as age, sex, or ancestry. The results of the sex specific Pearson's correlation coefficients are presented in Table 4.13. The results show that there is no statistical significance between stature and the cervical measurements; there is no relationship between stature and the cervical vertebral measurements.

Correlations between stature and all three vertebral measurements were examined using exploratory correlation scatter plots. Figure 4.8 shows an example of an exploratory correlation scatter plot. No linear relationship exists between the CAP, CTR, and CHT measurements and therefore there is no relationship between stature and the vertebral measurements.

Table 4.13 Correlations between stature and all three measurements (CAP, CTR and CHT) in males (N=55) and females (N=46) from a combined sample (Athens and Lopes Collections).

Measurement	Males (N=55)			Females (N=46)		
	N	r-value	p-value	N	r-value	p-value
C_1AP	45	-0.118	0.441	43	0.151	0.333
C_2AP	53	-0.077	0.586	43	0.225	0.148
C_3AP	52	-0.094	0.508	42	0.154	0.331
C_4AP	54	0.134	0.334	45	0.180	0.238
C_5AP	49	0.250	0.083	44	0.272	0.074
C_6AP	54	0.054	0.698	43	0.270	0.080
C_7AP	54	0.179	0.195	43	0.221	0.154
C_1TR	45	-0.076	0.618	43	0.193	0.214
C_2TR	53	-0.035	0.805	44	0.184	0.366
C_3TR	52	0.096	0.498	43	0.182	0.243
C_4TR	54	0.098	0.480	45	0.068	0.656
C_5TR	49	0.085	0.562	44	0.186	0.227
C_6TR	54	0.075	0.590	43	0.064	0.681
C_7TR	54	0.125	0.367	43	0.079	0.614
C_2HT	53	0.111	0.430	44	0.324	0.032
C_3HT	51	0.224	0.114	43	0.153	0.327
C_4HT	53	0.131	0.350	44	0.199	0.196
C_5HT	49	0.144	0.323	44	0.183	0.234
C_6HT	54	0.190	0.168	43	0.242	0.118
C_7HT	54	0.328	0.015	43	0.124	0.427

*Significant difference at p-value $\leq$ 0.001

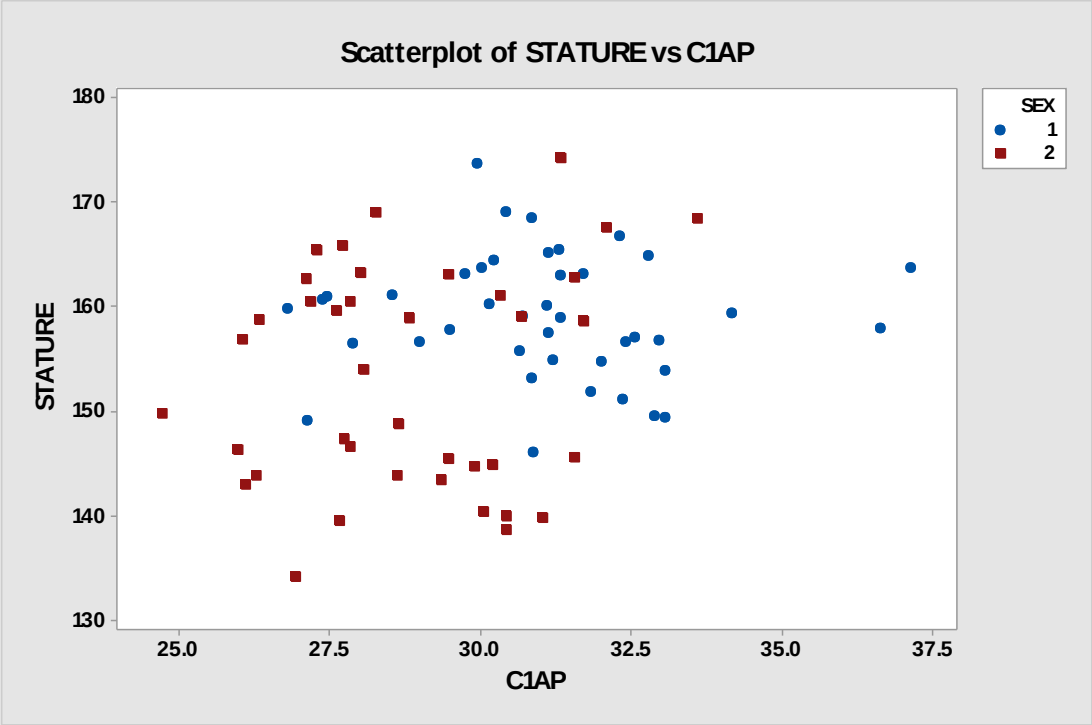

Figure 4.8 An example of an exploratory correlation scatter plot to visually asses the correlation between stature and C_1AP for males (sex = 1) and females (sex = 2).

4.6.2 *Relationships between CAP, CTR, and CHT measurements*

Pearson's correlation coefficients (r-value) were calculated between CAP, CTR and CHT measurements to examine the morphometric relationship between them. An independent sample of 101 individuals from the combined Athens and Lopes populations was assessed: 55 males and 46 females. A Bonferroni correction of $\alpha = 0.001$ ($\alpha = 0.05/42$) was used to account for type-1 errors in the calculations. If the correlation coefficient p-value is less than or equal to the Bonferroni significance level ($\alpha \leq 0.001$) then the two vertebral measurements are related in size. The results between CAP and CTR are presented in Table 4.14. The results show no statistical significance (p-value $\leq$ 0.001) between CAP and CTR in males and females exhibit only one correlation at the

first cervical vertebra (C_1). Therefore, the correlation relationship between CAP and CTR diameters is minimal.

Table 4.14 CAP versus CTR correlation between males and females in the combined sample (Athens and Lopes Collections).

Cervical Vertebrae	Males (N=55)			Females (N=46)		
	N	r-value	p-value	N	r-value	p-value
C_1	45	0.404	0.006	43	0.570	0.000*
C_2	53	0.227	0.101	43	0.184	0.237
C_3	52	0.292	0.036	42	0.202	0.199
C_4	54	0.266	0.051	45	0.171	0.261
C_5	49	0.273	0.057	44	0.255	0.095
C_6	54	0.172	0.213	43	0.231	0.136
C_7	54	0.331	0.015	43	0.194	0.213

*Significant difference at p-value ≤ 0.001

The results for CAP and CHT are presented in Table 4.15. A Bonferroni correction of $\alpha = 0.001$ ($\alpha = 0.05/42$) was used to account for type-1 errors in the calculations. If the p-value is less than or equal to the Bonferroni significance level ($\alpha \leq 0.001$) then the two vertebral measurements are related in size. The results indicate that there are no statistically significant correlations between CAP and CHT therefore, no significant relationship exists between the two measurements.

Table 4.15 CAP versus CHT correlation between males and females in the combined sample (Athens and Lopes Collections).

Cervical Vertebrae	Males (N=55)			Females (N=46)		
	N	r-value	p-value	N	r-value	p-value
C_2	53	-0.006	0.965	44	0.090	0.564
C_3	51	0.044	0.757	43	-0.066	0.678
C_4	53	0.351	0.010	44	-0.202	0.189
C_5	49	0.030	0.840	44	0.142	0.358
C_6	54	0.341	0.012	43	0.155	0.320
C_7	54	0.290	0.034	43	0.280	0.069

*Significant difference at p-value ≤ 0.001

The results for CTR and CHT are presented in Table 4.16. A Bonferroni correction of $\alpha = 0.001$ ($\alpha = 0.05/42$) was used to account for type-1 errors in the calculations. If the p-value is less than or equal to the Bonferroni significance level ($\alpha \leq 0.001$) then the two vertebral measurements are related in size. The results indicate that there are no statistically significant correlations between CTR and CHT therefore, no significant relationship exists between the two measurements.

Table 4.16 CTR versus CHT correlation between males and females in the combined sample (Athens and Lopes Collections).

Cervical Vertebrae	Males (N=55)			Females (N=46)		
	N	r-value	p-value	N	r-value	p-value
C_2	53	0.415	0.002	44	0.315	0.037
C_3	51	0.163	0.252	43	0.166	0.288
C_4	53	0.170	0.225	44	0.121	0.433
C_5	49	0.225	0.120	44	0.034	0.827
C_6	54	0.264	0.054	43	0.155	0.320
C_7	54	0.069	0.620	43	0.075	0.633

*Significant difference at p-value ≤ 0.001

4.7 Discriminant Functions

Canonical discriminant function coefficients and multivariate discriminant functions were created using SPSS version 21.0 statistical software to develop formulae to estimate sex from the cervical vertebrae. The CAP, CTR and CHT measurements were assessed with different combinations of cervical vertebrae to establish which bone and measurement arrangements were most accurate for estimating sex.

4.7.1 *Estimating Sex from a Single Vertebra*

Discriminant functions were created for independent vertebra C_1 through C_7 using all three measurements (CAP, CTR, CHT) to establish whether sex could be estimated from a single bone. Tables 4.17 to 4.23 show the discriminant functions for each vertebra using a combination of the skeletal measurements. Overall, sex estimation from a single vertebra ranges between 69.6% and 76.4% (66.9% to 74% in males; 70.2% to 79.5% in females) using all three measurements (CAP, CTR, and CHT). Sex estimation from the two vertebral foramen measurements (CAP and CTR) ranged between 60.0% and 70.3% (61.2% to 70.6% in males; 58.7% to 70.1% in females). The two most dimorphic characteristics (CTR and CHT) estimated sex with accuracy rates between 70.4% and 75.4% (67.6% to 73.3% in males; 70.4% to 78.5% in females) using a single vertebra. The results indicate that the sex estimating accuracy rates from any single vertebra do not meet 80%, which is the minimum required accuracy to successfully assign sex (Gama et al 2015; Marlow and Pastor 2011: 168; Molto 1979; Nichol and Turner 1986; Novotny and Işcan 1993; Rogers 1999; Rogers and Saunders 1994; Williams and Rogers 2006).

Therefore, a single cervical vertebra does not have strong sex estimating potential based on the methodology used in this research.

Table 4.17 Discriminant function, sectioning point, and overall accuracy rates using the C_1AP and C_1TR measurements from the first cervical vertebra (C_1).

Measurements	C_1AP C_1TR		
Discriminant Function	$y = 0.447(C_1AP) + 0.102(C_1TR) - 16.312$		
Sectioning Point	Females < -0.0165 < Males		
Overall Accuracy	**Male Accuracy**	70.6%	70.3%
	Female Accuracy	70.1%	

Table 4.18 Discriminant functions, sectioning points, and accuracies using the different combinations of measurements from the second cervical vertebra (C_2).

Measurements	C_2AP C_2TR C_2HT		
Discriminant Function	$y = 0.186(C_2AP) - 0.098(C_2TR) + 0.440(C_2HT) - 17.038$		
Sectioning Point	Females < -0.044 < Males		
Overall Accuracy	**Male Accuracy**	67.8%	73.3%
	Female Accuracy	79.5%	
Measurements	C_2AP C_2TR		
Discriminant Function	$y = 0.157(C_2AP) + 0.556(C_2TR) - 15.537$		
Sectioning Point	Females < -0.0165 < Males		
Overall Accuracy	**Male Accuracy**	61.6%	63.1%
	Female Accuracy	64.8%	
Measurements	C_2TR C_2HT		
Discriminant Function	$y = 0.001(C_2TR) + 0.426(C_2HT) - 15.886$		
Sectioning Point	Females < -0.04 < Males		
Accuracy	**Male Accuracy**	67.6%	72.7%
	Female Accuracy	78.5%	

Table 4.19 Discriminant functions, sectioning points, and accuracies using the different combinations of measurements from the third cervical vertebra (C_3).

Measurements	C_3AP C_3TR C_3HT	
Discriminant Function	$y = 0.016(C_3AP) + 0.163(C_3TR) + 0.816(C_3HT) - 14.667$	
Sectioning Point	Females < -0.0315 < Males	
Overall Accuracy	**Male Accuracy** 72.5%	71.4%
	Female Accuracy 70.2%	
Measurements	C_3AP C_3TR	
Discriminant Function	$y = 0.161(C_3AP) + 0.660(C_3TR) - 17.435$	
Sectioning Point	Females < -0.0145 < Males	
Overall Accuracy	**Male Accuracy** 61.2%	60.0%
	Female Accuracy 58.7%	
Measurements	C_3TR C_3HT	
Discriminant Function	$y = 0.811(C_3TR) + 0.175(C_3HT) - 14.658$	
Sectioning Point	Females < -0.029 < Males	
Overall Accuracy	**Male Accuracy** 72.5%	71.5%
	Female Accuracy 70.4%	

Table 4.20 Discriminant functions, sectioning points, and accuracies using the different combinations of measurements from the fourth cervical vertebra (C_4).

Measurements	C_4AP C_4TR C_4HT	
Discriminant Function	$y = -0.023(C_4AP) + 0.154(C_4TR) + 0.850(C_4HT) - 14.262$	
Sectioning Point	Females < -0.048 < Males	
Overall Accuracy	**Male Accuracy** 74.0%	76.4%
	Female Accuracy 79.2%	
Measurements	C_4AP C_4TR	
Discriminant Function	$y = -0.004(C_4AP) + 0.692(C_4TR) - 16.581$	
Sectioning Point	Females < -0.0185 < Males	
Overall Accuracy	**Male Accuracy** 62.5%	62.6%
	Female Accuracy 62.7%	
Measurements	C_4TR C_4HT	
Discriminant Function	$y = 0.927(C_4AP) + 0.217(C_4TR) - 14.471$	
Sectioning Point	Females < -0.0475 < Males	
Overall Accuracy	**Male Accuracy** 73.3%	75.4%
	Female Accuracy 77.7%	

Table 4.21 Discriminant functions, sectioning points, and accuracies using the different combinations of measurements from the fifth cervical vertebra (C_5).

Measurements	C_5AP C_5TR C_5HT		
Discriminant Function	$y = 0.183(C_5AP) + 0.176(C_5TR) + 0.805(C_5HT) – 16.741$		
Sectioning Point	Females < -0.0245 < Males		
Overall Accuracy	**Male Accuracy**	69.5%	71.2%
	Female Accuracy	73.1%	
Measurements	C_5AP C_5TR		
Discriminant Function	$y = 0.213(C_5AP) + 0.600(C_5TR) – 17.720$		
Sectioning Point	Females < -0.012 < Males		
Overall Accuracy	**Male Accuracy**	64.3%	63.8%
	Female Accuracy	63.2%	
Measurements	C_5TR C_5HT		
Discriminant Function	$y = 0.223(C_5TR) + 0.810(C_5HT) – 15.518$		
Sectioning Point	Females < -0.024 < Males		
Overall Accuracy	**Male Accuracy**	72.3%	74.5%
	Female Accuracy	76.9%	

Table 4.22 Discriminant functions, sectioning points, and accuracies using the different combinations of measurements from the sixth cervical vertebra (C_6).

Measurements	C_6AP C_6TR C_6HT		
Discriminant Function	$y = 0.111(C_6AP) + 0.267(C_6TR) + 0.734(C_6HT) – 17.532$		
Sectioning Point	Females < -0.042 < Males		
Overall Accuracy	**Male Accuracy**	66.9%	69.6%
	Female Accuracy	72.8%	
Measurements	C_6AP C_6TR		
Discriminant Function	$y = 0.208(C_6AP) + 0.591(C_6TR) – 17.525$		
Sectioning Point	Females < -0.0215 < Males		
Overall Accuracy	**Male Accuracy**	69.2%	66.2%
	Female Accuracy	62.8%	
Measurements	C_6TR C_6HT		
Discriminant Function	$y = 0.293(C_6TR) + 0.749(C_6HT) – 16.911$		
Sectioning Point	Females < -0.0415 < Males		
Overall Accuracy	**Male Accuracy**	70.3%	70.4%
	Female Accuracy	70.4%	

Table 4.23 Discriminant functions, sectioning points, and accuracies using the different combinations of measurements from the seventh cervical vertebra (C_7).

Measurements	C_7AP C_7TR C_7HT		
Discriminant Function	$y = -0.041(C_7AP) + 0.341(C_7TR) + 0.678(C_7HT) - 17.557$		
Sectioning Point	Females < -0.0465 < Males		
Overall Accuracy	**Male Accuracy**	69.0%	71.7%
	Female Accuracy	75.0%	
Measurements	C_7AP C_7TR		
Discriminant Function	$y = 0.170(C_7AP) + 0.549(C_7TR) - 15.618$		
Sectioning Point	Females < -0.028 < Males		
Overall Accuracy	**Male Accuracy**	67.1%	66.1%
	Female Accuracy	64.8%	
Measurements	C_7TR C_7HT		
Discriminant Function	$y = 0.330(C_7TR) + 0.669(C_7HT) - 17.704$		
Sectioning Point	Females < -0.0465 < Males		
Overall Accuracy	**Male Accuracy**	69.0%	71.1%
	Female Accuracy	75.00%	

4.7.2 *Estimating Sex from all Cervical Vertebrae (C_1 - C_7)*

All three measurements (CAP, CTR, and CHT) and all seven cervical vertebrae (C_1-C_7) were combined to create one discriminant function to estimate sex. The function was generated using 55.6% of the combined sample of White Europeans (Athens and Lopes Collections). Only a portion of the individuals (86 males and 78 females) from the combined population (Athens and Lopes Collections) were utilized because only these individuals had a complete set of seven undamaged cervical vertebrae. Table 4.24 shows the results when utilizing all 21 measurements of the cervical spine to estimate sex. The function resulted in 84.1% overall accuracy and 83.7% and 84.6% accuracy for males and females, respectively. The results indicate that the accuracy rates exceed 80%, the minimum required accuracy to successfully assign sex. Therefore, the 21 measurements from the seven cervical vertebrae can successfully estimate sex.

Table 4.24 Discriminant functions, sectioning points, and accuracies using all three measurements from all seven cervical vertebrae (C_1-C_7).

Measurements	C_1AP C_1TR C_2AP C_2TR C_2HT C_3AP C_3TR C_3HT C_4AP C_4TR C_4HT C_5AP C_5TR C_5HT C_6AP C_6TR C_6HT C_7AP C_7TR C_7HT	
Discriminant Function	$y = 0.201(C_1AP) + 0.015(C_1TR) – 0.111(C_2AP) – 0.384(C_2TR) + 0.151(C_2HT) + 0.222(C_3AP) + 0.177(C_3TR) + 0.325(C_3HT) – 0.447(C_4AP) – 0.180(C_4TR) + 0.135(C_4HT) + 0.252(C_5AP) – 0.467(C_5TR) + 0.338(C_5HT) – 0.105(C_6AP) + 0.133(C_6TR) + 0.068(C_6HT) + 0.058(C_7AP) + 0.508(C_7TR) - 0.058(C_7HT) – 15.219$	
Sectioning Point	Females < -0.0485 < Males	
Overall Accuracy	**Male Accuracy** 83.7%	84.1%
	Female Accuracy 84.6%	

The two vertebral foramen diameters (CAP and CTR) and all seven cervical vertebrae (C_1-C_7) were combined to create one discriminant function to estimate sex. The function was generated using 58.3% of the combined sample of White Europeans (Athens and Lopes Collections). Only a portion of individuals (86 males and 83 females) were utilized because only these individuals had a complete set of seven undamaged cervical vertebrae. Table 4.25 shows the results when utilizing the 14 measurements of the cervical vertebral foramina to estimate sex. The function resulted in an overall accuracy of 71.5%, 73.0% and 69.9% accuracy for males and females, respectively. The results indicate that the accuracy rates do not meet 80%, the minimum required accuracy to successfully assign sex. Therefore, the 14 cervical vertebral foramen measurements (CAP and CTR) from the seven cervical vertebrae do not exhibit strong sex estimating potential.

Table 4.25 Discriminant functions, sectioning points, and accuracies using the two vertebral foramen measurements (CAP and CTR) from all seven cervical vertebrae (C_1-C_7).

Measurements	C_1AP C_1TR C_2AP C_2TR C_3AP C_3TR C_4AP C_4TR C_5AP C_5TR C_6AP C_6TR C_7AP C_7TR	
Discriminant Function	$y = 0.401(C_1AP) + 0.027(C_1TR) – 0.257(C_2AP) – 0.266(C_2TR) + 0.372(C_3AP) + 0.245(C_3TR) – 0.743(C_4AP) – 0.140(C_4TR) + 0.392(C_5AP) – 0.175(C_5TR) – 0.170(C_6AP) – 0.028(C_6TR) + 0.197(C_7AP) + 0.459(C_7TR) – 11.824$	
Sectioning Point	Females < -0.0205 < Males	
Overall Accuracy	**Male Accuracy** 73.0%	71.5%
	Female Accuracy 69.9%	

The two most dimorphic measurements (CTR and CHT) and cervical vertebrae C_2 to C_7 were combined to create a discriminant function to estimate sex. The first cervical vertebra (C_1) was omitted from the discriminant function because it lacks a vertebral body. The function was generated using 63.4% of the combined sample of White Europeans (Athens and Lopes Collections). Only a portion (100 males and 87 females) of the combined sample was utilized because these individuals had a complete set of undamaged cervical vertebrae. Table 4.26 shows the results when utilizing the two most dimorphic measurements from cervical vertebrae C_2 to C_7 to estimate sex. The function resulted in an overall accuracy of 84.5%, 85.0% and 83.9% accuracy for males and females, respectively. The results indicate that the accuracy rates exceed 80%, the minimum required accuracy to successfully assign sex. Therefore, the 12 CTR and CHT measurements from the second to seventh cervical vertebrae (C_2-C_7) can successfully estimate sex.

Table 4.26 Discriminant functions, sectioning points, and accuracies using CTR and CHT measurements from all seven cervical vertebrae (C_2-C_7).

Measurements	C_2TR C_2HT C_3TR C_3HT C_4TR C_4HT	C_5TR C_5HT C_6TR C_6HT C_7TR C_7HT
Discriminant Function	$y = -0.240(C_2TR) + 0.197(C_2HT) + 0.179(C_3TR) + 0.327(C_3HT) - 0.232(C_4TR) + 0.251(C_4HT) - 0.322(C_5TR) + 0.153(C_5HT) + 0.234(C_6TR) + 0.101(C_6HT) + 0.358(C_7TR) - 0.018(C_7HT) - 17.246$	
Sectioning Point	Females < -0.0625 < Males	
Overall Accuracy	**Male Accuracy** 85.0%	84.5%
	Female Accuracy 83.0%	

4.7.3 *Estimating Sex from Atypical Vertebrae (C_1 and C_2)*

All three measurements (CAP, CTR, and CHT) and atypical cervical vertebrae (C_1 and C_2) were combined to create one discriminant function to estimate sex. The function was generated using 83.4% of the combined sample of White Europeans (Athens and Lopes Collections). Only a portion of individuals (127 males and 119 females) were utilized because only these individuals had a complete set of undamaged first and second cervical vertebral bones. Table 4.27 shows the results when utilizing the irregularly shaped cervical vertebrae to estimate sex. The function resulted in an overall accuracy of 72.8%, 69.3% and 75.6% accuracy for males and females, respectively. The results indicate that the accuracy rates do not exceed 80%, the minimum required accuracy to successfully assign sex. Therefore, C_1 and C_2 vertebrae do not exhibit strong sex estimating potential using all three measurements.

Table 4.27 Discriminant function, sectioning points, and accuracies using all measurements from the first and second cervical vertebrae (C_1-C_2).

Measurements	C_1AP C_1TR C_2AP C_2TR C_2HT		
Discriminant Function	$y = 0.253(C_1AP) + 0.074(C_1TR) – 0.093(C_2AP) – 0.192(C_2TR) + 0.334(C_2HT) – 16.173$		
Sectioning Point	Females $< -0.022 <$ Males		
Overall Accuracy	**Male Accuracy**	67.7%	72.8%
	Female Accuracy	78.2%	

4.7.4 *Estimating Sex from Typical Cervical Vertebrae ($C_3 – C_6$) and C_7*

All three measurements (CAP, CTR, and CHT), typical cervical vertebrae (C_3-C_6) and the transitional C_7 were combined to create a discriminant function to estimate sex. The function was generated using 67.1% of the combined sample of White Europeans (Athens and Lopes Collections). Only a portion of individuals (105 males and 93 females) were utilized because only these individuals had a complete set of undamaged C_3 to C_7 vertebral bones. Table 4.28 shows the results when utilizing C_3 to C_7 to estimate sex. The function resulted in an overall accuracy of 82.3%, 81.9% and 82.8% accuracy for males and females, respectively. The results indicate that the accuracy rates exceed 80%, the minimum required accuracy to successfully assign sex. Therefore, the 15 measurements from vertebrae C_3 to C_7 can successfully estimate sex.

Table 4.28 Discriminant function, sectioning point, and accuracies using all three measurements from typical cervical vertebrae (C_3-C_6) and C_7.

Measurements	C_3AP C_3TR C_3HT C_4AP C_4TR C_4HT C_5AP C_5TR C_5HT C_6AP C_6TR C_6HT C_7AP C_7TR C_7HT	
Discriminant Function	$y = 0.170(C_3AP) + 0.012(C_3TR) + 0.389(C_3HT) – 0.487(C_4AP) – 0.169(C_4TR) + 0.375(C_4HT) + 0.158(C_5AP) – 0.335(C_5TR) + 0.108(C_5HT) + 0.120(C_6AP) + 0.189(C_6TR) + 0.037(C_6HT) – 0.005(C_7AP) + 0.409(C_7TR) + 0.119(C_7HT) – 15.536$	
Sectioning Point	Females < -0.052 < Males	
Overall Accuracy	**Male Accuracy** 81.9%	82.3%
	Female Accuracy 82.8%	

The two vertebral foramen diameters (CAP and CTR) and typical cervical vertebrae (C_3-C_6) and the transitional C_7 vertebra were combined to create a discriminant function to estimate sex. The function was generated using 70.5% of the combined sample of White Europeans (Athens and Lopes Collections). Only a portion of the combined sample (108 males and 100 females) was utilized because these individuals had a complete set of undamaged C_3 to C_7 vertebral bones. Table 4.29 shows the results when utilizing the vertebral foramen of C_3 to C_7 to estimate sex. The function resulted in 68.3% overall accuracy, 67.6% and 69.0% accuracy for males and females, respectively. The results indicate that the accuracy rates do not reach 80%, the minimum required accuracy to successfully assign sex. Therefore, the 10 vertebral foramen measurements from the C_3 to C_7 vertebral bones cannot successfully estimate sex.

Table 4.29 Discriminant function, sectioning point, and accuracies using vertebral foramen (CAP and CTR) measurements from typical cervical vertebrae (C_3-C_6) and C_7.

Measurements	C_3AP C_3TR C_4AP C_4TR C_5AP C_5TR C_6AP C_6TR C_7AP C_7TR	
Discriminant Function	y = 0.446(C3AP) + 0.244(C3TR) – 0.994(C4AP) – 0.327(C4TR) + 0.385(C5AP) + 0.240(C5TR) + 0.077(C6AP) – 0.040(C6TR) + 0.161(C7AP) + 0.360(C7TR) – 12.754	
Sectioning Point	Females < -0.0165 < Males	
Overall Accuracy	**Male Accuracy** 67.6%	68.3%
	Female Accuracy 69.0%	

The two most dimorphic measurements (CTR and CHT), typical cervical vertebrae (C_3-C_6) and C_7 were combined to create a discriminant function to estimate sex. The function was generated using 67.1% of the combined sample of White Europeans (Athens and Lopes Collections). Only a portion of the combined sample (86 males and 78 females) was utilized because these individuals had a complete set of undamaged C_3 to C_7 vertebral bones. Table 4.30 shows the results when utilizing the two most dimorphic measurements from cervical vertebrae C_3 to C_7 to estimate sex. The function resulted in 83.3% overall accuracy, 82.9% and 83.9% accuracy for males and females, respectively. The results indicate that the accuracy rates exceed 80%, the minimum required accuracy to successfully assign sex. Therefore, the 10 CTR and CHT measurements from the C_3 to C_7 vertebral bones can successfully estimate sex.

Table 4.30 Discriminant function, sectioning point, and accuracies using the most dimorphic measurements (CTR and CHT) from typical cervical vertebrae (C_3-C_6) and C_7.

Measurements	C_3TR C_3HT C_4TR C_4HT C_5TR C_5HT C_6TR C_6HT C_7TR C_7HT		
Discriminant Function	$y = -0.003(C_3TR) + 0.377(C_3HT) - 0.130(C_4TR) + 0.342(C_4HT) - 0.367(C_5TR) + 0.107(C_5HT) + 0.215(C_6TR) + 0.104(C_6HT) + 0.395(C_7TR) + 0.133(C_7HT) - 16.568$		
Sectioning Point	Females < -0.05 < Males		
Overall Accuracy	**Male Accuracy**	82.9%	83.3%
	Female Accuracy	83.9%	

4.7.5 *Estimating Sex from Four Typical Cervical Vertebrae (C_3-C_6)*

Excluding the transitional C_7 vertebra, the remaining four typical vertebrae (C_3-C_6) and the three vertebral measurements (CAP, CTR and CHT) were combined to create a discriminant function to estimate sex. The function was generated using 73.6% of the combined sample of White Europeans (Athens and Lopes Collections). Only a portion of the combined sample (116 males and 101 females) was utilized because these individuals had a complete set of undamaged C_3 to C_6 vertebral bones. Table 4.31 shows the results when utilizing all the measurements from cervical vertebrae C_3 to C_6 to estimate sex. The function resulted in 80.6% overall accuracy, 80.2% and 81.2% accuracy for males and females, respectively. The results indicate that the accuracy rates exceed 80%, the minimum required accuracy to successfully assign sex. Therefore, the 12 CAP, CTR and CHT measurements from the C_3 to C_6 vertebral bones can successfully estimate sex.

Table 4.31 Discriminant function, sectioning point, and accuracies using all three measurements from typical cervical vertebrae (C_3-C_6).

Measurements	C_3AP C_3TR C_3HT C_4AP C_4TR C_4HT C_5AP C_5TR C_5HT C_6AP C_6TR C_6HT	
Discriminant Function	$y = 0.061(C_3AP) + 0.103(C_3TR) + 0.327(C_3HT) - 0.372(C_4AP) - 0.118(C_4TR) + 0.374(C_4HT) + 0.138(C_5AP) - 0.271(C_5TR) + 0.101(C_5HT) + 0.209(C_6AP) + 0.412(C_6TR) + 0.196(C_6HT) - 16.478$	
Sectioning Point	Females < -0.0555< Males	
Overall Accuracy	**Male Accuracy** 80.2%	80.6%
	Female Accuracy 81.2%	

The two vertebral foramen measurements (CAP and CTR) for the third through sixth typical cervical vertebrae (C_3-C_6) were combined to create a discriminant function to estimate sex. The function was generated using 77.3% of the combined sample of White Europeans (Athens and Lopes Collections). Only a portion of the combined sample (119 males and 109 females) was utilized because these individuals had a complete set of undamaged third through sixth typical cervical vertebral bones. Table 4.32 shows the results when utilizing the vertebral foramen measurements from cervical vertebrae C_3 to C_6 to estimate sex. The function resulted in 65.4% overall accuracy, 65.5% and 65.1% accuracy for males and females, respectively. The results indicate that the accuracy rates do not exceed 80%, the minimum required accuracy to successfully assign sex. Therefore, the eight vertebral foramen measurements from the C_3 to C_6 vertebral bones cannot successfully estimate sex.

