THE ESTIMATION OF STATURE FROM THE TARSALS: ENHANCING THE DISASTER VICTIM IDENTIFICATION PROCESS IN THAILAND USING THE CALCANEUS AND THE TALUS

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ABSTRACT

The Estimation of Stature from the Tarsals: Enhancing the Victim Identification Process in Thailand using the Calcaneus and the Talus

by Shelby Scott

The impact of climate change is estimated to be particularly severe in Thailand. Therefore, there is an urgent need for population-specific methodologies for the identification of unknown human remains in Thailand. The current research study focuses on the calcaneus and the talus to establish an accurate method of living stature estimation for a contemporary Thai population.

Paired calcanei and tali of 232 adult skeletonized individuals (115 males, 117 females), ranging from 19 to 96 years of age were studied from the contemporary Chiang Mai skeletal collection. Nine measurements were collected from each calcaneus: MAXL, MAXH, CFH, BH, MINB, LAL, MIDB, DAFB, DAFL. One measurement, MTAL, was collected from each talus.

All measurement variables of the calcaneus and the talus exhibit sexual dimorphism. Regression formulae, generated from other populations, were found not to be accurate predictors of stature when applied to the contemporary Thai population. Comparisons of calcaneal and talar size to other populations were made. There were significant differences for the calcaneus and the talus between the contemporary Thai and comparative populations. Therefore, population-specific regression formulae are necessary to accurately estimate stature in a contemporary Thai population. The results of the current research study will assist in estimating living stature of unknown contemporary Thai individuals, and will be useful in cases such as natural disasters where only fragmented remains are available for examination.

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CHAPTER 1: INTRODUCTION

1.1 Research Objectives

Skeletonized remains are commonly recovered within medico-legal contexts and mass disasters, requiring careful examination by a forensic anthropologist. Stature is an integral component of the biological profile, which examines characteristics such as sex, age at death, ancestry, and stature. Countries that have endured mass disasters, either natural (e.g. earth quakes, hurricanes, and tsunamis), or non-natural (e.g. terrorist activities, wars, or political crisis), have stressed the importance of including forensic anthropologists as part of the interdisciplinary teams which assist with disaster victim identification (Prinz et al., 2007; Traithepchanapai et al., 2016). In Thailand, the 2004 tsunami disaster highlighted the lack of forensic anthropology expertise in the country and the lack of population-specific methods in the region (Traithepchanapai et al., 2016). The objectives of this research are to:

1. investigate whether regression equations for the calcaneus, which were developed on a Black South African population (Bidmos and Asala, 2005), and regression equations for the talus, which were developed on a Black American population (Holland, 1995), can accurately predict the living stature of individuals from a contemporary Thai population.

2. develop population-specific simple regression and multiple regression equations for the calcaneus and the talus of the contemporary Thai population should the Black South African (Bidmos and Asala, 2005) and Black American (Holland, 1995) equations not accurately predict the living stature of the Thai individuals.

3. compare the results from the contemporary Thai population to other populations.

1.2   Potential for Stature Estimation from the Calcaneus and the Talus

The estimation of stature is a critical factor in the identification of unknown skeletal remains, providing one aspect of an individual's physiognomy. Most bones in the human body have been assessed for their potential in estimating stature. Long bones, such as the femur and the tibia, are preferred for stature estimation (Trotter and Glesner, 1952). In mass disaster and forensic contexts however, it is likely that these bones will be found fragmented due to postmortem damage and taphonomic changes. Previous researchers have used fragmentary long bones to derive regression equations for the estimation of stature (Simmons et al., 1990; Steele et al., 1969). However, accuracy rates are enhanced when stature is estimated from complete bones rather than fragmentary remains (Smith, 1996). Therefore, in order to ensure the most accurate estimation of stature from unknown human remains, it is necessary to develop methods of stature estimation from preservationally favoured and/or complete skeletal elements.

Previous research has cited stature estimation methods from less frequently analyzed complete skeletal elements such as the skull (Chiba and Terazawa, 1998; Fully, 1956; González-Colmenares et al., 2016; Introna et al., 1993; Krishan, 2008; Patil and Mody, 2005; Torimitsu et al., 2016), the sternum (Dwight, 1980; Marinho et al., 2012; Menezes et al., 2009, 2011; Singh et al., 2011; Zhang et al., 2015), the clavicle (Balvir et al., 2012; Jit and Singh, 1956; Rani et al., 2011; Singh and Sohal, 1952), the scapula (Campobasso et al., 1998; Giurazza et al., 2013; Shulin and Fangwu, 1983; Torimitsu et al., 2015; Zhang et al., 2016), the metacarpals (Khanpetch et al., 2012; Kimura, 1992; Meadows and Jantz, 1992; Musgrave and Harneja, 1978; Wilbur, 1998; Zaher et al., 2011), the hand phalanges (Habib and Kamal, 2010; Jasuja and Singh, 2004; Jee and Yun,

2015; Shintaku and Furuya, 1990), the vertebrae (Jason and Taylor, 1995; Nagesh and Kumar, 2006; Rodríguez et al., 2016; Terasawa et al., 1990; Tibbetts, 1981; Torimitsu et al., 2015), the sacrum (Fully, 1956; Giroux and Wescott, 2008; Karakas et al., 2011; Pelin et al., 2005; Pininski and Brits, 2014; Torimitsu et al., 2014), and the metatarsals (Bidmos, 2008; Byers et al., 1989; De Groote and Humphrey, 2011). However, there has been minimal research using osteometric criteria of individual tarsals, or bones of the foot, for stature estimation (Bidmos, 2006; Bidmos and Asala, 2005; Fully, 1956; Holland, 1995; Pablos et al., 2013).

The calcaneus and the talus, in particular, are underrepresented in the forensic and anthropological literature for stature estimation. Yet, these bones have been shown to be very accurate predictors of stature estimation. The anatomical method of stature reconstruction, first described by Fully (1956) and revised by Raxter et al. (2006), demonstrated the usefulness of the calcaneus and the talus for stature estimation, with 95% of individuals estimated correctly to within 4.5 cm. More recently, regression equations for the estimation of stature using measurements of the calcaneus and the talus have been generated for Black American, White American, Black South African, and South African populations (Bidmos, 2006; Bidmos and Asala, 2005; Holland, 1995; Pablos et al., 2013) with success. To date, these are the only studies employed for stature estimation using osteometric criteria of the calcaneus and the talus.

In the human body, the calcaneus and the talus are the largest tarsal bones and have been shown to produce high accuracy rates for human identification as they are often well preserved and able to withstand high tensile forces (Bidmos, 2006; Bidmos and Asala, 2005; Hall and Shereff, 1993). This increased preservation is related to the increased strength and density of the bones trabeculae and the smaller surface area of the

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calcaneus and the talus. Small, compact bones, such as the calcaneus and the talus, have a greater chance of being recovered intact as the bones smaller surface area expose less bone to destructive taphonomic elements (Bidmos and Asala, 2005). The calcaneus and the talus are often encased in socks and/or shoes, which serve as protection for the feet (Peckmann et al., 2015; Pickering, 1986; Saul and Saul, 2005). Furthermore, the unique morphology of the calcaneus and the talus allow for rapid and accurate anatomical identification during excavation (Lee et al., 2012; Susman, 1983). These characteristics make the calcaneus and the talus ideal for the estimation of stature and identification of unknown human remains.

1.3 Concepts of Identity and Terminology in Forensic Anthropology

1.3.1 Differences between Sex and Gender

The terms *sex* and *gender* are different concepts within anthropology (Little and McGivern, 2014). An individual's biological sex (i.e. *sex*) refers to the biological and physiological division into male and female at the time of conception, but may not correlate with the gender to which an individual identifies (Armelagos, 1998; Steckley and Kirby Letts, 2013).

An individual's sex can be consistently determined and accurately classified during life based on the existence of both genetic and morphological differences between males and females. Sex chromosomes are structurally distinct between males and females. Females carry two X chromosomes (XX) and males carry one X chromosome and one Y chromosome (XY (Charlesworth, 1991; Jacobs and Strong, 1959). The Y chromosome controls male development. The testis-determining factor (TDF) is found on

the Y chromosome and is responsible for the initiation of male sex determination in humans (Graves, 1995). Subsequent steps in male phenotype establishment are regulated by testicular hormones independent of the Y chromosome and other genes carried through the Y chromosome. Genes carried through the Y chromosome are expressed in the testis, which influence spermatogenesis, or the production and development of mature spermatozoa (Graves, 1995).

Sex hormones influence skeletal morphology and contribute to the sexually dimorphic differences observed in male and female skeletal anatomy (Kottak, 2011). Overall, female skeletal elements are smaller and less robust than male skeletal elements. Relative to female crania, male crania typically display: more prominent supraorbital ridges, a more prominent glabellar region, heavier temporal and nuchal lines, less frontal and parietal bossing, broader palates, squarer eye orbits, more rugose muscle attachments, and larger mastoid processes, sinuses, and occipital condyles (Buikstra and Ubelaker, 1994; Graw et al., 1999; Meindl et al., 1985). There are also functional differences between male and female pelvic morphology as a result of parturition, or the process of childbirth; female pelvic inlets are relatively wider than those of males with wider greater sciatic notches, elongated pubic portions of the os coxae, a larger subpubic angle, a more distinct preauricular sulcus, and a smaller acetabulum (Buikstra and Ubelaker, 1994; Phenice, 1969; Rogers and Saunders, 1994). The manifestation of these sexually dimorphic differences in the skeletal anatomy allow forensic anthropologists to estimate the sex of an individual based on biological features.

Gender refers to the roles, behaviours, and characteristics associated with biological males and females (Konigsberg et al., 1998). Concepts of gender are socially constructed and may vary between cultures, communities, and social classes (Kottak,

2011; Risman, 2004). Thailand, for example, has a three-gender system (i.e. male, female, and a third gender category called *kathoey*), which is best represented as a continuum with permeable boundaries that allow for the flow and co-existence of multiple gender identities (Ocha, 2012). As such, gender is unable to be estimated through the analysis of skeletal remains and therefore this terminology will not be used in the current research study.

An individual's *sex* may not be reflective of the *gender* to which that individual associates. As the term *sex* reflects biological differences in skeletal anatomy, and the term *gender* reflects a social construct, the term *sex* will be used to differentiate between male and female skeletal remains in the current research study.

1.3.2   The Origin and Construction of 'Race' in Physical Anthropology

The term *'race'* emerged between the sixteenth and eighteenth centuries and became synonymous with words such as, *'sort', 'kind', 'type', 'breed', and 'species'* (Allen, 1994, 1997; Hannaford, 1996; Smedley, 1998). Carl Linnaeus, an eighteenth-century botanist, was the first scientist to categorize humans into groups based on observable features: Europeaus *(albus)* or "white", Americanis *(rufescens)* or "red", Asiaticus *(fuscus)* or "dark", and Africanus *(niger)* or "black" (Harrison, 2010). Johan Blumenbach continued this categorization in 1779, classifying human "varieties" into the following 'races': the *Caucasian* or *European* "white" 'race' the *Mongolian* or "yellow" 'race' (including all East Asians and some Central Asians), the *Malayan* or "brown" 'race' (including Southeast Asians and Pacific Islanders), the *Ethiopian* or "black" 'race' (including sub-Saharan Africans), and the *American* or "red" 'race' (including American Indians) (Blumenbach, 1865:56,209). By the late eighteenth century, the concept of 'race'

had solidified as a reflection of social hierarchy based on the physical and observable differences of populations (Smedley, 1998; Smedley and Smedley, 2005). The emergence of 'race', as a social classification, arose from the ethnocentric European notions of superiority towards Indigenous (or Non-European) populations that were deemed to be savage, uncivilized, and inferior in comparison (Harrison, 2010; Prins, 2002; Smedley, 1998; Smedley and Smedley, 2005; Winant, 2000). This 'race' ideology developed in conjunction with the legal establishment of African slave labour and the conquest of North American Indigenous populations, thus rationalizing inequalities such as slavery, colonialism, eugenics, and segregation (Mukhopadhyay and Mosese, 1997; Smedley, 1998).

In the nineteenth century, scientists and anthropologists contributed to the perpetuation of 'race' and the notion of social hierarchies based on observable 'racial' features. Sociocultural anthropologists, such as L.H Morgan and E.B. Tylor, worked with physical anthropologists to rank human 'races' along an evolutionary path from 'savage' to 'civilized' using physical indicators and craniometric data (Mukhopadhyay and Mosese, 1997). Craniometry was used throughout the nineteenth century as a way of supporting the notion of 'race' superiority through the study of cranial size and weight to infer the mental capacity of various 'racial' groups (Mukhopadhyay and Mosese, 1997; Smay and Armelagos, 2000).

Twentieth century anthropologists helped expose the inaccuracies surrounding the biological concept of 'race'. In the early twentieth century, the cephalic index was utilized as a way of measuring evolutionary advancement. Franz Boas discredited craniometry and the hypothesis of a link between mental capacity and 'race' by demonstrating that cranial size and shape was dependent on environmental factors (Boas,

1912). In 1942, Ashley Montagu argued that external physical traits are not the cause of human variation, an assertion that further inspired abandonment of the 'race' concept (Montagu, 1997). The development of population genetics, in the mid-twentieth century, provided further evidence against the biological concept of 'race'. Population geneticists focused on how evolutionary processes such as genetic drift, migration, mutation, and natural selection could affect inherited biological traits (Mukhopadhyay and Mosese, 1997). By 1972, population geneticist Richard Lewontin had demonstrated that more genetic variation exists within, rather than between, the major 'racial' groups, thus demonstrating that 'race' has no genetic or taxonomic significance (Lewontin, 1972: 397; Mukhopadhyay and Mosese, 1997).

While most anthropologists now reject the existence of the traditional 'race' concept, the classification of individuals into groups persists in physical and forensic anthropology (Hunt and Megyesi, 2008; Kennedy, 1995; Ousley et al., 2009; Sauer, 1992). When creating a biological profile, forensic anthropologists analyze variation in skeletal components in order to classify human remains into population groups (Albanese and Saunders, 2006; Ousley et al., 2009; Sauer, 1992; Smay and Armelagos, 2000). For example, morphological features of the cranium show strong geographical patterning and have been used to classify groups of individuals based on geographic origins (Ousley et al., 2009; Patriquin et al., 2002). Populations of Asian origins display crania with robust zygomatic bones, circular eye orbits, and an elliptic shaped palate; populations of European origins display crania with receding/small zygomatic bones, heavy glabellar and supraorbital regions, and a parabolic shaped palate; and populations of African origins display crania with pronounced facial and alveolar prognathism, rectangular eye

orbits, and a hyperbolic shaped palate (Giles and Elliot, 1962; Gill, 1995; Gill and Rhine, 1990).

However, law enforcement members often use primary descriptors such as an individual's 'race' when compiling information on missing persons. The options available for categorization of missing persons may be limited; The National Centre for Missing Persons and Unidentified Remains (NCMPUR) of the Royal Canadian Mounted Police (RCMP) for example, provides the following descriptive options: "Aboriginal", "Asian", "Black", "East Indian", "White", "Other", or "Unknown" (NCMPUR, 2017). As forensic anthropologists function in cooperation with law enforcement, legal representatives, and members of the community or the jury, they must report their findings regarding unidentified human skeletal remains in terms meaningful to their audience; 'race' remains a primary descriptor for investigators working in law enforcement (Adams, 2007). As the term 'race' denotes no genetic or taxonomic relationships, and therefore will not be used in the current research study to define biological variation between human populations, manifested in skeletal morphology.

1.3.3 Terminology: Ethnicity and Ancestry

Ethnicity is defined as cultural distinctions between groups of individuals which share, for example, a common language, religion, history, system of beliefs or traditions, or geographical region (Smedley and Smedley, 2005:17). An individual's ethnicity, or associated ethnic group, is self-defined and flexible, or subject to change (Barth, 1998). Cultural traits are learned and are transmissible to others and, therefore, one may adopt the cultural traits of another ethnic group to become participants in that ethnicity (Smedley and Smedley, 2005). As ethnicity relates to a self-identifying cultural concept

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and does not describe genetic relationships or biological traits, the term *ethnicity* will not be used in the current research study to define biological variation between human populations, manifested in skeletal morphology.

Ancestry is defined as the grouping of individuals based on a shared genetic makeup (Bamshad, 2005:937). An individual's genetic makeup is determined by the geographic location from which they originated (Bamshad, 2005; Ember and Ember, 1988; Jorde and Wooding, 2004; Konigsberg et al, 2009). Individuals that originate from a specific geographic location will share a gene pool, or a collection of gene variants, and will display similarities in genetic allele frequencies and physical traits (Molnar, 1983; Witherspoon et al., 2007). Ancestry can thus be examined by a forensic anthropologist based on morphological skeletal traits, which are the result of microevolutionary processes and environmental stresses associated with geographic origin (Konigsberg et al., 2009). The term *ancestry* is based in biological traits and examines human genetic variation. Therefore, this term will be used in the current research study to define biological variation between human populations manifested in skeletal morphology.