Table 4.32 Discriminant function, sectioning point, and accuracies using vertebral foramen measurements (CAP and CTR) from typical cervical vertebrae (C_3-C_6).

Measurements	C_3AP C_3TR C_4AP C_4TR C_5AP C_5TR C_6AP C_6TR	
Discriminant Function	$y = 0.363(C_3AP) + 0.288(C_3TR) – 0.937(C_4AP) – 0.181(C_4TR) + 0.415(C_5AP) + 0.182(C_5TR) + 0.276(C_6AP) + 0.242(C_6TR) – 14.653$	
Sectioning Point	Females < -0.0185 < Males	
Overall Accuracy	**Male Accuracy** 65.5%	65.4%
	Female Accuracy 65.1%	

The two most dimorphic measurements (CTR and CHT) and the third through sixth typical cervical vertebrae (C_3-C_6) were combined to create a discriminant function to estimate sex. The function was generated using 73.9% of the combined sample of White Europeans (Athens and Lopes Collections). Only a portion of the combined sample (116 males and 102 females) was utilized because these individuals had a complete set of undamaged C_3 to C_6 vertebral bones. Table 4.33 shows the results when utilizing the two most dimorphic measurements from cervical vertebrae C_3 to C_6 to estimate sex. The function resulted in 80.3% overall accuracy, 80.2% and 80.4% accuracy for males and females, respectively. The results indicate that the accuracy rates exceed 80%, the minimum required accuracy to successfully assign sex. Therefore, the eight most dimorphic measurements from the C_3 to C_6 vertebral bones can successfully estimate sex.

Table 4.33 Discriminant function, sectioning point, and accuracies using the most sexually dimorphic measurements (CTR and CHT) from typical cervical vertebrae (C_3-C_6).

Measurements	C_3TR C_3HT C_4TR C_4HT C_5TR C_5HT C_6TR C_6HT	
Discriminant Function	$y = 0.089(C_3TR) + 0.306(C_3HT) – 0.064(C_4TR) + 0.373(C_4HT) – 0.367(C_5TR) + 0.092(C_5HT) + 0.498(C_6TR) + 0.251(C_6HT) – 16.974$	
Sectioning Point	Females < -0.049 < Males	
Overall Accuracy	**Male Accuracy** 80.2%	80.3%
	Female Accuracy 80.4%	

4.7.6 *Stepwise Discriminant Function Analysis to Estimate Sex from Cervical Vertebrae*

The SPSS statistical software was utilized to create a stepwise discriminant function to estimate sex. Only seven variables (C_1AP, C_2HT, C_2TR, C_3HT, C_5TR, C_5HT, and C_7TR) from the complete set of 21 measurements exhibited large t-value coefficients which indicate a high potential for estimation of sex. The seven measurements were combined to create a discriminant function to estimate sex. The function was generated using 55.6% of the combined sample of White Europeans (Athens and Lopes Collections). Only a portion of the combined sample (86 males and 78 females) was utilized because these individuals had a complete set of undamaged cervical vertebral bones. Table 4.34 shows the results when utilizing stepwise discriminant analysis to select the most dimorphic variables to estimate sex. The function resulted in 82.6% overall accuracy, 77.3% and 88.2% accuracy for males and females, respectively. The results indicate that the accuracy rates for males are less than 80% but the overall accuracy exceeds 80%, the minimum required accuracy to successfully assign sex. Therefore, the seven cervical vertebral measurements selected by stepwise discriminant analysis can successfully estimate sex.

Table 4.34 SPSS generated stepwise discriminant function, sectioning point, and accuracies.

Measurements	C_1AP C_2HT C_2TR C_3HT C_5HT C_5TR C_7TR	
Discriminant Function	$y = 0.190(C_1AP) - 0.355(C_2TR) + 0.175(C_2HT) + 0.363(C_3HT) - 0.430(C_5TR) + 0.428(C_5HT) + 0.565(C_7TR) - 16.994$	
Sectioning Point	Females $<$ -0.0465 $<$ Males	
Overall Accuracy	**Male Accuracy** 77.3%	82.6%
	Female Accuracy 88.2%	

The stepwise discriminant function analysis resulted in seven variables, of the 21 variables, exhibiting a high potential for sex estimation. Four measurements of the seven most dimorphic measurements are from the second and fifth cervical vertebrae (C_2 and C_5). The structural matrix coefficients of 0.632 (C_2HT), 0.587 (C_5HT), 0.278 (C_5TR), and 0.230 (C_2TR) indicate that both dimorphic measurements (CTR and CHT) from C_2 and C_5 bones exhibit high sexual dimorphism (Appendix B4). These four measurements were combined to create a new discriminant function to estimate sex. The function was generated using 86.8% of the combined sample of White Europeans (Athens and Lopes Collections). Only a portion of the combined sample (132 males and 124 females) was utilized because these individuals had a complete set of undamaged C_2 and C_5 cervical vertebrae. Table 4.35 shows the results when utilizing the two most dimorphic measurements from the two most dimorphic bones selected by stepwise discriminant analysis. The function resulted in 76.6% overall accuracy, 72.7% and 80.6% accuracy for males and females, respectively. The results indicate that the accuracy does not exceed 80%, the minimum required accuracy to successfully assign sex. Therefore, the four

cervical vertebral measurements selected by stepwise discriminant analysis cannot successfully estimate sex.

Table 4.35 Discriminant function, sectioning point, and accuracies using the two most dimorphic measurements (CTR and CHT) from the two most dimorphic cervical vertebrae (C_2 and C_5).

Measurements	C_2TR C_2HT C_5TR C_5HT		
Discriminant Function	$y = -0.168(C_2TR) + 0.301(C_2HT) + 0.159(C_5TR) + 0.478(C_5HT) - 17.084$		
Sectioning Point	Females $<$ -0.0225 $<$ Males		
Overall Accuracy	**Male Accuracy**	72.7%	76.6%
	Female Accuracy	80.6%	

Stepwise discriminant function analysis showed that the second and fifth vertebrae (C_2 and C_5) exhibited the most dimorphism. All three measurements (CAP, CTR and CHT) from the second and fifth cervical vertebrae (C_2 and C_5) were combined to create a new discriminant function to estimate sex. The function was generated using 85.1% of the combined sample of White Europeans (Athens and Lopes Collections). Only a portion of the combined sample (130 males and 121 females) was utilized because these individuals had a complete set of undamaged C_2 and C_5 cervical vertebrae. Table 4.36 shows the results when utilizing the two most dimorphic bones selected by stepwise discriminant analysis to estimate sex. The function resulted in 76.5% overall accuracy, 71.5% and 81.8% accuracy for males and females, respectively. The results indicate that the accuracy does not exceed 80%, the minimum required accuracy to successfully assign sex. Therefore, the two most dimorphic cervical vertebrae selected by stepwise discriminant analysis cannot successfully estimate sex.

Table 4.36 Discriminant function, sectioning point, and accuracies using all three measurements from the two most dimorphic cervical vertebrae (C_2 and C_5).

Measurements	C_2AP C_2TR C_2HT C_5AP C_5TR C_5HT	
Discriminant Function	$y = 0.100(C_2AP) – 0.258(C_2TR) + 0.309(C_2HT) + 0.115(C_5AP) + 0.121(C_5TR) + 0.513(C_5HT) – 17.856$	
Sectioning Point	Females < -0.027 < Males	
Overall Accuracy	**Male Accuracy** 71.5%	76.5%
	Female Accuracy 81.8%	

4.8 Sex Estimation Accuracy

Seven discriminant functions achieved overall accuracies above 80%, the minimum required accuracy to successfully assign sex (Table 4.37; Gama et al 2015; Marlow and Pastor 2011: 168; Molto 1979; Nichol and Turner 1986; Novotny and Işcan 1993; Rogers 1999; Rogers and Saunders 1994; Williams and Rogers 2006). The predicted sex estimating accuracies of these seven functions was cross-validated on a sample of 32 individuals of known sex from the Athens (N=6) and Lopes (N= 26) Collections. These individuals were not represented in the combined sample group used to generate the discriminate functions; they are an independent group. The results of the cross-validation accuracies for each function were compared to the SPSS predicted accuracies and are presented in Table 4.38.

Table 4.37 Seven discriminant functions that successfully estimated sex using measurements of the cervical vertebrae.

Function 1 (Table 4.26)	$y = -0.240(C_2TR) + 0.197(C_2HT) + 0.179(C_3TR) + 0.327(C_3HT) - 0.232(C_4TR) + 0.251(C_4HT) - 0.322(C_5TR) + 0.153(C_5HT) + 0.234(C_6TR) + 0.101(C_6HT) + 0.358(C_7TR) - 0.018(C_7HT) - 17.246$		
Sectioning Point	Females < -0.0625 < Males	**Overall Accuracy**	84.5%
Function 2 (Table 4.24)	$y = 0.201(C_1AP) + 0.015(C_1TR) - 0.111(C_2AP) - 0.384(C_2TR) + 0.151(C_2HT) + 0.222(C_3AP) + 0.177(C_3TR) + 0.325(C_3HT) - 0.447(C_4AP) - 0.180(C_4TR) + 0.135(C_4HT) + 0.252(C_5AP) - 0.467(C_5TR) + 0.338(C_5HT) - 0.105(C_6AP) + 0.133(C_6TR) + 0.068(C_6HT) + 0.058(C_7AP) + 0.508(C_7TR) - 0.058(C_7HT) - 15.219$		
Sectioning Point	Females < -0.0485 < Males	**Overall Accuracy**	84.1%
Function 3 (Table 4.30)	$y = -0.003(C_3TR) + 0.377(C_3HT) - 0.130(C_4TR) + 0.342(C_4HT) - 0.367(C_5TR) + 0.107(C_5HT) + 0.215(C_6TR) + 0.104(C_6HT) + 0.395(C_7TR) + 0.133(C_7HT) - 16.568$		
Sectioning Point	Females < -0.05 < Males	**Overall Accuracy**	83.3%
Function 4 (Table 4.34)	$y = 0.190(C_1AP) - 0.355(C_2TR) + 0.175(C_2HT) + 0.363(C_3HT) - 0.430(C_5TR) + 0.428(C_5HT) + 0.565(C_7TR) - 16.994$		
Sectioning Point	Females < -0.0465 < Males	**Overall Accuracy**	82.6%
Function 5 (Table 4.28)	$y = 0.170(C_3AP) + 0.012(C_3TR) + 0.389(C_3HT) - 0.487(C_4AP) - 0.169(C_4TR) + 0.375(C_4HT) + 0.158(C_5AP) - 0.335(C_5TR) + 0.108(C_5HT) + 0.120(C_6AP) + 0.189(C_6TR) + 0.037(C_6HT) - 0.005(C_7AP) + 0.409(C_7TR) + 0.119(C_7HT) - 15.536$		
Sectioning Point	Females < -0.052 < Males	**Overall Accuracy**	82.3%
Function 6 (Table 4.31)	$y = 0.061(C_3AP) + 0.103(C_3TR) + 0.327(C_3HT) - 0.372(C_4AP) - 0.118(C_4TR) + 0.374(C_4HT) + 0.138(C_5AP) - 0.271(C_5TR) + 0.101(C_5HT) + 0.209(C_6AP) + 0.412(C_6TR) + 0.196(C_6HT) - 16.478$		
Sectioning Point	Females < -0.0555< Males	**Overall Accuracy**	80.6%
Function 7 (Table 4.33)	$y = 0.089(C_3TR) + 0.306(C_3HT) - 0.064(C_4TR) + 0.373(C_4HT) - 0.367(C_5TR) + 0.092(C_5HT) + 0.498(C_6TR) + 0.251(C_6HT) - 16.974$		
Sectioning Point	Females < -0.049 < Males	**Overall Accuracy**	80.3%

Table 4.38 Cross-validation accuracies for the seven discriminant functions that achieved greater than 80% predicted accuracies by SPSS version 21.0.

Function	Total N	Male N	Female N	Cross Validation Accuracy		SPSS
				Correct Classification	Incorrect Classification	Predicted Accuracy
1	23	13	10	78.3% (18/23)	21.7% (5/23)	84.5%
2	19	10	9	84.2% (16/19)	15.7% (3/19)	84.1%
3	23	10	13	82.6% (19/23)	17.4% (4/23)	83.3%
4	23	9	14	87.0% (20/23)	13.0% (3/23)	82.6%
5	23	11	12	82.6% (19/23)	17.4% (4/23)	82.3%
6	24	9	15	79.2% (19/24)	20.8% (5/24)	80.6%
7	24	9	15	87.5% (21/24)	12.5% (3/24)	80.3%

4.8.1 *Cross Validating the Predicted Sex Estimating Potential of Function 1*

Function 1 (CTR and CHT from C_2 to C_7) achieved the highest predicted sex estimating accuracy at 84.5%, 85.0% and 83.0% for males and females, respectively (Table 4.26). A cross-validation analysis tested whether the sex of an independent sample could be successfully estimated using Function 1. Only a portion of the independent cross-validation sample (N=23; 13 males and 10 females) was utilized because these individuals had a complete set of undamaged C_2 to C_7 vertebral bones. The results of the Function 1 estimated sexes were compared to the documented biological sex of the individuals. The results indicated that 18 of 23 individuals (78.3%) were correctly

classified by sex; five of 19 individuals (21.7%) were misclassified. The results of the cross-validation accuracy is less than the SPSS predicted accuracy of 84.5% and less than 80%, the minimum required accuracy to successfully assign sex. Therefore, Function 1 does not successfully estimate sex.

4.8.2 *Cross Validating the Predicted Sex Estimating Potential of Function 2*

Function 2 (CAP, CTR, and CHT from C_1 - C_7) achieved the second highest predicted sex estimating accuracy at 84.1%, 83.7% and 84.6% for males and females respectively (Table 4.26). A cross-validation analysis tested whether the sex of an independent sample could be successfully estimated using Function 2. Only a portion of the independent cross-validation sample (N=19; 10 males and 9 females) was utilized because these individuals had a complete set of undamaged cervical bones. The results of the Function 2 estimated sexes were compared to the documented biological sex of the individuals. The results indicated that 16 of 19 individuals (84.21%) were correctly classified by sex; three of 19 individuals (15.70%) were misclassified. The cross-validation accuracy is nearly equal to the SPSS predicted accuracy of 84.1% therefore, Function 2 successfully estimated sex.

4.8.3 *Cross Validating the Predicted Sex Estimating Potential of Function 3*

Function 3 (CTR and CHT from C_3 – C_7) achieved the third highest predicted sex estimating accuracy at 83.3%, 82.9% and 83.9% for males and females respectively (Table 4.30). A cross-validation analysis tested whether the sex of an independent sample could be successfully estimated using Function 3. Only a portion of the independent

cross-validation sample (N=23; 10 males and 13 females) was utilized because these individuals had a complete set of undamaged C_3 to C_7 cervical bones. The results of the Function 3 estimated sexes were compared to the documented biological sex of the individuals. The results indicated that 19 of 23 individuals (82.61%) were correctly classified by sex; four of 23 individuals (17.39%) were misclassified. The cross-validation accuracy is slightly less than the SPSS predicted accuracy of 83.3% however, Function 3 successfully estimated sex by achieving greater than 80% accuracy, the minimum required to successfully assign sex.

4.8.4 *Cross Validating the Predicted Sex Estimating Potential of Function 4*

Function 4 (C_1AP, C_2HT, C_2TR, C_3HT, C_5HT, C_5TR, C_7TR) achieved a predicted sex estimating accuracy of 82.6%, 77.3% and 88.2% for males and females respectively (Table 4.34). A cross-validation analysis tested whether the sex of an independent sample could be successfully estimated using Function 4. Only a portion of the independent cross-validation sample (N=23; 9 males and 14 females) was utilized because these individuals had a complete set of undamaged C_1, C_2, C_3, C_5 and C_7 cervical bones. The results of the Function 4 estimated sexes were compared to the documented biological sex of the individuals. The results indicated that 20 of 23 individuals (86.96%) were correctly classified by sex; three of 23 individuals (13.04%) were misclassified. The cross-validation accuracy is greater than the SPSS predicted accuracy of 82.6% therefore, Function 4 successfully estimated sex.

4.8.5 *Cross Validating the Predicted Sex Estimating Potential of Function 5*

Function 5 (CAP, CTR, and CHT for $C_3 – C_7$) achieved a predicted sex estimating accuracy of 82.3%, 81.9% and 82.8% for males and females respectively (Table 4.28). A cross-validation analysis tested whether the sex of an independent sample could be successfully estimated using Function 5. Only a portion of the independent cross-validation sample (N=23; 11 males and 12 females) was utilized because these individuals had a complete set of undamaged C_3 to C_7 cervical bones. The results of the Function 5 estimated sexes were compared to the documented biological sex of the individuals. The results indicated that 19 of 23 individuals (82.61%) were correctly classified by sex; four of 23 individuals (17.39%) were misclassified. The cross-validation accuracy is nearly equal to the SPSS predicted accuracy of 82.3% therefore, Function 5 successfully estimated sex.

4.8.6 *Cross Validating the Predicted Sex Estimating Potential of Function 6*

Function 6 (CAP, CTR, and CHT for $C_3 – C_6$) achieved a predicted sex estimating accuracy of 80.6%, 80.2% and 81.2% for males and females respectively (Table 4.31). A cross-validation analysis tested whether the sex of an independent sample could be successfully estimated using Function 6. Only a portion of the independent cross-validation sample (N=24; 11 males and 12 females) was utilized because these individuals had a complete set of undamaged C_3 to C_6 cervical bones. The results of the Function 6 estimated sexes were compared to the documented biological sex of the individuals. The results indicated that 19 of 24 individuals (79.17%) were correctly classified by sex; five of 24 individuals (20.84%) were misclassified. The results of the

cross-validation accuracy is less than the SPSS predicted accuracy of 80.6% and less than 80%, the minimum required accuracy to successfully assign sex. Therefore, Function 6 does not successfully estimate sex.

4.8.7 *Cross Validating the Predicted Sex Estimating Potential of Function 7*

Function 7 (CTR and CHT for $C_3 – C_6$) achieved the lowest predicted sex estimating accuracy at 80.3%, 80.2% and 80.4% for males and females respectively (Table 4.33). A cross-validation analysis tested whether the sex of an independent cross-validation sample could be successfully estimated using Function 7. Only a portion of the independent sample (N=25; nine males and 15 females) was utilized because these individuals had a complete set of undamaged C_3 to C_6 cervical bones. The results of the Function 7 estimated sexes were compared to the documented biological sex of the individuals. The results indicated that 21 of 24 individuals (87.5%) were correctly classified by sex; three of 24 individuals (12.5%) were misclassified. The cross-validation accuracy is greater than the SPSS predicted accuracy of 80.3% therefore, Function 7 successfully estimated sex.

4.9 **The Effects of Age on Cervical Vertebrae**

4.9.1 *Age-Related Changes to the Cervical Vertebrae*

The third goal of this research was to evaluate the relationship between age and the cervical vertebrae in two White European skeletal populations. The size of the vertebral foramen remains constant from the time of complete fusion in early childhood development and throughout life (Clark 1985). One-way ANOVA statistical analyses (f-

value) evaluated whether aging affected the CAP, CTR and CHT measurements since dimensional changes may affect the estimation of sex. Individuals were grouped into eight age categories of 10 year increments (Table 4.39). Age categories zero and one indicate infants between birth to 9.99 years old (0: 0-9.99) and teens between 10 and 19.99 years of age (1: 10-19.99). Individuals under 20 years of age were not included in this study and were omitted from the analyses. Age categories two to nine represent the individuals studied in this research (2: 20-29.99, 3: 30-39.99, 4: 40-49.99. 5: 50-59.99, 6: 60-69.99, 7: 70-79.99, 8: 80-89.99, 9: 90-99.99 years of age). Table 4.39 shows the sample size for each age category.

Table 4.39 Age category sample sizes for males and females in the Athens and Lopes Collections.

Age Category	Age (years)	Athens Skeletal Collection			Lopes Skeletal Collection			Total (N)
		Males	Females	N	Males	Females	N	
2	20-29.99	10	3	13	8	9	17	30
3	30-39.99	5	6	11	13	5	18	29
4	40-49.99	12	11	23	16	5	21	44
5	50-59.99	9	10	19	16	12	28	47
6	60-69.99	13	11	24	16	12	28	52
7	70-79.99	14	13	27	9	15	24	51
8	80-89.99	7	8	15	9	12	21	36
9	90-99.99	0	3	3	0	3	3	6

Table 4.40 shows the one-way ANOVA for age-related changes to the 21 cervical vertebral measurements in the combined population of White Europeans. The individuals from the Athens and Lopes Collections were grouped into one combined sample group of White Europeans because there was minimal ancestral variation between the two

Collections. A Bonferroni correction of $\alpha = 0.002$ ($\alpha = 0.05/21$) was used to account for type-1 errors. If the p-value for an ANOVA was less than or equal to the Bonferroni significance level of $\alpha = 0.002$ ($\alpha \leq 0.002$) then the measurement exhibited age-related changes between the age categories. Exploratory interval plots were also created to visually compare variations in age-related changes to the cervical vertebrae; Figure 4.9 shows an example of an interval plot. The results of the ANOVA analyses indicate that males exhibit no variation in CTR and CHT measurements and only four CAP diameters (C_2AP, C_3AP, C_4AP, and C_6AP) exhibit statistical significance. Females exhibit no variation in vertebral measurements due to age-related changes.

Table 4.40 Results of ANOVA tests evaluating age-related dimensional changes to male and female cervical morphometrics in the combined sample (N=295).

Measurement	Males (N=157)			Females (N=138)		
	N	f-value	p-value	N	f-value	p-value
C_1AP	135	0.70	0.649	126	1.05	0.403
C_2AP	145	4.04	0.001*	128	0.69	0.681
C_3AP	139	5.03	0.000*	126	0.92	0.495
C_4AP	151	4.38	0.000*	134	0.95	0.472
C_5AP	142	2.80	0.013	133	0.97	0.453
C_6AP	145	4.28	0.001*	129	2.45	0.022
C_7AP	145	3.02	0.008	125	1.17	0.323
C_1TR	135	1.25	0.284	127	0.17	0.990
C_2TR	147	1.21	0.305	131	1.09	0.372
C_3TR	138	1.30	0.262	127	0.73	0.646
C_4TR	151	0.96	0.457	134	0.46	0.861
C_5TR	142	1.12	0.352	133	0.30	0.953
C_6TR	145	0.62	0.717	129	0.99	0.442
C_7TR	145	0.73	0.627	125	1.30	0.258
C_2HT	148	0.88	0.515	130	1.03	0.416
C_3HT	138	0.93	0.475	125	0.91	0.504
C_4HT	149	1.74	0.116	130	0.26	0.970
C_5HT	140	1.35	0.242	130	0.50	0.831
C_6HT	145	1.40	0.218	125	0.27	0.965
C_7HT	145	0.60	0.730	124	1.47	0.184

*Significant difference at p-value $\leq$ 0.002

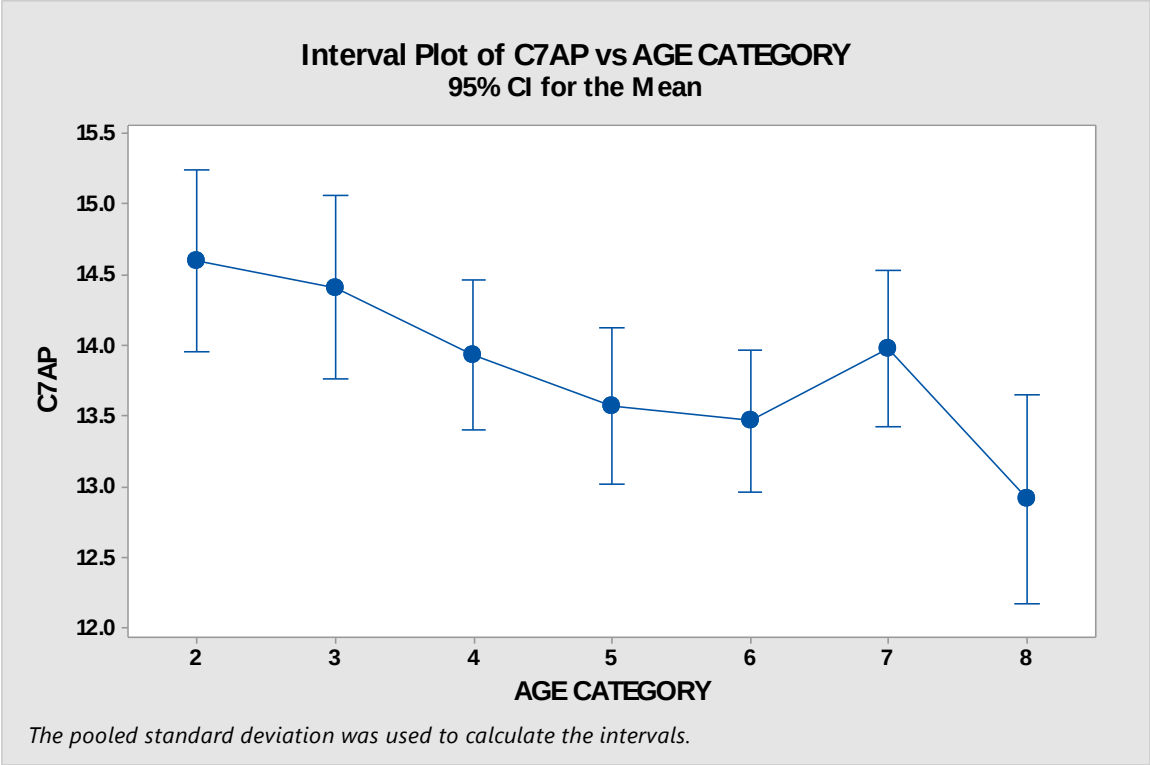

Figure 4.9 An example of an exploratory interval plot to visually asses the age-related changes to male C_7AP diameter from age category 2 to 8.

4.9.2 *Post-hoc Test of Age-Related Changes to Four CAP Diameters in the Males*

Four CAP diameters (C_2AP, C_3AP, C_4AP, and C_6AP) exhibited statistically significant age-related changes in the male population (p-value ≤ 0.002). No female vertebrae exhibited age-related changes. The four male CAP measurements were further tested using a post-hoc test in Minitab version 17.0 to determine at which age category the changes occurred.

A post-hoc test identifies the relatedness between the age categories. Age categories that exhibit similarities in their mean measurement diameters are grouped to indicate where variation in measurement sizes between age categories may occur. Minitab assigns a grouping letter (A, B, C, etc.) to differentiate the relatedness between

age categories. Table 4.41 shows the results of the post-hoc test for male C_2AP measurements to assess in which age category the age-related changes occurred. Age categories are listed in descending mean measurement diameter to show the decrease in size. The age categories that share a letter are more similar in their group means than letters that do not share a letter. If age categories do not share a grouping letter then the differences between the two categories are statistically significant (p-value ≤ 0.05). The results indicate that the mean measurements in age categories two, three and four are statistically different when compared to age category eight. Categories five, six, seven and eight exhibited no statistically significant differences in their means. Figure 4.10 shows the interval plot distribution of the age-related changes using a 95% confidence interval. The plot shows that as age increases, the diameter of C_2AP diameter decreases in age categories three through eight, 30 to 89.99 year olds.

Table 4.41 Results for male C_2AP measurement post-hoc test to assess age-related changes to the cervical vertebrae.

Age Category	Years	N	Mean (mm)	Grouping
3	30-39.99	18	16.87	A
2	20-29.99	15	16.70	A
4	40-49.99	26	16.29	A
6	60-69.99	27	16.04	A B
5	50-59.99	24	15.96	A B
7	70-79.99	23	15.84	A B
8	80-89.99	13	14.79	B

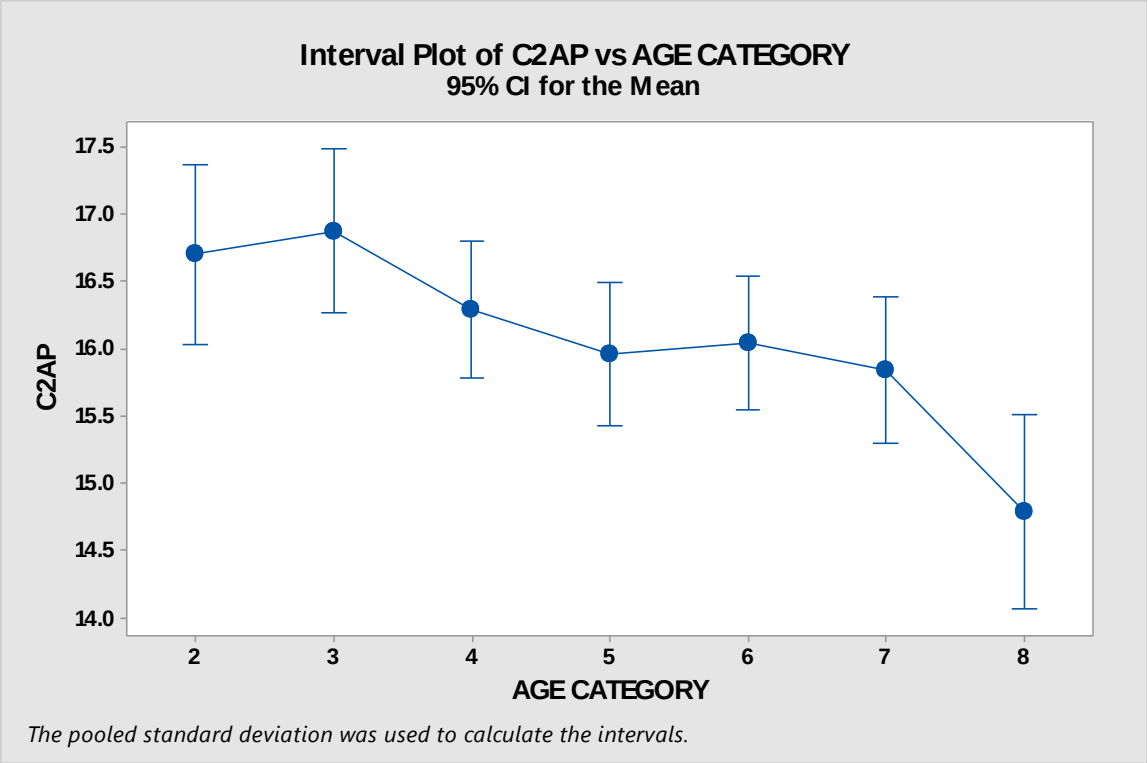

Figure 4.10 The exploratory interval plot to visually asses the age-related changes to male C_2AP diameter from age category 2 to 8.

Table 4.42 shows the results of the post-hoc test for male C_3AP measurements to assess in which age category the age-related changes occurred. Age categories are listed in descending mean measurement diameter to show the decrease in size. The age categories that share a letter are more similar in their group means than letters that do not share a letter. If age categories do not share a grouping letter then the differences between the two categories are statistically significant (p-value ≤ 0.05). The results indicate that the means of age categories two and three exhibit statistically significant variation from categories five, six and eight. Age category four also exhibits variation from category eight. Category seven exhibits no statistically significant variation with any other age category. Figure 4.11 shows the interval plot distribution of the age-related changes using

a 95% confidence interval. The plot shows a decrease in vertebral diameter in age category two to five, no changes between category five and six, an increase in category six to seven, and a sharp decline in category seven to eight. The increase in C_3AP diameter between categories six and seven may have been caused by a sampling error or an anomaly since the overall pattern is a decline in the diameter with age and it is unlikely the diameter increased in 70 year olds and then decline again in 80 year olds.

Table 4.42 Results for male C_3AP measurement post-hoc test to assess age-related changes to the cervical vertebrae.

Age Category	Years	N	Mean (mm)	Grouping
3	30-39.99	16	14.74	A
2	20-29.99	15	14.73	A
4	40-49.99	26	14.11	A B
7	70-79.99	20	13.96	A B C
6	60-69.99	24	13.60	B C
5	50-59.99	24	13.59	B C
8	80-89.99	15	13.00	C

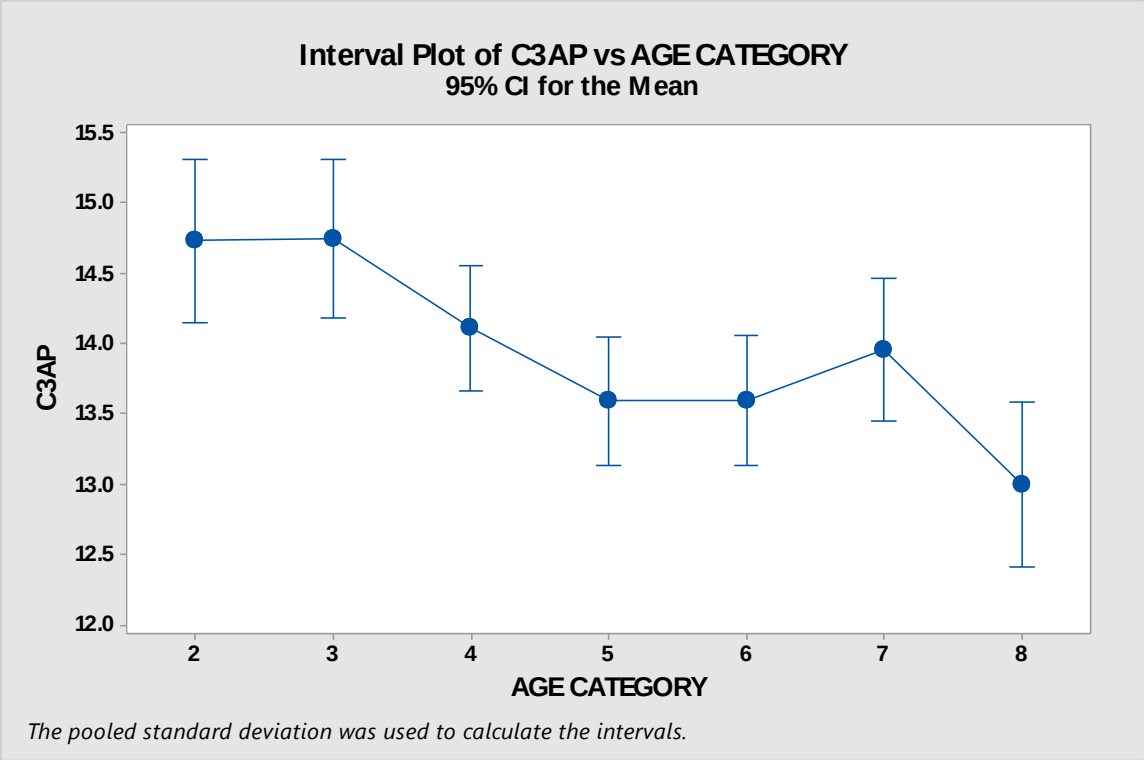

Figure 4.11 The exploratory interval plot to visually asses the age-related changes to male C_3AP diameter from age category 2 to 8.

Table 4.43 shows the results of the post-hoc test for male C_4AP measurements to assess in which age category the age-related changes occurred. Age categories are listed in descending mean measurement diameter to show the decrease in size. The age categories that share a letter are more similar in their group means than letters that do not share a letter. If age categories do not share a grouping letter then the differences between the two categories are statistically significant (p-value ≤ 0.05). The results indicate that the means of age category two exhibits variation from categories five, six, and eight. Also, age category three exhibits statistically significant variation from age category eight. Figure 4.9 shows the interval plot distribution of the age-related changes using a 95% confidence interval. The plot shows a decrease in vertebral diameter in age category

two to five, little changes between five and six, an increase from category six to seven, and a sharp decline from seven to eight. The increase in C_4AP diameter between categories six and seven may have been caused by a sampling error or an anomaly since the overall pattern is a decline in the diameter with age and it is unlikely the diameter increased in 70 year olds and then decline again in 80 year olds.

Table 4.43 Results for male C_4AP measurement post-hoc test to assess age-related changes to the cervical vertebrae.

Age Category	Years	N	Mean (mm)	Grouping
2	20-29.99	17	14.35	A
3	30-39.99	18	13.83	A B
4	40-49.99	28	13.57	A B C
7	70-79.99	22	13.37	A B C
6	60-69.99	27	13.17	B C
5	50-59.99	25	13.01	B C
8	80-89.99	15	12.46	C

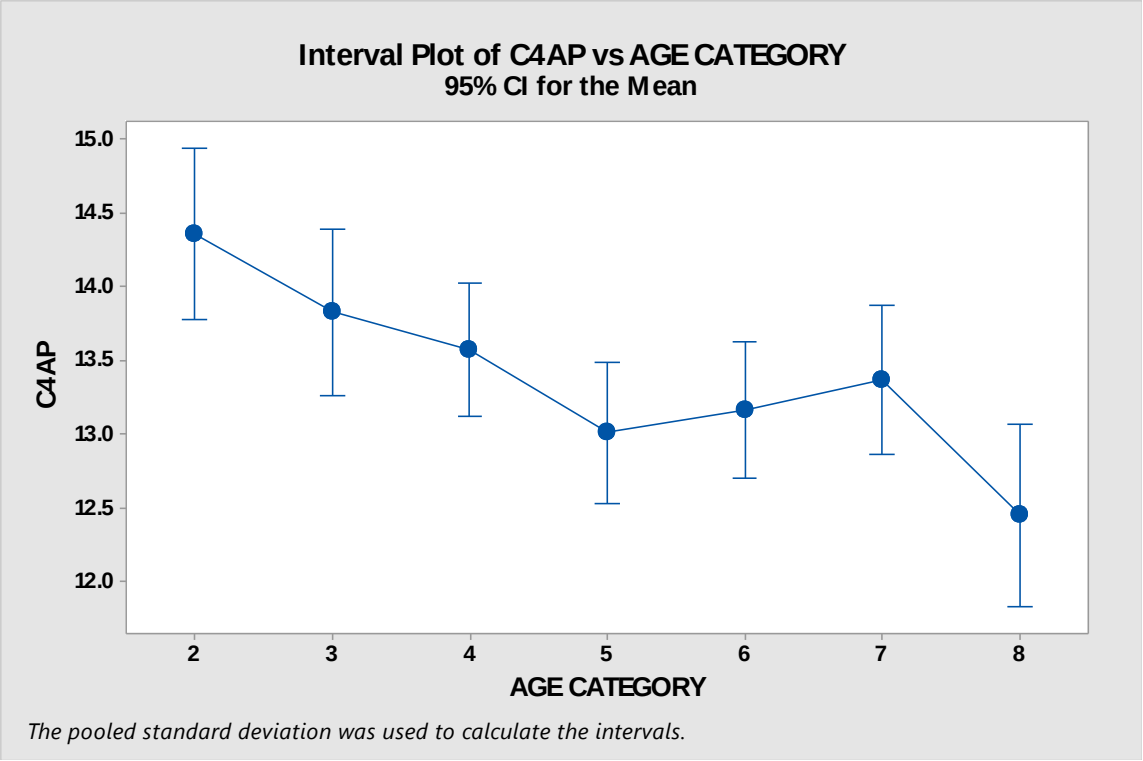

Figure 4.12 The exploratory interval plot to visually asses the age-related changes to male C_4AP diameter from age category 2 to 8.

Table 4.44 shows the results of the post-hoc test for male C_6AP measurements to assess in which age category the age-related changes occurred. Age categories are listed in descending mean measurement diameter to show the decrease in size. The age categories that share a letter are more similar in their group means than letters that do not share a letter. If age categories do not share a grouping letter then the differences between the two categories are statistically significant (p-value ≤ 0.05). The results indicate that the means of age categories two and three exhibit statistically significant variation from categories six and eight. Figure 4.13 shows the interval plot distribution of the age-related changes using a 95% confidence interval. The plot shows a decrease in vertebral diameter in age category three to six, an increase from category six to seven, and a sharp decline

from category seven to eight. The increase in C_6AP diameter between six and seven may have been caused by a sampling error or an anomaly since the overall pattern is a decline in the diameter with age and it is unlikely the diameter increased in 70 year olds and then decline again in 80 year olds.

Table 4.44 Results for male C_6AP measurement post-hoc test to assess age-related changes to the cervical vertebrae.

Age Category	Years	N	Mean (mm)	Grouping
2	20-29.99	16	14.38	A
3	30-39.99	16	14.35	A
4	40-49.99	26	13.67	A B
7	70-79.99	20	13.32	A B
5	50-59.99	25	13.17	A B
6	60-69.99	27	13.09	B
8	80-89.99	16	12.75	B

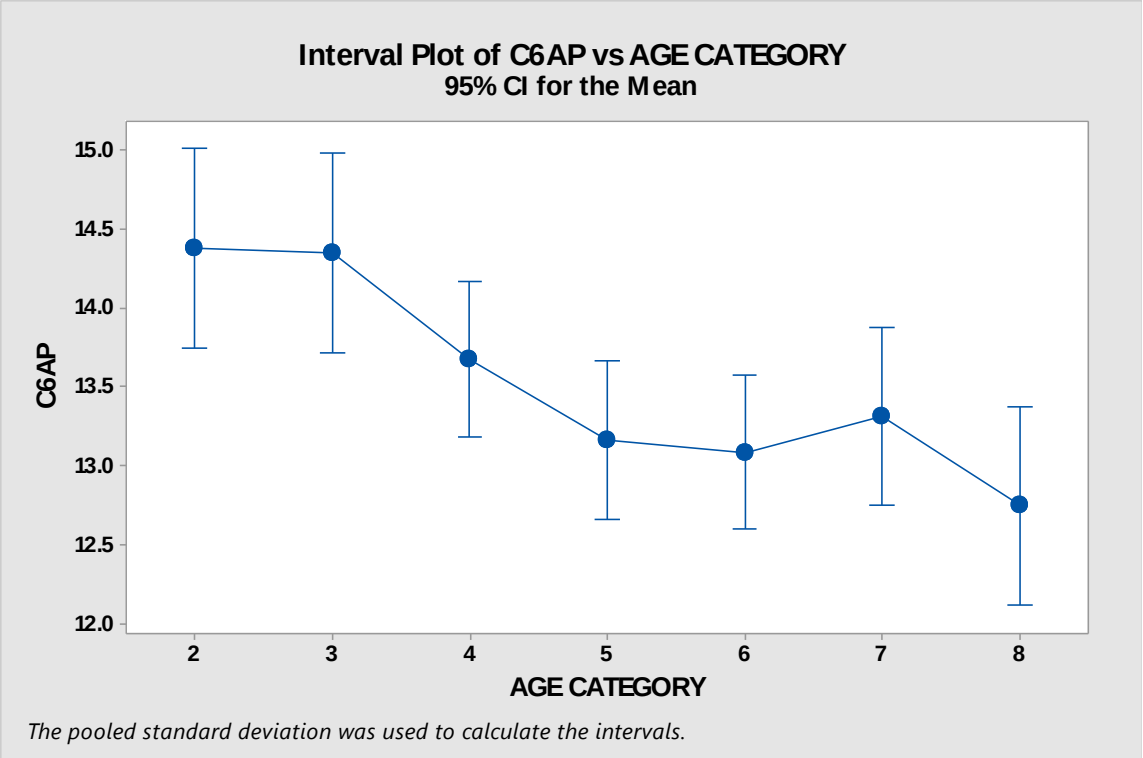

Figure 4.13 The exploratory interval plot to visually asses the age-related changes to male C_6AP diameter from age category 2 to 8.

CHAPTER 5: DISCUSSION

5.1 Context of the Current Research

The goal of forensic anthropology is to assist in identifying unknown human skeletal remains by forming a biological profile using standard scientific techniques. Creating new reliable methodologies for skeletal identification is an integral component of medico-legal investigations. Most bones in the human body have been assessed for their potential in estimating sex however, creating and testing new methods from less-frequently researched bones may increase the sex estimating potential (Byers 2008: 194; Spradley and Jantz 2011). The methodologies must also meet the Daubert and Mohan admissibility criteria to ensure valid, reliable and relevant scientific standards. Any method of analysis, such as those used for the estimation of sex, must prove high levels of reliability, accuracy, and precision to be considered admissible in the court of law (Christensen and Crowder 2009; Lesciotto 2015).

The current study focuses on the seven cervical vertebrae to establish an accurate and reliable sex estimation method for a White European skeletal population using only three measurements from each bone: the anterior-posterior vertebral foramen diameter (CAP), transverse vertebral foramen diameter (CTR), and maximum vertebral body height (CHT). The objectives of this research are to 1) understand the relationship between sex and the three morphometric characteristics of the cervical vertebrae; 2) understand the relationship between stature and the three measurements of the cervical vertebrae; and 3) evaluate the relationship between age and the three measurements of the cervical vertebrae.

5.2 The Relationship between Sex and Cervical Vertebral Morphometrics

Research involving the vertebral foramen of the cervical vertebrae has focused on the clinical aspects in the size and shape of the structure (Tatarek 1999). Although many researchers (Amores et al 2014; Bethard and Seet 2013; Clark 1985; Gama et al 2015; Grave et al 1999; Hashimoto and Tak 1977; Kibii et al 2010; Ishikawa et al 2003; Marino 1995; Marlow and Pastor 2011; Swenson 2013; Taitz 1996; Tatarek 1999, 2005; Wescott 2000) have found sexual dimorphism in the vertebral foramen, few have used it to estimate sex from human skeletal remains. Instead, sex estimation using the cervical vertebrae has focused on the centrum, the articular facets, and the length and width of the vertebra due to their greater sexually dimorphic characteristics (Amores et al 2014; Gama et al 2015; Kibii et al 2010; Marlow and Pastor 2011; Wescott 2000). However, some of these characteristics are more likely to sustain taphonomic damage and fragmentation upon recovery from a deposition site as compared to the three characteristics measured in the current research (CAP, CTR and CHT) (Dittrick and Suchey 1986; Gama et al 2015; Marlow and Pastor 2011; Voisin 2011; Waldron 1987). The vertebral foramen CAP and CTR diameters are enclosed and protected by the vertebral arches and the CHT measurement is located on the dense vertebral body resulting in resiliency to mechanical, taphonomic and architectural stresses (Dittrick and Suchey 1986; Marlow and Pastor 2011; Voisin 2011; Waldron 1987). The CAP, CTR and CHT morphometric characteristics are therefore more likely to be present in forensic cases for sex estimation analyses.

5.2.1 *Sexual Dimorphism in the Cervical CAP, CTR and CHT Morphometric*

The results of the current project show that two measurements (CTR and CHT), from a total of three (CAP, CTR, and CHT), exhibit sexual dimorphism in the cervical vertebrae. The most dimorphic is the maximum height of the vertebral body (CHT) followed by the transverse diameter of the vertebral foramen (CTR) at every cervical bone. The CAP diameter of the vertebral foramen is not sexually dimorphic with the exception of C_1, which does exhibit dimorphism between males and females.

The literature has shown that the centrum exhibits more dimorphism than other features of the spine which consequently results in CHT having greater sex estimating potential than the vertebral foramen measurements. Grave and colleagues (1999) reported that CHT in Australian White and Aboriginal individuals was sexually dimorphic when observed using lateral roentgenograms. Kibii and colleagues (2010) measured the dry bone of C_7 vertebrae and found that males had larger CHT measurements in Zulu, White and Coloured South African populations. Bethard and Seet (2013), Marlow and Pastor (2011), and Wescott (2000) also measured nine characteristics from the dry bones of C_2 vertebrae from contemporary American, White European, and White and Black Americans, respectively. The results by these authors found that CHT exhibited "highly significant" dimorphism between males and females (Marlow and Pastors 2001: 167). In Wescott's (2000) study, the CHT and four other measurements were also selected in a stepwise regression formula due to their increased potential for estimating sex. Stepwise regression did not select CHT in the research by Bethard and Seet (2013) or Marlow and Pastors (2001), which they attribute to population variability, i.e. discriminant functions for the estimation of sex from vertebrae are population specific.

Also in agreement with the current study, researchers have found significant sexual dimorphism in the CTR diameter. Tatarek (1999) has found that CTR measurements exhibited more dimorphism than CAP diameters in White and Black American populations. Tatarek (2005) has also found that the CTR diameter in vertebrae C_2 to C_7 in White and Black Americans is approximately 10 mm larger than the CAP diameter. Kibii and colleagues (2010) also found that CTR measurement was dimorphic; it was approximately 10 mm larger than CAP in the C_7 vertebrae of Zulu, White and Coloured South Africans. The current project concurs with Tatarek (2005) and Kibii and colleagues (2010) that CTR is sexually dimorphic in White European cervical vertebrae and approximately 10 mm larger than CAP in vertebrae C_2 to C_7. Taitz (1996) found that a Black South African population exhibited dimorphism in all seven cervical CTR diameters whereas the White South African population exhibited CTR dimorphism in only four vertebrae, C_3 to C_6.

In both the Athens and Lisbon Collections, mean vertebral foramen CAP diameters were larger in males as compared to females at every cervical bone. However, with the exception of C_1, the CAP diameters did not exhibit statistically significant sexual dimorphism. The lack of CAP dimorphism in the present study is similar to other researchers who have also found little or no dimorphism in CAP diameters (Epstein 1976; Hashimoto and Tak 1977; Kibii et al 2010; Singh and Balakrishnan 2013; Taitz 1996; Wolf et al 1956). Using lateral projection radiographs, Singh and Balakrishnan (2013) found that CAP diameters in an Indian population were slightly larger in males in comparison to females; however, the variation between the sexes was not statistically significant. Hashimoto and Tak (1977) also used lateral radiographs to observe cervical

vertebrae of a Japanese population. Hashimoto and Tak (1977) found no variation in the CAP diameters. Epstein (1976) and Wolf and colleagues (1956) found similar results when they examined clinical patients. Taitz (1996) has reported that measurements obtained from dry bone specimens exhibited no CAP sexual variation in Black South African population and only two vertebrae, C_6 and C_7, exhibited variation in a White South African population. Kibii and colleagues (2010) examined the C_7 vertebra and found no sexually dimorphic variation in C_7AP from a Zulu South African population.

In the current project, sexual dimorphism of the CAP diameter was only present in the first cervical vertebra (C_1AP). The etiology of the C_1AP dimorphism may be attributed to sexual variation between the male and female cranium (Marlow and Pastor 2011). The first cervical vertebra (C_1) cradles the weight of the skull and consequently shares a functional relationship with the cranial base. The dimorphic structures of the cranial base, such as the occipital condyles and foramen magnum, will therefore influence the morphological structure of C_1 such as the articular facets and the vertebral foramen (Marlow and Pastor 2011; Marino 1995). Studies by Holland (1986) and Gapert and colleagues (2009a, 2009b) have shown that the cranial base (occipital condyles and foramen magnum) exhibits sexual dimorphism. The functional relationship between the cranial base and C_1 influences C_1AP dimorphism (Marlow and Pastor 2011; Marino 1995).

In contrast to the current study, researchers have reported that sexual dimorphism exists in CAP diameters in various populations. Using lateral radiographs, Gupta and colleagues (1982) reported that the CAP diameter in cervical vertebrae from an Indian population exhibited a dimorphic variation of 1 mm between males and females. The only

exceptions were C_1 and C_3, which exhibited a difference of only 0.5 mm; this was not, however, a statistically significant dimorphic variation. Marlow and Pastor (2011) examined the dry bones of an historic White European population. Through stepwise regression analyses they found C_2AP to be one of the most dimorphic characteristics from a set of nine measurements. Amores and colleagues (2014) studied dry bones from a Mediterranean population. The mean male CAP diameters from C_7 vertebrae were found to be greater than in females. Their stepwise discriminant function analysis also selected the CAP diameter as the most dimorphic from a set of eight measurements. Tatarek (1999, 2005) found that CAP diameters from vertebrae C_2 to C_7 were sexually dimorphic in White and Black Americans. Wescott (2000) found dimorphism between male and female C_2AP dimensions in White and Black Americans however, the measurement did not exhibit a large enough variation to accurately estimate sex as compared to other measurements of the spine. Kibii and colleagues (2010) examined the C_7 vertebra and found that males exhibited greater C_7AP diameters than females in White and Coloured South African populations.

Human morphometrics can vary between populations due to differences in ancestral groups, genetic distance, environmental factors, and socioeconomic status, which influence the size and shape of skeletal characteristics (Albanese 2003; Clark 1985; Marlow and Pastor 2011; Taitz 1996; Tatarek 1999). These influences may have caused contrasting results between the current project and other population studies examining the cervical vertebrae. Also, variations in the methodological approaches and statistical tools applied by the researchers in each study may be a cause of non-biological

variability when comparing studies relating to the cervical vertebrae (Chandrakanth et al 2014).

Differences between ancestrally distinct groups have been cited in the anthropological research literature as contributing to skeletal morphological variability and diversity between geographic populations. Tatarek (1999) observed ancestral variation in some vertebral measurements between White and Black Americans while other measurements exhibited no ancestral variation. Variation due to ancestry in the cervical vertebrae has also been reported by Kibii and colleagues (2010) in three South African population groups (Zulu, White and Coloured). Murone (1974) found that the mean CAP diameters in Japanese men were 2.25 mm smaller than CAP diameters of White European men. Grave and colleagues (1999) have reported that a White Australian population exhibited sexual dimorphism with approximately 20% morphological difference between males and females, however, the Australian Aboriginal population only exhibited approximately 10% dimorphic variation between males and females. Grave and colleagues (1999) explained that greater sexual dimorphism in the White population is possibly due to the wide range of biological and environmental diversity within the ancestral group as compared to the indigenous aboriginals who are more geographically isolated and genetically homogenous. However, Marino (1997) studied ancestral variation in C_1 of White and Black Americans and found little ancestral differences in the vertebral foramen. Tatarek (1999) also found that some CAP, CTR and CHT measurements exhibited no ancestral variation between White and Black American populations. The results of the current project have also found that the CAP, CTR and CHT characteristics of the cervical vertebrae between two White European populations,

the Athens Collection from Greece and the Lopes Collection from Portugal, exhibit little variation due to ancestry. Females exhibited no differences between the Athens and Lopes Collections and only four (C_2TR, C_2HT, C_4HT, and C_6HT) of the 21 male measurements exhibited ancestral variation, however, these differences (only up to 2 mm) are not statistically significant. These differences may have been caused by genetic and/or environmental factors.

Genetic distance is another contributor to differences in cervical morphometrics between population groups (Kibii et al 2010; Tatarek 2005). Individuals originating from a specific geographic location form a gene pool of skeletal morphologic expression that is influenced by genetic heritability (Ember and Ember 1988: 110). Genetic alleles and gene frequencies are shared by closely affiliated populations and are shaped through generations of microevolution resulting in slight uniqueness in gene frequencies between population groups (Harrison 2010: 50-51; Konigsberg et al 1992). Eisenstein (1983) has reported that the variations of sexual dimorphism expressed between ancestrally distinct populations are caused by the slight genetic differences between the groups. Kibii and colleagues (2010) agree and have reported that within South African populations, White and Coloured groups exhibited sexual dimorphism in the CAP diameter whereas the Zulu group did not. The lack of CAP dimorphism in Zulus may be attributed to a homogeneous gene pool. The Zulu population experienced geographic isolation whereas the White and Coloured populations share genetic flow from other population groups. Grave and colleagues (1999) found similar results when comparing a White Australian population with an Australian Aboriginal population. The White Australians exhibited greater sexual variation between the sexes than the Australian Aboriginals due to a wider

range of genetic diversity in the White group. However, Tatarek (2005) and Kibii and colleagues (2010) have also demonstrated that observed variations in vertebral foramen diameters are not exclusively related to genetics but also influenced by other factors, such as environmental stresses.

According to Pollitzer and Anderson (1989: 1245), "genes do not determine destiny, but rather they set the stage upon which the environment operates". Although the current research found no sexual dimorphism present in the CAP diameter, other studies have found sexual dimorphism present in the CAP diameter (Amores et al 2014; Gupta et al 1982; Kibii et al 2010; Marlow and Pastor 2011; Tatarek 1999, 2005; Wescott 2000). Environmental factors influence genetic heritability and may contribute to the skeletal morphological variations observed in the vertebral foramen.

Environmental factors include dietary intake (calories, protein, vitamin D, and calcium), physical activity, environmental conditions, and hormonal levels (Pollitzer and Anderson 1989). Boas (1912) has demonstrated how environmental factors can influence skeletal morphology. Boas (1912) compared the cranial morphology of children born to immigrants in America and children born in the respective countries from where the parents immigrated. Boas' (1912) results suggest that the body exhibits plasticity and can be influenced by environmental factors. Therefore, environmental factors may also influence spinal morphology. The degree of sexual dimorphic expression exhibited in the vertebral foramen of White Europeans studied in the current project may be different when compared to other populations because of the different environmental influences acting on that population.

The effects of the environment on gene frequencies may also have contributed to the ancestral variations exhibited in four (C_2TR, C_2HT, C_4HT, and C_6HT) of the 21 male measurements within the Athens and Lopes Collections. Individuals can exhibit various environmental stresses that influence the physiology of the body and thereby influence the skeletal morphology and bone mass (Eisentstein 1983; Ember and Ember 1988: 110; Clark 1985; Kibii et al 2010; Pollitzer and Anderson 1989). Clark (1985) and Taitz (1996: 398) describe a "biological truism" that body development is not exclusively genetically influenced but rather the environment influences the body's morphological characteristics. Taitz (1996) further explains that environmental stresses coupled with genetic ancestral differences are the reason for the variance between White and Black South African cervical vertebrae. These influences may have contributed to the variations exhibited in four of the 21 male measurements within the Athens and Lopes Collections.

A study by Clark (1985) has illustrated that a lower socioeconomic status (i.e. poor overall health, malnutrition, and reduced activity) and physiological stresses will stunt the timing and rate of growth of the skeleton during embryonic and childhood development. 'Pervasive socioeconomic factors' refers to the negative and unwelcoming influences of a lower socioeconomic status that may lead to adverse physical effects on the body (Taitz 1996). Factors related to low socioeconomic conditions may negatively affect a child's early developmental years and influence the size of the vertebral foramen. The CAP diameter is especially susceptible to these influences since CAP development is complete by approximately four years of age. If the CAP diameter was negatively influenced this may result in stunted childhood growth (Clark 1985; Eisenstein 1983; Emmett and Jones 2014; Taitz 1996). Clark (1985) and others (Eisenstein 1983; Emmett

and Jones 2014; Taitz 1996) have also shown that lower maternal socioeconomic status during pregnancy will adversely affect the development of the fetus resulting in developmental complications after birth. Emmett and Jones (2014) have further correlated a lack of parental education and low household income to dietary deficiencies and poor health of children, especially in the vertebrae. Studies have found that spinal measurements, including those of the vertebral foramina, in Black populations are smaller than those in White populations (Eisenstein 1983; Grave et al 1999; Kibii et al 2010; Taitz 1996; Wescott 2000). This is attributed to a lower socioeconomic status within some Black populations. In the current research, some individuals may have been of lower socioeconomic status resulting in smaller vertebral foramen diameters. This may explain why four (C_2TR, C_2HT, C_4HT, and C_6HT) of the 21 male measurements exhibited ancestral differences between the Athens and Lopes Collections, although these differences were not statistically significant. The skeletal remains in the Athens and Lopes Collections were donated because families did not continue to pay the 'rental fee' for the gravesites of their loved ones. These individuals may have been from a lower socioeconomic status and therefore the families could not afford to continue the payments.

Some researchers have cited dimorphism in the CAP diameter while others have not (Amores et al 2014; Epstein 1976; Gupta et al 1982; Hashimoto and Tak 1977; Kibii et al 2010; Marlow and Pastor 2011; Singh and Balakrishnan 2013; Taitz 1996; Tatarek 1999, 2005; Wescott 2000; Wolf et al 1956). These differing conclusions may be related to the methodologies employed in the studies rather than morphological differences in the skeletons of the individuals examined (Chandrakanth et al 2014). The current study did

not find sexual dimorphism in the CAP measurement, which is contrary to the results found by Amores and colleagues (2014), Gupta and colleagues (1982), Kibii and colleagues (2010), Tatarek (1999, 2005), and Wescott (2000). These researchers accepted a type-1 error rate of 5% (p-value ≤ 0.05) to identify whether relationships existed between measurements. Type-1 error is the misclassification of a relationship between testable variables when one does not appear. Type-1 errors may be caused by procedural multiplicity error rather than a quantitative error in the data set resulting in a 'false positive' when examining relationships between variables (Chase et al 1978; Devane et al 2004; Meek, Personal Communication, December 10, 2014). When a p-value of 0.05 is selected, a 'false positive' is likely to occur five times out of every 100 tests when identifying variable relationships. Therefore, the researcher is willing to accept a 5% error in the relationship between variables when the true difference between the variables may be much smaller (Chase et al 1978; Devane et al 2004). A lack of CAP dimorphism in the current research may be attributed to the Bonferroni correction that adjusted the 5% statistical significance level (p-value ≤ 0.05) to reduce type-1 errors in the analyses. A Bonferroni correction was achieved by adjusting the 0.05 p-value according to the number of testable variables (n) in the testing hypotheses, since there is a greater likelihood that an error appears in the statistical outcome as the number of testable variables increases (Chase et al 1978; Devane et al 2004; Meek, Personal Communication, December 10, 2014). As a result, the current data found no variation in CAP diameters with the exception of C_1.

Singh and Balakrishnan (2013) and Kibii and colleagues (2010) have expressed concern over methods that involve collecting measurements from imaging techniques

(e.g. MRI and radiographs) rather than directly from the dry bones because they result in inaccurate data due to magnification errors. Eisenstein (1979), Ishikawa and colleagues (2003), and Miyasaka (1992) have found that methods utilizing imaging techniques can result in larger or smaller vertebral diameters when the results are compared to measurements from dry bones. Researchers have reported that between 1 mm and 3 mm variations may occur when reporting CAP diameters obtained from radiographs as compared to measurements from dry bone (Gupta et al 1982; Hashimoto and Tak 1977; Ishikawa et al 2003; Miyasaka 1992). However, Hashimoto and Tak (1977) have found that the dry bone dimorphic variation between male and female CAP diameters may be as small as 1 mm. Of the seven studies that show dimorphism does not exist in the CAP measurement, four were performed using imaging techniques (Singh and Balakrishnan 2013; Hashimoto and Tak 1977; Epstein 1976; Wolf et al 1956) and three were performed on dry bones samples (Taitz 1996; Kibii et al 2010), including the current project. Of the five studies that show dimorphism exists in the CAP diameter, one was performed using imaging techniques (Gupta et al 1982) and four studies were performed on dry bone samples (Amores et al 2014; Marlow and Pastor 2011; Tatarek 1999, 2005; Wescott 2000). The addition of magnification errors by researchers using imaging techniques may result in conclusions that dimensions are statistically significant when in fact they are not. This may be one of the reasons for the discrepancy between the conclusions in this research and those projects that utilized imagining techniques.