1.4   Forensic Anthropology and Disaster Victim Identification in Thailand

The history, development, and practice of forensic anthropology in Thailand have been relatively limited (Kranioti and Paine, 2011; Traithepchanapai et al., 2016). The anatomist H.S Sankas (1930) was the first Thai individual to study and publish within the field of physical anthropology, conducting research on the relationship between cranial modules and cranial capacity at the United States National Museum. The first research, although unpublished, investigating the skeletal anatomy of Thai individuals is attributed

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to Dr. Sood Sangvichien at the Department of Anatomy, Faculty of Medicine, Siriraj Hospital, in Bangkok, Thailand (Traithepchanapai et al., 2016). Sangvichien examined morphological features of the preauricular sulcus for the estimation of sex within a Thai population (Sangvichien et al., 1950). Most early anthropological research in Thailand, including that of Sangvichien, remained unpublished, or was only published domestically (i.e. not in English), which resulted in limited representation of Thai research within international forensic and anthropological literature (Traithepchanapai et al., 2016).

The lack of forensic and anthropological expertise in Thailand was demonstrated during the 'Boxing Day tsunami' (Traithepchanapai et al., 2016). On 26 December 2004, an earthquake measuring 9.1 on the Richter scale occurred off the west coast of Sumatra, Indonesia, triggering a catastrophic tsunami (i.e. 'The Boxing Day tsunami') that was responsible for 5,395 deaths in Thailand (James, 2005; Sribanditmongkol et al, 2017; Wright et al., 2015). The magnitude of this disaster was beyond the expectations and experiences of the Thai organizations responsible for victim identification and highlighted the need for more efficient forensic and victim identification management strategies (Traithepchanapai et al., 2016).

This disaster demonstrated Thailand's inability to independently handle a mass disaster of this magnitude, and the necessity of having locally trained forensic specialists and experts in the victim identification process. International experts and non-profit organizations joined in the identification effort under a consolidated Thai Tsunami Victim Identification (TTVI) operation. The TTVI operation promoted international cooperation under Thai authority, and was formed to standardize the identification process using the disaster victim identification (DVI) protocol outlined by INTERPOL (INTERPOL, 2014; Sribanditmongkol et al, 2017; Wright et al., 2015).

In the past, international anthropological involvement in the DVI process has been limited to the analysis of skeletal remains and subsequent establishment of a biological profile. More recently, however, the role of the forensic anthropologist in the DVI process has expanded to include the development and implementation of quality assurance and quality control, as well as greater participation at the disaster scene, in the morgue (particularly with initial triage), and with the reconciliation process (Blau and Briggs, 2011; Mundorff, 2012). Anthropological involvement in the DVI process in Thailand was limited; Kahana and Hiss (2009) stress that the DVI team in Thailand would have benefitted from the assistance of forensic anthropologists during the identification process.

To promote forensic anthropology and osteological research within Thailand, and thus enhance the DVI process in the region, the Forensic Osteology Research Center (FORC) in the Faculty of Medicine of Chiang Mai University, launched a doctoral program in forensic osteology in 2013. Researchers at the Forensic Osteology Research Center (FORC) created an osteological reference collection known as the Chiang Mai skeletal collection to assist in the development of population-specific methods of skeletal identification for the Thai population (Traithepchanapai et al., 2016). Despite these efforts, the development of forensic anthropology in Thailand remains limited in terms of training, professional opportunities, and representation within the forensic and anthropological literature (Traithepchanapai et al., 2016). The continuation of forensic anthropology research in Thailand is necessary in order to ensure population-specific methods are available for future tragic events.

1.5   Skeletal Collection: Forensic Osteology Research Center, Chiang Mai

University

The Chiang Mai skeletal collection is housed at the Forensic Osteology Research

Center (FORC) in the Faculty of Medicine of the Chiang Mai University in Chiang Mai,

Thailand. Skeletonization of individual remains for inclusion in the collection begins with

dismemberment and maceration, or defleshing, followed by wrapping the bones in plastic

mesh bags, and burial within a sand-filled container to allow for decomposition. Each

burial is marked and left for four to six months or until no soft tissue remains on the bone.

When the skeletal remains are recovered, they are kept in hydrogen peroxide for

approximately three days before they are allowed to air dry. Once dry, each bone

becomes labelled with its accession number and all the bones of each individual are

stored in a singular, labelled plastic container. Metacarpals, carpals, metatarsals, tarsals,

and phalanges are kept in labelled plastic bags (or are articulated with copper wire) to

avoid confusion or loss, and are included within their respective container (King et al.,

1998; Traithepchanapai et al, 2016).

The collection currently consists of 475 (291 males and 184 females) documented

skeletons (i.e. known sex, age at death, occupation, cause of death, birth dates, and death

dates) who donated their bodies for educational purposes. The donors were residents of

Chiang Mai and adjacent villages and, therefore, this collection is representative of a

northern Thai population (King et al., 1998; Traithepchanapai et al, 2016). Individuals

represented in the Chiang Mai skeletal collection resided within the lower middle to

middle socioeconomic range, with recorded occupations such as farmer, civil servant,

teacher, or retiree (King et al., 1998; Traithepchanapai et al, 2016). Individuals used for

the current research study have birth dates between 1914 and 1995 and death dates between 2006 and 2014. This skeletal collection was chosen for the current research study as it represents a contemporary population from Thailand; all of the individuals lived the majority of their life during the twentieth century.

CHAPTER 2: BACKGROUND

2.1   The Skeletal System and Anatomy of the Human Foot

The skeletal system is the supporting framework of the body and is formed by bony and cartilaginous elements, which are articulated via connective tissue structures. The skeletal system also functions to protect internal organs from injury, assist in movement, maintain mineral homeostasis, produce blood cells in a process called *hemopoiesis*, and to store triglycerides, a potential chemical energy reserve (Faller et al, 2004:116; Tortora and Derrickson, 2014:170).

At the microscopic level, the structure of bone contains an extracellular matrix composed of 15% water, 30% collagen fibers, and 55% crystallized mineral salts. The most abundant mineral salt is calcium phosphate $[Ca_3(PO_4)_2]$, which combines with calcium hydroxide $[Ca(OH)_2]$ to form hydroxyapatite crystals $[Ca_{10}(PO_4)_6(OH)_2]$. Additional mineral salts such as calcium carbonate, and ions such as magnesium and potassium, combine with the hydroxyapatite crystals as they are deposited in the collagen fibre matrix, crystallizing and hardening the tissue in a process known as *calcification*. While the crystallized mineral salts are responsible for the hardness of bone, the collagen fibres provide tensile strength, and are responsible for the bone's flexibility (Tortora and Derrickson, 2014:172).

Adult human bone is composed of two types of bone tissue. A solid, dense external layer known as compact or dense (cortical) bone functions to provide overall protection and to resist the stresses associated with weight and movement. An internal marrow cavity, comprised of spongy or cancellous (trabecular) bone, which resembles an open lattice structure, that functions to reduce the overall weight of the bone, allowing it

to move more readily when pulled by skeletal musculature (Martini and Nath, 2009:188;

Tortora and Derrickson, 2014:173).

The skeletal system can be divided into two principle divisions: the axial skeleton,

consisting of bones surrounding the longitudinal axis of the body, and the appendicular

skeleton, consisting of the bone of the upper and lower limbs and those which form the

pelvic and shoulder girdles that connect the limbs to the axial skeleton (Tortora and

Derrickson, 2014:193). The bones of the foot (i.e. the tarsals, the metatarsals, and the

phalanges) are part of the appendicular skeleton and are arranged in two arches that are

held in position by ligaments and tendons, which function to support and distribute the

weight of the body (Hicks, 1954; Salathé et al., 1986). The foot consists of fourteen

phalanges, five metatarsals, and seven tarsal bones including the calcaneus, talus,

navicular, cuboid, and three cuneiform bones: medial (first) cuneiform, intermediate

(second) cuneiform, and lateral (third) cuneiform (Figure 2.1). The calcaneus and the

talus are important tarsal bones, owing to their role in locomotion and weight distribution

(Figure 2.2).
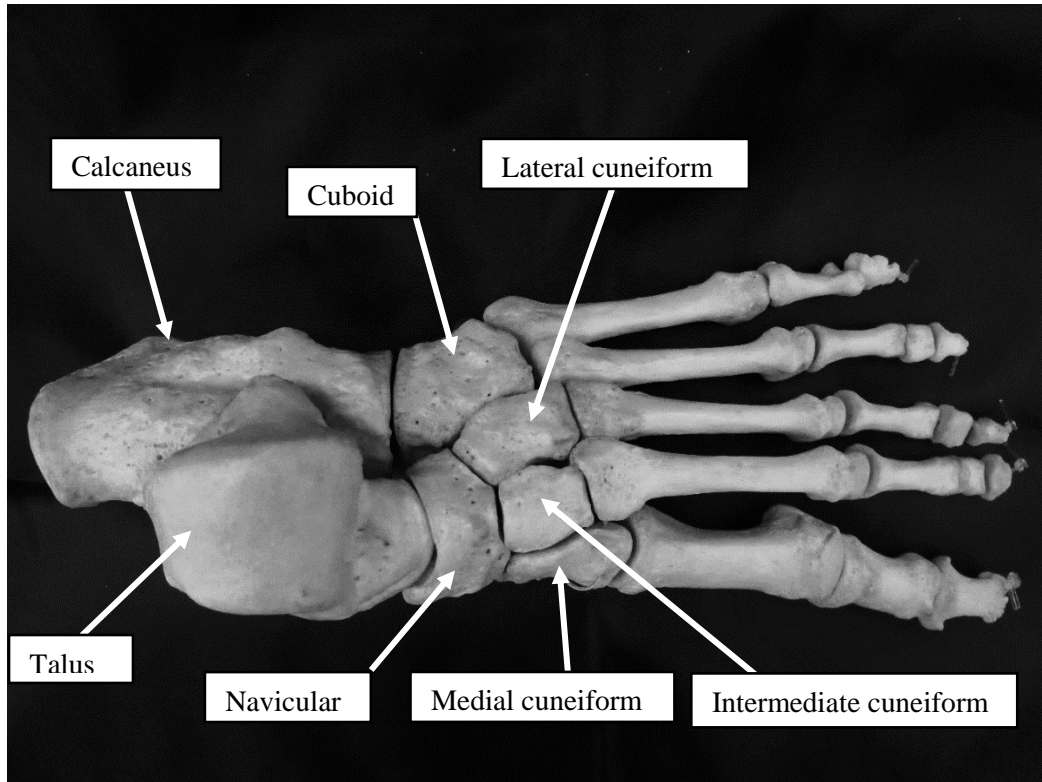
Figure 2.1 Dorsal (superior) view of the left human foot depicting the tarsal bones. (Photo by Shelby Scott)

Figure 2.2 Medial view of a typical left calcaneus and typical left talus depicting the articulation between the calcaneus and the talus. (Photo by Shelby Scott)

2.1.1   Calcaneus and Talus: Growth and Development

Postcranial skeletal tissue is formed from mesenchymal cells while connective tissue cells are derived from the mesoderm (the middle layer of cells formed in the early development of an embryo). Mesenchymal cells condense and form models of bone in areas where ossified tissue will ultimately form. Embryonic bone tissue development proceeds through two ossification processes: intramembranous ossification and endochondral ossification. Intramembranous ossification is the process by which bone tissue is formed directly within the mesenchyme, and is responsible for the creation of the skull and the vertebrae. Endochondral ossification is the process by which bone tissue is formed within hyaline cartilage that develops from the mesenchyme, and is responsible for the development of the upper and lower limbs (Tortora et al., 2014:253).

The skeleton of the lower limbs is derived from mesoderm and developed through endochondral ossification (Tortora et al., 2014:254). At approximately four weeks of prenatal development, a mesenchymal skeleton (i.e. a skeletal model consisting of mesenchyme) exists in the lower limb buds, which will eventually form the left and right legs. The first appearance of tarsal and metatarsal elements of the foot also occurs at four weeks of prenatal development, though tarsal elements are not fully developed at this time and the feet cannot be differentiated from the lower limb buds (Henke and Reyher, 1874; Leboucq, 1886; Meredith, 1944; Scheuer and Black, 2004; Straus, 1927; Viladot et al., 1984). By the sixth week of prenatal development, a cartilaginous skeleton has formed from the mesenchyme through endochondral ossification. At this time, the lower limb buds have developed into foot plates, distal segments of the lower limb buds that represent the beginning of the feet. By the eighth week of prenatal development, the

lower limb buds have developed into their definitive postnatal form in which the thigh, the leg, and the foot are distinguishable from one another (Meredith, 1944; Straus, 1927; Viladot et al., 1984). Viladot et al. (1984) have noted that it is at approximately this time that modifications of the subtalar joint occur as the sustentaculum tali appears and the talus becomes positioned superior to the calcaneus, forming the ankle in its definitive form.

At the end of the eighth week of prenatal development, endochondral ossification of the lower limbs and tarsals has begun (Fritsch et al., 1996; Gardner et al., 1959; Tortora et al., 2014: 254). Studies have demonstrated that the calcaneus is the first of the tarsal bones to begin ossification (Gardner et al., 1959; Hasselwander, 1903; Hintzsche, 1930; Scheuer and Black, 2004). Pryor (1923) shows that ossification of the calcaneus occurs at approximately 16 weeks of prenatal development for females and at approximately 20 weeks of prenatal development for males. Though the cartilage of the talus is the first of the tarsal bones to demonstrate vascular invasion, ossification of the talus does not begin until approximately 22 to 29 weeks of prenatal development in females and 24 to 32 weeks of prenatal development in males (Gardner et al., 1959; Pryor, 1923).

2.1.2   *Calcaneus: Anatomy and Function*

The calcaneus, or "heel bone", is the largest tarsal bone of the foot, located inferior to the talus and articulating anteriorly with the cuboid. The calcaneus is comprised of several important and distinguishable structures: the calcaneal tuberosity,

the lateral and medial processes, the peroneal tubercle, the sustentaculum tali, the

posterior facet, and the sustentacular sulcus (Figures 2.3, 2.4).
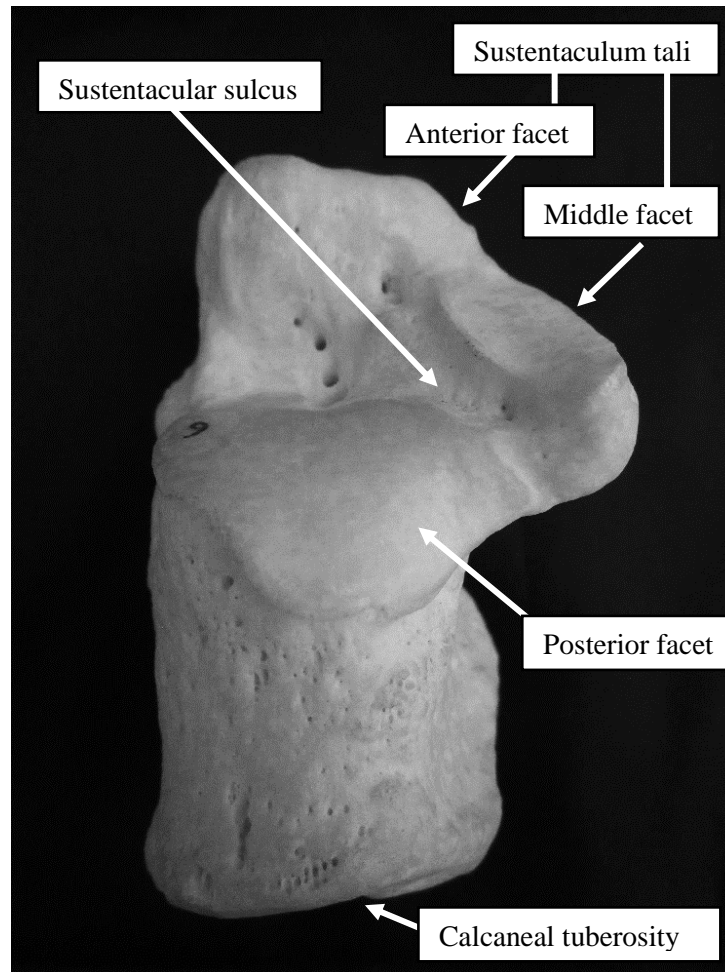
Figure 2.3 Dorsal (superior) view of a typical left calcaneus. (Photo by Shelby Scott)
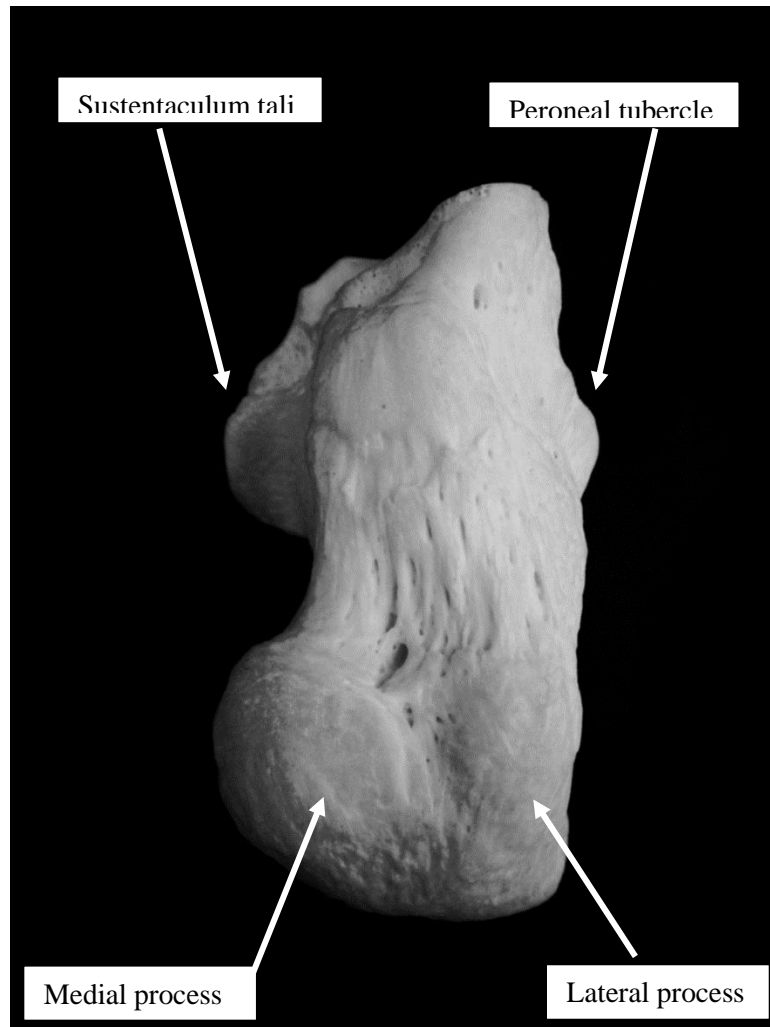
Figure 2.4 Plantar (inferior) view of a typical left calcaneus. (Photo by Shelby Scott)