The results of the current study found that only two cervical measurements (CTR and CHT) exhibited sexual dimorphism. The maximum heights of the vertebral bodies (CHT) exhibited the greatest dimorphic variation between males and females. The

transverse diameters of the vertebral foramina (CTR) are the next best dimorphic indicators of sex. With the exception of C_1, the anterior-posterior diameters of the vertebral foramina (CAP) exhibited the least potential for estimating sex. Tatarek (1999) explains that the length of maturation time for the vertebral measurements is inversely proportional to the degree of sexual dimorphism. In other words, the longer the growth and development, the more sexual dimorphism is exhibited by the characteristic. The CAP diameter grows rapidly after birth and abruptly stops growing at approximately four years of age. The CAP diameter then remains constant throughout the child's developmental years and into adulthood. Wholey and colleagues (1958) have found that the ranges in CAP diameters for children between three and 14 years of age were nearly identical to those in adults. Ishikawa and colleagues (2003) have found only a small difference in the CAP diameters between individuals 11 to 19 years of age and adults over the age of 20 years. The differences, however, were not statistically significant. Clark (1985) and Porter and Pavitt (1987) have also found that the CAP diameter reaches its full adult length by age four or five years. Therefore, the CAP diameter is established before puberty, which begins at approximately 8 years of age, and is not influenced by secondary sex hormones. This may account for the lack of dimorphism expressed in the CAP measurement in the current project.

According to Tatarek's (1999) model of vertebral growth, the CTR and CHT measurements develop more slowly and for a longer period of time than CAP and are therefore influenced by secondary sexual development and environmental factors. Clark (1985) and Porter and Pavitt (1987) have found that by six years of age the vertebral foramen has reached approximately 90% of its complete adult size. During this

developmental time, biomechanical forces will change the vertebral foramen from a circular to a triangular shape to reflect the necessary range of neck motions that will morphologically protect the spinal cord (Clark 1985). The majority of dimensional increases occur in the CTR diameter, which reaches its adult size by approximately 10 years of age (Clark 1985; Porter and Pavitt 1987; Tatarek 1999). Therefore, the development of CTR extends into early puberty and is therefore influenced by secondary sexual development and biomechanical forces. The height of the vertebral bodies (CHT) has the longest period of growth reaching its full length at approximately 20 years of age (Tatarek 1999; Cardoso & Rios 2011; Albert et al 2010). In comparison, the development of CHT is 1.5 times slower than CAP (Tatarek 1999; Cardoso & Rios 2011; Albert et al 2010). In the current project, CHT exhibited the greatest dimorphism. This could be related to CHT development being exposed to secondary sexual development for a longer period of time, which corroborates the vertebral growth model proposed by Tatarek (1999).

5.2.2 *Sex estimation in the Cervical Vertebrae*

Sex estimation research of the cervical region of the spine has focused on three bones: C_1, C_2, and C_7 (Bethard and Seet 2013, Grave et al 1999; Kibii et al 2010; Marino 1995; Marlow and Pastor 2011; Wescott 2000). The morphological uniqueness of the atlas (C_1), axis (C_2) and the transitional seventh vertebra (C_7) have made these bones more popular to study as compared to the other cervical bones (C_3 to C_6) which are more difficult to sequentially identify. Focusing on an individual vertebra requires that the method utilizes a greater number of morphometric traits so as to increase the likelihood

of predicting sex from one individual bone (Amores et al 2014; Bethard and Seet 2013; Marino 1995; Marlow and Pastor 2011; Swenson 2013; Wescott 2000). Marino (1995) has suggested that if skeletal remains are damaged, any method of analysis that attains higher methodological accuracy while utilizing fewer measurements is most beneficial. Forensic anthropologists have a greater chance of estimating sex if the method requires fewer morphometric characteristics, from boney elements that are more taphonomically resilient, as compared to methods that require a greater number of characteristics from boney elements that are prone to damage (Marino 1995). Following Marino's (1995) suggestion, the current project created a method for estimating sex from the cervical vertebrae using three measurements from boney elements that are taphonomically resilient.

The current project first tested whether sex could be accurately estimated from a single cervical vertebra (C_1 to C_7) using three combinations of traits: all three measurements (CAP, CTR, CHT); vertebral foramen measurements only (CAP and CTR) and; the two most dimorphic measurements (CTR and CHT). When utilizing all three vertebral foramen measurements (CAP, CTR, and CHT), accuracies for estimating sex ranged between 69.6% and 76.4% for any single bone. When utilizing the two vertebral foramen measurements (CAP and CTR), accuracies for estimating sex ranged between 60.0% and 70.3% for any single bone. When the two most dimorphic characteristics (CTR and CHT) were utilized, accuracies ranged between 70.4% and 75.4%. Therefore, in the current research, a single vertebra did not accurately estimate sex above 80%, the minimum accuracy required to meet the Mohan and Daubert criteria for admissibility (Gama et al 2015; Marlow and Pastor 2011: 168; Molto 1979; Nichol and Turner 1986;

Novotny and Işcan 1993; Rogers 1999; Rogers and Saunders 1994; Williams and Rogers 2006).

In contrast to the current project, other researchers have successfully estimated sex from a single cervical vertebra. Amores and colleagues (2014) examined eight measurements from C_7 using four discriminant functions and achieved between 65.5% and 80.2% accuracy. Marino (1995) examined eight characteristics from C_1 using seven regression equations and achieved 77% to 85% accuracy. Seven discriminant functions were also created and achieved 75% to 85% accuracy. Wescott (2000) examined eight dimensions from C_2 vertebrae and created five discriminant functions, which achieved between 81.7% and 83.4% accuracy. Bethard and Seet (2013) tested Westcott's (2000) discriminant functions and achieved accuracies between 78% and 90.6% using five measurements from the C_2 vertebra. Marlow and Pastor (2011) also tested Wescott's (2000) discriminant functions on C_2 vertebrae and achieved between 70.91% and 78.9% accuracy. A stepwise regression formula achieved 83.3% accuracy. Swenson (2013) examined C_1 vertebrae using eight measurements and achieved accuracies between 86.7% and 89.1%. The successful sex estimation from a single cervical vertebra may be attributed to the greater number of morphometric characteristics utilized in the analysis. Bethard and Seet (2013) and Wescott (2000) cited that with every increase in the number of measurements used in a discriminant function, the accuracy for estimating the sex also increases. The current research concurs and has found that utilizing a greater number of measurements and a greater number of cervical vertebrae achieves higher accuracies than utilizing fewer measurements and fewer bones. For instance, when two cervical vertebrae and all three measurements (C_1 and C_2; CAP, CTR and CHT) were used to estimate sex

the function achieved 72.8% accuracy. When the number of cervical vertebrae increased to four (C_3 to C_6) the accuracy of the discriminant function utilizing all three measurements (CAP, CTR, and CHT) increased to 80.6%. When all seven cervical vertebrae and all three measurements were used, the discriminant function achieved a higher accuracy of 84.1%.

Only seven discriminant functions (Functions 1, 2, 3, 4, 5, 6, and 7) from the current study achieved predictive accuracies above 80%, rendering them useful in a forensic context. Greater than or equal to 80% accuracy rate with an intra-observer error rate less than or equal to 10% has been cited as the minimum standard needed for a methodology to meet the *Mohan* and *Daubert* evidence admissibility criteria (Gama et al 2015; Marlow and Pastor 2011; Ostrofsky and Churchill 2015; Rogers 1999; Williams and Rogers 2006). A cross-validation study was performed on the seven discriminant functions using a subset of individuals from the Athens and Lisbon Collection, an independent cross-validation sample. The subset group was not used to create the discriminant functions and therefore can measure the predictive performance of the seven functions. Cross-validation resampling evaluates the reliability of a procedure and avoids over-optimistic predicted accuracy estimates by recognizing possible variations in the performances of a discriminant function when tested on an independent sample (Bernau et al 2014; Christensen and Crowder 2009). The cross-validation test showed that four of the seven functions (Functions 2, 4, 5, and 7) achieved accuracies equal to or greater than their predictive accuracies, which indicates they are strong statistical algorithms. However, the cross-validation accuracies for Functions 1, 3, and 6 were lower than their predicted accuracies. Function 1 utilized the two most dimorphic measurements (CTR

and CHT) from vertebrae C_2 to C_7 and achieved an overall predictive accuracy of 84.5% however, the cross-validation accuracy only achieved 78.3%. Function 3 utilized the two most dimorphic measurements (CTR and CHT) from vertebrae C_3 to C_7 and achieved an overall predictive accuracy of 83.3%; a cross-validation test only achieved 82.6% accuracy. Function 6 utilized all three measurements (CAP, CTR, and CHT) from vertebrae C_3 to C_6 and achieved a predictive accuracy of 80.6%. The cross-validation test only achieved 79.2% accuracy. The differences between the predicted and cross-validation accuracies for Functions 1, 3, and 6 are 6.2%, 0.7%, and 1.4%, respectfully. The variance for Functions 3 and 6 are low and within the acceptable margins of a 5% significance level, which indicates that the overall differences are not significant and the discriminant functions are still accurate at estimating sex. Function 1 achieved significantly lower cross-validation accuracy than predicted accuracy.

Christensen and Crowder (2009) have acknowledged that although some methods may achieve accuracies less than 80% (e.g. between 70% and 80% accuracy where the estimation is greater than chance yet below the acceptable standard) the method may still be valuable in a forensic context especially if the method is the most accurate technique to the disposal of forensic anthropologists based on available skeletal material. Therefore, although Functions 1 and 6 exhibit less than 80% accuracy in the cross validation, they may still be used in sex estimation if the available skeletal material does not allow for other methods to be used.

A small cross-validation sample size and 'batch effects' may have contributed to the lower accuracies in the cross-validation study as compared to the overall predicted accuracies. The suggested sample size for a cross-validation analysis is 10% of the

independent sample (Bernau et al 2014; Refaeilzadeh et al 2009). The population size of the current project was 295 individuals therefore 30 individuals is the recommended sample size for the analysis. Although a sample size of 32 individuals was measured for this purpose, the actual sample sizes for each of the seven functions ranged between 19 and 25 individuals (Table 4.38) due to damage of the measured characteristics or missing vertebrae. 'Batch effects' is another source of variation that occurs in high-throughput experiments (Leek et al 2010). "Batch effects" is the statistical variation that occurs when conditions vary during the course of an experiment (Leek et al 2010). Due to the different sample sizes used to test each discriminant function, the conditions changed which may have led to a change in the accuracy response for each function. In general, the sex classification accuracies of the seven functions presented in the current research are comparable to other studies (Amores et al 2014; Bethard and Seet 2013; Marino 1995; Marlow and Pastor 2011; Swenson 2013; Wescott 2000).

5.3 The Relationship between Stature and Cervical Vertebrae

The relationship between stature and the three measurements of the cervical vertebrae (CAP, CTR and CHT) were investigated. If a correlation exists between stature, CAP, CTR and CHT than these characteristics are influenced by growth and the overall size of the body rather than being influenced by other variables such as age, sex, or ancestry. The results of the current study show that there is no statistical significance between stature and any of the three measurements of the cervical vertebrae (CAP, CTR, and CHT). There is also no relationship between the vertebral foramen diameters (CAP and CTR) and CHT. The vertebral foramen diameters (CAP and CTR) exhibited no

significant relationship with the exception of C_1AP and C_1TR. The relationship between the vertebral foramen diameters of C_1 may be caused by both the C_1AP and C_1TR measurements exhibiting sexual dimorphism rather than a correlated length relationship between these two diameters.

Tatarek (1999, 2005) examined the dry bones of White and Black American populations to observe whether an individual's body composition (weight and height) influenced vertebral morphometrics. Tatarek (1999, 2005) found that there was no relationship between the CAP, CTR and CHT measurements; however, there was some linear relationship between stature and vertebral foramen diameters (CAP and CTR). Tatarek (1999, 2005) tested the relationship between stature and vertebral foramen diameters and found that it could not be explain by more than 5% of the variation indicating that there was little relationship between stature and the vertebral foramen. In contrast to the current project and Tatarek (1999 2005), Gupta and Srivastava (1982) measured lateral radiographs in an Indian population. Their study showed a relationship between the CAP diameters and stature in males but no relationship in females. However, in males the CAP diameter increased between 0.5 mm and 1 mm with every 4 cm increase in stature resulting in "some [linear] relationship to height" (Gupta et al 1982: 46). Gupta and Srivastava (1982) further investigated whether a relationship existed between the CAP diameter and an individual's weight, however, no relationship was found.

Ishikawa and colleagues (2003) used MRI and lateral radiographs to investigate whether the CAP and CTR diameters of the vertebral foramen are related to stature in a Japanese population. Contrary to the current project and Tatarek (1999, 2005), the results

indicated that the vertebral foramen and stature are positively correlated which demonstrated that CAP and CTR increase with an increase in height. Torimitsu and colleagues (2015) studied CT scans from a Japanese population to examine the relationship between three measurements of the C_2 vertebra (maximum height, the length from the anterior-inferior point of the vertebral body to the posterior point of the spinous process, and the length from the top of the dens to the posterior point of the spinous process) and stature. They found a positive correlation. The authors also stated that stature could be estimated from the three C_2 measurements although accuracy rates were not presented (Torimitsu et al 2015)

Torimitsu and colleagues (2015) cited that cadaveric stature measurements are different from those of living stature due to physiological changes that occur after death such as the loss of muscle tone and a reduction of spinal curvature. Methods of stature research that utilize imaging technology to measure the bones of living individuals, as compared to deceased individuals, may exhibit variations exceeding 2.5 cm in length due to these physiological changes and magnification errors (Torimitsu et al 2015). Also, a variance of up to 2 cm may be exhibited between measurements from fresh or 'wet' (specimens with soft tissue present) cadaveric bone specimens and 'dry' (skeletonized specimens) bone samples (Torimitsu and colleagues 2015). These sources of error may account for the differences observed in the relationship between stature and cervical vertebra between the current study and those that utilize imaging technology.

The utilization of different error rates may also explain the variations cited in the literature between stature and vertebral morphometric correlations. An error rate of 5% significance (p-value= 0.05) was used in other studies to identify the relationship between

stature and the cervical vertebra (Gupta and Srivastava 1982; Ishikawa et al 2003; Tatarek 2005; Torimitsu et al 2015). The current study, however, adjusted the 5% significance level to account for the possibility of a type-1 error using a Bonferroni correction value and thereby reducing the chance of type-1 errors in the analysis. As a result, the current data found no statistically significant relationship between stature and the cervical vertebrae with the exception of C_1.

Sexual dimorphism is known to influence human stature since males are on average taller than females in most populations (Gray and Wolfe 1980). The difference between male and female stature is attributed to environmental factors, genetic growth potential, and sexual selection (mating practices) among different populations (Gray and Wolfe 1980). Stature and vertebral morphometrics may therefore exhibit a relationship due to both characteristics exhibiting sexual dimorphism rather than a correlated growth relationship.

5.4 The Relationship between Age and the Cervical Vertebrae

The relationship between the cervical vertebrae (CAP, CTR, and CHT) and age was examined. The size of the vertebral foramen remains constant from the time of complete fusion, at approximately 10 years of age, throughout life (Clark 1985; Wholey et al 1958). However, the vertebrae may exhibit age-related changes. The current method created seven sex estimating discriminant functions for adults from 20 to 99.99 years of age. If the vertebrae exhibit age-related changes between younger (20-49.99 years of age) and older (50-99.99 years of age) individuals, the accuracy of these functions may be negatively affected.

The current study examined cervical vertebrae from individuals 20 to 100 years old to understand if age-relate changes occurred in the cervical spine. The results of the analyses indicated that females exhibited no variation in vertebral measurements due to age-related changes to the spine. Males exhibited no variation in CTR and CHT measurements and only four CAP diameters (C_2AP, C_3AP, C_4AP, and C_6AP) exhibited differences due to age. Further testing of these four CAP characteristics revealed a gradual decline in the diameter of CAP beginning between 40 and 50 years of age. The C_4AP diameter began to decline earlier, at approximately 30 to 40 years of age. The differences between the smallest and largest mean diameters of C_2AP, C_3AP, C_4AP, and C_6AP were 2.08 mm, 1.72 mm, 1.89 mm, and 1.63 mm, respectively. However, a variation of less than 2 mm in only four measurements from a total of 17 measurements may not be considered biologically significant in the overall results (Rühli et al 2006; Tatarek 1999). Therefore, minimal age-related changes to the cervical vertebrae are exhibited.

The results of the current project are similar to those of other researchers (Rühli et al 2006; Taitz 1996). Rühli and colleagues (2006) studied the impact of aging on the adult (20+ years of age) vertebral column using 14 measurements. Comparisons were made between a modern population group from Switzerland and an historic European population from the Late Upper Palaeolithic to Late Medieval time period. The results indicated that the vertebral foramen dimensions (CAP and CTR) and vertebral height (CHT) did not change significantly in adults as they aged. Approximately 20% of all the measurements exhibited age-related changes to the spine with no significant differences between historic and modern populations. Modern females did not exhibit age-related

changes in any of the 14 measurements whereas modern males exhibited changes to dimensions of the vertebral bodies and pedicles. Historic females exhibited only one age-related change whereas historic males exhibited similar frequencies of dimensional changes as found in modern males. Rühli and colleagues (2006) concluded that the age-related changes to the spinal column occurred mostly in males and were concentrated to soft tissue changes to the spine, such as the degeneration of intervertebral disks. A physiological reaction may also have occurred resulting in increased robustness of the cortical bone surface in elderly men. The remodeling in males, who exhibit greater muscle mass than females, is to compensate for decreased "stiffness" and bone mass in cancellous bone; however, the vertebral foramen was minimally affected (Rühli et al 2006). Taitz (1996) also examined the effects of aging on White and Black South African populations. The results found no relationship between aging and the size of the vertebral foramen diameters (CAP and CTR) in males or females.

In contrast to the current study and others (Rühli et al 2006; Taitz 1996), Ishikawa and colleagues (2003) found that the CTR diameter decreased with age in males and females in a Japanese population. The total vertebral foramen area also became narrower with age. Tatarek (1999) also found that the CAP and CTR diameters decreased as age increased in White and Black American populations. Tatarek (1999) showed that most individuals exhibiting smaller canal sizes were older in age, which would indicate the canal diameters became smaller with age.

CHAPTER 6: CONCLUSIONS

The current study focused on the seven cervical human vertebrae to establish an accurate sex estimation method for a White European skeletal population. The objectives of this thesis were:

(1) To understand the relationship between sex and the measurements of the cervical vertebral foramen (anterior-posterior and transverse diameters) and the cervical vertebral body (maximum body height) in the contemporary Athens and the historic Lopes White European skeletal populations.

(2) To understand the relationship between stature and the measurements of the cervical vertebral foramen (anterior-posterior and transverse diameters) and cervical vertebral body (maximum body height) in the contemporary Athens and the historic Lopes White European skeletal populations.

(3) To evaluate the relationship between age and the measurements of the cervical vertebral foramen (anterior-posterior and transverse diameters) and the cervical vertebral body (maximum body height) in the contemporary Athens and the historic Lopes White European skeletal populations.

In this study, the seven cervical vertebrae from 295 individuals (157 males and 138 females) of White European ancestry were examined for their potential in estimating sex. One thousand and twenty (N=1020) individual vertebrae were studied from two White European skeletal collections, the Athens Collection representing a contemporary population and the Luis Lopes Collection representing an historic population. Only

vertebrae of adult individuals (ages 20 years and older) were studied to ensure that the cervical vertebrae are skeletally mature and reached their maximum size. Damaged or pathologically remodeled vertebrae were excluded from the study with the exception of mild osteoarthritis. Following the inclusionary criteria from previous researchers (Eisenstein 1983; Jones and Thomson 1968; Tatarek 2005; Voisin 2011) vertebrae exhibiting mild osteoarthritis were studied if the degeneration did not inhibit the measurable characteristics. Cervical vertebrae were numerically identified as C_1 through C_7 according to their anatomical location in the spine. Following the measurement protocols from previous researchers (Clark 1985; Eisentstein 1983; Jones and Thomson 1968; Kibii et al. 2010; Taitz 1996; Tatarek 1999, 2005; Verbiest 1955), three morphometric traits were measured from each cervical vertebra: Cervical Anterior-Posterior Diameter (CAP), Cervical Transverse Diameter (CTR), and Maximum Cervical Vertebral Body Height (CHT). The CAP and CTR vertebral foramen diameters are enclosed and protected by the vertebral arches and the CHT measurement is located on the dense vertebral body resulting in resiliency to mechanical, taphonomic and architectural stresses for sex estimation analyses in forensic cases. A total of 21 characteristics were measured for each individual, i.e. three measurements for each of the seven cervical bones.

Intra-observer error exhibited statistically significant variation in five of the 21 measurements (C_3TR, C_4TR, C_5TR, C_6TR, C_4HT), however, intra-observer error rates were less than 10%; the Mohan and Daubert evidence admissibility criteria require that intra-observer error rates are less than 10% for measurable characteristics. Inter-observer error exhibited statistically significant variations in six of the 21 measurements (C_3AP,

C_1TR, C_3TR, C_5TR, C_6TR, C_3HT). With the exception of C_1TR, inter-observer error rates were less than the 10% standard. The least consistency occurred in the CTR diameter suggesting extra care must be taken when measuring CTR. Therefore, the CAP, CTR and CHT characteristics are reproducible measurements.

To date, no study has used the combination of vertebral foramen measurements (CAP and CTR) and the vertebral body height (CHT) from the cervical vertebrae to estimate sex. The CTR and CHT measurements were found to be sexually dimorphic and they contributed to the differentiation of biological sex. The CHT characteristic exhibited the greatest dimorphic variation between males and females followed by the CTR diameter. The CAP diameter was not significantly dimorphic. Previous literature has shown that CHT is the most dimorphic measurement of the cervical vertebrae followed by CTR and then the CAP diameter. The variations of sexually dimorphic expression exhibited between the CAP, CTR and CHT measurements are due to the timing of maturation and the influences of sexual hormones during the development of each characteristic.

Utilizing the cervical vertebrae, this study developed seven multivariate discriminant functions that successfully classified individuals as either male or female with greater than 80% accuracy, which is the minimum standard needed for a methodology to meet the Mohan and Daubert criteria. Function 1 utilized CTR and CHT from C_2 to C_7 and achieved the highest predicted sex estimating accuracy at 84.5% (85.0% males; 83.0% females). Function 2 utilized CAP, CTR, and CHT from C_1 to C_7 and achieved the second highest predicted sex estimating accuracy at 84.1% (83.7% males; 84.6% females). Function 3 utilized CTR and CHT from C_3 to C_7 and achieved

the third highest predicted sex estimating accuracy at 83.3% (82.9% males; 83.9% females). Function 4 was a step-wise discriminant function selecting seven of the 21 measurements (C_1AP, C_2HT, C_2TR, C_3HT, C_5HT, C_5TR, C_7TR) and achieved a predicted sex estimating accuracy of 82.6% (77.3% males; 88.2% females). Function 5 utilized CAP, CTR, and CHT from C_3 to C_7 and achieved a predicted sex estimating accuracy of 82.3% (81.9% males; 82.8% females). Function 6 utilized CAP, CTR, and CHT from C_3 to C_6 and achieved a predicted sex estimating accuracy of 80.6% (80.2% males; 81.2% females). Function 7 utilized CTR and CHT from C_3 to C_6 and achieved the lowest predicted sex estimating accuracy at 80.3% (80.2% male; 80.4% female). Females exhibited greater accuracies in six of the seven functions (Functions 2 to 7) as compared to males. Overall, discriminant functions that utilized a greater number of measurements and a greater number of cervical vertebrae achieved higher accuracies than those that utilized fewer measurements and fewer bones.

A cross-validation study evaluated the reliability of the seven functions to estimate sex by testing the predictive performance of each function on a subset group that was not used to create the discriminant functions. Functions 2, 4, 5, and 7 achieved accuracies equal to or greater than their predictive accuracies, 84.2%, 87.0%, 82.6%, and 87.5%, respectively, which indicates that these are strong statistical algorithms. Functions 1, 3, and 6 achieved cross-validation accuracies lower than their predicted accuracies, 78.3%, 82.6%, and 79.2%, respectively. Although Functions 1 and 3 achieved less than 80% accuracy in cross validation, they may still be reliable for estimating an individual's sex if the available skeletal material does not allow for other methods to be used.

No significant ancestral differences were exhibited between the contemporary Athens and the historic Lopes Collections therefore the same discriminant functions can be used for both populations. Future research should explore the possibility of estimating sex using the cervical vertebrae from other ancestral groups to test the accuracy and reliability of these discriminant functions on other populations.

In this study, the relationship between stature and the measurements of the cervical vertebrae (CAP, CTR and CHT) was investigated to understand whether correlations existed between these characteristics. No relationship existed between stature and any of the three measurements. Vertebral foramen diameters (CAP and CTR) exhibited no relationship with CHT. This illustrates that an individual's overall body size, weight and height, do not influence the CAP, CTR and CHT characteristics. Therefore, the current method of sex estimation from the cervical vertebrae may be applied to individuals of various body compositions. Also, the diameters of the vertebral foramen (CAP and CTR) exhibited no relationship between each other, with an exception in the C_1 vertebra. A functional relationship exists between the cranial base and C_1 since the first vertebra cradles the weight of the skull. Consequently, the dimorphic structures of the cranial base, such as the occipital condyles and foramen magnum, will influence the morphological structure of C_1 such as the articular facets and the vertebral foramen. The vertebral foramen of C_1 (CAP and CTR) exhibit sexual dimorphism because the size and shape of the foramen magnum is also sexually dimorphic.

In this study, the effects of aging on the cervical vertebrae were evaluated in relation to the CAP, CTR, and CHT measurements. If the size of the three morphometric characteristics change as an individual ages from 20 years of age to 100 years, then the

accuracy for estimating sex from the cervical vertebrae using the seven multivariate discriminant functions may be affected. Females were found to exhibit no age-related changes in the cervical morphometrics. Males exhibited no age related changes in CTR or CHT measurements; however, four CAP diameters (C_2AP, C_3AP, C_4AP, and C_6AP) did exhibit statistically significant changes with increasing age. Further statistical testing revealed that these four male CAP diameters gradually decrease in size between 30 years and 90 years of age. However, the CAP diameter exhibited no significant dimorphic potential for estimating sex even though Functions 2, 3 and 7 utilize CAP in the discriminant functions. Therefore, the current method of sex estimation from the cervical vertebrae may be applied to all adult individuals of White European ancestry from Greece and Portugal.

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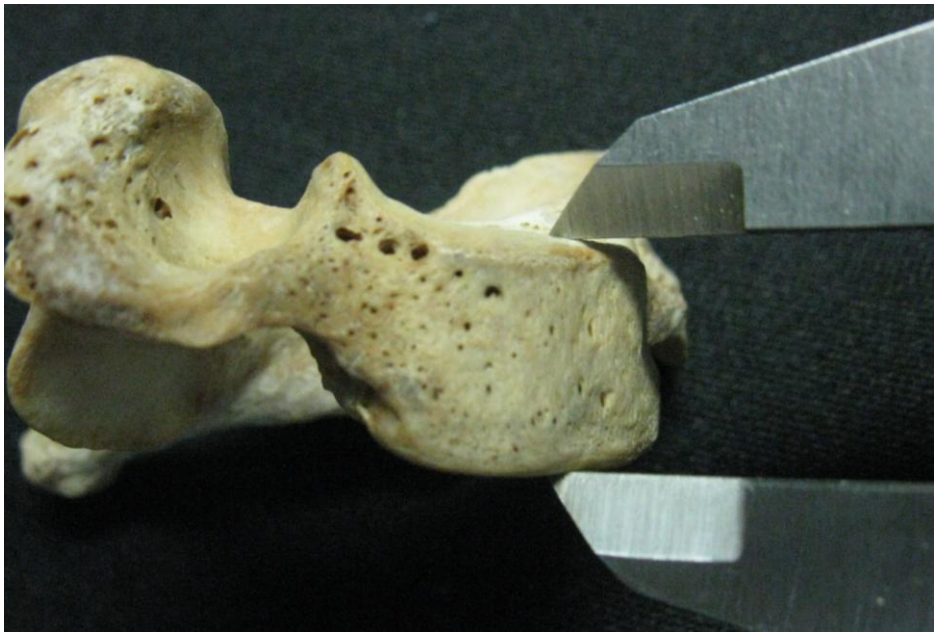
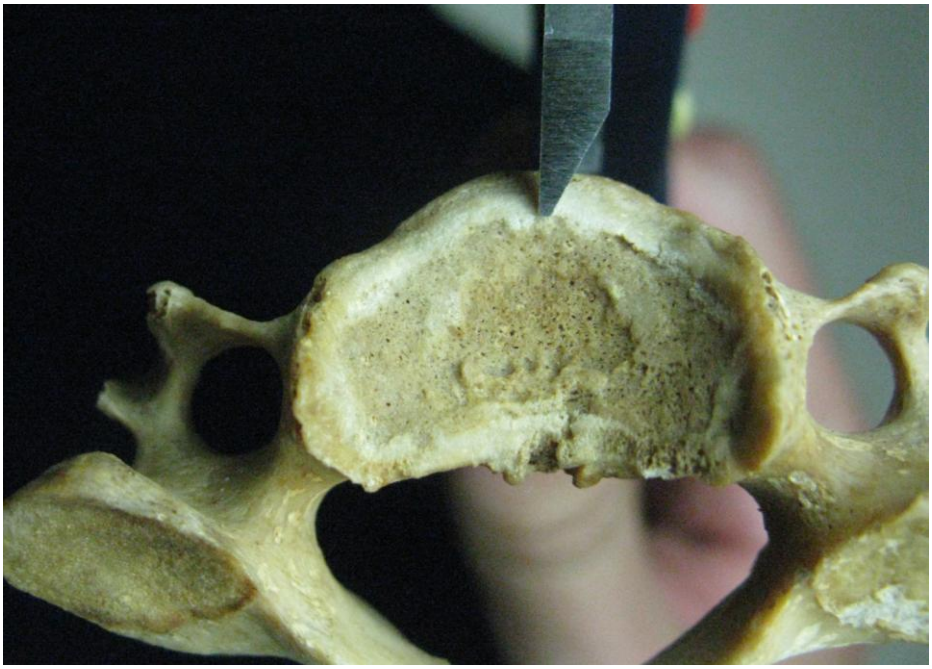
APPENDIX A: Cervical Vertebrae Skeletal Measurements

Cervical Maximum Vertebral Body Height (CHT):

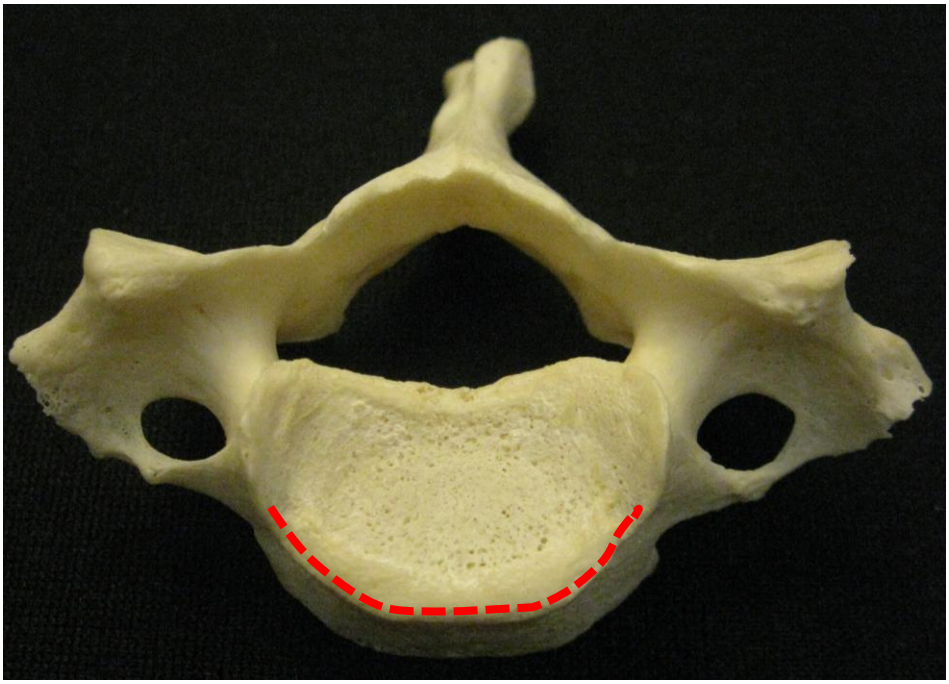
The maximum cervical vertebral body height (CHT) measurement is defined as the maximum superior to inferior height of the vertebral body centrum (Fully 1956 in Raxter et al 2006). Hold the vertebra in your hand with its superior surface facing up and the inferior surface facing down. Using the outside measuring arms of the sliding caliper (to measure external diameters), place the immovable caliper arm on the superior surface of the vertebral centrum and the sliding arm on the inferior surface of the centrum (Appendix A1). Place the tips of the caliper arms on the vertebral body rims and not the centra (Appendix A2). Systematically slide both caliper arms across the anterior one-third area (Appendix A3) to find the maximum height of each body (Appendix A4). Ensure that the caliper is held as closely as possible to the perpendicular plane of the vertebral body's superior and inferior surfaces (Appendix A1). The anterior-inferior vertebral body surface for vertebrae C_2 to C_5 may project anteriorly and the centrum may resemble a saddle or dome shape rather than a straight level surface in the medio-lateral plane (Appendix A5). Both caliper arms cannot rest at the anterior rims while maintaining the perpendicular plane in this instance. To correct for this, ensure the immovable arm (superior) is held in the perpendicular plane with the superior body surface. The inferior rim will rest at the center of the caliper arm instead of the tip (Appendix A5). Avoid any osteophytic growth or bone spurs that are present (Fully 1956 in Raxter et al 2006).



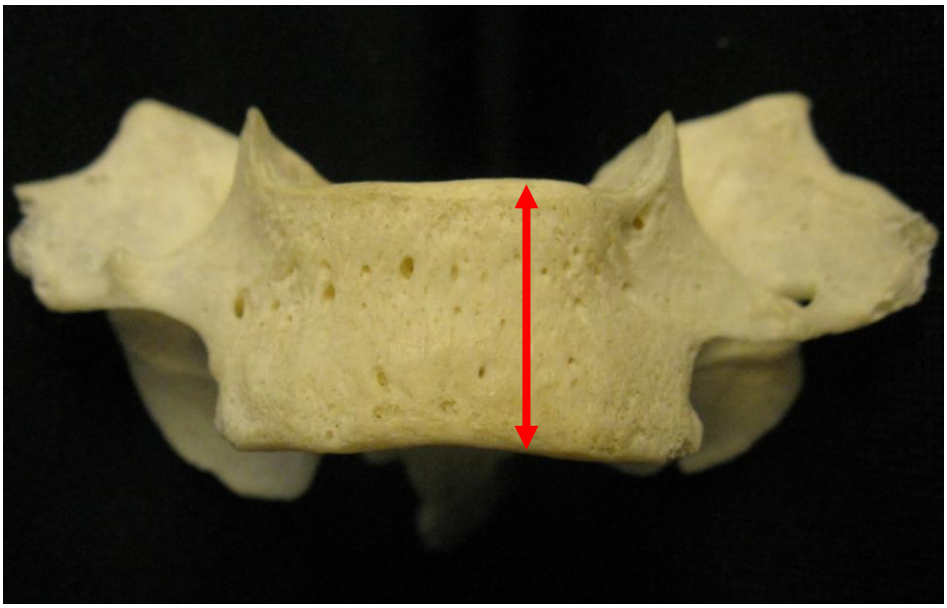
Appendix A 1 Medial view of a typical cervical vertebra. Vernier caliper placement from superior to inferior surfaces to measure the Maximum Cervical Vertebral Body Height (CHT). (Photo by Andrew S. Rozendaal)



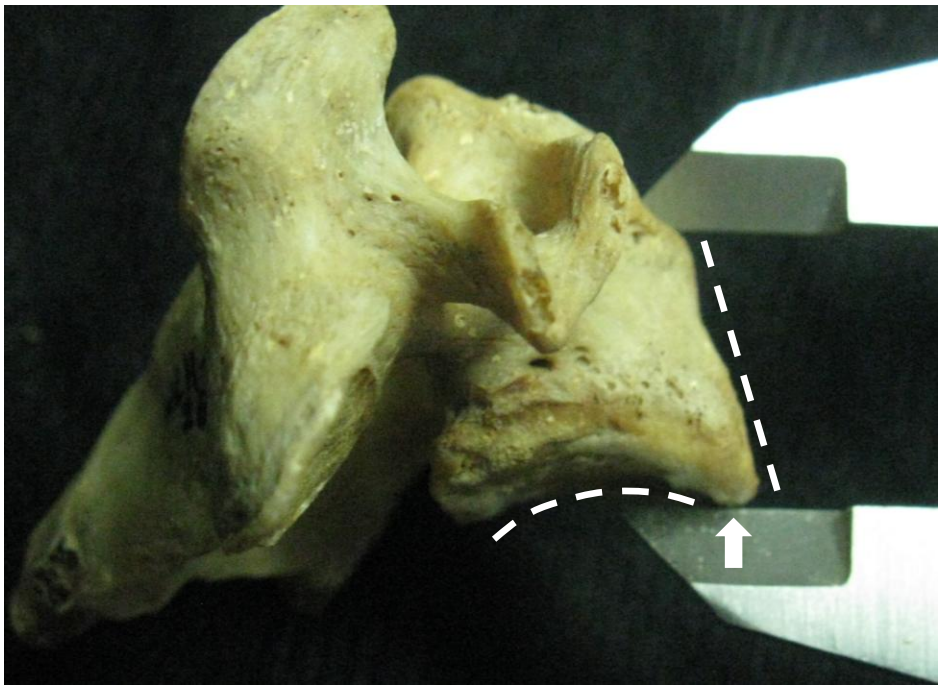
Appendix A 2 Superior aspect of a typical cervical vertebra. Caliper placement on the anterior vertebral border and not the center of the body. (Photo by Andrew S. Rozendaal)



Appendix A 3 Superior view of a typical cervical vertebra. The red dotted line indicates the one-third area along the anterior border for measuring the Maximum Cervical Vertebral Body Height (CHT) using Vanier calipers. (Photo by Andrew S. Rozendaal)



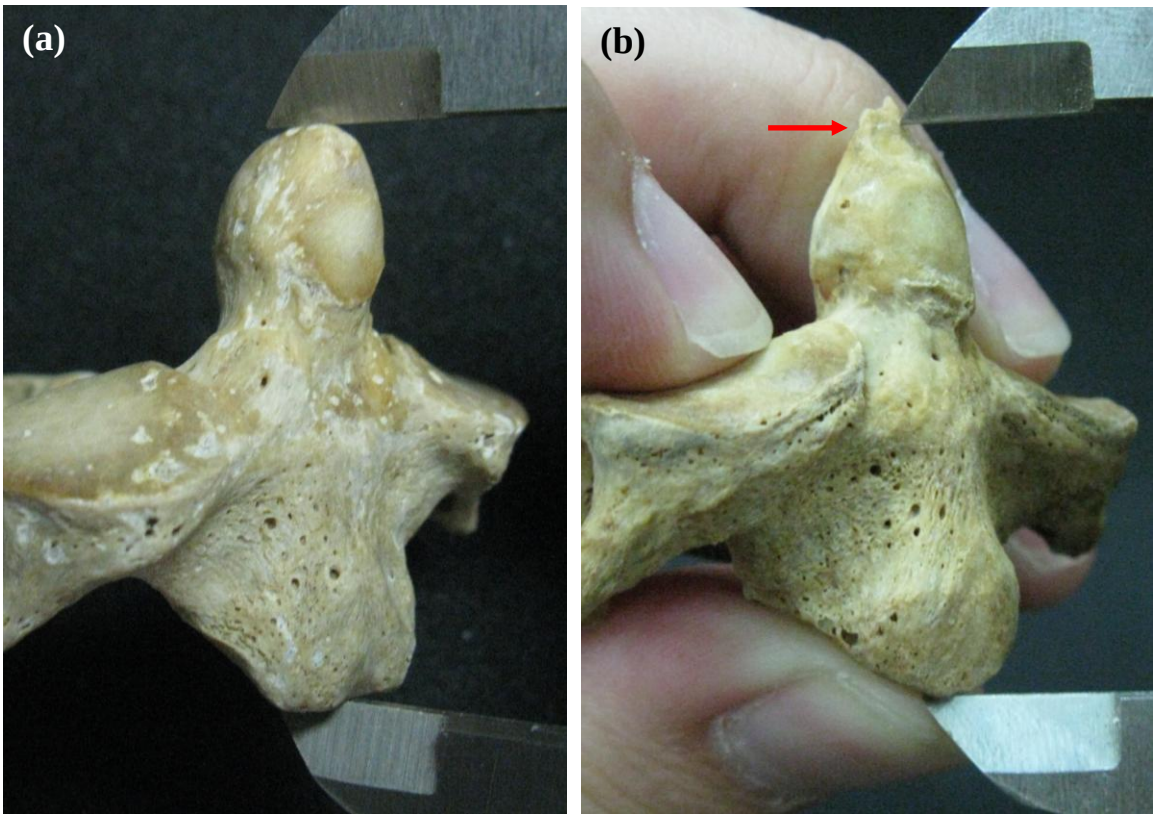
Appendix A 4 Anterior view of a typical cervical vertebra. Measuring the Maximum Cervical Vertebral Body Height (CHT) from superior to inferior surfaces of the vertebral body. (Photo by Andrew S. Rozendaal)



Appendix A 5 Lateral view. Measuring CHT from a vertebra exhibiting an anterior projection of the inferior border (white line) and a saddle or dome shaped inferior body surface (white curve). Note the inferior vertebral body rim rests at the centre of the caliper arm in this measurement (white arrow) and not the tip. (Photo by Andrew S. Rozendaal)

The first cervical vertebra (C_1) is a uniquely structured vertebra that cradles the skull. The morphological structure of C_1 is roughly circular and lacks a vertebral body therefore C_1HT was not measured. The second cervical vertebra (C_2) CHT was measured from the most superior point of the odontoid process (the dens) to the most inferior point of the anterior border using sliding calipers (Appendix A6a) (Fully 1956 in Raxter et al 2006). C_2HT is the only vertebra measured exclusively at the mid-sagittal plane, and not the anterior one-third area, due to the apex of the odontoid process. Osteophytic growth on the superior most aspect of the dense was not included in the C_2 measurement. If a bony growth was present, the immovable caliper arm was placed at the observed scarring

line between the superior most aspect of the dense and the inferior aspect of the osteophytic growth (Appendix A6b).

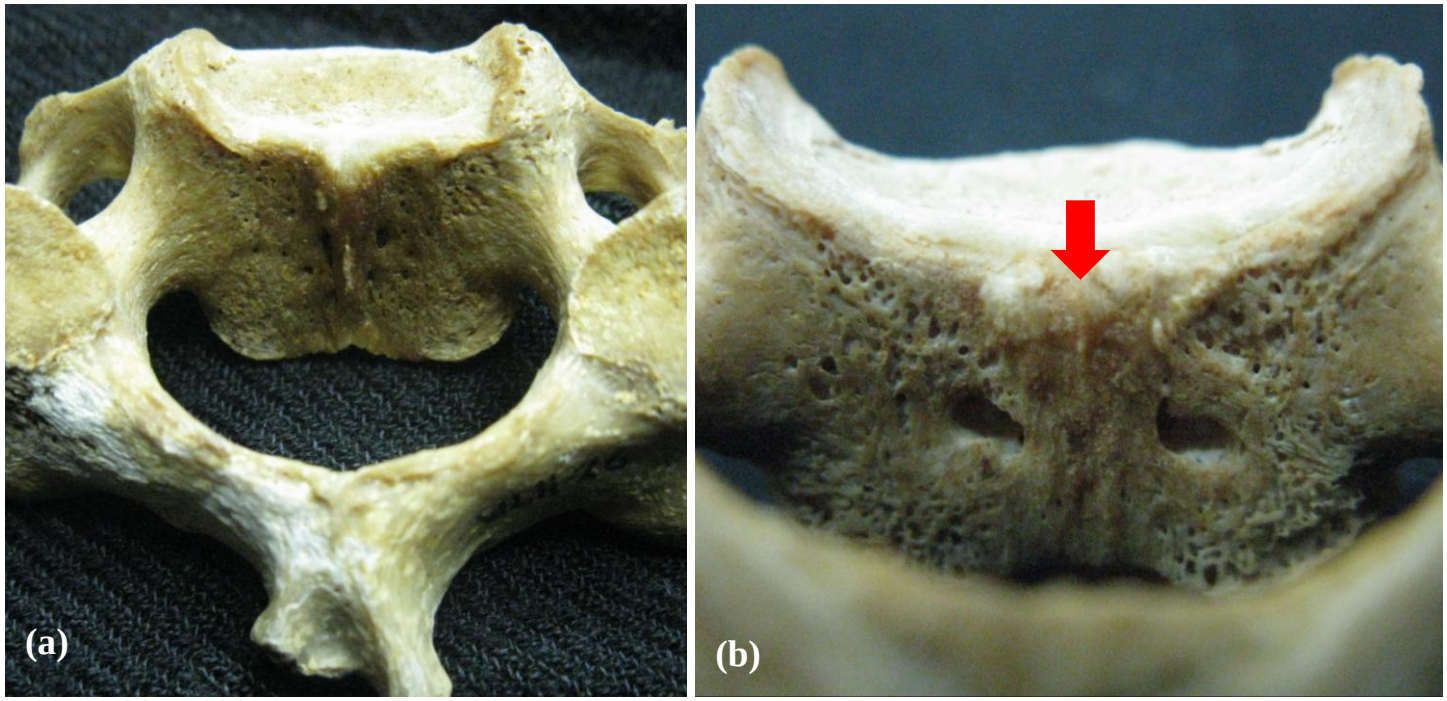


Appendix A 6 Antero-medial aspect of C_2 vertebra. Caliper placement measuring C_2HT of an individual with (a) no osteophytic growth on the dens and (b) osteophytic growth on the dens. Note the scaring line between the dens and osteophytic growth of the dens (red arrow). (Photos by Andrew S. Rozendaal)

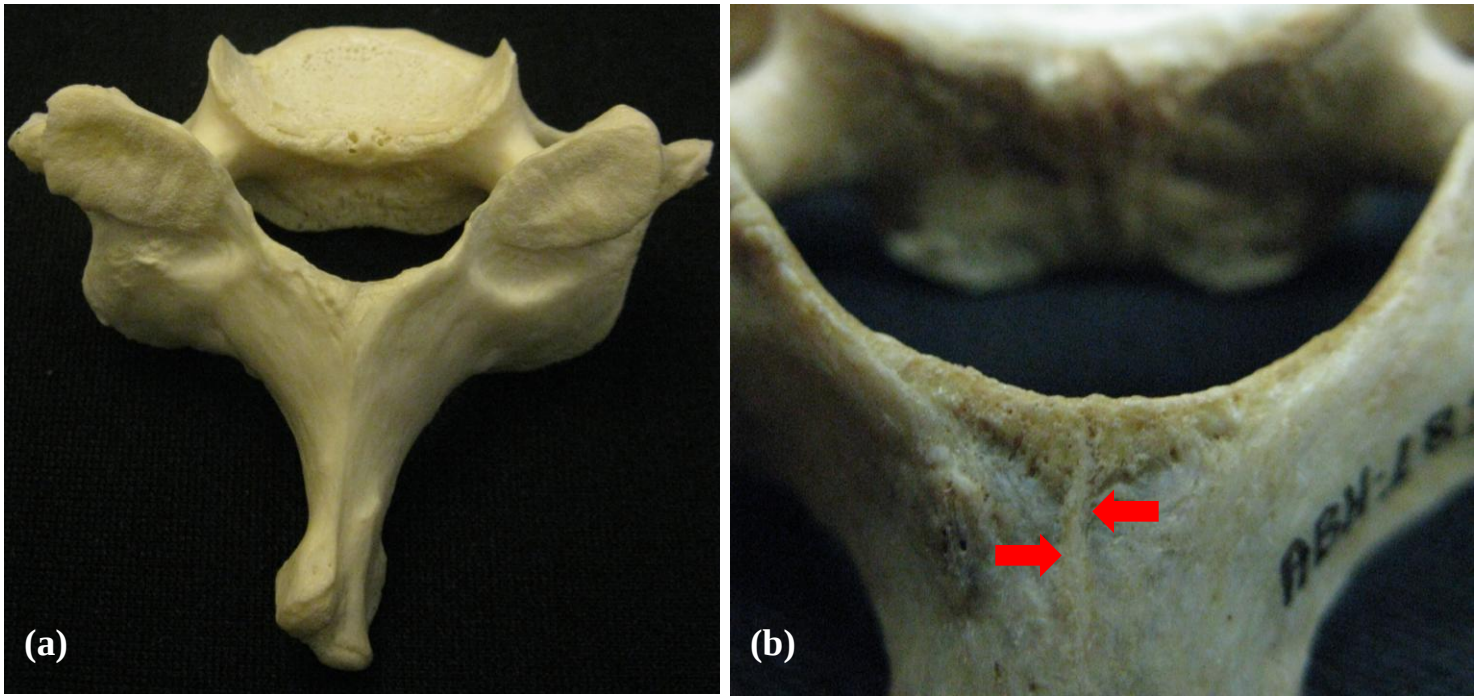
Cervical Anterior-Posterior Diameter (CAP):

The cervical anterior-posterior vertebral foramen diameter (CAP), also known as the sagittal canal, is the maximum mid-sagittal diameter from the anterior to posterior aspects of the vertebral foramen (Appendix A7) (Clark 1985; Taitz 1996; Tatarek 1999, 2005; White et al 2012). Hold the vertebral body in your hand with the superior surface facing up and the inferior surface facing downward. All measurements of CAP are obtained from the superior aspect of the canal opening with the exception of C_2 which is measured from the inferior aspect. Using the sliding calipers inside measuring arms (used to measure internal diameters), place the immovable caliper arm at the mid-sagittal line of the posterior vertebral body within the canal (Appendix A8a). The mid-sagittal line is a distinct skeletal landmark that appears similar to an obliterated point of fusion between two bones (Appendix A8b). It is located between the left and right basivertebral vein foramina. The entire immovable caliper arms measuring surface should rest against the mid sagittal line (Appendix A7). Slide the movable caliper arm to the point of fusion between the left and right vertebral arches within the canal ensuring the caliper is measuring perpendicular to the mid-sagittal plane (Appendix A9 a, b). The point of fusion between the two arches is an observable line acting as a distinct skeletal landmark (Appendix A9 b). Ensure the caliper measuring arms are pressed securely against the bone to measure the maximum diameter most accurately.

Appendix A 7 Superior-medial view of a typical cervical vertebra. Vernier caliper placement within the vertebral foramen to measure CAP. (Photo by Andrew S. Rozendaal)

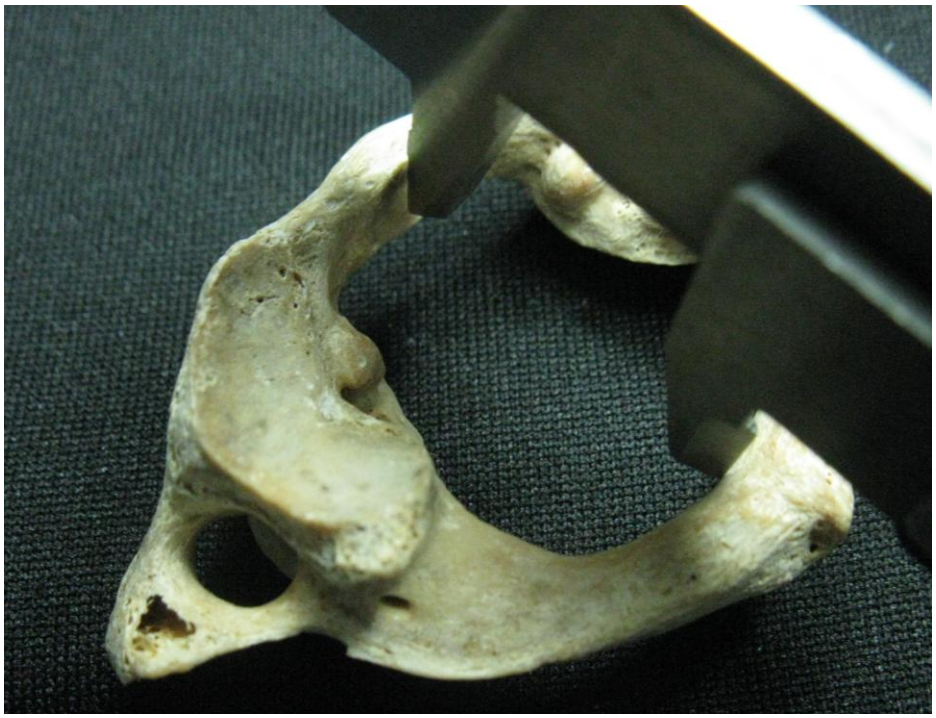


Appendix A 8 Posterior view of a typical cervical vertebra posterior aspect of vertebral body. The anterior CAP skeletal marker (a) within the vertebral foramen and (b) a close-up of the mid sagittal line (red arrow). (Photos by Andrew S. Rozendaal)

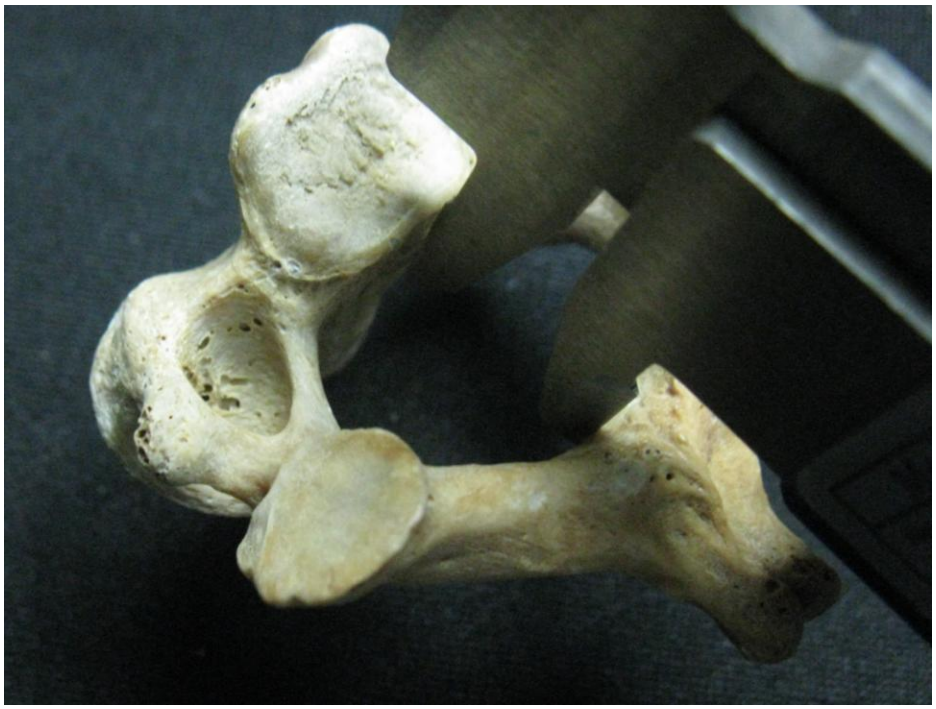


Appendix A 9 Superior-anterior view of a typical cervical vertebra. The posterior CAP landmark where (a) left and right arches fuse and (b) create the skeletal landmark (red arrows). (Photos by Andrew S. Rozendaal)

The anatomy of C_1 is unique compared to the typical vertebrae. There is no vertebral body or mid sagittal line to fix the immovable caliper arm for the CAP diameter. The C_1AP measurement however, is taken in the same manner as the typical vertebra with the immovable arm measuring from the midpoint of the facet along the anterior arch, where the odontoid process rests, to the point of fusion between the left and right vertebral arches within the canal (Appendix A10). The unique anatomy of C_2 poses a problem measuring C_2AP. The odontoid process hinders the caliper arms from slipping into the vertebral foramen from the superior aspect and prevents the immovable caliper arms from reaching the mid-sagittal line on the posterior vertebral body. To correct for this dilemma C_2AP was measured from the inferior aspect of the vertebral foramina opening for all individuals in this study (Appendix A11).



Appendix A 10 Superior view of the first cervical vertebra. The C_1AP measurement from the center of the facet for the dense to the point of fusion between the left and right arches. (Photo by Andrew S. Rozendaal)



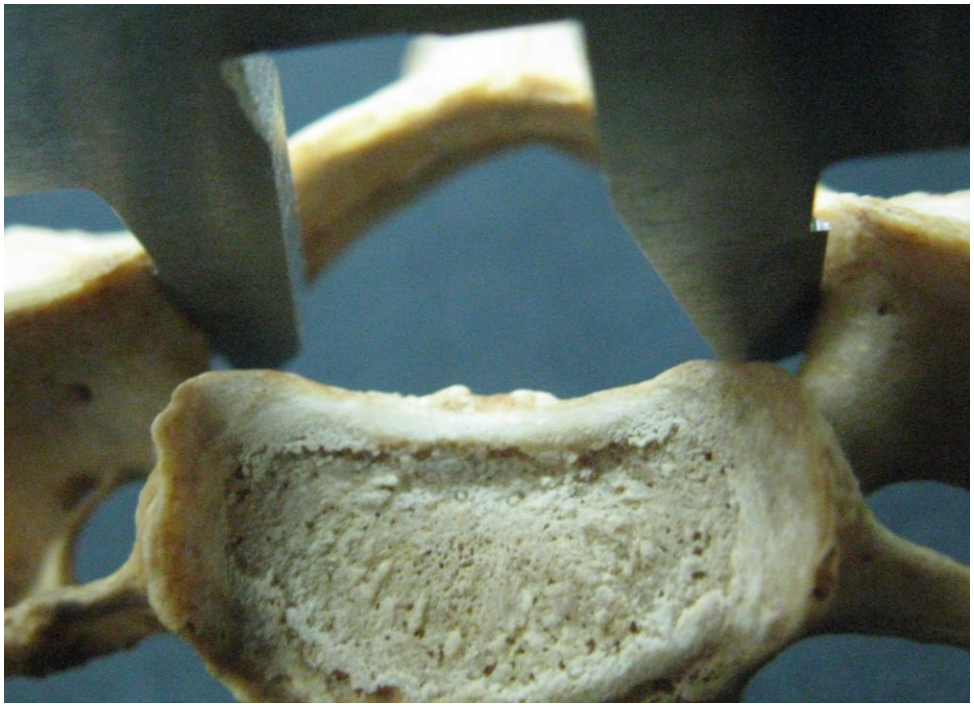
Appendix A 11 Inferior view of the second cervical vertebra. The C_2AP measurement from the mid sagittal line to the point of fusion between the left and right arches. (Photo by Andrew S. Rozendaal)

Cervical Transverse Diameter (CTR):

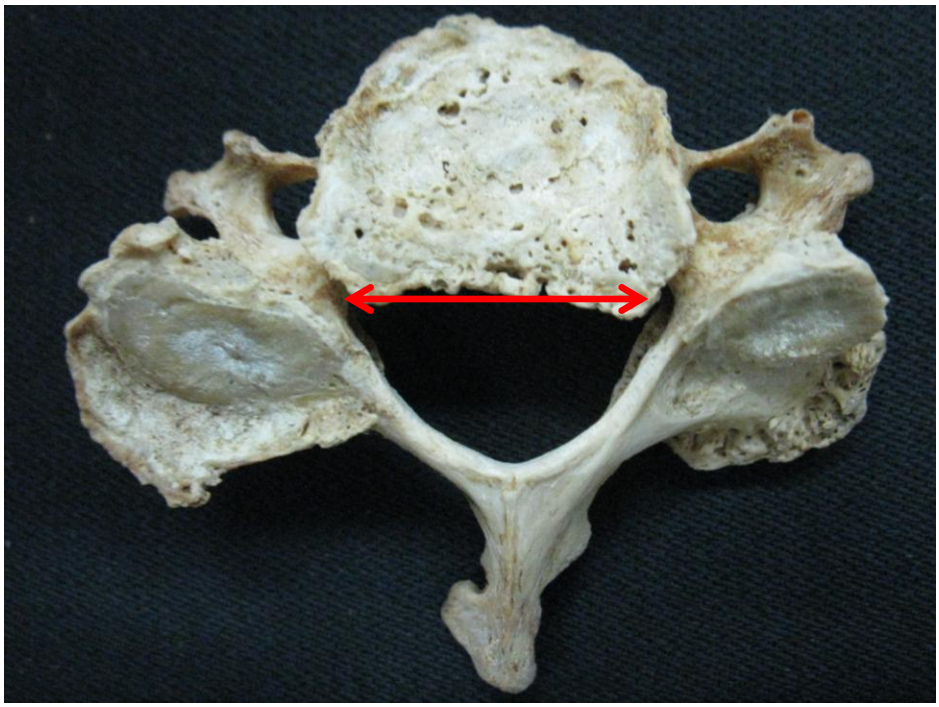
The cervical transverse vertebral foramen diameter (CTR), also known as the transverse canal, is the maximum medial-lateral diameter measured from the left to the right pedicles within the vertebral foramen (Appendix A12) (Clark 1985; Taitz 1996; Tatarek 1999, 2005; White et al 2012). Hold the vertebral body in your hand with the superior surface facing you and the inferior surface facing away from you. All measurements of CTR are obtained from the superior aspect of the canal opening. Using the sliding calipers inside measuring arms (used to measure internal diameters), place the immovable caliper arm at the medial aspect on the left pedicle inside the canal. Slide the movable caliper arm to the medial aspect on the right pedicle ensuring the caliper is

measuring perpendicular to the transverse plane. The caliper measuring arms must be pressed securely against the bone to ensure the most accurate measurement. Glide the caliper arms from anterior to posterior within the canal to locate the largest diameter in the transverse plane. The largest diameter is typically anterior of the superior articular facets.