The calcaneal tuberosity is the large, blunt, nonarticular, posterior process of the foot and is the insertion point for the calcaneal (Achilles) tendon (Doral et al., 2010; Keener and Sizensky, 2005). Tendons are responsible for the transmission of force from muscle to bone (Tai and Williams, 2007). The calcaneal insertion of the Achilles tendon is designed to aid the dissipation of stress from the tendon to the calcaneus, thus offering a mechanical advantage during locomotion (Doral et al., 2010). The lateral and medial processes of the calcaneal tuberosity are located on the inferior (plantar) aspect, and

function to anchor several intrinsic muscles of the foot (Keener and Sizensky, 2005).

Latimer and Lovejoy (1989) have hypothesized that the lateral process may also serve to increase the surface area of the foot in order to aid in force dissipation during locomotion.

The peroneal, or fibular, tubercle is a bony projection located on the lateral surface of the calcaneal body. The peroneus longus and peroneus brevis tendons, which function in plantarflexion and eversion of the foot, are separated by the peroneal tubercle (Agarwal et al., 1984; Hofmeister et al., 1996; Hyer et al., 2005; Gill et al., 2014; Shibata et al., 2014). Previous research has suggested that the primary function of the peroneal tubercle is to act as a fulcrum for the peroneus longus tendon, directing it towards the cuboid, but the peroneal tubercle also functions as the insertion site for the inferior peroneal reticulum and separates the sheaths of the peroneus longus and brevis tendons (Berenter and Goldman, 1989; Hofmeister et al., 1996; Ruiz et al., 1993).

The calcaneus articulates with the talus to form the subtalar joint. The subtalar joint is fundamental to the transmission of rotations from the foot to the leg during locomotion. The articulation between the calcaneus and the talus can be seen in Figure 2.2 and the subtalar joint (in situ) can be seen in Figure 2.5.

Figure 2.5 Medial view of the left human foot depicting the articulation between the calcaneus and the talus to form the subtalar joint. (Photo by Shelby Scott)

The calcaneus articulates with the talus on two separate articular surfaces: the sustentaculum tali (bearing a middle and anterior facet) and the posterior facet. The sustentaculum tali is located on the medial side of the calcaneus and articulates with the talus as it functions to support the talar head (Keener and Sizensky, 2005; Mahato, 2011; Sharadra et al., 2012; Viladot et al., 1984). The sustentaculum tali bears a middle facet and an anterior facet, which influence subtalar joint stability (Sharadra et al., 2012). Often, the anterior facet and the middle facet are joined but are separate from the posterior facet. In this scenario, the individual would display two facets (Piazza, 2005). However, there is substantial variation in the configuration of the anterior, middle, and posterior facets; they may appear as three separate facets (i.e. an anterior facet, a middle facet, and a posterior facet) or as one contiguous facet (Bunning and Barnett, 1965; Keener and Sizensky, 2005; Piazza, 2005; Saadeh et al., 2000; Viladot et al., 1984). The

morphological variability of the anterior articular facets may be influenced by factors such as biological affinity and/or sex (Bunning and Barnett, 1965; Saadeh et al., 2000; Sharadra et al., 2012).

The sustentacular sulcus, or groove, is located inferior to the sustentaculum tali. The tendon of the flexor hallucis longus muscle is located within the sustentacular sulcus and is responsible for plantarflexion of the foot and of the hallux (Keener and Sizensky, 2005; Mahato, 2011).

2.1.3   Talus: Anatomy and Function

The talus is the second largest of the tarsal bones and is located inferior to the tibia and fibula and superior to the calcaneus. The talus articulates inferiorly with the calcaneus, distally with the navicular, and superiorly with the tibia and fibula. The talus is comprised of three major structures: the talar head, the talar neck, and the talar body (Figure 2.6).
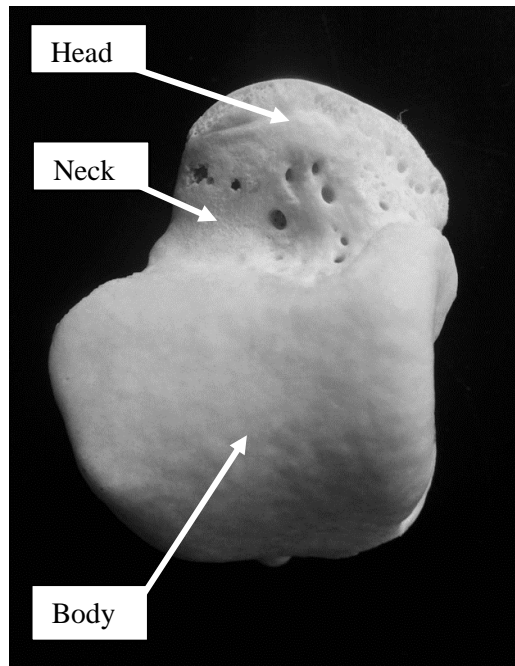
Figure 2.6 Dorsal (superior) view of a typical left talus. (Photo by Shelby Scott)

The talar neck connects the head of the talus with the body of the talus. This junction subtends an angle of approximately 120° (measured between the axis of the talar head and a transverse coronal plane passing across the superior articular surface of the talus) (Mahato and Murthy, 2012). Previous studies have demonstrated that the angle of the talar neck may change throughout life and may be influenced by the amount of weight placed on the talus (de Palma et al., 2003; Mahato, 2011; Mahato and Murthy, 2012; Sarrafian, 1993). The talar neck may display articular facets (also known as "squatting facets") that are formed through contact with the anterior surface of the distal tibia as a result of strong dorsiflexion of the foot at the talocural joint (Barnett, 1954; Oygucu et al., 1998; Pandey and Singh, 1990; Rao Prasada, 1966; Satinoff, 1959; Singh, 1959; Thomson, 1889, 1890; Trinkaus, 1975). The talocrural (ankle) joint is formed through the articulation of the talus, tibia, and the fibula, and assists in transferring the weight of the

body to the articulated foot during locomotion (Figure 2.7) (Dul and Johnson, 1985; Hicks, 1953; Inkster, 1927; Isman and Inman, 1969; Leardini et al., 2001; Manter, 1941; Piazza, 2005; Sharada et al., 2012).

Figure 2.7 Posterolateral view of the left human foot depicting the articulation between the talus, the tibia, and the fibula to form the talocrural (ankle) joint. (Photo by Shelby Scott)

The talar body is square in shape and is located posterior to the talar neck. The trochlea, located on the talar body, is a wedge-shaped articular surface with two sides known as the lateral malleolar surface and the medial malleolar surface. The lateral malleolar surface articulates with the fibula and the medial malleolar surface articulates with the tibia forming the talocrural joint (Figure 2.7). The calcaneal or subtalar articular surfaces are located on the inferior aspect of the talar body and are often variable in shape and number (see section 2.1.2). Located on the posterior surface of the talar body is the

groove for the flexor hallucis longus muscle. This groove transmits the tendon of the flexor hallucis longus muscle and is continuous with the sustentacular sulcus of the calcaneus (Keener and Sizensky, 2005; Mahato, 2011).

2.2   Methods of Stature Estimation in Forensic Anthropology

The estimation of stature is a critical factor in the identification of unknown skeletal remains, providing one aspect of an individual's biological profile. Forensic practitioners require precise and accurate methodologies for estimating stature in unidentified human remains. The theoretical foundation of stature estimation from skeletal remains dates back to 1755, when French anatomist Jean Joseph Sue (1710 to 1792) published data on maximum long bone length and stature in order to provide artists with information regarding body proportions (Stewart, 1979; Sue, 1755). These measurements were introduced to the medico-legal community by Matthieu Joseph Bonaventure Orfila (1787 to 1853). Orfila also added cadaveric and skeletal measurements to Sue's original data set, thus creating the 'Sue-Orfila stature estimate' database (Langley and Tersigni-Tarrant, 2017). In 1894, American anatomist Thomas Dwight distinguished between two methods of stature estimation, which are used in forensic anthropology today: anatomical and mathematical (Brandt, 2009; Dwight, 1984; Fully, 1956; Raxter et al., 2006; Trotter and Gleser, 1952; Wilson et al., 2010).

The anatomical method of stature estimation involves reassembling the skeleton in anatomical position, applying a correction factor for soft tissue, and measuring height (Langley and Tersigni-Tarrant, 2017). A major advantage of this method is that individual differences in body proportions are intrinsically incorporated. The anatomical approach to

stature estimation is generally attributed to Fully (1956), who developed an anatomical

reconstruction method by taking the following measurements from a French population

(102 skeletonized males):

- Basion-bregma height of the cranium

- Maximum height of the corpus of the C2 to L5 vertebrae measured individually

- Anterior height of the first sacral segment

- Oblique (physiological) length of the femur

- Maximum length of the tibia without the tibial spine, and including the malleolus

- Articulated height of the calcaneus and the talus, from the most superior point on
  the talus to the most inferior point on the calcaneus

For the femur, the tibia, the calcaneus, and the talus, Fully's (1956) method cites that an

average value from both left and right measurements should be used in calculating

stature. Each of these individual measurements should then be summed to obtain skeletal

height. In order to attain a final estimation of total stature (as opposed to total skeletal

height), Fully (1956) presented soft tissue correction factors that then added to the

calculated skeletal height value. The proposed soft tissue correction factors are as

follows:

- Skeletal height equal to or less than 153.5 cm, add 10 cm

- Skeletal height between 153.6 cm and 165.4 cm, add 10.5 cm

- Skeletal height equal to or greater than 165.5 cm, add 11.5 cm

In 2006, Raxter et al. reviewed and revised the Fully (1956) anatomical reconstruction

method. In a cadaveric study of Black American and White American individuals, Raxter

et al. (2006) tested the accuracy and applicability of the method, and concluded that statures derived from the original Fully (1956) method underestimated total stature, in their sample, by approximately 2.4 cm on average. Earlier studies, which have reviewed the Fully technique, cite similar findings and have reported a systematic bias resulting in an underestimation of total stature (Bidmos, 2005; King, 2004). This suggests that the soft tissue correction factors, as outlined by Fully (1956), are too small. To remedy this, Raxter et al. (2006) clarified the measurement procedures of Fully (1956) and developed new formulae, for calculating total stature from skeletal height, which yielded stature estimates with a 95% accuracy rate (within 4.5 cm). Raxter et al. (2006) found no evidence of sex- or ancestry-related effects on the accuracy of stature estimation and therefore, sex and ancestry do not need to be known when utilizing these formulae. When the age of the individual is known, Raxter et al. (2006) recommend utilizing the following equation:

$$\text{Total stature (cm)} = 1.009 \times \text{skeletal height} - 0.0426 \times \text{age} + 12.1$$

When the age of the individual is unknown, Raxter et al. (2006) recommend utilizing the following equation:

$$\text{Total stature (cm)} = 0.996 \times \text{skeletal height} + 11.7$$

While the anatomical method has been cited as providing accurate estimations of total stature, it requires a largely articulated skeleton, which is often not present in a forensic or disaster contexts (Gocha et al., 2013; Raxter et al., 2006; Ruff et al., 2012). As a result, relatively few studies continue to employ the anatomical approach, as regression formulae from individual skeletal elements (i.e. utilizing the mathematical method of stature estimation) are more applicable in a forensic or disaster context (Auerbach et al., 2009).

The mathematical method of stature estimation involves the derivation of regression formulae, which demonstrate linear relationships between measurements of individual skeletal elements and stature. Some of the most commonly used regression equations are those developed by Trotter and Gleser (1952), based on Black Americans and White Americans from the Terry skeletal collection. Trotter and Gleser (1952) measured the left and the right upper and lower limb bones of Black American and White American males and females, and developed univariate and multivariate regression equations for stature estimation. Resulting estimates of total stature incorporate correction factors as well as an adjustment for the effect of aging on stature (Trotter and Gleser, 1952). Recently, Wilson et al. (2010) reviewed the Trotter and Gleser (1952) method and noted several problems with the application of these stature equations, the most problematic being the regional and temporal bias of their sample population (Wilson et al., 2010). The average birth date of individuals, specifically females, in the Terry skeletal collection is between 1850 and 1900, a period in which Meadows and Jantz (1999) cite Black Americans and White Americans as having the shortest stature. As a result, the equations derived from this population may not be accurate when applied to a modern American population. To remedy this, the Wilson et al. (2010) study used a contemporary American sample, and generated temporally-specific total stature estimation formulae using long bone lengths.

Stature estimation research in forensic anthropology typically utilizes the mathematical approach, which involves the extrapolation of living stature from individual skeletal elements through regression analyses (Auerbach et al., 2009). Using the regression formulae of:

$$y \text{ (stature)} = b(x) + a$$

where *b* refers to the regression coefficient for the first variable (or measurement), *x* refers to the first variable (or measurement), and *a* refers to the constant, one can calculate stature from individual skeletal elements. In other words, the estimate of living stature is the sum of the products of the unstandardized coefficient and the magnitude of the corresponding measurement variables and the constant value, or intercept.

When regression formulae are calculated, the statistical output (model summary) provides a standard error of the estimate (SEE) value. To obtain a range for individual stature, rather than an absolute value, the standard error of the estimate can be added to, or subtracted from, the final estimate (*y*) (Bidmos and Asala, 2005; Bidmos, 2006). In forensic anthropology, a range for stature estimation is useful because it enhances the accuracy of an estimate by increasing the chance that the unidentified individual will fall within that particular range. The SEE can be defined as "a measure of expected accuracy of a stature estimate of an individual who belongs to the same population from which the equation was derived" (Trotter and Gleser, 1958: 115). Therefore, the SEE of a regression equation is a measure of the accuracy of the estimation of stature (i.e. how close the estimate is to the documented living stature). The lower the SEE as presented by a regression equation, the more accurate is the estimate of stature.

The statistical output (model summary) also provides Pearson correlation values (*r*-values) when regression formulae are calculated. The r-value indicates the strength and direction of the relationship between measurement variables. For example, if a correlation coefficient of 0.99 ($r = 0.99$) was found when estimating stature from the calcaneus in a Black South African population, this would demonstrate that there is a strong relationship between measurements of the calcaneus and living stature, and would prove the accuracy

of the calcaneus for stature estimation in a Black South African population (Bidmos and

Asala, 2005).

One of the most important aspects of the mathematical approach is the notion of

population-specificity regression formulae. Researchers are advised to be cautious when

applying stature regression formulae to their study population if the methods were derived

from a different population (Trotter and Gleser,1952; Wilson et al., 2010). Human

proportions vary systematically between populations. Therefore, the most accurate

mathematical estimates of stature will be obtained when the population being investigated

is as similar as possible to the population that was used to derive the regression formulae

(Holliday and Ruff, 1997; Wilson et al., 2010).

2.2.1 Stature Estimation: Regression Formulae from the Long Bones

Long bones (i.e. the humerus, ulna, radius, femur, tibia, and fibula) are most often

used for estimating stature from unidentified skeletal remains as they provide the most

accurate estimation of stature. The formulae for long bone estimation that are typically

utilized by forensic anthropologists are those developed by Trotter and Gleser (1952) (see

section 2.2.2) and Trotter (1970). The results of these studies have demonstrated a high

correlation between the length of long bones and stature, i.e. correlation coefficients

ranging from 0.63 to 0.84 in Black Americans and from 0.72 to 0.87 for White

Americans; the highest single correlation is typically that of the femur (Steele, 1970;

Steele and McKern, 1969; Trotter, 1970; Trotter and Gleser, 1952).

In disaster identification contexts, long bones are often found fragmented, which

precludes any measurements of long bone length and, thus, the use of formulae for stature

estimation from long bone length. To remedy this, researchers have used fragmentary long bones to derive regression equations for the estimation of stature in a number of populations (Müller, 1935; Simmons et al., 1990; Steele, 1970; Steele and McKern, 1969). Steele and McKern (1969) for example, examined the femur, tibia, and humerus in order to determine whether fragments of these skeletal elements provide an accurate estimation of stature in a prehistoric American Indian population. While the results of this research suggest fragments of the femur, tibia, and humerus show high accuracy rates for stature estimation, Steele and McKern (1969) note that these methods are problematic in practical forensic applications due to the difficulty in identifying the anatomical landmarks required for collecting the measurements. Simmons et al. (1990) revised the Steele and McKern (1969) method for stature estimation from fragmentary femora using a Black American and White American population. Simmons et al. (1990) used clearly defined standard measurements from the proximal, midshaft, and distal regions of the femur. The results of this analysis show correlation coefficients that range from 0.220 to 0.677. This suggests that fragmentary long bones have lower accuracy rates than when using intact long bones for stature estimation.

2.2.2 Stature Estimation: Regression Formulae from the Skull

Studies that have investigated the estimation of stature from measurements of the skull have shown varying degrees of accuracy across a number of populations (Chiba and Terazawa, 1998; Fully, 1956; González-Colmenares et al., 2016; Introna et al., 1993; Krishan, 2008; Patil and Mody, 2005; Torimitsu et al., 2016). Fully (1956) first used the skull for stature estimation in a French population as one of the skeletal elements measured when using the Fully method (see section 2.2.1). In 1993, Introna et al.

measured the maximum anterior-posterior length and the maximum breadth of the skull in an Italian population (358 males) in order to evaluate the correlation between measurements of the skull and skeletal height. The results of this study indicate that the dimensions of the skull are positively correlated with skeletal height, with correlation coefficients ranging from 0.16 to 0.26 (Introna et al., 1993). In 1998, Chiba and Terazawa conducted a cadaveric study in a Japanese population (77 males, 47 females) in order to investigate the estimation of stature from the diameter (distance from the glabella to the external protuberance) and circumference (total length around the skull through the glabella and external protuberance) of the skull. The results of this study demonstrate correlation coefficients ranging from 0.32 to 0.53 (Chiba and Terazawa, 1998). In 2016, Torimitsu et al. also assessed the correlation between the skull and stature in a contemporary Japanese population (123 males, 105 females), using five cranial measurements: minimum frontal breadth, bi-zygomatic breadth, maximum cranial length, parietal chord, and maximum cranial breadth. The results of this study demonstrated higher correlation coefficients for stature estimation from parameters of the skull (0.459 to 0.764) than did the parameters of the skull measured by Chiba and Terazawa (1998).

Other studies have investigated cephalometric landmarks using lateral cephalogram radiography. Patil and Mody (2005) derived a regression equation for estimating stature from the maximum length of the skull (measured from the glabella to the opisthocranion) in a Central Indian population (75 males, 75 females). They found high accuracy rates for the estimation of stature using this equation, though absolute correlation coefficient values were not provided for this study. In a more recent study, utilizing lateral cephalogram radiography, González-Colmenares et al. (2016) investigated the accuracy of cephalo-facial measurements for stature estimation in a

contemporary Colombian Mestizo population (54 males, 16 females). For males, there

was a correlation from 0.28 to 0.47 between stature and the following measurements:

nasion to menton, glabella to opisthocranion, basion to nasion, mastoidale to the sella-

nasion plane, and basion to anterior nasal spine. There were no significant correlations

between the cephalometric measurements and stature in females (González-Colmenares

et al., 2016). Overall, the literature suggests that measurements of the cephalic region

(head) have a stronger correlation with stature than measurements of the facial region

(González-Colmenares et al., 2016; Krishan, 2008; Krishan and Kumar, 2007;

Mahalakshmi and David, 2013; Patil and Mody, 2005).

2.2.3 Stature Estimation: Regression Formulae from the Vertebrae

Numerous studies have been published for the estimation of stature from the

vertebrae in various populations (Dwight, 1894; Jason and Taylor, 1995; Nagesh and

Kumar, 2006; Rodríguez et al., 2016; Terazawa et al., 1990; Tibbetts, 1981; Torimitsu et

al., 2015). In 1894, Dwight published a study that introduced a method for estimating

stature from the vertebral column in an unknown population. The results of this study

indicated that the vertebral column can provide an accurate estimation of stature, though

correlation coefficients were not produced (Dwight, 1894). The method published

however, requires a fresh and articulated spine and, thus, this method is not applicable in

a forensic anthropological context when human remains are skeletonized (Dwight, 1894).

In 1981, Tibbetts developed regression equations for the estimation of stature

from the vertebral column and from segments of the vertebral column for a Black

American population (100 males, 100 females). The vertebral column was divided into

contiguous segments for analyses, containing from one to 23 vertebrae (second cervical

vertebra [C2] to the fifth lumbar vertebra [L5]). The regression equations showed

correlation coefficients that ranged from 0.18 to 0.64, suggesting that the vertebral

column may have high accuracy rates for the estimation of stature in the absence of more

accurate predictors of stature, such as complete long bones.

Jason and Taylor (1995) developed regression equations for the estimation of

stature from the vertebral column and vertebral segments of a Black American (43 males,

31 females) and White American (167 males, 58 females) population. The vertebral

column was divided into the following vertebral segments: (i) cervical, (ii) thoracic, (iii)

lumbar, (iv) thoraco-lumbar, and (v) cervico-thoraco-lumbar (Jason and Taylor, 1995).

Regression equations were generated for both males and females of each population,

showing correlation coefficients from 0.353 to 0.823 (Jason and Taylor, 1995). More

recently, Nagesh and Kumar (2006) completed a study using a South Indian population

(72 males, 45 females) that aimed to estimate stature using a methodology similar to that

of Jason and Taylor (1995). The correlation coefficients ranged from 0.583 to 0.776 for

males and from 0.325 to 0.708 for females. For both males and females, the total length

of the vertebral column provided a more accurate estimate of stature than the individual

vertebral segments (Nagesh and Kumar, 2006). This is consistent with the results of

previous research and suggests that, when available, the vertebral column should be

analyzed in its entirety for the most accurate estimation of stature (Dwight, 1894; Jason

and Taylor, 1995; Tibbetts, 1981).

In a forensic context however, it is unlikely that the entire vertebral column will

be present and, thus, it is necessary to develop methods of stature estimation using

individual vertebrae or vertebral segments. The results of Nagesh and Kumar (2006)

demonstrate that the cervical segment of the vertebral column has the lowest correlation

coefficient (0.325 to 0.583), and the lumbar segment of the vertebral column shows the

highest correlation coefficient (0.624 to 0.659). The low correlation coefficient value of

the cervical segment is consistent with the results of Jason and Taylor (1995) in a Black

American and White American population, and Torimitsu et al. (2015) in a Japanese

population, who cited correlation coefficients from cervical vertebrae of 0.343 to 0.735

and 0.392 to 0.594, respectively. The high correlation demonstrated between the lumbar

segment and stature is in concurrence with Terazawa et al. (1990) and Tibbetts (1981).

However, it contrasts with the results of Jason and Taylor (1995) who cited correlation

coefficients from 0.537 to 0.686 for the lumbar vertebra. Overall, the literature suggests

that, in the absence of an entire vertebral column, the lumbar segment of the vertebral

column will provide the most accurate estimation of stature (Nagesh and Kumar, 2006;

Terazawa et al. 1990, Torimitsu et al., 2015).

2.2.4 Stature Estimation: Regression Formulae from Other Post Cranial Elements

   Researchers have used a variety of post cranial elements to estimate stature.

Estimations of stature have been attempted using the sternum (Dwight, 1980; Marinho et

al., 2012; Menezes et al., 2009, 2011; Singh et al., 2011; Yonguc et al., 2015; Zhang et

al., 2015), clavicle (Balvir et al., 2012; Jit and Singh, 1956; Rajesh, 2014; Rani et al.,

2011; Singh and Sohal, 1952; Torimitsu et al., 2017), scapula (Campobasso et al., 1998;

Giurazza et al., 2013; Shulin and Fangwu, 1983; Torimitsu et al., 2015; Zhang et al.,

2016), metacarpals (Kimura, 1992; Meadows and Jantz, 1992; Musgrave and Harneja,

1978; Wilbur, 1998; Zaher et al., 2011), hand phalanges (Habib and Kamal, 2010; Jasuja

and Singh, 2004; Jee and Yun, 2015; Shintaku and Furuya, 1990), sacrum (Fully, 1956;

Giroux and Wescott, 2008; Karakas et al., 2011; Pelin et al., 2005; Pininski and Brits,

2014; Torimitsu et al., 2014) and the metatarsals (Bidmos, 2008; Byers et al., 1989; Cordeiro et al., 2009; De Groote and Humphrey, 2011; Rodríguez et al., 2013). These studies demonstrate that postcranial elements, other than long bones, should be used with caution for the estimation of stature.

Dwight (1890), an American anatomist from Harvard University, was the first to investigate the relationship between the sternum and stature in White and Black American populations. Recent studies have also examined the accuracy of the sternum for the estimation of stature in various populations (Marinho et al., 2012; Menezes et al., 2009, 2011; Singh et al., 2011; Yonguc et al., 2015; Zhang et al., 2015). Menezes et al. (2009, 2011) derived linear regression equations for stature estimation from the sternum in 35 males and 40 females of a South Indian population. Menezes et al. (2009, 2011) concluded that sternum length was correlated with stature as they produced correlation coefficients of 0.638 in males and 0.639 in females. Other studies have demonstrated similar correlation coefficients in a Northwest Indian population (Singh et al., 2011) and in a Western Chinese population (Zhang et al., 2015). More recently, Yonguc et al. (2015) investigated the accuracy of the sternum for stature estimation in a Turkish population (65 males, 30 females). This study demonstrated correlation coefficients of up to 0.721 in Turkish males, and up to 0.740 in Turkish females. The results of these studies (Dwight, 1980; Menezes et al., 2009, 2011; Singh et al., 2011; Yonguc et al., 2015; Zhang et al., 2015) suggest that the sternum is an accurate predictor stature in the absence of more accurate skeletal elements. However, Marinho et al., (2012), who studied stature estimation from the sternum in a Portuguese population and found correlation coefficient values of only 0.329, state that the sternum has limited forensic value and does not have high accuracy rates for stature estimation in this population. Therefore, further studies are

needed to better understand the accuracy of the sternum for stature estimation in different populations.

The clavicle has also been investigated for its accuracy for stature estimation in various populations (Balvir et al., 2012; Jit and Singh, 1956; Rajesh, 2014; Rani et al., 2011; Singh and Sohal, 1952; Torimitsu et al.,2017). Singh and Sohal (1952) were the first researchers to investigate the accuracy of the clavicle for stature estimation, using maximum length of the clavicle to predict stature in a Punjabi population. In 1956, Jit and Singh re-examined the study of Singh and Sohal (1952), and found correlation coefficients ranging from 0.56 to 0.72. The authors of this study concluded that the clavicle was not an accurate predictor of stature in a Punjabi population (Singh and Sohal, 1952). However, more recent studies have investigated the correlation between length of the clavicle and stature in various Indian populations and concluded that the clavicle may show high accuracy rates for stature estimation if more accurate skeletal elements (e.g. long bones) are not available (Balvir et al., 2012; Rajesh, 2014; Rani et al., 2011). Torimitsu et al. (2017) reached a similar conclusion when investigating the correlation between measurements of the clavicle and stature estimation. They used three-dimensional computed tomographic images in a Japanese population (131 males, 118 females) and found correlation coefficients ranging from 0.510 to 0.816. Overall, however, the literature suggests that the clavicle is not as accurate for stature estimation as other skeletal elements.

Early studies of stature estimation using measurements of the scapula can be attributed to Shulin and Fangwu (1983) and Campobasso et al. (1998). In 1983, Shulin and Fangwu took the morphological breadth of scapulae in a Southern Chinese population and concluded that the scapula is not as accurate for stature estimation as other skeletal

elements, such as the os coxa. In 1998, Campobasso et al. investigated the correlation between measurements of the scapula (i.e. maximum length, maximum breadth, maximum acro-coracoid distance, maximum length of acromion, maximum length of coracoid, length of glenoid cavity, and width of glenoid cavity) and stature in a southern Italian population (40 males, 40 females). From this study, Campobasso et al. (1998) concluded that the scapula shows high accuracy rates for stature estimations with resulting correlation coefficients ranging from 0.23 to 0.62. More recent studies support this conclusion, demonstrating correlation coefficients from 0.70 to 0.74 in an Italian population (longitudinal scapular length; Giurazza et al., 2013), 0.749 to 0.816 in a Japanese population (left longitudinal scapular length; Torimitsu et al., 2015), and 0.529 to 0.604 in a Chinese population (multiple regression) (Zhang et al., 2016). More studies are needed to determine the accuracy of scapular measurements for stature estimation in different populations.

Several studies have utilized the metacarpals for adult stature estimation with high rates of accuracy (Karaman et al., 2008; Meadows and Jantz, 1992; Musgrave and Harneja, 1978; Zaher et al., 2011). Musgrave and Harneja (1978) measured the inter-articular length of each of the five metacarpal bones in a British population (120 males, 46 females) and derived regression equations for the estimation of stature. The results of this study demonstrate correlation coefficients ranging from 0.53 to 0.67 in males, and from 0.49 to 0.84 for females. Meadows and Jantz (1992) completed a similar study for a Black American (53 males, 55 females) and a White American (56 males, 48 females) population and also found the metacarpals to be an accurate predictor of stature, with correlation coefficient values ranging from 0.565 to 0.828. Karaman et al. (2008) also revealed significant correlation coefficient values for the estimation of stature in a

Turkish population (54 males, 46 females) using the second metacarpal length (0.785) and the third metacarpal length (0.743). However, a study by Zaher et al. (2011) revealed a slightly weaker correlation between measurements of the metacarpals and stature. Zaher et al. (2011) also found low correlation coefficient values between the length and the breadth of the second and the third metacarpal and stature in an Egyptian population (82 males, 75 females), ranging from 0.16 to 0.40 in Egyptian females and from 0.10 to 0.287 in Egyptian males. Overall, the literature suggests that metacarpal dimensions, particularly of the second and third metacarpals, are not highly accurate predictors of stature (Karaman et al., 2008; Meadows and Jantz, 1992; Musgrave and Harneja, 1978; Zaher et al., 2011).

The phalanges of the hand have also been investigated for stature estimation in a number of populations (Habib and Kamal, 2010; Jasuja and Singh, 2004; Jee and Yun, 2015; Shintaku and Furuya, 1990). Shintaku and Furuya (1990) investigated the correlation between the length of the proximal phalanges of the hand and stature in 231 Japanese women. The authors found a statistically significant correlation, with correlation coefficient values ranging from 0.521 to 0.696 (Shintaku and Furuya, 1990). Similarly, Jasuja and Singh (2004) found a statistically significant correlation between the phalanges (of each finger) and stature in a Punjabi Jat Sikh population (30 males, 30 females), with correlation coefficient values from 0.327 to 0.502 in males and from 0.336 to 0.529 in females. However, when measurements of phalange length were taken from an inked handprint, rather than directly from the skeletal element, correlation coefficient values increased to 0.394 to 0.652 in males and to 0.376 to 0.577 in females (Jasuja and Singh, 2004). Overall, the literature suggests that total hand length is more accurate for stature

estimation than individual lengths of the hand phalanges (Habib and Kamal, 2010; Jee and Yun, 2015).