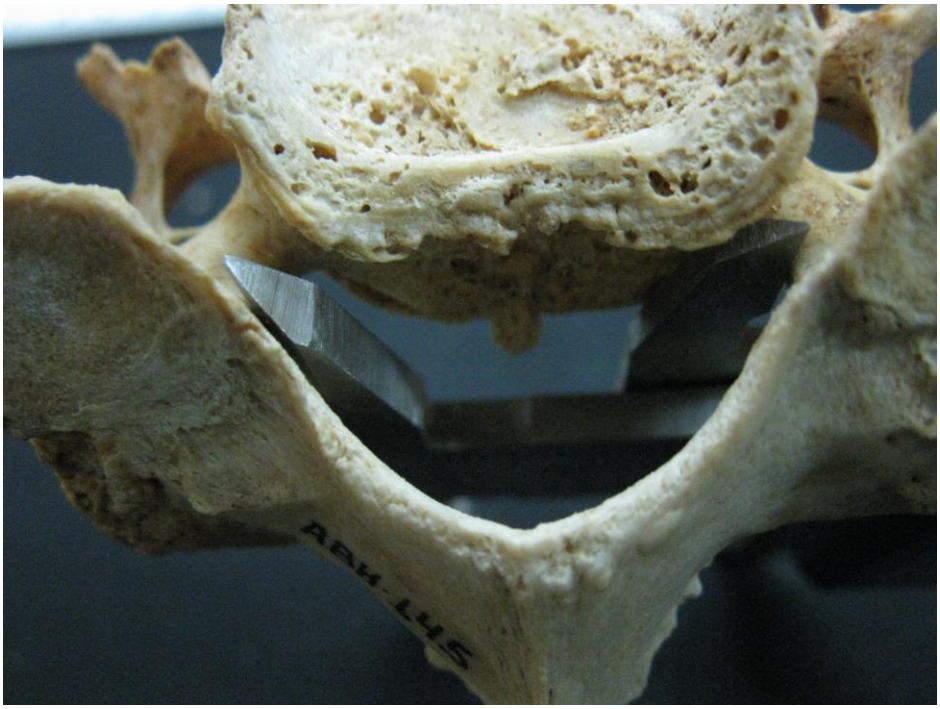
Modifications to the CTR measurement must be made when osteophytic growth inhibits access to the pedicles from the superior side of the vertebral foramen (Appendix A13). Bone growth in the form of 'mushroomed' edges along the superior-posterior or inferior-posterior borders of the vertebral body or the superior articular facets do not allow the caliper arms from reaching either one or both pedicles. To correct for the limited access, measurements should be taken from the inferior aspect of the vertebral foramen from pedicle to pedicle in the transverse plane (Appendix A14).



Appendix A 12 Superior view of a typical cervical vertebra. Vernier caliper placement within the vertebral foramen to measure CTR. (Photo by Andrew S. Rozendaal)



Appendix A 13 Superior view of a typical cervical vertebra. 'Mushroomed' edges along the superior-posterior vertebral body inhibit CTR measurement (red arrow) from the superior side of vertebral foramen. (Photo by Andrew S. Rozendaal)



Appendix A 14 Superior view. CTR diameter measured from the inferior side of the vertebral foramen using sliding calipers. (Photo by Andrew S. Rozendaal)

APPENDIX B: SPSS Discriminant Function Data for Functions 1 to 7

8.1 Appendix B1: SPSS Discriminant Function 1 Analysis Results

Analysis Case Processing Summary

Unweighted Cases		N	Percent
Valid		187	63.4
Excluded	Missing or out-of-range group codes	0	.0
	At least one missing discriminating variable	108	36.6
	Both missing or out-of-range group codes and at least one missing discriminating variable	0	.0
	Total	108	36.6
Total		295	100.0

Log Determinants

SEX	Rank	Log Determinant
1.0	12	-2.431
2.0	12	-6.390
Pooled within-groups	12	-3.539

The ranks and natural logarithms of determinants printed are those of the group covariance matrices.

Test Results

Box's M		135.549
F	Approx.	1.619
	df1	78
	df2	103902.107
	Sig.	.000

Tests null hypothesis of equal population covariance matrices.

Eigenvalues

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
1	.809[a]	100.0	100.0	.669

a. First 1 canonical discriminant functions were used in the analysis.

Wilks' Lambda

Test of Function(s)	Wilks' Lambda	Chi-square	df	Sig.
1	.553	106.086	12	.000

Standardized Canonical Discriminant Function Coefficients

	Function 1
C2TR	-.424
C3TR	.261
C4TR	-.361
C5TR	-.521
C6TR	.374
C7TR	.594
C2HT	.473
C3HT	.361
C4HT	.282
C5HT	.163
C6HT	.106
C7HT	-.020

Structure Matrix

	Function 1
C4HT	.719
C3HT	.712
C2HT	.693
C5HT	.638
C6HT	.620
C7HT	.548
C7TR	.391
C6TR	.361
C3TR	.338
C5TR	.329
C4TR	.303
C2TR	.285

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

Variables ordered by absolute size of correlation within function.

Canonical Discriminant Function Coefficients

	Function 1
C2TR	-.240
C3TR	.179
C4TR	-.232
C5TR	-.322
C6TR	.234
C7TR	.358
C2HT	.197
C3HT	.327
C4HT	.251
C5HT	.153
C6HT	.101
C7HT	-.018
(Constant)	-17.246

Unstandardized coefficients

Functions at Group Centroids

SEX	Function 1
1.0	.834
2.0	-.959

Unstandardized canonical discriminant functions evaluated at group means

Classification Processing Summary

Processed		295
Excluded	Missing or out-of-range group codes	0
	At least one missing discriminating variable	108
Used in Output		187

Prior Probabilities for Groups

SEX	Prior	Cases Used in Analysis	
		Unweighted	Weighted
1.0	.500	100	100.000
2.0	.500	87	87.000
Total	1.000	187	187.000

Classification Results[a]

			Predicted Group Membership		
		SEX	1.0	2.0	Total
Original	Count	1.0	85	15	100
		2.0	14	73	87
	%	1.0	85.0	15.0	100.0
		2.0	16.1	83.9	100.0

a. 84.5% of original grouped cases correctly classified.

Classification Function Coefficients

	SEX	
	1.0	2.0
C2TR	-2.680	-2.250
C3TR	4.242	3.922
C4TR	.490	.906
C5TR	-4.796	-4.219
C6TR	6.033	5.614
C7TR	4.371	3.728
C2HT	3.008	2.655
C3HT	3.617	3.031
C4HT	.486	.035
C5HT	2.629	2.355
C6HT	1.614	1.433
C7HT	3.633	3.665
(Constant)	-236.825	-206.009

Fisher's linear discriminant functions

8.2 Appendix B2: SPSS Discriminant Function 2 Analysis Results

Analysis Case Processing Summary

Unweighted Cases		N	Percent
Valid		164	55.6
Excluded	Missing or out-of-range group codes	0	.0
	At least one missing discriminating variable	131	44.4
	Both missing or out-of-range group codes and at least one missing discriminating variable	0	.0
	Total	131	44.4
Total		295	100.0

Log Determinants

SEX	Rank	Log Determinant
1.0	20	-5.617
2.0	20	-11.260
Pooled within-groups	20	-6.372

The ranks and natural logarithms of determinants printed are those of the group covariance matrices.

Test Results

Box's M		312.281
F	Approx.	1.295
	df1	210
	df2	78662.049
	Sig.	.003

Tests null hypothesis of equal population covariance matrices.

Eigenvalues

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
2	1.004[a]	100.0	100.0	.708

a. First 2 canonical discriminant functions were used in the analysis.

Wilks' Lambda

Test of Function(s)	Wilks' Lambda	Chi-square	df	Sig.
2	.499	105.690	20	.000

Standardized Canonical Discriminant Function Coefficients

	Function 2
C1AP	.432
C1TR	.028
C2HT	.371
C2AP	-.154
C2TR	-.670
C3HT	.361
C3AP	.266
C3TR	.256
C4HT	.148
C4AP	-.555
C4TR	-.270
C5HT	.361
C5AP	.344
C5TR	-.728
C6HT	.070
C6AP	-.142
C6TR	.203
C7HT	-.066
C7AP	.082
C7TR	.808

Structure Matrix

	Function 2
C3HT	.636
C4HT	.633
C2HT	.604
C5HT	.561
C6HT	.559
C7HT	.467
C1AP	.427
C7TR	.360
C6TR	.301
C3TR	.267
C5TR	.265
C4TR	.247
C2TR	.220
C1TR	.215
C7AP	.194
C2AP	.125
C6AP	.116
C5AP	.113
C3AP	.065
C4AP	-.004

Pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions
Variables ordered by absolute size of correlation within function.

Canonical Discriminant Function Coefficients

	Function 2
C1AP	.201
C1TR	.015
C2HT	.151
C2AP	-.111
C2TR	-.384
C3HT	.325
C3AP	.222
C3TR	.177
C4HT	.135
C4AP	-.447
C4TR	-.180
C5HT	.338
C5AP	.252
C5TR	-.467
C6HT	.068
C6AP	-.105
C6TR	.133
C7HT	-.058
C7AP	.058
C7TR	.508
(Constant)	-15.219

Unstandardized coefficients

Functions at Group Centroids

SEX	Function 2
1.0	.949
2.0	-1.046

Unstandardized canonical discriminant functions evaluated at group means

Classification Processing Summary

Processed		295
Excluded	Missing or out-of-range group codes	0
	At least one missing discriminating variable	131
Used in Output		164

Prior Probabilities for Groups

SEX	Prior	Cases Used in Analysis	
		Unweighted	Weighted
1.0	.500	86	86.000
2.0	.500	78	78.000
Total	1.000	164	164.000

Classification Results[a]

		SEX	Predicted Group Membership		Total
			1.0	2.0	
Original	Count	1.0	72	14	86
		2.0	12	66	78
	%	1.0	83.7	16.3	100.0
		2.0	15.4	84.6	100.0

a. 84.1% of original grouped cases correctly classified.

Classification Function Coefficients

	SEX	
	1.0	2.0
C1AP	3.129	2.729
C1TR	3.798	3.769
C2HT	1.628	1.327
C2AP	.258	.478
C2TR	-7.569	-6.802
C3HT	3.616	2.968
C3AP	.027	-.417
C3TR	7.228	6.875
C4HT	-.964	-1.233
C4AP	5.683	6.575
C4TR	1.761	2.120
C5HT	5.190	4.515
C5AP	-1.621	-2.124
C5TR	-8.602	-7.671
C6HT	.430	.294
C6AP	2.862	3.071
C6TR	5.740	5.475
C7HT	5.187	5.304
C7AP	-4.418	-4.533
C7TR	4.728	3.715
(Constant)	-286.665	-256.407

Fisher's linear discriminant functions

8.3 Appendix B3: SPSS Discriminant Function 3 Analysis Results

Analysis Case Processing Summary

Unweighted Cases		N	Percent
Valid		198	67.1
Excluded	Missing or out-of-range group codes	0	.0
	At least one missing discriminating variable	97	32.9
	Both missing or out-of-range group codes and at least one missing discriminating variable	0	.0
	Total	97	32.9
Total		295	100.0

Log Determinants

SEX	Rank	Log Determinant
1.0	10	-3.467
2.0	10	-6.963
Pooled within-groups	10	-4.570

The ranks and natural logarithms of determinants printed are those of the group covariance matrices.

Test Results

Box's M		105.316
F	Approx.	1.812
	df1	55
	df2	120376.817
	Sig.	.000

Tests null hypothesis of equal population covariance matrices.

Eigenvalues

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
3	.692[a]	100.0	100.0	.639

a. First 3 canonical discriminant functions were used in the analysis.

Wilks' Lambda

Test of Function(s)	Wilks' Lambda	Chi-square	df	Sig.
3	.591	100.437	10	.000

Standardized Canonical Discriminant Function Coefficients

	Function
	3
C3HT	.415
C3TR	-.004
C4HT	.380
C4TR	-.201
C5HT	.112
C5TR	-.593
C6HT	.110
C6TR	.344
C7HT	.152
C7TR	.658

Structure Matrix

	Function
	3
C4HT	.790
C3HT	.751
C5HT	.693
C6HT	.678
C7HT	.612
C7TR	.440
C6TR	.402
C3TR	.371
C5TR	.363
C4TR	.335

Pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions
Variables ordered by absolute size of correlation within function.

Canonical Discriminant Function Coefficients

	Function
	3
C3HT	.377
C3TR	-.003
C4HT	.342
C4TR	-.130
C5HT	.107
C5TR	-.367
C6HT	.104
C6TR	.215
C7HT	.133
C7TR	.395
(Constant)	-16.568

Unstandardized coefficients

Functions at Group Centroids

SEX	Function 3
1.0	.779
2.0	-.879

Unstandardized canonical discriminant functions evaluated at group means

Classification Processing Summary

Processed		295
Excluded	Missing or out-of-range group codes	0
	At least one missing discriminating variable	97
Used in Output		198

Prior Probabilities for Groups

SEX	Prior	Cases Used in Analysis	
		Unweighted	Weighted
1.0	.500	105	105.000
2.0	.500	93	93.000
Total	1.000	198	198.000

Classification Function Coefficients

	SEX	
	1.0	2.0
C3HT	4.618	3.993
C3TR	2.631	2.636
C4HT	1.194	.627
C4TR	1.839	2.055
C5HT	2.558	2.381
C5TR	-4.734	-4.125
C6HT	.775	.602
C6TR	5.531	5.175
C7HT	5.639	5.419
C7TR	4.018	3.363
(Constant)	-218.909	-191.520

Fisher's linear discriminant functions

Classification Results[a]

			Predicted Group Membership		
		SEX	1.0	2.0	Total
Original	Count	1.0	87	18	105
		2.0	15	78	93
	%	1.0	82.9	17.1	100.0
		2.0	16.1	83.9	100.0

a. 83.3% of original grouped cases correctly classified.

8.4 Appendix B4: SPSS Discriminant Function 4 Analysis Results

Analysis Case Processing Summary

Unweighted Cases		N	Percent
Valid		164	55.6
Excluded	Missing or out-of-range group codes	0	.0
	At least one missing discriminating variable	131	44.4
	Both missing or out-of-range group codes and at least one missing discriminating variable	0	.0
	Total	131	44.4
Total		295	100.0

Log Determinants

SEX	Rank	Log Determinant
1.0	7	4.057
2.0	7	1.690
Pooled within-groups	7	3.198

The ranks and natural logarithms of determinants printed are those of the group covariance matrices.

Test Results

Box's M		43.196
F	Approx.	1.472
	df1	28
	df2	89640.093
	Sig.	.051

Tests null hypothesis of equal population covariance matrices.

Eigenvalues

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
4	.917[a]	100.0	100.0	.692

a. First canonical discriminant functions were used in the analysis.

Wilks' Lambda

Test of Function(s)	Wilks' Lambda	Chi-square	df	Sig.
4	.522	103.153	7	.000

Standardized Canonical Discriminant Function Coefficients

	Function
	4
C1AP	.409
C2HT	.428
C2TR	-.619
C3HT	.403
C5HT	.456
C5TR	-.670
C7TR	.899

Structure Matrix

	Function
	4
C3HT	.666
C2HT	.632
C4HT[a]	.616
C5HT	.587
C6HT[a]	.546
C7HT[a]	.474
C1AP	.447
C7TR	.377
C6TR[a]	.290
C4TR[a]	.285
C5TR	.278
C3TR[a]	.274
C7AP[a]	.257
C1TR[a]	.238
C2TR	.230
C2AP[a]	.225
C6AP[a]	.200
C3AP[a]	.187
C5AP[a]	.178
C4AP[a]	.176

Pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions
Variables ordered by absolute size of correlation within function.
a. This variable not used in the analysis.

Canonical Discriminant Function Coefficients

	Function
	4
C1AP	.190
C2HT	.175
C2TR	-.355
C3HT	.363
C5HT	.428
C5TR	-.430
C7TR	.565
(Constant)	-16.994

Unstandardized coefficients

Functions at Group Centroids

SEX	Function 4
1.0	.906
2.0	-.999

Unstandardized canonical discriminant functions evaluated at group means

Classification Processing Summary

Processed		295
Excluded	Missing or out-of-range group codes	0
	At least one missing discriminating variable	105
Used in Output		190

Prior Probabilities for Groups

SEX	Prior	Cases Used in Analysis	
		Unweighted	Weighted
1.0	.500	86	86.000
2.0	.500	78	78.000
Total	1.000	164	164.000

Classification Function Coefficients

	SEX	
	1.0	2.0
C1AP	3.523	3.161
C2HT	2.872	2.540
C2TR	-3.552	-2.874
C3HT	3.259	2.568
C5HT	6.666	5.849
C5TR	-.026	.793
C7TR	8.193	7.116
(Constant)	-235.780	-203.481

Fisher's linear discriminant functions

Classification Results[a]

			Predicted Group Membership		
		SEX	1.0	2.0	Total
Original	Count	1.0	75	22	97
		2.0	11	82	93
	%	1.0	77.3	22.7	100.0
		2.0	11.8	88.2	100.0

a. 82.6% of original grouped cases correctly classified.

8.5 Appendix B5: SPSS Discriminant Function 5 Analysis Results

Analysis Case Processing Summary

Unweighted Cases		N	Percent
Valid		198	67.1
Excluded	Missing or out-of-range group codes	0	.0
	At least one missing discriminating variable	97	32.9
	Both missing or out-of-range group codes and at least one missing discriminating variable	0	.0
	Total	97	32.9
Total		295	100.0

Log Determinants

SEX	Rank	Log Determinant
1.0	15	-5.922
2.0	15	-10.176
Pooled within-groups	15	-6.907

The ranks and natural logarithms of determinants printed are those of the group covariance matrices.

Test Results

Box's M		198.380
F	Approx.	1.521
	df1	120
	df2	115596.535
	Sig.	.000

Tests null hypothesis of equal population covariance matrices.

Eigenvalues

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
5	.747[a]	100.0	100.0	.654

a. First 1 canonical discriminant functions were used in the analysis.

Wilks' Lambda

Test of Function(s)	Wilks' Lambda	Chi-square	df	Sig.
5	.572	105.216	15	.000

Standardized Canonical Discriminant Function Coefficients

	Function
	5
C3HT	.428
C3AP	.214
C3TR	.018
C4HT	.415
C4AP	-.640
C4TR	-.261
C5HT	.113
C5AP	.219
C5TR	-.541
C6HT	.039
C6AP	.162
C6TR	.302
C7HT	.137
C7AP	-.007
C7TR	.683

Structure Matrix

	Function
	5
C4HT	.760
C3HT	.722
C5HT	.667
C6HT	.652
C7HT	.589
C7TR	.424
C6TR	.387
C3TR	.357
C5TR	.349
C4TR	.322
C7AP	.266
C6AP	.201
C5AP	.175
C3AP	.159
C4AP	.075

Pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions
Variables ordered by absolute size of correlation within function.

Canonical Discriminant Function Coefficients

	Function
	5
C3HT	.389
C3AP	.170
C3TR	.012
C4HT	.375
C4AP	-.487
C4TR	-.169
C5HT	.108
C5AP	.158
C5TR	-.335
C6HT	.037
C6AP	.120
C6TR	.189
C7HT	.119
C7AP	-.005
C7TR	.409
(Constant)	-15.536

Unstandardized coefficients

Functions at Group Centroids

SEX	Function 5
1.0	.810
2.0	-.914

Unstandardized canonical discriminant functions evaluated at group means

Classification Processing Summary

Processed		295
Excluded	Missing or out-of-range group codes	0
	At least one missing discriminating variable	97
Used in Output		198

Prior Probabilities for Groups

SEX	Prior	Cases Used in Analysis	
		Unweighted	Weighted
1.0	.500	105	105.000
2.0	.500	93	93.000
Total	1.000	198	198.000

Classification Results[a]

			Predicted Group Membership		
		SEX	1.0	2.0	Total
Original	Count	1.0	86	19	105
		2.0	16	77	93
	%	1.0	81.9	18.1	100.0
		2.0	17.2	82.8	100.0

a. 82.3% of original grouped cases correctly classified.

Classification Function Coefficients

	SEX	
	1.0	2.0
C3HT	4.181	3.510
C3AP	2.228	1.935
C3TR	1.944	1.924
C4HT	.970	.324
C4AP	2.283	3.123
C4TR	3.099	3.390
C5HT	3.049	2.862
C5AP	-2.476	-2.747
C5TR	-5.173	-4.596
C6HT	.574	.511
C6AP	5.590	5.384
C6TR	5.327	5.002
C7HT	5.920	5.714
C7AP	-3.866	-3.858
C7TR	3.662	2.957
(Constant)	-238.058	-211.370

Fisher's linear discriminant functions

8.6 Appendix B6: SPSS Discriminant Function 6 Analysis Results

Analysis Case Processing Summary

Unweighted Cases		N	Percent
Valid		217	73.6
Excluded	Missing or out-of-range group codes	0	.0
	At least one missing discriminating variable	78	26.4
	Both missing or out-of-range group codes and at least one missing discriminating variable	0	.0
	Total	78	26.4
Total		295	100.0

Log Determinants

SEX	Rank	Log Determinant
1.0	12	-4.309
2.0	12	-7.494
Pooled within-groups	12	-5.278

The ranks and natural logarithms of determinants printed are those of the group covariance matrices.

Test Results

Box's M		110.164
F	Approx.	1.329
	df1	78
	df2	140410.329
	Sig.	.028

Tests null hypothesis of equal population covariance matrices.

Eigenvalues

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
6	.646[a]	100.0	100.0	.627

a. First canonical discriminant functions were used in the analysis.

Wilks' Lambda

Test of Function(s)	Wilks' Lambda	Chi-square	df	Sig.
6	.607	104.202	12	.000

Standardized Canonical Discriminant Function Coefficients

	Function
	6
C3HT	.359
C3AP	.075
C3TR	.149
C4HT	.408
C4AP	-.487
C4TR	-.178
C5HT	.106
C5AP	.190
C5TR	-.422
C6HT	.210
C6AP	.284
C6TR	.638

Structure Matrix

	Function
	6
C4HT	.812
C3HT	.759
C5HT	.718
C6HT	.689
C6TR	.421
C3TR	.398
C5TR	.389
C4TR	.371
C6AP	.237
C5AP	.189
C3AP	.165
C4AP	.079

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

Variables ordered by absolute size of correlation within function.

Canonical Discriminant Function Coefficients

	Function
	6
C3HT	.327
C3AP	.061
C3TR	.103
C4HT	.374
C4AP	-.372
C4TR	-.118
C5HT	.101
C5AP	.138
C5TR	-.271
C6HT	.196
C6AP	.209
C6TR	.412
(Constant)	-16.478

Unstandardized coefficients

Functions at Group Centroids

SEX	Function 6
1.0	.747
2.0	-.858

Unstandardized canonical discriminant functions evaluated at group means

Classification Processing Summary

Processed		295
Excluded	Missing or out-of-range group codes	0
	At least one missing discriminating variable	78
Used in Output		217

Prior Probabilities for Groups

SEX	Prior	Cases Used in Analysis	
		Unweighted	Weighted
1.0	.500	116	116.000
2.0	.500	101	101.000
Total	1.000	217	217.000

Classification Results[a]

			Predicted Group Membership		
		SEX	1.0	2.0	Total
Original	Count	1.0	93	23	116
		2.0	19	82	101
	%	1.0	80.2	19.8	100.0
		2.0	18.8	81.2	100.0

a. 80.6% of original grouped cases correctly classified.

Classification Function Coefficients

	SEX	
	1.0	2.0
C3HT	4.345	3.819
C3AP	1.214	1.116
C3TR	2.985	2.820
C4HT	2.211	1.611
C4AP	1.972	2.568
C4TR	2.515	2.705
C5HT	2.069	1.907
C5AP	-.720	-.941
C5TR	-4.523	-4.088
C6HT	4.505	4.192
C6AP	3.288	2.952
C6TR	7.739	7.079
(Constant)	-235.083	-208.735

Fisher's linear discriminant functions

8.7 Appendix B7: SPSS Discriminant Function 7 Analysis Results

Analysis Case Processing Summary

Unweighted Cases		N	Percent
Valid		218	73.9
Excluded	Missing or out-of-range group codes	0	.0
	At least one missing discriminating variable	77	26.1
	Both missing or out-of-range group codes and at least one missing discriminating variable	0	.0
	Total	77	26.1
Total		295	100.0

Log Determinants

SEX	Rank	Log Determinant
1.0	8	-2.482
2.0	8	-5.247
Pooled within-groups	8	-3.474

The ranks and natural logarithms of determinants printed are those of the group covariance matrices.

Test Results

Box's M		65.098
F	Approx.	1.737
	df1	36
	df2	151741.791
	Sig.	.004

Tests null hypothesis of equal population covariance matrices.

Eigenvalues

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
1	.584[a]	100.0	100.0	.607

a. First 1 canonical discriminant functions were used in the analysis.

Wilks' Lambda

Test of Function(s)	Wilks' Lambda	Chi-square	df	Sig.
7	.632	97.444	8	.000

Standardized Canonical Discriminant Function Coefficients

	Function
	7
C3HT	.337
C3TR	.128
C4HT	.409
C4TR	-.097
C5HT	.098
C5TR	-.571
C6HT	.273
C6TR	.773

Structure Matrix

	Function
	7
C4HT	.839
C3HT	.787
C5HT	.741
C6HT	.699
C6TR	.451
C3TR	.422
C5TR	.412
C4TR	.395

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

Variables ordered by absolute size of correlation within function.

Functions at Group Centroids

	Function
SEX	7
1.0	.713
2.0	-.811

Unstandardized canonical discriminant functions evaluated at group means

Functions at Group Centroids

SEX	Function 7
1.0	.713
2.0	-.811

Unstandardized canonical discriminant functions evaluated at group means

Classification Processing Summary

Processed		295
Excluded	Missing or out-of-range group codes	0
	At least one missing discriminating variable	77
Used in Output		218

Prior Probabilities for Groups

SEX	Prior	Cases Used in Analysis	
		Unweighted	Weighted
1.0	.500	116	116.000
2.0	.500	102	102.000
Total	1.000	218	218.000

Classification Function Coefficients

	SEX	
	1.0	2.0
C3HT	4.272	3.805
C3TR	3.468	3.333
C4HT	2.588	2.021
C4TR	1.980	2.078
C5HT	1.412	1.272
C5TR	-4.096	-3.536
C6HT	4.830	4.447
C6TR	8.828	8.069
(Constant)	-214.524	-188.733

Fisher's linear discriminant functions

Classification Results[a]

			Predicted Group Membership		
		SEX	1.0	2.0	Total
Original	Count	1.0	93	23	116
		2.0	20	82	102
	%	1.0	80.2	19.8	100.0
		2.0	19.6	80.4	100.0

a. 80.3% of original grouped cases correctly classified.