Fully (1956) was the first researcher to use the sacrum for stature estimation; he measured it as one of the skeletal elements employed as a part of the Fully method (see section 2.2.1). Pelin et al. (2005) were the first to publish information on the relationship between stature and sacral and coccygeal vertebrae dimensions through lateral magnetic resonance images taken from 42 Turkish males. The results of this study show correlation coefficient values from 0.088 to 0.677, with overall sacral height and the sum of vertebral dimensions providing the most accurate estimations of stature as compared to individual vertebral measurements (Pelin et al., 2005). Giroux and Westcott (2008) completed a similar study in 2008, measuring anterior length of the sacrum from dry bone in a Black American (57 males, 38 females) and White American (92 males, 60 females) population. The results of this study show correlation coefficient values from 0.13 to 0.46. More recent studies that investigate the relationship between stature and dimensions of the sacrum show correlation coefficients ranging from 0.17 to 0.54 in an Anatolian Caucasian population (Karakas et al., 2011), from 0.16 to 0.66 in a Black South African and White South African population (Pininski and Brits, 2014), and from 0.587 to 0.716 in a Japanese population (Torimitsu et al., 2014). These studies demonstrate results that are consistent with the previous literature (Giroux and Westcott, 2008; Pelin et al., 2005). Overall, the literature suggests that the sacrum should only be used for stature estimation when more accurate skeletal elements are not available for analyses (Giroux and Wescott, 2008; Karakas et al., 2011; Pelin et al., 2005; Pininski and Brits, 2014; Torimitsu et al., 2014).

There has been some research in a number of populations examining the accuracy of metatarsals for stature estimation (Bidmos, 2008; Byers et al., 1989; Cordeiro et al., 2009; De Groote and Humphrey, 2011; Rodríguez et al., 2013). Byers et al. (1989) investigated the relationship between metatarsal length and stature on a sample of male and female Black Americans (13 males, 9 females) and White Americans (57 males, 51 females). They demonstrated significant correlation coefficients ranging from 0.58 to 0.89. In 2008, Bidmos investigated stature estimation using linear measurements of metatarsals in an indigenous South African (60 males, 53 females) and White South African (58 males, 55 females) population. The results from Bidmos (2008) support the conclusions of Byers et al. (1989) with correlation coefficient values ranging from 0.44 to 0.76. More recent studies demonstrate similar findings, suggesting that the metatarsals are accurate for stature estimation (Cordeiro et al., 2009; De Groote and Humphrey, 2011; Rodríguez et al., 2013).

2.2.4   *The Potential for Stature Estimation from the Calcaneus and the Talus*

In the human body, the calcaneus and the talus are the largest tarsal bones and have been shown to produce high accuracy rates for human identification as they are often well preserved and able to withstand high tensile forces (Bidmos, 2006; Bidmos and Asala, 2005; Hall and Shereff, 1993). This increased preservation is related to the increased strength and density of the bones trabeculae and the smaller surface area of the calcaneus and the talus. Small, compact bones, such as the calcaneus and the talus, are often recovered intact as the bones smaller surface area expose less bone to destructive taphonomic elements (Bidmos and Asala, 2005). The calcaneus and the talus are often

encased in socks and/or shoes, which serve as protection for the feet (Peckmann et al., 2015a,b; Pickering, 1986; Saul and Saul, 2005). Furthermore, the unique morphology of the calcaneus and the talus allow for rapid and accurate anatomical identification during excavation (Lee et al., 2012; Susman, 1983). These characteristics suggest that the calcaneus and the talus may provide accurate results for the estimation of stature and identification of unknown human remains.

Despite this, the calcaneus and the talus are underrepresented in the forensic and anthropological literature for stature estimation. Yet, these bones have been shown to be accurate predictors of individual stature. Regression equations for the estimation of stature using measurements of the calcaneus and the talus have been generated for Black American, White American, Black South African, and White South African populations with a high degree of accuracy (Bidmos, 2006; Bidmos and Asala, 2005; Holland, 1995; Pablos et al., 2013).

In 1995, Holland examined both the calcanei and tali of 60 Black Americans (30 males, 30 females) and 60 White Americans (30 males, 30 females) to determine the accuracy of certain measurements of the calcaneus and of the talus for stature estimation. Regression formulae for the calcaneus and for the talus were created for Black Americans and White Americans separately. Holland (1995) utilized Black American individuals from the Hamann-Todd Collection at the Cleveland Museum of Natural History. These individuals are representative of a mixed temporal population, i.e. an historic Black American population and a modern early 20th century Black American population. The Black American population shows birth dates ranging from 1908 to 1939 (personal communication, LM Jellema, Collections Manager, Cleveland Museum of Natural History). The results of this study demonstrate that maximum length of the calcaneus

(MCAL), posterior length of the calcaneus (PCAL), and maximum length of the talus (MTAL) are positively correlated with stature, with correlation coefficients of 0.723, 0.817, and 0.731, respectively. In 2013, Pablos and colleagues completed a similar study using a more robust statistical method known as least trimmed squares (LTS). These authors examined both the calcanei and tali of 48 Black Americans (23 males, 25 females) and 46 White Americans (25 males, 21 females) to determine if the maximum length of the calcaneus and the maximum length of the talus were correlated with stature. The results of this study show correlation coefficients less than those found by Holland (1995), with the maximum length of the calcaneus demonstrating correlation coefficients ranging from 0.205 to 0.738 and the maximum length of the talus demonstrating correlation coefficients ranging from 0.1472 to 0.663. To date, these are the only studies employed for stature estimation using osteometric criteria of both the calcaneus and the talus.

However, studies have been completed using only measurements of the calcaneus for stature estimation. In 2005, Bidmos and Asala examined the calcanei of 116 Black South Africans (60 males, 56 females) in order to examine which measurements of the calcaneus could provide the most accurate estimation of individual stature. Nine parameters were measured for each calcaneus: maximum length (MAXL), load arm length (LAL), minimum breadth (MINB), body height (BH), maximum height (MAXH), middle breadth (MIDB), dorsal articular facet length (DAFL), dorsal articular facet breadth (DAFB), and cuboidal facet height (CFH). The results of this study show correlation coefficients ranging from 0.27 to 0.47 for Black South African males, and from 0.35 to 0.65 for Black South African females for individual variables of the calcaneus. For Black South African males, the MIDB measurement demonstrated the

highest correlation with individual stature (0.47), while the DAFL measurement demonstrated the highest correlation with individual stature (0.65) for Black South African females. When combinations of variables of the calcaneus were tested (i.e. multiple regression analyses), correlation coefficients ranged from 0.52 to 0.60 for Black South African males (with the highest correlation using the MAXL, MAXH, MIDB and DAFB measurements) and from 0.72 to 0.77 for Black South African females (with the highest correlation using the MAXL, LAL, BH, and DAFL measurements). Overall, Bidmos and Asala (2005) conclude that the MAXL and MIDB measurements are individually the most accurate measurements of the calcaneus for stature estimation and that the accuracy of stature estimation in a Black South African population is enhanced when multiple calcaneal variables are analyzed. In 2006, Bidmos completed a similar study on a White South African population (85 individuals; 41 males, 44 females). The results of this study are similar to those found by Bidmos and Asala (2005); correlation coefficients for individual calcaneal variables ranged from 0.45 to 0.72 for White South African males and from 0.50 to 0.75 for White South African females, with the MAXL measurement demonstrating the highest correlation with individual stature for both males (0.72) and females (0.75). When combinations of variables of the calcaneus were tested (i.e. multiple regression analyses), correlation coefficients ranged from 0.74 to 0.78 for White South African males (with the highest correlation using the MAXL, BH, CFH measurements) and from 0.76 to 0.81 for White South African females (with the highest correlation using the BH, DAFB, MAXL, and MINB measurements).

More recently, Zhang et al. (2016) studied the calcanei of 293 Han Chinese individuals (121 males, 172 females) in order to examine which measurements of the calcaneus could provide the most accurate estimation of individual stature and sex. Five

parameters were measured for each right calcaneus, including: maximum length (X_1), body length (X_2), maximum height (X_3), minimum height (X_4), and cuboidal facet height (X_5). These measurements were recorded from computed radiography (CR) technology, rather than from dry bone as was the protocol of previous studies (Bidmos, 2006; Bidmos and Asala, 2005; Holland, 1995). The results of the Zhang et al. (2016) study show correlation coefficients ranging from 0.25 to 0.61 for Han Chinese males and from 0.31 to 0.62 for Han Chinese females for individual variables of the calcaneus. For both Han Chinese males and Han Chinese females, the maximum length (X_1) measurement demonstrated the highest correlation with individual stature (0.61 for males, 0.62 for females). When combinations of variables of the calcaneus were tested (i.e. multiple regression analyses), correlation coefficients were 0.66 for Han Chinese males and Han Chinese females (using all measurement variables in each equation). Overall, Zhang et al. (2016) conclude that the calcaneus is not as accurate for stature estimation in a Han Chinese population as it was found to be in previous studies (i.e. Bidmos, 2006; Bidmos and Asala, 2005). This may be because the data utilized in the Zhang et al. (2016) study were obtained from computed radiography (CR) technology; it has been shown that taking measurements from digital imaging may not be as accurate as taking the measurements directly from dry bone (Berg et al., 2007; Guenoun et al., 2012; Lagravère et al., 2010; Major et al., 1994; Spoor et al., 2000).

Overall, studies that have investigated the accuracy of the calcaneus and the talus for stature estimation (i.e. Bidmos, 2006; Bidmos and Asala, 2005; Holland, 1995; Pablos et al., 2013) indicate that these bones are accurate predictors of individual stature and may be used for stature estimation in the absence of intact long bones. However, these studies have shown that methods of stature estimation to be population specific. The current

project is important as, currently, there are no calcanei or talar regression formulae for stature estimation that employ a Thai population. Therefore, research is needed in order to determine the accuracy of these bones for stature estimation in a Thai population.

2.3   Climate Change in Thailand: Implications for Forensic Anthropology

For decades, global climate change has been cited as a major cause for concern. Scientists have listed various greenhouse gases which alter the climate of the Earth through absorption of energy and re-emission, including carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) (Bolin et al., 1986; Montzka et al., 2011; Rodhe, 1990; Solomon et al., 2010). The impact of global climate change includes overall increases in global temperature and rainfall, rising sea levels, and the erosion of natural protective barriers of coastlines such as mangroves and coral reefs, all of which may contribute to an increase in severe climate change events and natural disasters (Anthes et al., 2006; Marks, 2011; Van Aalst, 2006; Webster et al., 2005).

The impacts of climate change are particularly severe in developing countries and coastal regions. The Intergovernmental Panel on Climate Change (IPCC) has listed Southeast Asia as one of the most vulnerable regions in the world and states that Thailand is particularly susceptible to the effects of climate change, namely coastal flooding and natural disasters such as tsunamis and cyclones, because of the natural low water level and small tidal range of the region. An analysis of meteorological data collected from the Thai Meteorological Department between 1980 and 2009 indicates an upward trend in monthly average temperatures and annual rainfall amount in Thailand (Thavorntam and Tantemsapya, 2013). The IPCC noted that this upward drift is likely due to an increase in

greenhouse gas concentrations caused by anthropogenic activity (Intergovernmental Panel on Climate Change, 2007).

A number of researchers have demonstrated a link between global climate change and an increase in the frequency and severity of natural disasters such as hurricanes, tsunamis, and tropical cyclones (Anthes et al., 2006; Van Aalst, 2006; Webster et al., 2005). One of the most infamous natural disasters that may be attributed to climate change effects in Thailand is the 'Boxing Day Tsunami' that occurred on December 26, 2004, killing 5,395 individuals in Thailand (James, 2005; Sribanditmongkol et al., 2017; Wright et al., 2015). Major flooding events have also been a cause for concern in Thailand, with the city of Chiang Mai in Northern Thailand flooding five times between August and November 2005 (Jarungrattanapong and Manasboonphempool, 2011; Jothityangkoon et al., 2013). Listed as the most severe floods in the region in over four decades, researchers have demonstrated that these floods were a direct result of climate change, as the high volume and long duration of rainfall caused riverbeds to overflow (Jarungrattanapong and Manasboonphempool, 2011).

Recent studies have also shown that the effects of climate change will continue to impact Thailand; flooding and natural disasters will multiply in both frequency and severity and will have negative impacts in terms of death and destruction (Arunrat and Pumijumnong, 2015; Jinsart et al., 2014; Jothityangkoon et al., 2013; Thavorntam and Tantemsapya, 2013; Wang et al., 2014). Recently, Wang et al. (2014) used a regional climate model called PRECIS (Providing Regional Climate for Impact Studies) for Thailand in order to identify changes in annual temperature and rainfall amount as a result of climate change. Results indicated that average annual temperature and rainfall amount will increase in the upcoming decades (Wang et al., 2014). Jinsart and Thepanondh

(2014) also investigated future climate change scenarios using a computer based modelling system to simulate the impact of future climate change on temperature and rainfall amount. The results of this study also showed an overall increase in both annual temperature and rainfall amount in the next 50 to 100 years (Jinsart and Thepanondh, 2014). Overall, there is a consensus throughout the literature that climate change and climate change events will have a significant impact on the country of Thailand in the future (Arunrat and Pumijumnong, 2015; Jinsart et al., 2014; Jothityangkoon et al., 2013; Marks, 2011; Thavorntam and Tantemsapya, 2013; Wang et al., 2014).

Given that climate change events such as flooding and natural disasters are predicted to increase in both frequency and severity in Thailand, resulting in a higher number of deaths, it is crucial that population-specific methods of victim identification be derived for a Thai population. Therefore, this project is timely and important as it will add to the methodologies employed by forensic anthropologists to assist with the identification of Thai victims in mass disasters.

2.4   The Admissibility of Forensic Anthropology Methods in Court

Forensic anthropologists are increasingly called upon to provide expert witness testimony for cases involving unknown human skeletal remains, and as a result, must consider the applications of their findings to legal matters. In the United States and in Canada, legislation dictates that in order to be considered admissible in a court of law, scientific techniques used by expert witnesses must adhere to the legal admissibility criteria outlined in *Daubert* and *Mohan*, respectively (Christensen, 2004; Holobinko,

2012; Williams and Rogers, 2006). By adhering to these recognized standards, forensic anthropologists will ensure that their analyses are of the highest quality and reliability.

Reliability refers to the degree of reproducibility of a method, or the ability of a method to produce consistent results. Reliability can be judged based on the use of tested scientific methods, description in peer-reviewed publications, and general scientific acceptance (Dirkmaat et al., 2008). Accuracy rates and levels of precision may determine the reliability of a given method (Christensen and Crowder, 2009). Accuracy refers to the measure of correct assessments that a method can estimate, and is typically reported in percentages (Sokal and Rohlf, 1995; Williams and Rogers, 2006). Precision refers to the ability of a method to produce consistent results regardless of whether the method is correct, and can be evaluated by measuring the degree of intra- and inter-observer error (Christensen and Crowder, 2009; Williams and Rogers, 2006). Osteological methods are considered to be reliable if they meet the established critical values of accuracy ($\geq 80\%$) and precision ($\leq 10\%$) (Williams and Rogers, 2006). For quality assurance purposes, accuracy and precision rates must be presented for all forensic anthropological research. This will establish transparency of newly developed methods and techniques and ensure that they are derived using scientifically accepted principles (Christensen and Crowder, 2009; Williams and Rogers, 2006). To ensure reliable, accurate, and precise methodological standards when developing new methods (e.g. those used for stature estimation), forensic anthropological research and testimony must now meet the standards of *Daubert* (in the United States) and *Mohan* (in Canada).

The first important ruling regarding the standard by which admissibility of scientific evidence was judged in the United States Federal Courts, was issued in the federal appeals court case *Frye v. United States* (293 F.2s 1013, 1923). The ruling of this

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case would eventually lead to the formation of the *Daubert* guidelines that are now

standard in the United States. During the *Frye v. United States* (293 F.2s 1013, 1923)

case, the Court, on the standard for admissibility of scientific expert witness testimony,

ruled that: "…in admitting expert testimony deduced from a well-recognized scientific

principle or discovery, the thing from which the deduction is made must be sufficiently

established to have gained general acceptance in the particular field in which it belongs"

(*Frye v. United States*, 54 App.D.C. 46, 293 F. 1013 1923). This ruling, also known as the

Frye Rule, became the legal standard for determining admissibility of scientific evidence,

and required that scientific methods and techniques be generally accepted within the field

from which they were derived in order to be admissible (Christensen, 2004; Holobinko,

2012).

The primary shortcoming of the *Frye* standard was that newly developed and

implemented techniques, such as DNA evidence, were not considered admissible

(Christensen, 2004; Holobinko, 2012; Masten and Strzelczyk, 2001). In the 1993 court

case *Daubert v. Merrell Dow Pharmaceuticals,* parents of Jason Daubert and Eric

Schuller filed suit against the Merrell Dow pharmaceutical company on the premise that

their child's birth defects were a result of the mothers' prenatal ingestion of the

respondent's drug. Epidemiologic testimony, which demonstrated a causal relationship

between prenatal use of the drug and birth defects, was deemed inadmissible according to

the *Frye* Rule because it was based on a methodology that had not been generally

accepted or reviewed by the scientific community. *Daubert* was dismissed based on the

petitioner's failure to produce sufficient evidence (i.e. The *Frye* precedent), and the case

was eventually appealed (*Daubert v. Merrell Dow Pharmaceuticals, Inc*., 509 U.S. 579,

1993). Ultimately, the United States Supreme Court concluded that the *Frye* Rule should

not be considered a standard and that a reasonable minority opinion may be admitted into

evidence, usually in the form of emerging research based on reliable and well-designed

scientific studies (Christensen, 2004). A set of standards, known as the *Daubert*

guidelines, were introduced in order to clarify some of the ambiguous tenants of the *Frye*

Rule.

The *Daubert* guidelines for determining whether evidence is scientific and

admissible are: (1) The content of testimony can be/has been empirically tested using the

scientific method, (2) The technique or methodology has been subject to peer review,

preferably in the form of publication in peer reviewed literature, (3) There are

consistently and reliably applied professional standards and known or potential error rates

for the technique, and (4) The Court may consider general acceptance by identifying the

relevant scientific community and assessing the degree of acceptance (Christensen, 2004;

Daubert v. Merrell Dow Pharmaceuticals, Inc., 509 U.S. 579, 1993). However, scientific

evidence meeting the reliability and relevance criteria set out by the *Daubert* guidelines

are not guaranteed admissibility; the *Daubert* criteria also prohibits the admission of

scientific evidence where its "…potentially prejudicial, confusing, or misleading nature

outweighs its probative value" (Holobinko, 2012: 394.e3).

Similar to the *Daubert* criteria, the *Mohan* admissibility criteria, created as a result

of the 1994 Canadian Supreme Court trial *Regina v. Mohan* (*Regina v. Mohan,* 2 S.C.R. 9

File No. 23063), greatly impacted the admissibility of forensic evidence and scientific

testimony in Canada. These criteria arose from a case in which the respondent, a

paediatrician (Dr. Mohan), was charged with four counts of sexual assault from four

female patients. Council of the respondent indicated intent to call a psychiatrist to testify

that the perpetrator of the alleged offences is part of a limited group of individuals

exhibiting sexually deviant tendencies and that the respondent did not possess the characteristics of such an individual. Ultimately, the evidence was ruled inadmissible and the respondent was found guilty. However, an appeal was filed, and the Ontario Court of Appeal stated that opinion evidence regarding likelihood of individual membership in a group characterized by abnormal proclivities was relevant and, therefore, should be judged based on relevance and not sufficiency (Holobinko, 2012; *Regina v. Mohan*, 2 S.C.R. 9 File No. 23063).

From the Mohan case, four governing factors of evidence admissibility, known as the *Mohan* criteria, were devised in order to allow Canadian trial judges to decide on the admissibility of expert testimony (Holobinko, 2012). The *Mohan* criteria are: (1) Relevance: the admission of expert evidence must be relevant to the case at hand; logically relevant evidence may be excluded if its probative value is overborne by its prejudicial effect, if the time required is not commensurate with its value, or if it can influence the trier of fact our of proportion to it's reliability, (2) Necessity: expert evidence, in order to be necessary, must be outside the experience/knowledge of a judge or jury, (3) The absence of any exclusionary rule: evidence must be given by a witness who has acquired special knowledge through study or experience in the matter; evidence must not be obtained illegally or inappropriately, and (4) A properly qualified expert: the expert witness must be qualified with proper training/certification in relevant scientific principles (*Regina v. Mohan*, 2 S.C.R. 9 File No. 23063).

As a result of the *Daubert v. Merrell Dow Pharmaceuticals, Inc*., and the *Regina v. Mohan* course cases, forensic anthropology in the United States and Canada has adopted a proactive approach towards testing and refining methodologies, evaluating intra- and inter-observer error, estimating error rates, and providing detailed statistical

analyses. As a result, the methodologies used by forensic anthropologists have become

more widely accepted by the legal system in terms of evidence admissibility and

courtroom testimony (Lesciotto, 2015).

CHAPTER 3: MATERIALS AND METHODS

3.1   Research Objectives

The current research study focuses on nine measurements of the calcaneus (Maximum Length, Maximum Height, Cuboidal Facet Height, Body Height, Minimum Breadth, Load Arm Length, Middle Breadth, Dorsal Articular Facet Breadth, and Dorsal Articular Facet Length) and one measurement of the talus (Maximum Length of the Talus) to establish an accurate method of living stature estimation for a contemporary Thai population. The objectives of this research are to:

1. investigate whether regression equations for the calcaneus, which were developed on a Black South African population (Bidmos and Asala, 2005), and regression equations for the talus, which were developed on a Black American population (Holland, 1995), can accurately predict the living stature of individuals from a contemporary Thai population.

2. develop population-specific simple regression and multiple regression equations for the calcaneus and the talus of the contemporary Thai population should the Black South African (Bidmos and Asala, 2005) and Black American (Holland, 1995) equations not accurately predict the living stature of the Thai individuals.

3. compare the results from the contemporary Thai population to other populations

3.2   Materials and Method

3.2.1 Demographics of Skeletal Materials Utilized for this Research

Measurements were taken from the paired calcaneus and talus of 233 adult skeletonized individuals (116 males, 117 females) of Thai ancestry from the Chiang Mai

skeletal collection housed in the Forensic Osteology Research Center, at the Faculty of

Medicine, Chiang Mai University, Thailand. All individuals utilized for this research

must have had both the calcaneus and the talus available for inclusion in this study; if

measurements could not be taken from the calcaneus, then the talus of that individual was

excluded as well. Similarly, if measurements could not be taken from the talus of an

individual then the calcaneus of that individual would be excluded as well.

In total, 466 individual bones ($N_{total\ bones} = 466$; $N_{calcaneus} = 233$, $N_{talus} = 233$) were

examined from a total of 233 adult skeletonized individuals ($N_{individuals} = 233$) (Table 3.1).

Table 3.1 Sample size distribution for the Thai sample utilized in this research study*.

	Male	*Female*	*Total Bones Examined*
$N_{calcaneus}$	116	117	233
N_{talus}	116	117	233
$N_{total\ bones}$			466
$N_{individuals}$	116	117	

* One paired calcaneus and talus was examined from each individual

Individuals included in this research study were randomly selected with priority given to

approximate equal numbers between the sexes (116 male calcanei and 116 male tali, 117

female calcanei and 117 female tali). Demographic information, including biological sex,

living stature (height), age-at-death, year-of-death, and ancestry is available for each

individual in the Chiang Mai skeletal collection. Total living stature was collected in the

Department of Anatomy at Chiang Mai University at the time of body donation. Prior to

soft tissue removal, a metal measuring tape was used to measure the length of the body, to

the nearest centimeter, from the vertex of the head to the heel of the foot with the cadaver

lying in a supine position (Mahakkanukrauh et al., 2011). The year-of-death for each

individual in the collection is recorded in Buddhist years. To convert the year-of-death

from Buddhist years to Christian years, the following formula must be used (as provided

by the curators of the Chiang Mai skeletal collection):

Christian year-of-death = Buddhist year-of-death – 543

The year-of-birth is not recorded on the demographic data sheets. Instead, it was

calculated by the current researcher by subtracting the age-at-death, as documented on the

demographic data sheets, from the calculated Christian year-of-death. Individuals utilized

for this research sample have birth dates between 1914 and 1995 and death dates between

2006 and 2014. Therefore, this skeletal sample is considered contemporary because all

individuals lived during the 20th and 21st centuries.

Sub-adult individuals, or individuals under the age of 19 years of age (< 19 years),

were not included in this study. The talus reaches skeletal maturity with fusion of the talar

epiphysis. This occurs at approximately 9 years of age in females and 12 years of age in

males. The calcaneus reaches skeletal maturity with complete fusion at the calcaneal

epiphysis between the ages of 15 years and 16 years in females and between the ages of

18 years and 20 years in males (Scheuer and Black, 2004). All individuals utilized for this

research study were skeletally adult and between 19 years and 96 years of age (Figure

3.1).
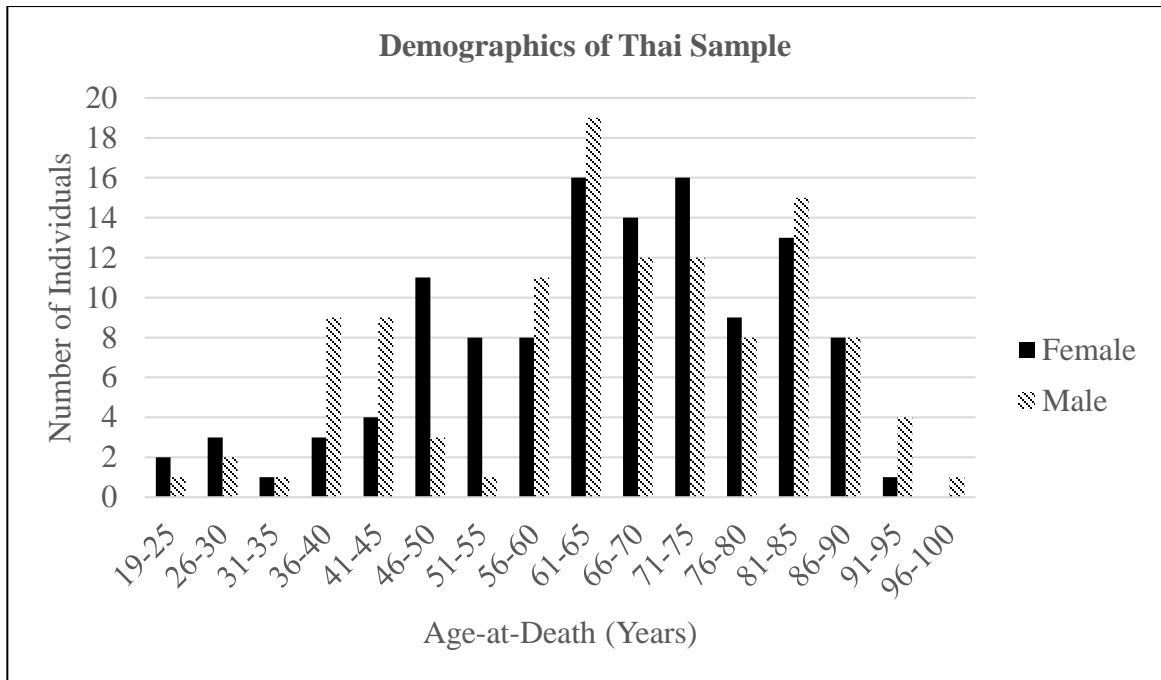
Figure 3.1 Distribution of age-at-death in the Thai skeletal sample utilized for this research study.

3.2.2 Skeletal Materials Excluded from this Research

Individuals were excluded from this study if both the calcaneus and the talus (from an individual pair) were not present for analysis, if the bones exhibited any form of taphonomic damage, post mortem trauma, or extreme pathologic remodeling of the morphometric characteristics which would inhibit the collection of accurate measurements (see Appendix B for examples of calcanei and tali which were excluded). Extreme pathologies included severe osteoarthritis, Diffuse Idiopathic Skeletal Hyperostosis (DISH), severe ankylosing spondylitis (AS) arthritis, and cancer (metastasis condition). Individuals over the age of 50 years (and possibly some younger individuals) may exhibit some form of osteoarthritic pathology as a result of natural mechanical stresses to the skeleton caused by physical activity, muscular strain, and age (Soren, 1993). The vast majority of skeletons in the Chiang Mai skeletal collection exhibited

some osteoarthritic bone remodeling. Therefore, excluding these individuals would bias the independent sample from accurately representing the Thai population as a whole. Calcanei and tali exhibiting mild osteoarthritis, in which measured morphometric traits of the calcaneus and talus were not affected, were included in this study.

3.2.3 Skeletal Measurements

Following the protocol of Bidmos and Asala (2005), nine measurements ("measurement variables") were collected from the calcaneus: Maximum Length (MAXL), Maximum Height (MAXH), Cuboidal Facet Height (CFH), Body Height (BH), Minimum Breadth (MINB), Load Arm Length (LAL), Middle Breadth (MIDB), Dorsal Articular Facet Breadth (DAFB), and Dorsal Articular Facet Length (DAFL). Six of the nine measurement variables (Maximum Length, Cuboidal Facet Height, Load Arm Length, Middle Breadth, Dorsal Articular Facet Breadth, and Dorsal Articular Facet Length) follow the definitions by Martin and Knußman (1988). Three of the nine measurement variables (Maximum Height, Body Height, and Minimum Breadth) follow the definitions of Bidmos and Asala (2005). For detailed explanations of the calcaneal measurement variables utilized for this study, refer to Table 3.2. For visual depictions of the calcaneal measurement variables taken for this study refer to Figure 3.2 and Figure 3.3.

Table 3.2 Measurement variable descriptions of the calcaneus

Measurement variable	Description
Maximum Length (MAXL)	The maximum distance between the most anterior point of the calcaneus and the most posterior point of the calcaneal tuberosity *
Maximum Height (MAXH)	The maximum distance between the most superior point of the calcaneal tuberosity and the most inferior point and of the calcaneal tuberosity **
Cuboidal Facet Height (CFH)	The maximum distance between the most superior point of the cuboidal articular facet and the most inferior point of the cuboidal articular facet *
Body Height (BH)	The maximum distance between the superior surface of the calcaneal body, and the inferior surface of the calcaneal body **
Minimum Breadth (MINB)	The minimum distance between the medial and lateral surfaces of the superior part of the calcaneal body **
Load Arm Length (LAL)	The maximum distance between the most anterior point of the calcaneus and the most posterior point of the posterior articular facet *
Middle Breadth (MIDB)	The maximum distance between the most lateral point of the posterior articular facet and the most medial point of the sustentaculum tali *
Dorsal Articular Facet Breadth (DAFB)	The maximum distance from the most medial point of the posterior articular facet to the most lateral points of the posterior articular facet *
Dorsal Articular Facet Length (DAFL)	The maximum distance between the most posterior point of the posterior articular facet and the most anterior point of the posterior articular facet *

* Modified from Martin and Knußman, 1988
** Modified from Bidmos and Asala, 2005
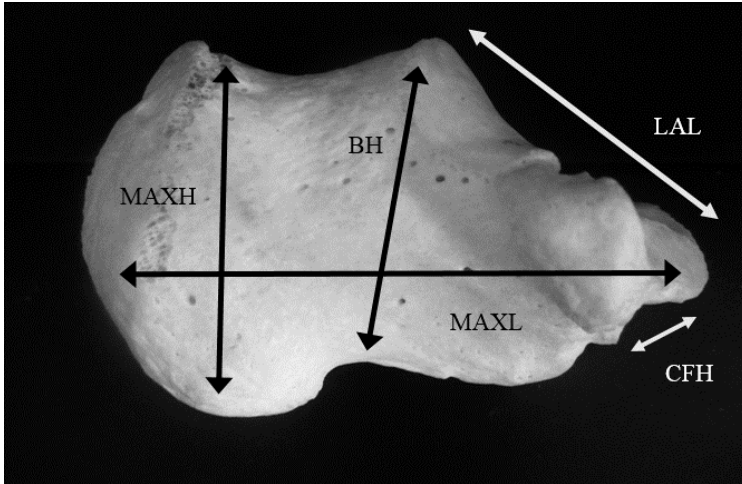
Figure 3.2 Medial view of a typical left calcaneus depicting calcaneal measurement variables: Maximum Length (MAXL), Maximum Height (MAXH), Cuboidal Facet Height (CFH), Body Height (BH), and Load Arm Length (LAL). (Photo by Shelby Scott)
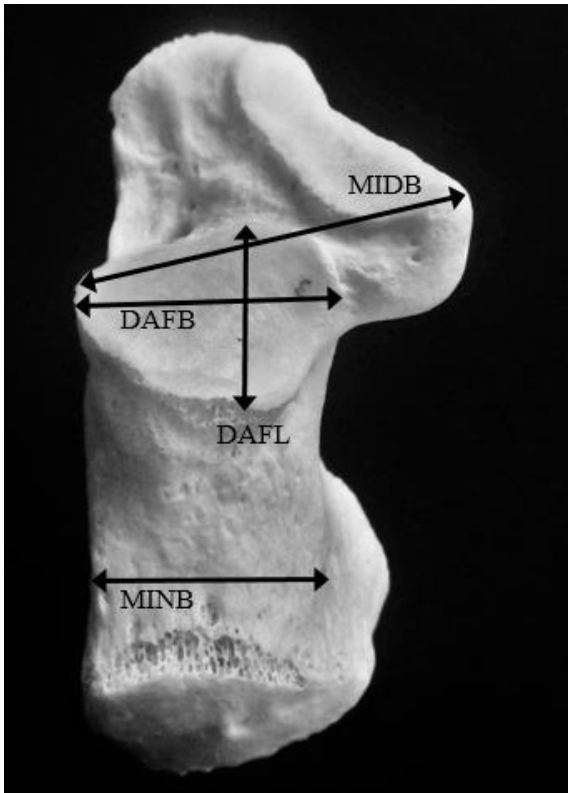
Figure 3.3 Superior view of a typical left calcaneus depicting calcaneal measurement variables: Minimum Breadth (MINB), Middle Breadth (MIDB), Dorsal Articular Facet Breadth (DAFB), and Dorsal Articular Facet Length (DAFL). (Photo by Shelby Scott)

Following the protocol of Holland (1995), one measurement variable was collected for the talus: Maximum Length of the Talus (MTAL). For a detailed explanation of this talar measurement variable refer to Table 3.3. For a visual depiction of this talar measurement refer to Figure 3.4.