APPENDIX C: Raw Data

9.1 Appendix C1: Athens Collection Raw Data

ID	Sex	YR Death	Age	Hght	C1 AP	C1 TR	C2 HT	C2 AP	C2 TR	C3 HT	C3 AP	C3 TR	C4 HT	C4 AP	C4 TR	C5 HT	C5 AP	C5 TR	C6 HT	C6 AP	C6 TR	C7 HT	C7 AP	C7 TR
WLH 001	1	1964	85		25.73	26.73	37.99	12.94	22.44	15.4	11.95	21.93	14.49	11.2	22.69	14.46	10.3	23.12	15.9	10.64	21.79	17.32	11.69	22.05
WLH 002	1	1965	64	153.13	30.87	31.64	36.7	15.35	27.87	13.96	13.59	25.8	13.18	13.37	26.74	13.7	13.85	26.62	13.71	13.53	26.38	15.36	16.41	27.07
WLH 003	2	1987	79		29.1	27.29	34.95	14.55	22.89	12.24	13.63	22.93				11.1	13.75	25.04	11.6	13.11	24.71	12.32	13.55	24.09
WLH 004	2	1988	68	143.92	26.3	28.73	33.48	16.31	21.37	13.14	14.17	21.69	11.86	13.9	22.89	10.97	13.24	23.67	12.58	13.28	24.44	14.48	12.97	25.15
WLH 007	1	1988	76		32.3	27.1	37.48	15.24	21.73	11.34	13.75	21.72	11.34	13.19	23.07	11.11	12.93	23.9				11.13	13.77	24.49
WLH 008	1	1976	60	156.53	32.43	27.66	37.59	15.28	25.47	14.02	12.94	24.96	13.5	11.34	24.4	12.98	11.32	24.74	13.19	11.49	24.84	15.38	13.19	24.94
WLH 009	1	1960	76	146.09	30.88	31.27	38.57	13.87	25.37				13.29	12.51	23.92	13.77	11.6	25.63	13.92	12.8	26.08	12.88	11.94	26.68
WLH 010	2	1987	68	146.53			38.54	15.31	23.47	11.09	12.86	24.15	10.56	12.13	25.55	9.92	12.83	25.93	10.95	13.84	26.64	12.81	14.61	25.5
WLH 011	1	1963	82		33.8	26.55							13.63	14.54	24.25	12.57	13.72	25.11	13.09	14.6	26.36	14.98	14.61	24.74
WLH 017	1	1986	76	149.40	33.07	29.79	34.66	19.26	23.73	14.26	15.68	24.02	15.12	14.28	25.43	13.92	13.92	27.09	13.98	14.32	26.21	14.51	13.52	24.72
WLH 020	1	1985	67	149.52	32.9	32.12	35.83	18.73	23.28	11.32	16.39	22.06				11.65	16.04	22.98	11.88	14.48	25.67	12.23	12.5	25.62
WLH 021	1	1987	76	154.69	32.01	28.61	38.43	16.08	23.22	13.87	13.47	23.97	13.02	14	25.02				12.83	13.06	25.13	14.42	14.06	25.55
WLH 022	2	1983	94							12.65	14.17	25.24	12.56	14.67	25.37		14.73	26.36	12.87	13.7	27.76	14.66	14.99	27.71
WLH 023	1	1971	48	154.79	31.22	29.51	40.31	15.8	24.81	12.72	13.77	24.08	12.22	12.71	25.78	12.72	12.81	26.08	14.35	13.42	27.03	15.13	13.97	26.82
WLH 024	1	1985	87	156.06			43.55	14.58	25.13	12.07	13.11	24.06	12.47	11.49	24.42	12.91	12.69	25.2	12.43	12.1	25.95	15.41	12.87	25.34
WLH 026	1	1987	46	155.70	30.66	26.8	37.6	16.31	25.9	16.75	13.42	23.16	15.51	12.13	22.89	15.01	12.07	23.84	13.42	11.67	23.94	15.47	12.56	23
WLH 032	2	1988	44		30.75	27.05	34.83	17.02	22.76	13.09	14.59	22.22	12.94	14.08	24.01	11.85	13.42	24.88	11.89	11.05	24.31	14.02	11.79	23.74
WLH 033	2	1984	72	143.48	29.36	28.66	36.52	14.37	24.02				13.12	12.74	24.88	12.72	14.15	24.95	12.81	14.09	25.35	14.53	13.31	24.9
WLH 036	2	1983	63		28.3	27.8	34.77	16.76	21.33				10.3	13.42	22.46	11.29	10.9	23.14	11.9	12.72	22.7			
WLH 037	2	1965	44	138.68	30.44	26.69	37.11	15.42	22.31	11.38	14.1	22.31	10.79	14.27	23.83				11.66	13.4	25.25	13.23	14.34	22.6
WLH 039	1	1977	70		30.76	31	44.94	16.16	28.27	13.96	15.26	26.82	14.94	14.95	26.85	14.34	14.35	27.53	12.11	13.74	26.81	14.84	13.65	26.03
WLH 040	2	1985	71	145.68	31.57	32.4	36.04	17.15	22.72				12.48	14	25.47	11.59	13.34	26.24	13.42	13.1	25.73	14.5	13.47	23.38
WLH 041	2	1975	27	146.6	27.86	26.18	34.99	16.09	25.56	14.3	15.59	24.13	12.07	15.55	25.32	11.7	15.95	25.46	12.75	16.18	25.28	13.41	15.5	24.42

ID	Sex	YR Death	Age	Height	C1 AP	C1 TR	C2 HT	C2 AP	C2 TR	C3 HT	C3 AP	C3 TR	C4 HT	C4 AP	C4 TR	C5 HT	C5 AP	C5 TR	C6 HT	C6 AP	C6 TR	C7 HT	C7 AP	C7 TR
WLH 042	2	1984	50		33.8	30.04	40.52	17.02	26.61	12.78	14.9	25.98	11.73	14.42	26.92	12.42	14.33	27.6	12.01	12.93	27.53	14.13	13.09	27.1
WLH 044	1	1977	64	153.47			41.17	16.32	24.66				13.92	14.37	25.7	13.61	13.08	25.73	14.01	12.62	26.08	16.82	13.29	25.54
WLH 045	1	1971	57	155.11			36.57	18.29	25.02	14.31	15.62	24.3	13.63	13.79	25.81	11.48	13.96	27.29	11.9	13.27	26.25	14.35	13.06	23.23
WLH 046	1	1981	60	157.05	32.58	30.08	43.05	15.65	25.78	15.12	13.57	25	14.37	12.34	26.05	11.96	10.67	26.51	12.09	11.04	27.13	14.97	10.22	24.56
WLH 047	2	1973	46	139.88	31.05	26.74	36.84	15.46	23.49	10.93	13.72	22.8	12	13.41	24.89	10.87	12.64	25.19				13.82	12.89	25.37
WLH 048	1	1966	50				37.82	17.57	24.75	12.43	14.74	22.96	13.16	14.25	23.45	12.69	15.01	24.27	14.03	14.53	26	15.97	16.45	25.18
WLH 049	1	1986	56	160.04	31.12	28.29	40.86	16.45	23.64	11.92	14.82	23.32	12.72	15.22	24.01				13.33	14.31	24.41	15.84	14.32	24.65
WLH 052	2	1984	82		26.83	28.27	38.93	12.66	24.03	13.43	11.84	24.87		12.04	25.34	13.8	11.25	25.9	14.7	12.07	25.08			
WLH 053	2	1976	63	147.43	27.75	30.74	33.72	17.75	24.69	11.83	15.64	24.87	12.36	15	24.29	13.64	14.61	24.16	13.11	15.03	24.68	14.44	12.58	24.11
WLH 054	1	1984	77		32.48	26.55	39.07	16.03	23.78	12.71	12.8	22.92	12.27	10.76	23.17	10.73	13.35	23.47	13.02	12.06	24.74	15.2	11.4	23.8
WLH 055	1	1978	58	156.67	32.98	31.4	40	18.38	25.84	14.08	15.7	24.09	14.36	14.57	25.12				13.73	12.69	25.22	15.77	14.62	25.37
WLH 056	1	1987	39		30.6	31.58	38.89	17.16	22.82				13.54	14.11	22.96	12.5	14.87	24.57	13.75	14.99	23.02	16.17	15.59	23.65
WLH 060	2	1980	45	142.24						12.61	12.23	20.27	13.35	11.57	21.57	11.81	12.33	21.72	11.81	12.39	21.33	13.89	13	19.81
WLH 061	2	1981	54		30.1	30.59	35.64	18.46	25.66	12.59	15.33	24.29				12.69	13.06	27.06	15.28	12.17	27.77	16.21	13.41	27.75
WLH 062	1	1986	41		34.26	30.21	43.81	16.29	25.42				15.68	12.3	23.99	15.3	12.63	25.53				16.57	13.6	24.69
WLH 063	1	1984	79	149.85			40.39	14.92	23.64	13.92	14.02	23.51	15.04	11.84	23.48	14.6	11.11	23.75	15.46	14.13	23.99	15.66	13.98	23.38
WLH 066	1	1969	29		30.2	28.9				12.94	15.16	24.39	13.08	15.29	25.57	13.8	14.56	26.03	15.17	13.27	24.86			
WLH 067	1	1974	56	160.19	30.15	29.9	44.52	15.23	24.55	13.87	13.58	24.02	13.53	13.52	25.02	13.97	14.49	25.68	13.6	14.28	26.22	17.02	15.64	25.53
WLH 068	1	1975	26	157.45	31.14	28.93	39.52	16.81	24.98	13.87	14.35	24.71	13.34	13.68	25.86	13.04	13.17	25.1	13.33	13.38	24.62	15.27	14.77	25.74
WLH 070	1	1972	48	151.13	32.37	29.83	39.58	17.06	25.27	11.97	14.25	25.78	12.04	13.56	25.51	12.68	12.48	26.32	15.49	15.22	26.79			
WLH 072	1	1960	27		32.61	27.62	38.17	17.36	23.35				15.57	14.88	23.73	13.58	14.55	24.54				16.69	15.1	24.88
ABH 073	1	1988	62		30.01	28.2	36.64	14.44	23.28	12.94	12.08	22.52	13.78	11.62	23.52	12.82	10.89	23.51	13.32	11.76	24.43	14.98	11.12	22.9
ABH 074	1	1991	26				39.81	19.73	26.53	14.18	17.43	25.7	14.66	17.43	27.06	12.88	17.47	28.55	14.05	16.72	28.14	15.53	16.29	28.96
ABH 075	2	1988	81	135.44			35.23	13.5	20.43	11.48	11.32	22.06	11.08	9.78	23.29	10.19	9.94	24.3	10.64	10.53	24.73	11.89	11.23	25.12

ID	Sex	YR Death	Age	Height	C1 AP	C1 TR	C2 HT	C2 AP	C2 TR	C3 HT	C3 AP	C3 TR	C4 HT	C4 AP	C4 TR	C5 HT	C5 AP	C5 TR	C6 HT	C6 AP	C6 TR	C7 HT	C7 AP	C7 TR
ABH 077	2	1984	54	144.85	30.2	30.45	33.96	18.82	24.86	11.7	16.52	25.19	10.26	15.56	27.14	10.94	14.79	28.43	11.43	14.01	29.32	15.1	14.76	28.2
ABH 078	1	1995	43	154.84			37.94	16.46	25.06	12.42	14.84	23.1	13.24	14.96	24.31				11.56	13.37	24.53	13.97	14.62	23.85
ABH 079	2	1988	51	145.48	29.48	26.84	38.01	15.85	23.65				11.82	13.13	22.9	10.61	13.25	23.5	11.33	13.46	22.69	12.51	14.21	21.48
ABH 080	2	1993	57		28.95	27.5	36.59	15.84	23.21	13.87	13.14	22.6	12.58	13.7	23.53	11.97	12.87	24.07	11.63	10.81	24.41			
ABH 081	1	1990	87		31.46	28.28	39.28	14.25	22.91	14.12	12.32	23.21	13.39	11.31	24.43	12.45	11.63	25.29	13.42	12.15	25.91			
ABH 082	2	1980	48		27.92	26.59	34.05	15.4	23.16	12.11	14.65	23.35	10.62	15.07	23.93	11.4	15.13	25.25	12.41	15.02	26.34	14.91	14.07	23.95
ABH 083	1	1988	81		35.54	32.36	46.74	15.17	25.67	15.26	13.17	24.39	14.91	10.69	26.29		11.78	26.47	13.83	12.6	27.04	13.33	12.19	25.07
ABH 084	2	1984	65	140.5	30.07	27.79	36.68	14.51	22.82	11.87	13.7	23.12	11.42	13.23	24.73	11.34	13.68	24.99	12.91	14.17	25.01	15.95	13.92	23.22
ABH 086	2	1983	61	143.93	28.63	26.13	37.17	17.2	19.93	13.8	13.87	19.41	12.59	12.3	21.59	12.72	11.8	22.09	13.29	11.6	22.24	15.44	13.29	20.68
ABH 087	1	1980	36				36.11	19.86	26.22	14.61	18.11	23.79	14.67	15.77	25.9	13.63	15.44	27.28	12.74	15.49	28.01	12.93	14.63	27.77
ABH 088	2	1984	35		28.68	25.6	35.93	16.2	22.8	12.78	14.51	22.48	12.18	14.61	22.89	12.6	14.69	23.65	13.74	14.99	24.52	14.18	14.82	24.17
ABH 089	2	1990	81		32.45	29.69	37.18	19.12	24.72	13.22	16.05	22.88	12.66	14.27	24.4	11.24	15.18	25.01	13.04	13.8	24.54	15.08	14.96	22.52
ABH 090	2	1992	72		30.27	29.55	37.14	14.71	25.56	12.64	13.57	23.39	12.18	13.54	24.51	12.4	13.97	25.11	12.27	14.58	25.37	14.31	15.81	24.87
ABH 091	2	1989	51		32.45	28.32	36.95	17.69	23.73	12.66	14.97	23.64	13.05	14.1	24.84	11.4	13.86	25.77	11.78	12.92	25.94	13.47	11.26	24.68
ABH 095	2	1988	37	140.03	30.43	27.55	34.49	15.58	22.92	12.96	13.58	21.63		12.85	22.42	12.67	13.24	23.31				13.21	13.19	23.25
ABH 096	2	1987	33	139.59	27.67	27.32	35.78	14.6	23.22	12.34	12.81	24.62	12.22	12.51	25.83	11.14	12.89	26.31	11.94	12.9	27.24	14.14	13	26.34
ABH 097	2	1975	46		32.35	28.46	38.23	17.35	23.93				11.33	12.76	25.72	10.97	13.97	25.79				11.09	13.14	25.09
ABH 099	2	1973	70		29.6	28.4	36.63	15.96	24.17	13.38	14.38	23.55	12.62	13.94	23.7	12.33	13.27	24.82	11.55	12.67	25.37	13.25	12.64	24.5
ABH 100	1	1988	64	157.68	29.5	29.96	39.17	15.15	26.14	13.7	13.97	24.32	12.8	11.88	23.61	12.82	12.78	26.76	13.01	12.28	25.99	13.6	11.99	25.5
ABH 103	1	1986	24	156.02			40.79	16.67	23.53	15.4	14.17	21.95	15.75	14.05	22.51	14.46	14.51	23.34	14.79	14.54	22.65	15.59	14.27	21.56
ABH 104	2	1988	57	148.79	28.65	26.89	37.48	13.79	23.15	13.54	12.47	24.27	13.44	11.7	26.38	12.79	11.32	26.07	12.91	11.92	26.2	15.42	13.26	24.31
ABH 105	1	1988	78	163.62	37.15	27.64	44.84	18.12	26.95	17.69	15.65	24.48	17.51	15.92	25.15	13.79	15.79	27.31	14.25	11.19	27.26	17.16	12.85	26.38
ABH 106	1	1980	46		32.79	26.64	39.94	17.07	24.77	15.3	14.74	24.1	13.26	13.51	25.07	12.67	12.25	25.69	12.99	12.81	26.22	16.22	13.75	24.4
ABH 108	1	1983	23		31.21	32.47	40.24	15.12	25.28	14.81	14.12	24.39	14.01	13.67	26.05	14.12	14.23	26.16	15.35	15.49	26.29	16.37	15.41	25.46

ID	Sex	YR Death	Age	Height	C1 AP	C1 TR	C2 HT	C2 AP	C2 TR	C3 HT	C3 AP	C3 TR	C4 HT	C4 AP	C4 TR	C5 HT	C5 AP	C5 TR	C6 HT	C6 AP	C6 TR	C7 HT	C7 AP	C7 TR
ABH 109	1	1972	68		30.41	26.35				11.81	13.96	22.5	14.68	14.43	24.18	12.55	14.1	25.95	14.53	13.91	26.73	17.33	13.57	25.62
ABH 110	1	1972	58		29.81	28.41	37.24	15.12	23.95	13.13	12.93	23.76	13.92	12.77	24.53	14.07	13.74	25.54	14.37	13.36	26.52	15.01	13	26.82
ABH 111	1	1982	44	156.6	29.01	31.41	41.59	15.8	24.96	16.66	13.41	24.19	14.73	13.23	25.79	13.85	13.09	27.51	14.69	11.95	27.56	16.85	14.89	25.7
ABH 113	1	1993	67		29.11	27.35	32.57	15.78	21.41	12.05	14.26	21.98	12.09	13.32	23.11	10.31	13.7	24.52				13.88	14.7	23.25
ABH 114	2	1988	80		31.61	28.08	36.88	14.28	23.84	12.83	12.62	23.87	12.35	13.33	25.15	12.95	13.63	26.21	13.14	12.65	25.37	14.81	12.47	24.76
ABH 117	2	1976	96		30.66	26.16	33.18	17.9	21.62	12.67	14.25	22.67	12.54	13.14	24.53	11.65	13.18	25.03	11.84	12.24	27.51	14.24	13.77	24.94
ABH 118	2	1979	45		29.78	26.09	36.75	15.78	21.69	11.53	14.16	22.05	12.03	14.05	22.76	11.21	14.5	23.78	12.69	14.61	23.41	14.67	14.39	22.78
ABH 121	2	1989	27		25.88	27.35	33.97	15.24	22.24	12.82	13.16	21.15	12.7	12.6	21.78	12.24	12.99	22.6	12.31	13.19	23.91	15.03	13.77	22.97
ABH 122	2	1983	78		26.63	24.6	34.93	14.11	20.34	10.87	11.54	19.99				10.92	10.06	21.94	11.68	11.22	22.05	13.53	10.23	21.24
ABH 123	2	1983	71		30.7	29.67	38.03	15.7	24.72	12.28	13.21	24.2	12.45	12.41	24.66	12.61	12.35	25.65	12.68	12.02	25.68	14.02	13.66	25.24
ABH 125	1	1984	50		32.26	29.55	38.26	16.09	25.07	14.79	12.71	25.1	14.27	12.01	26.43	12.94	11.88	27.25	13.12	10.3	26.16	14.37	14.1	26.01
ABH 126	1	1985	74		31.75	29.73	43.57	15.31	23.84	14.38	13.83	24.04	14.86	13.28	26.01	13.66	17.16	23.48	15.52			18.14	16.47	25.59
ABH 129	1	1994	65				37.47	15.69	24.78	13.67	12.65	23.53	14.42	12.07	24.48	13.48	12.28	25.1	13.11	13.07	25.47	15.01	12.58	23.73
ABH 130	2	1993	69				32.79	15.15	20.78	12.68	12.81	20.4	11.57	11.05	21.45	11.41	10.34	22.38	12.73	11.1	22.24	11.21	10.71	22.88
ABH 131	2	1984	46				36.61	16.51	26.31	13.94	13.76	23.43	13.92	14.27	24.29	12.39	15.05	24.36	12.82	14.22	23.34	14.31	13.53	23.11
ABH 132	2	1986	74							13.82	14.76	22.19	12.27	13.55	23.06	11.83	13.95	24.03	12.98	13.45	24.91	15.18	14	24.59
ABH 135	1	1989	34		34.87	33.05	47.16	17.6	26.51	17.05	15.1	25.53	15.58	12.56	26.95	15.86	13.39	28.21	16.46	14.77	27.93	17.27	14.96	26.79
ABH 136	2	1979	62		26.57	27.99	32.31	16.34	23.09	11.14	13.85	23.32	12.89	14.08	23.89	10.85	14.4	24.75	12.94	13.65	24.79			
ABH 137	2	1972	41		26.85	26.87	35.6	15.18	20.57				11.9	11.93	21.24	11.46	12.39	21.92	11.91	11.99	22.01	13.33	11.89	21.6
ABH 138	2	1980	52		26.94	26.77	37.75	12.34	22.44	12.52	10.94	22.06	12.46	12.47	22.92	12.38	11.56	22.98	13.62	12.28	23.14	15.05	11.49	22.28
ABH 139	1	1983	44							13.63	15.01	22.24	13.67	15.09	22.55	13.24	14.51	23.65	12.76	14.01	24.32	14.88	14.03	24.09
ABH 140	1	1995	46		30.05	27.61	36.03	16.54	21.96	14.34	14.54	22.06	14.21	14.83	23.23				13.39	14.3	25.26	16.94	14.76	24.15
ABH 141	1	1984	48	151.78	31.84	29.6	38.35	17.82	23.57	13.58	15.79	22.84	13.28	15.32	24.13	11.44	15.77	25.39	11.83	15.69	27.02	14.73	16.18	25.11
ABH 143	2	1989	79		27.97	26.08	31.96	15.24	23.68	11.87	12.95	23.27	10.16	12.15	23.69	11.53	10.77	24.14	11.51	10.9	24.46	12.76	13.23	23.61

ID	Sex	YR Death	Age	Height	C1 AP	C1 TR	C2 HT	C2 AP	C2 TR	C3 HT	C3 AP	C3 TR	C4 HT	C4 AP	C4 TR	C5 HT	C5 AP	C5 TR	C6 HT	C6 AP	C6 TR	C7 HT	C7 AP	C7 TR
ABH 144	2	1977	60	143.04	26.12	27.59	33.81	14.68	21.67	12.04	13.02	20.23	12.02	12.52	20.23	11.07	12.6	22.08	12.22	12.19	21.88	13.32	11.62	21.56
ABH 145	1	1985	80		31.12	27	42.11	14.44	22.41	13.25	13.04	22.46	11.72	12.11	22.23	11.62	13.71	23.79	14.06	13.91	25.84	16.95	12.85	25.45
ABH 146	1	1976	55		30.34	26.53	35.93	13.48	22.68	13.77	12.19	22.45	13.74	12.58	24.45	12.12	12.54	25.64	12.7	11.01	25.83	13.79	11.97	24.35
ABH 148	1	1977	71		30.22	30.86	42.18	16.67	27.99	13.73	15.11	25.13	14.16	14.67	24.78	14.16	16.68	25.1	15.22	15.76	26.1	17.24	15.99	27.61
ABH 151	2	1985	63		32.36	30.14	39.42	14.68	25.56	12.86	12.56	24.98	11.96	11.38	25.59	12.13	13.67	26.92	12.29	13.67	26.93	14.72	14.07	25.94
ABH 152	1	1970	81		30.03	31.03				12.8	13.05	26.29	12.51	12.69	26.81	14.05	12.89	26.55	13.34	12.25	26.31			
ABH 155	1	1968	74	157.82	36.65	30.01	42.31	17.39	26.84	13.42	14.69	27.38	13.47	13.12	27.69	12.46	13.26	28.3	13.47	14.66	27.28	16.51	16.67	27.27
ABH 156	1	1968	59		31.09	29.33	38.3	17	23.59	14.89	15.01	22.69	12.08	13.57	24.42	12.57	13.34	25.35	13.82	12.29	25.53	15.53	12.47	24.75
ABH 157	1	1983	64		30.96	30.97	40.47	17.45	23.01				13.03	14.56	25.15				14.49	13.99	26.18	14.13	15.6	24.65
ABH 158	1	1986	78	153.83	33.08	29.21	42.42	16.4	23.38	14.34	14.22	23.9	14.1	13.67	24.9	11.86	14.42	25.88	13.59	15.23	25.36	16.67	14.5	23.75
ABH 159	2	1987	79		30.92	27.45	34.07	15.43	22.96	11.06	13.83	22.18	10.91	12.71	22.88	9.88	11.73	24.17		11.63	23.85	12.39	12.1	22.52
ABH 162	2	1986	69		29.44	26.24	35.1	17.38	22.08				12.48	15.66	24.41	12.54	16.15	24.89	12.56	14.27	25.76	13.97	14.78	26.43
ABH 163	1	1987	78		32.82	29.67	42.13	16.5	27.12	13.32	13.72	24.49	13.96	13.93	24.33	13.75	14.91	25.01	12.96	14.34	25.2	16.57	15.79	24.77
ABH 166	2	1989	49		29.16	30.27	35.26	17.43	26.19	14.03	15.74	24.12	12.76	15.43	24.23	12.08	14.98	24.72				13.59	15.76	24.48
ABH 167	2	1985	99			27.93	35.46	17.04	24.96	13.01	15.29	23.45	11.43	14.42	23.94	11.05	14.04	23.78		14.67	24.7	13.81	14.54	24.11
ABH 168	1	1976	66		32.82	31.85	36.41	18.69	25.34				13.07	14.25	25.7	13.03	14.44	27.09	13.45	14.96	28.28	15.06	15.01	27.8
ABH 169	2	1988	84		29.71	27.96	34.5	18.37	24.39	14.67	15.53	23.25	14.71	14.03	24.34	12.98	13.22	25.32				14.87	14.9	23.69
ABH 170	2	1981	73		27.93	26.88	34.92	15.78	21.09	11.84	13.72	20.9	11.34	12.78	22.76	10.39	11.8	22.97	11.06	12.13	23.86	13.69	10.78	22.98
ABH 176	2	1989	81	144.77	29.92	28.72	36.61	16.49	21.32	12.02	14.77	21.64	12.16	13.89	23.36	10.67	13.32	24.3	11.2	13.34	24.14	13.73	14.01	23.99
ABH 177	1	1988	65		31.82	28.48	38.55	15.34	22.23	13.34	13.89	22.08	12.55	13.73	23.34	11.43	13.59	24.07	12.38	12.67	25.82			
ABH 178	1	1977	73		29.24	26.65	38.07	16.13	24.67	12.37	13.48	22.83	12.19	16.55	24.22	10.03	15.94	24.71				15.23	15.12	24.4
ABH 179	2	1982	87	146.35	26	29.15	35.1	15.07	22.58	12.62	14	22.79	11.76	13.12	24.2	11.9	13.75	25.18	12.12	12.54	25.16	14.72	13.38	24.48
ABH 180	2	1989	81	134.28	26.94	25.44	33.52	14.27	23.39	11	12.56	21.22	11.09	11.81	22.16	11.49	12.16	23.26	11.13	11.26	24.05	13.37	11.93	22.07
ABH 183	2	1989	59		26.25	24.51	34.33	15.57	22.01	12.52	13.77	22.22	12.43	12.96	22.79	12.23	12.79	23.73	12.67	13.13	23.8	15.25	12.86	22.76

ID	Sex	YR Death	Age	Height	C1 AP	C1 TR	C2 HT	C2 AP	C2 TR	C3 HT	C3 AP	C3 TR	C4 HT	C4 AP	C4 TR	C5 HT	C5 AP	C5 TR	C6 HT	C6 AP	C6 TR	C7 HT	C7 AP	C7 TR
ABH 184	2	1982	72		30.94	25.29	34.16	18.19	23.58				11.31	12.63	22.99	10.36	12.52	23.61	11.14	12.03	23.57	12.03	11.37	23.7
ABH 185	2	1986	72		29.52	32.67	34.42	18.77	24.35	10.39	15.24	22.72	10.81	16.4	23.45	10.95	15.56	24.5				14.04	15.13	22.78
ABH 186	1		26		30.92	26.98	39.43	15.1	21.46	14.65	12.68	21.14	14.32	12.61	21.71	12.84	13.84	23.52						
ABH 192	1	1973	27	163.01	31.71	29.62	43.51	15.81	23.24	15.86	13.67	24.11	15.01	13.95	25.01	13.37	14.15	26.41	14.82	14.57	26.38	16.84	14.29	24.5
ABH 193	1	1987	25		32.51	34.47	44.57	15.26	24.44				14.82	12.75	25.03	14.21	12.41	26.43				13.88	12.94	27.09
ABH 194	2	1990	35		28.52	27.36	37.18	14.11	22.9	13.39	12.44	22.29				13.19	12.11	22.96	14.21	13.48	23.19	15.42	14.57	21.38
ABH 196	2	1965	50		28.76	28.64	36.48	16.21	22.37	13.15	13.93	23.28	11.89	13.34	24.37				12.45	12.54	24.33	14.63	14.79	22.61
ABH 198	2		45		28.04	28.28	37.08	15.29	22.47	13.48	13.07	23.14	12.12	11.61	24.12				12.24	10.85	24.31	14.12	13.11	23.48
ABH 200	1		43	158.81	34.34	30.91	39.46	18.92	24.49	14.46	14.1	24.23	14.98	13.34	25.23	14.44	13.34	26.14	15.52	13.86	25.19	17.56	13.75	23.06
ABH 203	2	1988	24		33.56	28.84	37.22	17.36	24.76	13.43	15.08	24.68	12.14	15.1	25.23				12.72	15.7	26.29	13.44	15.33	24.82
ABH 205	2	1975	47		30.9	27.71	35.77	16.95	23.95	12.98	15.4	24.87	12.53	15.29	25.68				13.46	14.6	25.39	14.89	15.36	24.56
ABH 209	1	1971	44		26.3	28.52	39.08	14.07	25.29	13.03	12.76	24.89	13.51	12.98	26.15	13.23	13.64	26.81	12.24	11.95	26.84	15.45	11.32	25.27
ABH 210	1	1991	43		28.31	26.18	36.01	14.73	23.35	12.92	13.77	22.7	13.34	13.41	22.97	12.34	13.66	23.93				14.89	12.84	23.56
ABH 213	1	1969	32		31.84	26.48	37.86	16.24	22.98	12.77	14.48	23.37	12.08	13.63	24.63	12.07	13.86	25.04	12.3	13.83	25.51	14.01	13.12	24.86
ABH 214	1	1969	33		30.04	31.86	38.72	15.25	25.33				14.67	13.86	23.58				14.82	14.47	26.41	17.06	14.95	24.07
ABH 215	2	1988	32		29.34	29.01	35.06	15.15	22.4	13.79	13.05	22.47	14.35	12.83	23.5	13.41	13.35	25.35	12.87	13.37	26.09	14.78	13.82	25.1
ABH 218	1	1991	29		31.06	25.99	36						14.34	14.21	23.56	13.85	14.83	24.21	14.24	14.22	24.51	15.69	14.07	23.19
ABH 220	2	1967	35		28.09	23.28	33.84	15.99	20.72				13.14	14.64	23.27	12.15	14.62	23.96	11.71	14.19	24.34	13.14	14.07	21.96
ABH 221	1	1972	25		30.87	29.58	41.74	16.44	23.18	15.69	13.66	23.2	15.41	13.83	23.71	15.42	14.43	24.27	15.73	14.81	23.98	17.87	15.25	22.51

9.2 Appendix C2: Lopes Collection Raw Data

ID	Sex	YR Death	Age	Hght	C1 AP	C1 TR	C2 HT	C2 AP	C2 TR	C3 HT	C3 AP	C3 TR	C4 HT	C4 AP	C4 TR	C5 HT	C5 AP	C5 TR	C6 HT	C6 AP	C6 TR	C7 HT	C7 AP	C7 TR
4	1	1968	88		30.09	30.22	35.25	15.63	23.46	13.62	12.57	23.08		12.45	23.99		12.91	25.63		10.81	24.27		13.43	24.01
5	2	1937	78	163.19	28.03	26.27	35.9		20.32	14.09		22.21	14.02	11.94	22.81	13.51	12.34	23.87	14.98	12.18	22.56			
6	2	1959	65		30.51	27.82	34.17	17.17	23.68	11.56	14.42	22.66	12.47	14.88	23.44	11.74	14.19	24.21	11.82	14.34	24.33			
9	2		50		28.07	23.28	36.49	14.06	22.03	13.18	12.7	21.35		11.72	23.3	12.46	12.01	23.38	12.31	11.93	23.5			
10	2	1954	74		29.36	29.48	36.49	15.41	25.12	12.37	12.79	23.54	12.86	13.18	23.67	11.97	13.26	24.41	12.68	12.48	24.38	13.97	14.13	23.35
18	2	1963	84	158.99	30.7	30.04	38.93	15.62	22.14	14.03	12.84	23.08	13.38	11.7	25.08	11.24	12.07	25.75	12.49	13.26	25.48	13.53	13.69	25.24
24	1	1914	65	152.69			35.37	16.63	21.32	14.53	13.72	21.31	13.81	13.37	22.54				12.28	11.07	23.49	15.85	12.61	23.13
25	1	1938	81				37.62	17.64	22.92	14.67	14.32	23.15				13.96	13.29	25.31	14.35	12.84	25.84	16.39	13.95	26.2
27	1	1923	67	168.15			37.46	14.8	21.42	13.2	14.02	22.46	13.68	13.83	24.17	12.31	14.11	26.41	14.14	13.11	25.62	16.61	13.34	24.6
30	2	1917	54	168.91	28.29	28.79	39.03	15.62	22.58	13.12	13.83	22.74	13.28	13.69	23.65	12.53	12.83	24.43	13.45	13.11	24.36	16.23	13.11	22.39
31	1	1942	82				35.1	17.17	22.94	13.48	14.83	22.39	13.53	15.36	24.49	13.69	15.74	25.45	12.45	15.2	24.78			
34	1	1929	65		29.78	24.02	35.39	15.24	20.35	13.27	13.44	20.07	12.64	13.45	20.85	12.16	13.99	21.43	12.64	13.58	21.61	14.61	12.27	22.56
35	1	1931	47	173.61	29.95	29.15	38.72	16.82	24.92	12.34	13.83	24.93	13.37	12.38	25.96	13.97	12.76	25.9	14.02	12.31	25.81	15.62	12.51	26.23
48	1	1944	68	160.68	27.41	24.91	34.51	14.09	19.94	11.73	12.18	19.61	12.31	12.11	20.56	11.28	12.29	20.28	11.61	13.14	21.24	13.42	12.6	21.27
52	2	1959	83		26.06	28.12	37.62	13.52	22.2	13.42	11.83	22.97	12.84	11.09	23.92	11.56	11.04	25.05	12.24	12.67	25.38	14.12	14.39	24.19
61	2	1934	66		27.38	26.21	36.53	13.47	20.35	10.66	11.18	20.14	10.94	11.46	21.41	12.03	11.99	21.66	12.72	11.69	22.28	12.78	10.39	21.13
62	2	1958	84		28	32.19	36.2	15.32	21.79	12.77	13.26	22.52	12.45	13.3	23.83	11.96	13.7	24.3	11.45	12.94	24.75			
63	2	1939	48		27.39	26.18	35.77	14.44	19.77				11.76	12.12	21.69	11.38	12.44	23.13	11.19	12.56	23.97	13.24	12.88	23.03
72	2	1952	94		29.09	28.41	36.4	13.6	24.32	11.28	11.49	23.87	11.07	11.57	24.17	10.22	11.95	25.07	11.21	12.57	25.47	13.3	12.18	25.17
73	1	1928	47	151.79			35.62	15.85	24.34	11.66	13.78	23.84	10.36	12.6	24.41	10.81	13.09	25.04	10.78	13	25.86	14.01	13.75	23.99
75	1	1956	30				37.62	17.83	24.1	14.93	16.15	23.26	13.23	14.2	25.24	13.95	14.81	24.76				15.59	13.08	23.737
77	2	1933	65		33.46	28.41	36.45	15.88	23.97	12.97	14.48	23.72	12.98	13.78	25.33	10.76	13.41	25.63	10.95	12.11	25.58	12.71	12.22	24.45
80	2	1946	74	165.43	27.31	27.16	34.18	17.42	22.82	11.28	15.32	21.58	11.83	14.45	22.23	12.02	14.69	22.84	11.64	14.48	22.99	12.69	14.69	23.09
82	2	1917	81		29.03	28.16	35.31	15.59	24.72	13.32	14.07	23.29	11.03	13.86	23.22	11.92	14.3	24.27	12.48	12.27	23.93			