Table 3.3 Measurement variable description of the talus.

Measurement variable	Description *
Maximum Length of the Talus	Maximum length between the most anterior point of the head and the posterior tubercle

* Modified from Holland, 1995
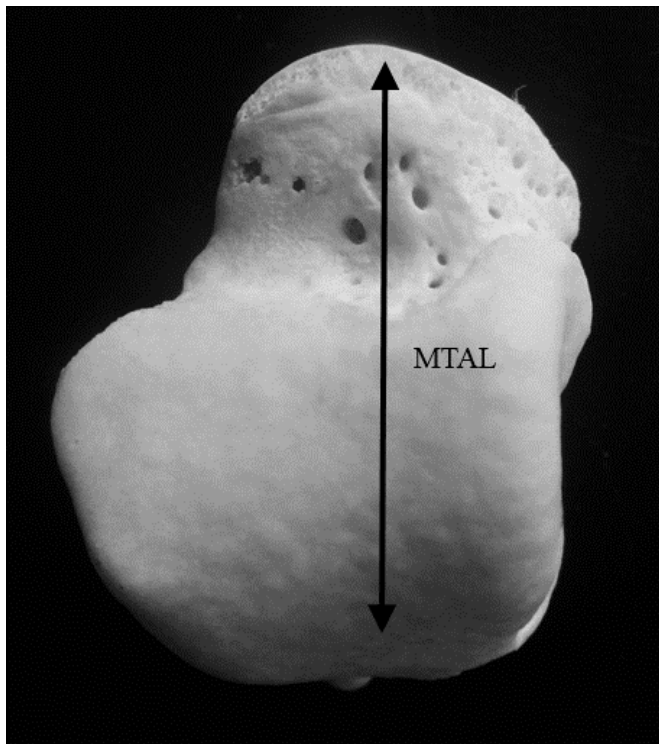
Figure 3.4 Superior view of a typical left talus depicting the Maximum Length of the Talus (MTAL) measurement variable. (Photo by Shelby Scott)

All measurements were collected to the nearest 0.001 mm using a Vernier sliding caliper (Figure 3.5). The data were entered into a Microsoft Excel spreadsheet with males and females recorded separately.

Figure 3.5 Mastercraft electronic (Vernier) caliper used for skeletal measurements. (Photo by Shelby Scott)

3.3   <u>Statistical Analyses</u>

3.3.1 Normality

Tests for normality were performed for each of the nine measurement variables of the calcaneus (Maximum Length, Maximum Height, Cuboidal Facet Height, Body Height, Minimum Breadth, Load Arm Length, Middle Breadth, Dorsal Articular Facet Breadth, and Dorsal Articular Facet Length) and one measurement variable of the talus (Maximum Length of the Talus) for both males and females separately. The Kolmogorov-Smirnov test for normality was utilized. Normality probability plots were created using Minitab version 17.0 statistical software in order to examine the distribution of data and

highlight any potential outliers present in the dataset. A normal distribution is indicated when plotted measurement points display a linear distribution.

A statistical significance level of 5% error rate ($\alpha = 0.05$) to measure normal data distribution was adjusted using a Bonferroni correction of $\alpha = 0.005$. This was completed by dividing the Bonferroni correction ($\alpha = 0.05$) by the number of testable measurement variables ($N_{variables} = 10$) to give a Bonferroni correction of $\alpha = 0.005$. As the number of comparisons between measurement variables increases (i.e. the number of statistical tests), so does the likelihood that a Type 1 error may appear in the statistical outcome. A Bonferroni correction value is used to reduce the rate of Type 1 errors associated with multiple statistical comparisons. In the current research study, if the p-value is less than, or equal to, 0.005 ($p \leq 0.005$) then the data are considered to be statistically not normal and non-parametric tests will be employed for further analyses. If the p-value is greater than 0.005 ($p > 0.005$), then the data are considered to be normal and parametric tests will be employed for the statistical analyses.

3.3.2 Descriptive Statistics

Descriptive statistics were generated for each of the nine measurement variables of the calcaneus and the one variable of the talus. This was done separately for both males and females of the Thai population using Minitab version 17.0 statistical software. To examine the central tendency of the data, means were used as all data were determined to be statistically normal. The variability of the data was described using the maximum, minimum, and standard deviation.

3.3.3   Analysis of Side Differences in the Thai Population

To determine if there was a statistically significant difference between the sides of the body, both left and right calcanei and left and right tali were measured using a randomized sub-sample of 60 individuals ($N_{\text{total individuals}} = 60$; $N_{\text{males}} = 30$, $N_{\text{females}} = 30$) from the Chiang Mai skeletal collection. Measurements were taken from both the left and right calcanei and tali for each individual. Therefore, four bones were examined for each individual. In total, 240 bones ($N_{\text{total bones}} = 240$; $N_{\text{calcaneus}} = 120$, $N_{\text{talus}} = 120$) were examined from 60 individuals ($N_{\text{individuals}} = 60$). For each of the nine calcanei and one talar measurement variables, a paired t-test was performed using SPSS version 23.0 statistical software. This was done separately for males and females. There were no statistically significant differences between the left and right calcanei or the left and right tali ($p >$ 0.05). As there was no significant difference between the calcanei and tali of the left side of the body versus the calcanei and tali of the right side of the body, only left calcanei and left tali were measured following the protocol of Bidmos and Asala (2005). In circumstances where the left calcaneus and talus pair were not available due to them being absent, damaged, or affected by trauma or pathologies, the right calcanei and right tali pair were used and this was noted in the data collection spreadsheet.

3.3.4 Analysis of Sexual Dimorphism in the Thai Population

Two-sample t-tests were used in order to determine whether statistically significant differences existed between male and female calcaneal and talar measurement variables. In total, ten two-sample t-tests were completed using SPSS version 23.0 statistical software, i.e. one test for each of the nine measurement variables of the

calcaneus and one test for the one measurement variable of the talus. A statistical

significance level of 5% error rate (α = 0.05) is used in this research and was adjusted by

dividing the Bonferroni correction (α= 0.05) by the number of testable measurement

variables (N$_{variables}$ = 10) to give a Bonferroni correction of α= 0.005. Values with a p-

value of less than 0.005 ($p < 0.005$) indicate a statistically significant difference between

the male and female calcaneal and talar measurements.

3.3.5 Analysis of Observer Error and Reproducibility

A number of different methods of statistical analyses have been suggested and

used for testing precision and accuracy and evaluating error bias in scientific studies

(Bidmos, 2006). The present study calculates intra-observer and inter-observer error rates

using paired t-tests to evaluate error bias, following the protocol of Holland (1995), and

also utilizes the concordance correlation of reproducibility method (Lin, 1989) following

the protocol of Bidmos and Asala (2005). While these methods are similar in that they

both measure precision and accuracy of the measuring technique, they are not quite the

same. Intra-observer and inter-observer error take the difference between measurements,

for each measurement variable, and compare the mean (average) difference to zero. This

method is investigating overall deviations between repeated measurements. The

concordance correlation of reproducibility method, however, investigates the agreement

between paired measurements by measuring the variation from the concordance line,

which is a 45° line through the origin (i.e. the line one may see if all measurements were

identical) (Lin, 1989; Meek, personal communication August 2017).

Intra-observer error and inter-observer error were analyzed, and were calculated

separately for each of the nine measurement variables of the calcaneus and one

measurement variable of the talus. Intra-observer error analyzes the differences between a single observer re-evaluating the same phenomenon, while inter-observer error analyzes the variation between two or more different individuals evaluating the same phenomenon. To ensure high accuracy and repeatability of the calcaneus and talus measurements, intra-observer and inter-observer error were calculated to ensure that measurements were free of researcher bias, measuring error, and gave similar results each time they were performed.

To test for intra-observer error, 60 skeletonized individuals ($N_{\text{total individuals}} = 60$; $N_{\text{males}} = 30$, $N_{\text{females}} = 30$) from the Chiang Mai skeletal collection were randomly selected. The left calcanei and left tali from each individual were re-measured by the current author one week after the initial measurements had been recorded. In total, 120 left foot bones ($N_{\text{total bones}} = 120$; $N_{\text{calcaneus}} = 60$, $N_{\text{talus}} = 60$) were examined from 60 individuals ($N_{\text{individuals}} = 60$; $N_{\text{male}} = 30$, $N_{\text{female}} = 30$). Buikstra and Ublelaker (1994) cite that a sub-sample group that is 20% of the original sample group is adequate for intra- and inter-observer error analyses; the current sub-sample is large enough to allow accurate conclusions to be drawn about the original sample group. Each of the nine calcanei measurement variables and one talus measurement variable was re-measured and statistically analyzed using paired t-tests. A statistical significance level of 5% error rate ($\alpha = 0.05$) is used in this research and was adjusted by dividing the Bonferroni correction ($\alpha = 0.05$) by the number of testable measurement variables ($N_{\text{variables}} = 10$) to give a Bonferroni correction of $\alpha = 0.005$. The measurements were considered to be repeatable, with no error bias, when the original data set and the re-measured sub-sample were compared and no significant difference ($p > 0.005$) was found. Each of the nine calcanei measurement variables and one talus measurement variable from this sample were also

statistically analyzed using Lin's (1989) concordance correlation in order to evaluate

intra-observer agreement. The measurements were considered to be repeatable and the

measuring technique satisfactory, when the range of the concordance correlation

coefficient obtained fell between the internationally accepted range of 0.90 to 0.98

(Cameron, 1984; Lin, 1989).

Inter-observer error was assessed at Chiang Mai University with the aid of a

research assistant from the University of Central Lancashire (UCLan). The research

assistant was provided with written descriptions and visual demonstrations on how to

collect each measurement variable of the calcaneus and talus. She was instructed to

record the measurement values for each measurement variable in a Microsoft Excel

spreadsheet. A randomly selected sample of 60 skeletonized individuals ($N_{total\ individuals}$ =

60; N_{males} = 30, $N_{females}$ = 30) from the Chiang Mai skeletal collection were randomly

selected and the left calcanei and left tali from each individual were re-measured and

recorded into an Excel spreadsheet by the research assistant. In total, 120 left foot bones

($N_{total\ bones}$ = 120; $N_{calcaneus}$ = 60, N_{talus} = 60) were re-measured from 60 individuals (N_{total}

$_{individuals}$ = 60; N_{males} = 30, $N_{females}$ = 30). Buikstra and Ublelaker (1994) cite that a sub-

sample group that is 20% of the original sample group is adequate for intra- and inter-

observer error analyses; the current sub-sample is large enough to allow accurate

conclusions to be drawn about the original sample group. Paired t-tests were used to

examine statistical differences between the original data collected by the author and the

data re-measured by the research assistant. A statistical significance level of 5% error rate

(α = 0.05) is used in this research, and was adjusted by dividing the Bonferroni correction

(α= 0.05) by the number of testable variables ($N_{variables}$ = 10) to give a Bonferroni

correction of α= 0.005. The measurements were considered to be repeatable, and free of

error bias, when the original data set and the re-measured sub-sample were compared, and no significant difference ($p > 0.005$) was found. Each of the nine calcanei measurement variables and one talus measurement variable from this sample were also statistically analyzed using Lin's (1989) concordance correlation in order to evaluate inter-observer agreement. The measurements were considered to be repeatable and the measuring technique satisfactory, when the range of the concordance correlation coefficient obtained fell between the internationally accepted range of 0.90 to 0.98 (Cameron, 1984; Lin, 1989).

3.3.6 Simple and Multiple Regression Analyses

The first objective of this research study is to investigate whether regression equations for the calcaneus, which were developed on a Black South African population (Bidmos and Asala, 2005) and regression equations for the talus, which were developed on a Black American population (Holland, 1995) can accurately predict the living stature of individuals from a Thai population.

There has been minimal research published on the estimation of living stature from skeletonized calcanei and tali using simple and multiple regression analyses. Methods of living stature estimation from the calcaneus have been developed only on a Black South African (Bidmos and Asala, 2005) and White South African (Bidmos, 2006) population. Methods of living stature estimation from the talus have been developed only on a Black American population (Holland, 1995). Pablos et al. (2013) investigated the relationship between living stature and maximum calcaneal and talar lengths in a Black and White American population using a robust regression method known as least trimmed

squares (LTS). However, this method of statistical analyses is not commonly used in the forensic anthropology literature for the estimation of sex from skeletal remains and therefore cannot be compared with the current data (Bidmos and Asala, 2005; Bidmos, 2006; Holland, 1995). Furthermore, Zhang et al. (2016) investigated the relationship between living stature and measurement variables of the calcaneus in a Han Chinese population using computed radiography (CR) technology. Studies have shown that projection, landmark identification, and measurement errors may occur using radiographic imaging technologies such as computed radiography (CR), and that results from such studies may not be as accurate as those obtained using dry bone (Guenoun et al., 2012; Lagravère et al., 2010). As the current research study records calcaneal measurement variables from dry bone rather than computed radiography (CR) technology, the Zhang et al. (2016) study cannot be compared with the current data. Therefore, the current project tests the Thai calcanei data with Black South African (Bidmos and Asala, 2005) and White South African (Bidmos, 2006) simple and multiple regression equations and tests the tali data with Black American (Holland, 1995) simple regression equations.

The simple and multiple regression equations of Bidmos and Asala (2005) provide an estimate of living stature. To use the simple and multiple regression equations created by Bidmos and Asala (2005) for a Black South African population (Table 3.4), the corresponding measurement variable value(s) from the Thai calcanei are multiplied by the appropriate coefficient and the product is added to the corresponding constant.

Table 3.4 Regression equations (in cm) for estimated skeletal height from the calcaneus of Black South Africans (Bidmos and Asala, 2005)

Simple Regression Equations*	
Male	Female
0.63(MAXL) + 100.87	0.82(MAXL) + 82.49
0.75(MAXH) + 118.67	1.03(MAXH) + 100.97
0.75(BH) + 123.63	1.08(BH) + 105.81
0.51(MINB) + 138.53	1.17(MINB) + 117.46
0.50(LAL) + 128.47	0.64(LAL) + 115.80
1.07(MIDB) + 105.67	1.16(MIDB) + 97.24
1.15(DAFB) + 124.80	1.54(DAFB) + 110.72
0.96(DAFL) + 122.48	1.76(DAFL) + 94.48
Multiple Regression Equations*	
Male	Female
0.38(MAXL) + 0.35(MAXH) + 0.59(MIDB) + 0.56(DAFB) + 68.17	0.69(MAXL) – 0.67(LAL) + 0.37(BH) + 1.27(DAFL) + 72.24
0.44(MAXL) + 0.37(MAXH) + 0.69(MIDB) + 70.86	0.81(MAXL) – 0.73(LAL) + 1.41(DAFL) + 75.22
0.46(MAXL) + 0.85(MIDB) +78.37	0.30 (MAXL) + 0.51 (MAXH) + 1.16(DAFL) + 68.11
0.55(MAXL) + 0.59(MAXH) + 81.91	0.71(MAXH) + 1.43(DAFL) + 74.88

* (y/predicted height =)

The outcome of the simple and multiple regression equations created by Bidmos and Asala (2005) is a preliminary estimation of skeletal height (in cm). Bidmos and Asala (2005) obtained estimates of skeletal height for each individual in their study from the sum of the following bone measurements: basibregmatic height of the skull, anterior body height of the second cervicle vertebra (C2) (including the odontoid process) to the fifth lumbar vertebrae (L5), the bicondylar (physiological) length of the femur, the condylomalleolar length of the tibia, and the articulated talocalcaneal height. This estimate of skeletal height does not however, take into account the thickness of the scalp,

intervertebral discs, or the soft tissue of the sole of the foot (Bidmos and Asala, 2005) and is thus not reflective of an individual's living stature. To gain a final estimation of an individual's living stature, Bidmos and Asala (2005) add a soft tissue correction factor to the estimated skeletal height values generated from their simple and multiple regression equations, following the protocol of Fully (1956). In this way, the estimate of skeletal height, originally obtained through the simple and multiple regression equations of Bidmos and Asala (2005), is merely a first step in obtaining an estimate of living stature. With the addition of soft tissue correction factors, an estimate of living stature is obtained from the simple and multiple regression equations of Bidmos and Asala (2005).