ID	Sex	YR Death	Age	Height	C1 AP	C1 TR	C2 HT	C2 AP	C2 TR	C3 HT	C3 AP	C3 TR	C4 HT	C4 AP	C4 TR	C5 HT	C5 AP	C5 TR	C6 HT	C6 AP	C6 TR	C7 HT	C7 AP	C7 TR
89	2	1940	50		28.39	30.22	36.44	15.45	24.31	12.61	13.93	23.15	13.19	12.51	24.25	12.28	13.6	24.17	13.06	12.31	24.28	14.82	12.02	23.99
91	2	1927	83	149.82	24.73	25.73	33.69	13.81	19.59	10.58	12.51	19.62	10.23	12.04	20.21	10.36	12.51	22.13	10.64	12	20.48	13.12	11.77	19.43
92	1		55		28.77	27.56	38.08	14.88	22.05	14.16	13.36	22.28	12.53	12.66	22.82	13.34	12.39	23.19	12.92	13.49	23.74	15.56	14.44	23.46
97	1	1967	81		29.58	26.29	33.94	14.14	22.61	13.82	12.46	22.8	12.93	12.26	24.44	13.15	13	24.8	12.47	13.16	25.77	13.55	13.2	24.93
102	1	1958	48		33.59	29.69	39.2	17.28	23.02	13.26	13.98	22.52	14.18	13.96	24.02	13.64	14.04	24.92	13.82	13.87	24.84	15.55	13.94	24.87
104	2	1949	59		28.53	26.13	38.43	14.3	23.62	13.92	13.69	22.18	13.34	13.01	22.67	13.32	11.01	22.65	13.3	12.54	22.37	15.17	12.65	22.91
109	1	1938	54	158.82	31.33	27.35	36.99	14.78	22.12	13.56	11.24	22.3	13.71	11.2	22.81	13.67	11.82	23.21	12.2	11.16	23.34	15.64	13.31	22.08
115	2	1929	28		28.03	25.99	32.66	15.38	23.05	13.18	13.12	22.71	13.71	13.77	22.41	12.46	13.39	23.7	12.03	13.19	24.07	15.02	12.78	22.71
127	2	1949	67	168.36	33.61	32.44	36.16	17.16	25.13	14.08	13.2	25.09	12.69	11.43	27.33	11.95	12.97	27.65	14.01	13.24	27.69	15.84	13.95	24.94
131	1	1923	58		28.39	28.57	37.67	14.47	21.91	14.48	12.44	22.05	12.56	11.87	23.12	12.28	12.25	24.05	13.49	11.67	25.76	16.1	12.16	22.19
138	2	1945	61	163	29.49	29.31	37.38	17.39	25.18	12.01	15.41	24.25	12.74	16.05	24.31	11.66	16.51	25.52	12.43	16.09	26.78	15.39	14.58	25.84
150	1	1922	70		27.06	28.33	33.93	15.22	20.51	10.64	13.59	21.95	11.91	12.95	23.28	11.76	12.91	23.83	11.61	12.15	24.53	13.96	13.29	25.16
152	1	1938	33	162.67			39.58	15.4	25.13	13.78	14.31	24.22	13.09	13.15	24.11	10.88	12.86	24.38	12.2	12.36	25.35	14.99	13.25	24.37
153	2	1947	87		28.62	26.14	33.92	16.16	21.59	11.31	14.29	21.03	10.67	13.77	23.46	10.88	12.49	24.64	12.56	15.1	23.57			
154	1	1926	35		34.12	33.45	37.16	18.02	25.23	14.64	14.87	23.45	15.07	14.51	25.73	13.92	15.21	27.02	13.85	15.83	26.77	14.59	15.67	25.95
158	2	1943	76		30.24	27.04	33.77	15.19	22.45	12.03	13.78	22.14	11.81	14.68	21.99	10.59	13.95	22.63		12.96	23.7	13.31	14.51	22.95
163	1	1920	37				35.61	16.82	23.88	12.42	13.41	24.65	13.46	13.21	26.41	13.26	12.76	26.94	15.3	13.23	24.53			
176	1	1951	45				37.77	16.42	20.81	12.81	14.34	20.61	12.88	13.62	21.35	12.63	13.43	23.05	13.85	14.77	22.32	14.26	14.84	21.03
177	2	1925	23	160.47	27.19	27.52	37.82	16.4	23.22	13.27	14.68	23.04	12.14	15.13	24.35	12.25	15.3	24.65	13.05	15.04	23.91	14.86	14.98	22.12
181	2	1948	44		26.44	26.84	35.88	14.69	21.8				11.78	12.65	23.88	11.35	12.82	24.55	12.47	13.22	24.6			
185	2	1949	80		25.14	28.64	31.59	14.7	22.01	10.48	13.78	21.06	10.25	12.85	21.86	10.56	12.51	22.64	10.34	12.1	22.52	12.44	10.69	22.23
189	2	1949	75		29.56	30.26	38.61	15.29	23.3	13.54	12.75	23.04	12.66	10.76	23.25	12.51	10.85	24.46	14.92	9.67	24.36			
190	2	1956	85		28.57	25.67	34.72	13.52	22.01	12.36	12.12	22.4	11.39	12.18	23.47	11.66	11.67	24.24	11.53	10.59	24.39	13.46	11.25	23.97
191	1	1950	49		33.76	30.17	38.22	15.55	23.47				13.04	12.93	24.82	12.03	12.58	25.78	11.84	12.81	25.2	14.94	12.67	24.03
196	2	1944	69		29.1	25.5	35.42	15.02	23.01		12.49	21.53	12.76	12.37	22.9	11.46	12.58	23.08	10.87	12.22	23.63	13.73	11.78	23.49

ID	Sex	YR Death	Age	Height	C1 AP	C1 TR	C2 HT	C2 AP	C2 TR	C3 HT	C3 AP	C3 TR	C4 HT	C4 AP	C4 TR	C5 HT	C5 AP	C5 TR	C6 HT	C6 AP	C6 TR	C7 HT	C7 AP	C7 TR
198	1	1928	68	163.07	29.76	29.63	36.82	16.39	23.02	14.97	13.72	22.71	12.69	13.35	24.8	13.8	13.57	24.79	12.66	13.59	24.97	15.06	13.59	22.92
202	1	1918	40		31.47	29.31	39.02	16.64	25.32	14.27	14.18	24.03	13.39	13.46	25.19	13.73	14.12	25.57	14.64	14.56	25.72	16.25	14.95	25.25
203	2	1936	59		25.69	24.59	31.89	14.93	20.38	12.38	13.13	19.44	11.44	11.94	21.36	10.77	10.94	22.41	10.44	10.72	21.86	14.05	10.06	20.43
210	2	1943	78		28.45	26.58	36.16	14.69	23.02	11.73	13.17	22.68	11.71	12.63	23.56	11.85	10.26	23.38	11.73	11.06	22.35	13.14	11.44	22.16
221	2	1941	20		27.73	26.93	34.47	15.82	23.09	11.87	14.68	21.63	11.89	14.56	23.09	11.71	14.59	24.11	12.48	14.32	24.33	14.67	14.38	23.08
223	2	1942	61		29.18	28.39	36.47	14.21	24.76	13.18	12.29	24.83	12.01	13.4	24.95	12.79	12.32	24.62	12.54	11.87	25.23	13.74	11.6	24.11
228	2	1912	63		27.05	24.44	36.77		20.36	11.6	12.77	20.32	11.65	13	20.64	12.49	13.07	22.24	12.59	12.06	22.87	13.42	11.25	21.74
232	2	1936	76				34.16	15.36	22.6	12.47	12.37	21.8	12.32	11.86	23.44	12.1	12.33	23.97	12.44	12.15	24.92	13.94	13.71	23.98
233	1	1934	67		29.64	26.39	40.86		22.97	13.92	11.14	23.98	14.97	11.37	26.32	14.52	11.37	26.93	15.52	11.82	27.13	16.99	12.74	26.34
238	1	1924	35		29.56	30.61	35.89	16.22	22.78	11.28	14.07	22.94	11.52	13.93	24.88	11.89	14.1	25.82	12.31	14.14	25.69	13.72	14.28	24.7
239	1	1944	58	156.5	27.9	25.78	36.22	14.2	21.88	13.1	11.24	22.18	11.13	10.74	22.83	10.9	11.17	23.01	11.24	11.98	23.26	13.44	11.44	22.29
240	2	1930	52	159.57	27.62	26.81	35.59	16.02	21.96	11.56	13.68	22.65	11.31	13.1	23.66	10.26	13.12	24.31	11.92	13.79	24.02			
242	1	1934	52	164.35	30.24	32.68	34.81	15.57	26	12.86	13.24	25.05	12.69	12.98	26.55				11.95	12.92	26.93	13.72	13.95	25.68
247	2	1940	29		29.61	28.53	35.63	14.79	23.95	14.19	12.56	23.6	14.4	12.15	24.14	13.32	12.94	24.51				14.13	13.55	24.06
251	2	1934	50	162.57	27.13	26.89	35.16	17.23	22.29	11.61	14.46	20.24	10.43	13.75	21.61				10.86	12.81	23.7	12.45	13.43	23.57
253	1	1925	82		25.97	27.41	35.69	12.58	20.17	12.41	12.2	20.24	12.21	11.26	21.39	12.05	12.76	21.96	12.42	12.31	22.99	16.43	11.27	22.15
267	1	1948	69	165.42	31.32	32.53	39.75	17.48	26.05	13.27	15.33	24.28	13.36	15.65	25.61	12.72	15.88	28.15	12.92	14.61	28.85	14.53	16.47	26.14
270	1	1941	50		30.6	27.95	35.11	14.93	22.78				13.87	12.48	24.41				13.38	13.18	24.99	15.01	13	24.23
271	2	1937	84		28.44	24.04	35.98	14.58	21.8	12.85	12.19	22.49	12.27	11.14	24.02	11.61	11.97	25.13	12.09	12.52	25.47	13.13	12.67	24.27
273	1	1941	65	168.94	30.43	31.57	38.53	16.29	23.61				11.67	13.12	25.25	12.61	14.44	25.7				14.29	17.2	26.32
274	2	1909	77		30.44	28.99	36.01	17.42	23.16	12.91	14.01	22.75	12.18	13.9	22.82	11.92	13.71	23.27				12.78	14.26	20.93
275	2	1925	70		31.96	28.07	34.23	15.45	24.34	12.35	11.15	22.88	11.94	11.12	23.44	12.76	10.26	24.22	12.32	11.39	23.77	14.19	11.89	22.53
276	2	1945	27	160.54	27.84	27.72	33.94	15	22.55	11.4	13.43	23.61	10.35	13.02	24.57	10.31	12.95	25.01	12.25	13.22	25.65	12.76	13.71	24.22
280	2	1924	83		27.68	24.17	36.97		18.75	12.33	12.74	19.81	12.65	12.31	20.3	11.46	12.39	20.79	10.41	12.99	20.82	14.76	13.23	20.63
285	2	1933	68	158.76	26.35	25.93	34.56	13.06	22.63	12.4	11.31	22.89	11.98	11.1	23.98	11.07	10.5	24.71	11.48	11.79	24.16	13.49	12.79	22.82

ID	Sex	YR Death	Age	Height	C1 AP	C1 TR	C2 HT	C2 AP	C2 TR	C3 HT	C3 AP	C3 TR	C4 HT	C4 AP	C4 TR	C5 HT	C5 AP	C5 TR	C6 HT	C6 AP	C6 TR	C7 HT	C7 AP	C7 TR
292	2	1918	52	162.8	31.58	28.18	36.86	15.57	23.82	12.42	14.08	22.63	11.92	13.07	23.09	12.24	13.25	24.8	12.76	13.03	24.61	15.19	13.22	23.41
295	2	1938	83		28.26	27.38	37.06	15.88	20.93	12.67	13.65	22.49	12.96	13.17	24.09	12.95	13.64	24.97	13.09	14.23	24.81	13.97	14.98	23.13
296	2	1940	78		29.9	27.87	35.05	16.69	22.56	12.37	15.19	22.61	11.09	14.18	22.83	11.22	14.8	24.06	11.46	15.24	24.93	13.72	15.05	24.36
297	2	1943	69		29.85	29.81	35.29	17.55	24.42	10.87	14.33	23.89	11.45	14.34	25.31	10.21	13.79	26.09	10.42	14.46	26.63	12.51	15.73	27.61
301	1	1952	20		33.49	31.91	40.05	19.78	26.55	13.17	16.83	24.49	11.98	15.11	26.58	11.95	15.26	28.71	12.96	15.44	28.87	15.24	16.84	27.72
302	1	1927	40	159.82	26.82	26.21	35.87	15.76	21.13	14.64	13.52	22.48	13.45	12.48	24.88	13.12	13.38	25.29	13.69	13.51	25.76	14.3	13.66	25.25
305	1	1937	30		30.84	27.15	38.78	16.92	22.02	14.19	15.24	23.05	14.16	14.33	25.17	13.26	14.35	25.84	12.63	13.9	24.88	14.56	12.97	22.96
307	1	1944	69		32.4	27.75	41.46	14.53	23.67	13.82	13.18	23.77	13.04	13.08	25.32	12.84	13.31	24.81	13.93	13.09	24.61	15.41	14.35	23.56
308	1	1937	43		31.63	27.65	36.76	17.35	20.81	13.01	15.16	21.26	10.61	16.08	21.67	10.32	16.52	22.28	11.63	16.64	23.6	13.23	16.14	24.19
309	1	1942	30		33.74	29.15	38.33	16.12	23.65	13.33	12.56	24.29	13.76	10.51	24.97	12.85	11.61	26.12	11.64	12.57	26.45	12.76	12.03	24.97
311	1	1913	57		32.53	29.66	41.13	16.57	23.59	14.11	14.22	23.44	14.31	13	24.91	14.48	13.62	24.99	13.5	13.71	26.11	14.54	15.06	23.84
312	1	1941	69		29.44	31.03	40.57	15.13	22.65	14.2	12.84	22.34	12.08	12.17	24.01	11.06	13.51	25.97	11.14	13.2	25.91	14.68	11.86	25.75
314	2	1940	20		32.19	32.67	37.76	16.03	24.22	14.15	14.02	23.21	12.39	12.94	23.88	12.09	13.1	24.08	12.39	13.11	23.3	13.48	13.19	22.86
317	2	1943	52	174.17	31.34	29.49	37.17	14.88	23.07	14.03	12.91	22.83	14.15	12.67	23.62	13.31	13.31	25.42	12.21	12.58	25.88	14.19	11.34	24.5
318	1	1942	29	166.64	32.33	29.77				14.89	15.68	25.43	14.36	15.13	25.28	12.92	15.59	24.63	14.3	16.21	24.84	16.54	16.06	24.73
319	2	1939	93		27.52	29.76	37.48	16.59	23.88	13.58	14.59	23.45	12.37	14.1	24.35	13.36	11.78	24.54	12.53	13.08	25.01	14.56	13.74	25.48
321	1	1940	54	159.26	34.19	30.01	38.66	17.62	27.5	14.67	16.19	25.85	14.22	14.9	26.6	13.94	15.13	27.91	14.39	15.61	27.76	15.01	15.82	26.98
322	2	1944	87		25.92	26.87		15.36	22.32		12.58	21.05		12.37	21.43		11.87	22.35	12.25	11.19	23.23	14.02	11.97	23.01
323	2	1946	57				33.72	14.71	22.3	11.13	12.99	20.7	10.18	12.32	20.18	11.27	12.37	20.56	12.97	10.97	22.44	13.68	11.78	22.33
324	1	1950	43	160.97	27.47	25.56				13.06	13.26	20.05	12.52	13.38	20.97	11.49	13.56	21.99	11.43	13.26	22.55	14.2	12.78	21.41
327	2	1940	35	153.92	28.07	26.38	34.18	16.06	20.43	10.65	13.56	20.44	10.91	12.4	22.48	11.14	11.12	23.04						
328	2	1937	65	158.59	31.71	29.97	36.14	16.8	21.41	11.97	14.06	22.03	11.28	14.63	23.21	9.49	14.36	24.35	11.81	14.18	24.92	13.87	14.53	24.59
329	1	1955	38		32.11	29.56	35.53	17.53	24.22	13.37	14.8	23.03	13.69	13.93	23.48	12.31	13.56	24.28	13.21	14.32	25.09	16.19	14.86	23.63
333	2	1953	39				35.77	12.88	23.04	10.63	10.67	21.42	12.74	10.45	22.37	11.76	11.68	22.55	13.34	11.55	21.12	15.6	10.91	20.78
342	2	1943	65	156.83	26.08	24.37				12.97	13.17	21.08	12.93	13.03	22.29	11.67	13.03	22.71	11.89	13.37	22.68	13.86	13.64	22.33

ID	Sex	YR Death	Age	Height	C1 AP	C1 TR	C2 HT	C2 AP	C2 TR	C3 HT	C3 AP	C3 TR	C4 HT	C4 AP	C4 TR	C5 HT	C5 AP	C5 TR	C6 HT	C6 AP	C6 TR	C7 HT	C7 AP	C7 TR
344	1		27				36.97	4.92	23.11	13.57	12.88	22.99	13.36	11.72	24.08	12.56	11.92	24.57	12.5	12.41	23.85	14.76	13.56	23.95
348	2	1934	54	158.83	28.82	30.14	38.25	16.08	23.23	12.75	14.89	22.5	12.24	14.84	25.1	12.25	15.62	25.74	12.32	14.96	25.07	16.1	14.55	24.99
349	2	1940	57		28.71	28.26	36.75	14.34	23.96	11.39	13.09	23.28		13.92	23.71		13.78	24.23		14.12	25.39		13.63	24.82
350	2	1943	74		30.49	25.7	32.3	17.78	20.92	12.57	14	20.96	12.99	13.87	22.3	12.19	13.51	23.34	11.85	13.19	23.59	13.59	14.38	21.36
351	2	1936	90		26.94	25.39	37.18	14.78	21.1	11.71	13.21	21.11	10.42	13.32	22.42	10.62	13.77	23.89	12.19	13.87	23.85	14.02	13.65	22.89
353	2	1944	77		29.58	25.85	35.06	15.71	21.82	13.24	13.37	20.91	12.5	12.42	22.13	12.51	12.96	22.39	12.65	12.98	22.33	13.66	11.83	20.29
355	1	1956	31		29.28	28.96	38.82	16.2	23.51	13.71	14.43	22.36	13.75	14.01	23.08							17.32	14.83	22.06
354	1	1943	72		29.53	27.78	36.36	16.29	23.65				14.32	13.75	22.93	12.54	13.35	23.03	12.29	13.29	23.46	14.92	14.51	22.24
361	2	1948	21		29.23	27.86				12.29	13.38	21.65	11.34	12.89	22.75	11.56	13.25	23.09	11.82	12.97	23.01	13.14	12.93	21.67
364	2	1942	51		28.98	27.5	33.43	15.67	21.67	11.19	13.6	20.85	10.41	13.56	21.21	10.16	13.98	21.97	10.19	14.09	22.44	11.35	13.737	22.34
367	2	1951	32		33.34	30.12	32.42	18.4	23.79	12.05	16.08	23.05	10.71	16.68	24.5	9.69	16.41	26.02	9.84	15.07	26.36	12.35	14.32	26.27
373	1	1938	65		31.24	31.36	35.67	16.6	24.98	13.89	13.45	24.97				14.32	12.17	24.11	14.44	12.1	24.19	13.94	13.2	24.32
376	1	1937	76		29.19	29.22	36.54	15.58	22.46	11.03	13.88	23.37	11.87	13.42	24.35	10.76	12.85	24.65	12.29	12.5	25.61	13.96	13.89	25.23
383	1	1950	84		30.15	28.1	42.43	15.03	23.06	13.26	13.34	23.53	13.58	13.69	24.48				12.57	13.55	25.26	12.54	13.51	25.25
386	1	1940	74	158.98	30.72	25.58	35.72	16.92	21.11	13.71	13.92	20.99	12.86	13.51	22.18	11.5	13.62	23.56	11.42	14.37	24.15	14.72	14.1	22.72
388	1	1941	75		30.44	29.57	38.01	15.99	23.73	12.51	14.4	22.68				11.61	14.27	24.31	11.24	13.97	24.99	13.38	13.46	22.94
391	1	1945	20		30.14	28.26	39.21	17.22	23.03	14.77	15.67	24.41	14.26	14.74	25.76	13.69	14.63	27.13	12.7	14.16	26.88	15.54	14.26	24.7
396	1	1957	82		28.8	26.32	35.44	14.25	20.13	13.1	12.02	21.52	13.9	12.89	22.55	12.39	12.87	23.33	12.13	11.63	23.51	12.81	12.32	23.09
401	1	1936	72		27.8	25.45	36.25	15.44	21.99	13.92	13.36	23.85	14.33	12.97	24.92	12.96	13.93	25.84	13.58	13.08	26.84	15.08	13.94	26.15
404	2	1923	43	165.85	27.72	27.58	35.39	13.95	23.77	10.32	13.29	23.48	10.68	13.67	23.92	10.43	14.31	24.92	10.94	14.05	24.9	12.68	13.9	24.65
405	1	1944	32	168.41	30.86	28.42	37.68	16.03	24.06	13.51	14.02	23.67	15.54	13.73	24.92	13.74	14.33	25.57	13.61	14.07	25.73	15.04	15.03	25.94
411	1	1923	67		30.05	30.83	38.79	15.41	24.28	12.69	12.26	22.87	13.88	10.88	24.08	14.24	11.28	25.58	14.31	11.52	26.17	15.88	12.51	25.11
414	1	1954	49		29.45	26.62	36.9	15.79	21.56	14.48	15.25	23.58	12.29	15.46	24.68	10.95	15.53	24.6	11.69	15.15	24.92	13.49		
416	1	1943	76		30.64	24.18	38.42	14.12	20.91				11.32	11.37	20.88				11.97	11.64	22.41	13.92	11.73	21.35
419	1	1946	31		32.36	26.79	40.46	18.09	23.69	13.06	15.23	24.28	13.52	15.26	25.61	13.43	16.32	26.08	13.48	16.99	26.43	14.89	16.74	27.12

ID	Sex	YR Death	Age	Height	C1 AP	C1 TR	C2 HT	C2 AP	C2 TR	C3 HT	C3 AP	C3 TR	C4 HT	C4 AP	C4 TR	C5 HT	C5 AP	C5 TR	C6 HT	C6 AP	C6 TR	C7 HT	C7 AP	C7 TR
422	1	1944	21		29.21	29.15	37.54	16.46	24.94	14.41	14.52	23.71	14.13	14.29	24.76				13.33	13.49	25.35	15.43	13.61	25.35
426	1	1938	79		29.75	30.33	37.02	13.37	24.15	14.95	12.29	24.59	14.56	11.98	25.83	14.44	10.59	27.73	14.56	10.71	27.51	15.95	13.8	28.3
427	1	1943	56	163.64	30.03	27.36	41.43	15.59	24.58	15.43	14.04	25.34	14.94	13.95	26.46	15.07	14.48	26.34	14.73	15.9	25.84	16.35	14.82	24.56
433	1	1913	33		32.39	27.88	38.22	16.99	22.61	14.59	15.21	21.61	13.79	14.25	23.15	13.57	14.17	24.32	13.63	13.86	24.19	15.23	13.95	24.02
453	1	1927	88		30.43	26.14	35.68	14.47	20.23	13.15	13.17	21.61	11.46	12.43	22.86	10.55	11.15	24.06	11.53	12.3	23.78	11.96	13.02	21.95
457	1	1929	66	165.02	31.15	28.55	36	17.2	24.6	14.01	14.67	24.43	13.42	14.17	23.71	12.52	15.63	27.09	15.5	15.24	27.64	17.21	13.76	26.77
458	1	1932	59		32.4	30.72	39.25	17.23	24.32	15.62	13.72	22.85	14.92	13.04	24.07	14.17	13.73	24.69	14.75	14.39	25.6			
460	1	1933	52		34.12	30.88	39.4	16.99	24	13.01	14.48	24.43	12.56	14.07	26.03	12.75	14.28	26.93	13.18	14.53	27.04	15.73	14.76	27.28
462	1	1931	43		32.95	30.48	40.34	20.1	26.67	15.94	16.78	25.81	14.61	15.06	26.34	14.55	14.04	27.53	13.74	12.76	27.62	14.45	14.69	25.92
464	1	1912	71		28.55	28.2	42.53	13.34	23.68	14.79	12.06	25.42	12.79	11.52	27.18	12.15	12.62	27.31	12.82	13.3	26.53	13.73	13.16	26.78
465	1	1909	47		30.42	30.17	34.59	14.82	22.16	11.41	11.81	22.95	9.86	11.5	23.89	10.41	12.66	24.55	10.47	13.18	24.33	12.44	13.96	25.16
467	1	1931	45		30.94	25.64	37.61	15.98	21.44	13.17	13.44	21.16	13.36	13.77	22.1	11.55	13.57	23.16	13.19	13.02	24.55	14.64	13.03	23.47
468	2	1944	25		27.76	26.02	33.63	14.92	21.8	13.34	12.86	22.68	12.19	12.97	23.53	11.9	13.41	23.41	11.56	13.41	23.67	13.45	12.81	22.37
470	1	1933	68		28.31	30.33	36.85	16.46	23.69				11.81	13.59	25.61	12.49	12.04	25.8	12.48	13.43	25.29	15.18	14.18	26.87
471	1	1928	55		29.37	28.69	38.24	15	23.7	13.31	12.41	23.62	12.79	12.39	23.97	12.92	13.74	24.29	12.69	14.06	24.2	14.02	14.29	24.9
472	1	1933	28		28.75	29.42	36.08	15.12	23.83	12.83	12.26					13.86	12.48	26.49	14.2	11.97	25.78	15.1	13.43	25.12
474	1	1928	23	161.04	28.55	27.85	39.41	15.26	22.38	15.88	13.68	22.44	13.64	14.06	23.17	13.43	13.74	24.63	12.9	14.23	25.22	14.95	14.47	26.06
477	1	1926	54	164.83	32.79	29.79	41.2	16.58	23.29	14.38	13.71	23.35	13.87	12.56	24.2	13.41	11.73	24.95	13.61	13.46	25.13	15.26	13.17	23.84
491	1	1921	66		34.3	34.29	43.76	17.83	27.19	13.46	15.37	27.02	13.66	14.86	27.99	13.24	14.66	28.55	13.28	15.26	28.43	14.29	15.09	27.46
493	1	1945	82							13.71	13.48	23.25	14.02	12.45	24.63	13.19	14.23	24.31	14.81	13.97	24.99	16.88	13	25.02
494	2	1935	44		30.09	29.84	33.28	16.76	22.43	11.59	14.5	22.09	11.36	12.86	23.74	11.68	12.64	24.17	11.71	13.66	24.45	13.27	13.78	23.21
497	1	1909	47		32.88	29.51	38.02	16.7	23.77	14.06	14.53	24.43	14.31	14.27	24.73	13.17	14.4	25.3	14.84	14.46	25.09	15.96	15.14	25.18
498	2	1924	24	167.53	32.1	28.39	39.04	15.85	25.09	12.04	13.72	23.98	12.53	12.2	25.27	12.26	13.32	26	12.97	13.33	25.46	15.31	14.07	24.21
500	1	1891	45		31.71	27.93	35.99	15.67	23.46	13.27	13.73	21.69	14.05	12.9	22.46	11.73	13.24	23.59	12.66	13.61	24.57	14.63	13.84	24.25
501	1	1934	23	149.12	27.14	27	34.71	16.46	20.8	12.09	14.94	21.2	11.81	13.29	22.73	11.35	13.66	23.29	12.24	13.67	24.21	13.85	14.24	22.58

ID	Sex	YR Death	Age	Height	C1 AP	C1 TR	C2 HT	C2 AP	C2 TR	C3 HT	C3 AP	C3 TR	C4 HT	C4 AP	C4 TR	C5 HT	C5 AP	C5 TR	C6 HT	C6 AP	C6 TR	C7 HT	C7 AP	C7 TR
503	2	1936	46		31.13	28.7	37.33	16.18	23.93	13.02	12.89	23.67	12.39	11.51	26.47	13.24	12.09	26.67	12.94	12.48	26.19	14.26	13.02	23.71
504	1	1922	59		35.09	36.21	39.57		22.19	12.91	13.1	22.41	12.92	12.08	21.88	13.76	12.08	21.92	13.19	12.54	22.33	15.05	11.4	22.15
505	2	1912	32	161.08	30.33	29.22	36.02	15.88	24.19	11.27	13.32	23.89	11.18	13.57	24.03	11.01	14.12	23.93	11.12	14.51	24.39	12.76	14.85	24.33
506	1	1934	30		31.38	25.95	38.03	15.38	24.95	13.67	13.91	25.44	13.19	13.91	26.04	13.18	14.76	27.33	13.09	14.75	27.98	15.81	15.11	26.91
507	1	1937	51		31.93	28.85	34.84	15.83	24.67	12.84	11.93	24.77	12.2	11.22	25.99	12.66	11.01	26.49	14.18	11.15	26.2	13.45	11.01	25.67
508	1	1954	53		30.12	27.08	36.56	16.19	23.38	13.79	14.14	22.69	12.19	13.91	23.23	12.28	13.39	23.16	13.55	12.41	23.81	13.17	12.48	23.31
509	2	1934	72		29.56	28.25	33.07	15.66	22.23	12.29	13.81	23.81	11.14	13.39	24.68	11.03	12.84	25.83	11.51	12.39	24.86	13.22	12.98	23.97
510	1	1937	49		31.36	29.1	42.31	14.78	24.04	14.29	13.01	23.26	14.49	12.14	24.01	13.98	12.9	24.49	13.56	14.22	24.11			
511	1	1917	64		31.96	28.91	36.02	15.11	23.44	13.76	13.83	22	12	13.17	22.82	12.57	13.77	23.84	11.87	12.82	23.97	13.8	11.3	24.77
513	1	1905	50		28.26	26.84	37.65	13.91	21.07	12.29	12.83	22.32	12.26	12.64	23.16	10.42	13.7	24.25	12.06	14.49	23.08			
514	1	1921	27	162.97	31.34	30.75	41.05	17	24.74		14.83	23.85		13.64	25.75	14.31	14.23	26.17	14.77	13.88	26.21	14.95	13	25.52
517	2	1898	35		30.09	28.66	35.79	16.94	24.23	12.25	14.18	23.15	11.83	13.14	24.13	10.45	12.33	24.77	11.43	11.83	25.18	12.9	12.25	24.19
518	2	1915	73		29.88	26.84				11.34	16.22	23.1	10.84	16.29	23.4	11.07	15.3	23.87	10.68	13.77	24.52	12.16	13.08	23.71
520	2	1900	74		29.91	28.59				13.62	13.42	22.07	12.48	13.18	23.01	12.82	13.86	23.97	13.41	13.82	23.81	15.24	13.28	21.84
545	2	1951	78				36.02	16.76	21.66	12.09	13.16	22.21	12.36	12.02	22.64	12.49	13.19	23.85	12.37	12.76	23.84	13.54	11.94	22.67