For the calcaneus, eight simple regression equations and four multiple regression equations, created by Bidmos and Asala (2005) from a Black South African population, were applied to the Thai sample, and soft tissue correction factors were added to provide an estimate of living stature, and facilitate a comparison between estimated living stature and the total documented stature associated with individuals in the Thai sample. Males and females were analyzed separately. The Bidmos and Asala (2005) regression equations are shown in Table 3.4. A simple regression equation for the Cuboidal Facet Height (CFH) measurement variable could not be tested on the Thai sample because it was not provided by Bidmos and Asala (2005), as it did not demonstrate a significant correlation in the Black South African population.

In contrast to the simple and multiple regression equations of Bidmos and Asala (2005), the simple regression equations created by Holland (1995) provide a value of estimated living stature (in cm) from the talus and therefore no soft tissue correction factors are utilized when testing the equations of Holland (1995). To use the simple regression equations created by Holland (1995), the corresponding measurement variable

(Maximum Length of the Talus) from the Thai tali is multiplied by the appropriate

coefficient and the product is added to the corresponding constant. The final answer is a

prediction of living stature (in cm).

For the talus, one simple regression equation, created by Holland (1995) from a

Black American population, was applied to the Thai sample to determine its accuracy for

estimating the living stature of Thai individuals. Males and females were analyzed

separately. The Holland (1995) regression equations are illustrated in Table 3.5.

Table 3.5 Regression equations (in cm) for estimated living stature from the talus of
Black Americans (Holland, 1995).

Simple Regression Equations*	
Male	Female
1.046(MTAL) + 112.26	1.046(MTAL) + 97.55

 * (y/predicted living stature =)

From each simple regression equation and each multiple regression equation of

the calcaneus and the talus, p-values and Pearson correlation values ("*r*-values", also

known as correlation coefficients) were obtained. The p-value indicates if there is a

statistically significant relationship between documented living stature and predicted

living stature. In this research, a statistical significance level of 5% error rate ($\alpha = 0.05$) is

used and was adjusted by dividing the Bonferroni correction ($\alpha = 0.05$) by the number of

testable measurement variables ($N_{variables} = 10$) to give a Bonferroni correction of $\alpha =$

0.005. Therefore, if the p-value is less than 0.005 ($p < 0.005$) then the relationship is

statistically significant. The accuracy of each simple regression equation and each

multiple regression equation of the calcaneus and the talus, generated from a Black South

African population (Bidmos and Asala, 2005) and Black American (Holland, 1995)

population and tested on the Thai sample data, was determined by the strength of the the

correlation coefficient (r-value). The correlation coefficient (r-value) indicates the

strength and direction of the relationship between measurement variables. Simple

scatterplots were created to illustrate the strength of the relationship between documented

living stature and the predicted living stature using the regression equations from Black

South African (Bidmos and Asala, 2005) and Black American (Holland, 1995)

populations. If the Black South African (Bidmos and Asala, 2005) and Black American

(Holland, 1995) equations accurately estimated the living stature for Thai individuals, the

scatterplot will display a linear pattern showing a statistically significant relationship

between documented living stature and predicted living stature.

The second goal of this research was to develop population-specific regression

equations for the calcaneus and the talus of the contemporary Thai population should the

Black South African (Bidmos and Asala, 2005) and Black American (Holland, 1995)

equations not accurately classify the individuals. To fulfill this goal, two sub-samples

were created from the original Thai sample: Sample 1 and Sample 2. Sample 1 (main data

set) was used in the derivation of regression equations for living stature estimation.

Sample 2 was an independent sample used to cross-validate the accuracy of the regression

equations derived using Sample 1. Sample 2 was established by importing all the data

into Minitab version 17.0 statistical software and generating a randomized sample

consisting of paired bones from 60 left calcanei and 60 left tali ($N_{total\ bones} = 120; N_{calcaneus}$

$= 60, N_{talus} = 60$) from 60 individuals ($N_{individuals} = 60; N_{male} = 30, N_{feamle} = 30$). These

individuals were excluded from the main data set, i.e. Sample 1, and formed an independent sample (Sample 2), which was used for cross-validation.

To develop regression equations from Sample 1, regression analyses were performed and equations were created using the unstandardized coefficient, constant values, and the Standard Error of the Estimate (SEE) for each equation. Simple regression analysis, in which individual measurement variables of the calcaneus and the talus were regressed against documented living stature to obtain simple regression equations, was performed. Nine simple regression equations were calculated for each measurement variable of the calcaneus following Bidmos and Asala (2005). One simple regression equation was calculated for the talar measurement variable following Holland (1995). This was done for males and females separately. Multiple regression analysis, in which combinations of these measurement variables were regressed against documented living stature to obtain multiple regression equations, was also performed. Using a direct method, a multiple equation was generated using all nine measurement variables of the calcaneus to determine whether accuracy rates are enhanced when utilizing all available measurement variables of the calcaneus. This was done for males and females separately. Multiple regression equations were also generated separately for males and females, using a stepwise method, in order to determine which combination of calcaneal measurement variables produced the most accurate estimation of living stature. To each multiple regression equation that was generated using measurement variables from the calcaneus, for both males and females, the talar measurement variable was added in order to create additional multiple regression equations. This was completed to investigate whether the addition of the talus measurement variable increased the accuracy rate for the estimation of living stature.

The p-values, correlation coefficients (*r*-values), f-statistics, and the Standard

Error of the Estimate (SEE) were obtained for each simple and multiple regression

equation generated following the protocol of Bidmos and Asala (2005). A statistical

significance level of 5% error rate ($\alpha = 0.05$) is used in this research and was adjusted by

dividing the Bonferroni correction ($\alpha = 0.05$) by the number of testable measurement

variables ($N_{variables} = 10$) to give a Bonferroni correction of $\alpha = 0.005$. Therefore, if the p-

value is less than 0.005 ($p < 0.005$) a statistically significant relationship exists. Overall,

the accuracy of the estimation of stature (i.e. how close the estimate is to the documented

living stature) for each simple and multiple regression equation is measured by the

Standard Error of the Estimate (SEE); the lower the SEE as presented by a regression

equation, the more accurate the estimate of stature.

Following the protocol of Bidmos and Asala (2005), ranges for living stature were

obtained using the Standard Error of the Estimate (SEE) that was generated from each

simple and each multiple regression equation created. This Standard Error of the Estimate

(SEE) was added to, or subtracted from, the predicted living stature value to give the

range for living stature.

3.3.7 Cross-Validation of Thai Regression Equations

An independent sample (Sample 2) was used to test the accuracy of the simple and

multiple regression equations derived from Sample 1. Sample 2 consisted of paired tali

from 60 left calcanei and 60 left tali ($N_{total\ bones} = 120$; $N_{calcaneus} = 60$, $N_{talus} = 60$) from 60

skeletonized individuals ($N_{individuals} = 60$; $N_{male} = 30$, $N_{female} = 30$). Simple and multiple

regression equations that were derived from Sample 1 were tested on individuals from

Sample 2 to give an estimate of living stature. Only those simple and multiple regression equations from Sample 1, which showed a statistically significant positive relationship with documented living stature (i.e. $p < 0.005$), were tested on Sample 2. Predicted living stature ranges were correlated with documented living stature using Minitab version 17.0 statistical software. Simple scatterplots were created to illustrate the strength of the relationship between documented living stature and the living stature predicted through cross-validation of the Thai simple and multiple regression equations. The p-values, correlation coefficients (*r*-values), and the Standard Error of the Estimate (SEE) values were obtained. Following the protocol of Bidmos and Asala (2005) and Holland (1995), the accuracy of the estimation of living stature for each of the simple and multiple regression equations was assessed by calculating in what percent of cases, from Sample 2, did predicted living stature fall within 1 SEE and 2 SEE of the documented living stature.

3.3.8 *Population Comparison*

Measurements from the Thai population were compared to the Black South African (Bidmos and Asala, 2005), White South African (Bidmos, 2006), and Black American (Holland, 1995) populations using descriptive statistics. This was done for males and females, and for each measurement variables of the calcaneus and talus, separately. Two-sample t-tests were performed with Minitab version 17.0 statistical software in order to determine if there was a difference between the total number of individuals (*N*), mean measurement values, and the standard deviations for each measurement variable of the calcaneus and talus between the Thai population and the Black South African (Bidmos and Asala, 2005), White South African (Bidmos, 2006), and Black American (Holland, 1995) populations.

CHAPTER 4: RESULTS

4.1   Research Objectives

The current research study focuses on nine measurements of the calcaneus (Maximum Length, Maximum Height, Cuboidal Facet Height, Body Height, Minimum Breadth, Load Arm Length, Middle Breadth, Dorsal Articular Facet Breadth, and Dorsal Articular Facet Length) and one measurement of the talus (Maximum Length of the Talus) to establish an accurate method of living stature estimation for a contemporary Thai population. The objectives of this research are to:

1. investigate whether regression equations for the calcaneus, which were developed on a Black South African population (Bidmos and Asala, 2005), and regression equations for the talus, which were developed on a Black American population (Holland, 1995) can accurately predict the living stature of individuals from a contemporary Thai population.

2. develop population-specific simple regression and multiple regression equations for the calcaneus and the talus of the contemporary Thai population should the Black South African (Bidmos and Asala, 2005) and Black American (Holland, 1995) equations not accurately predict the living stature of the Thai individuals.

3. compare the results from the contemporary Thai population to other populations.

4.2   Normality

Normality was assessed for each of the nine calcaneal measurement variables (Maximum Length, Maximum Height, Cuboidal Facet Height, Body Height, Minimum Breadth, Load Arm Length, Middle Breadth, Dorsal Articular Facet Breadth, and Dorsal

Articular Facet Length) and one talar measurement variable (Maximum Length of the

Talus) using Minitab version 17.0 statistical software. Males and females were

independently assessed resulting in a total of 20 variables ($N_{total\ variables}$= 20; $N_{male\ variables}$=

10, $N_{female\ variables}$= 10). Table 4.1 shows the results of the calculated normality probability

for calcaneal and talar measurement variables for both males and females. Due to the

large number of measurement variables being analyzed, a statistical significance level of

5% error rate (α = 0.05) was adjusted using a Bonferroni correction of α= 0.005 in order

to account for type-1 error. If the p-value is less than, or equal to, 0.005 ($p \leq 0.005$), then

the data are considered to be not normally distributed. If the p-value is greater than 0.005

($p > 0.005$) then the data are considered to be normally distributed. The results show that

the male and female data were normally distributed for all calcaneal and talar

measurement variables. As all data were normally distributed, statistical analyses

proceeded using parametric tests (i.e. tests for normally distributed data).

Table 4.1 Normality probability p-values assessed in males and females.

Measurement variable	p-value (Male)	p-value (Female)
Calcaneus		
MAXL	> 0.150	0.075
MAXH	> 0.150	> 0.150
CFH	> 0.150	0.088
BH	> 0.150	0.050
MINB	> 0.150	> 0.150
LAL	> 0.150	0.070
MIDB	> 0.150	> 0.150
DAFB	0.077	> 0.150
DAFL	> 0.150	> 0.150
Talus		
MTAL	> 0.150	> 0.150

Normality probability plots were created for males and females for each calcaneal and talar measurement variable in order to allow for a visual observation of the data distribution and to highlight any potential outliers present in the dataset. If the data exhibit a linear pattern, then the data are normally distributed. For the current research, all normality probability plots indicated normally distributed data with no significant outliers present in the dataset. Figure 4.1 is an example of a probability plot for the male Maximum Length (MAXL) calcaneal measurement variable. Refer to Appendix C for the probability plots of each calcaneal and talar measurement variable.
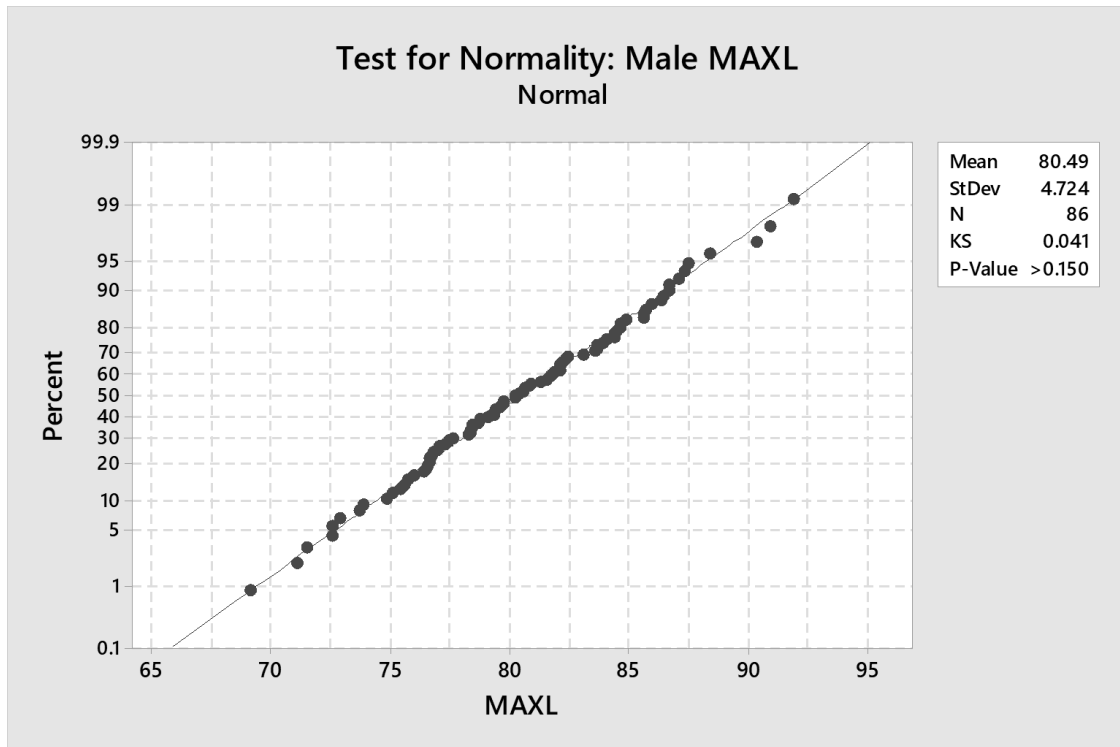
Figure 4.1 Normality probability plot for the male Maximum Length (MAXL) calcaneal measurement variable.

4.3   <u>Descriptive Statistics</u>

The calcaneus and the talus from 233 skeletonized individuals ($N_{total\ individuals} =$ 233; $N_{males} = 116$, $N_{females} = 117$) of Thai ancestry were examined for their potential in estimating living stature. In total, 466 individual calcanei and tali ($N_{total\ bones} = 466$; $N_{calcaneus} = 233$, $N_{talus} = 233$) were studied from the Chiang Mai skeletal collection in Chiang Mai, Thailand. Nine measurements of the calcaneus were collected: Maximum Length, Maximum Height, Cuboidal Facet Height, Body Height, Minimum Breadth, Load Arm Length, Middle Breadth, Dorsal Articular Facet Breadth, and Dorsal Articular Facet Length. This method follows the protocol of Bidmos and Asala (2005). One measurement of the talus was collected (Maximum Length of the Talus), following the protocol of Holland (1995).

Table 4.2 shows the descriptive statistics for males and females for each of the nine calcaneal measurement variables and the one talar measurement variable. This table illustrates the number (N) of calcanei or tali assessed for each measurement variable, as well as maximum measurement length (Maximum), minimum measurement length (Minimum), mean, and standard deviation (SD). These measurement values are shown in millimeters (mm).

Table 4.2 Descriptive statistics for calcaneal and talar measurement variables for both males and females.

Measurement variable	*N*	Mean (mm)	SD (mm)	Minimum Length (mm)	Maximum Length (mm)
Calcaneus					
Male					
MAXL	86	80.49	4.72	69.11	91.86
MAXH	86	43.62	3.56	31.32	51.98
CFH	86	26.79	2.19	21.69	32.29
BH	86	39.06	2.91	32.45	49.14
MINB	86	25.71	1.88	21.55	30.26
LAL	86	48.68	2.82	42.32	57.35
MIDB	86	40.97	2.21	35.10	46.57
DAFB	86	29.37	1.88	24.56	32.89
DAFL	86	29.25	1.95	22.13	33.90
Female					
MAXL	87	73.44	4.26	66.47	84.05
MAXH	87	39.53	3.57	27.24	50.16
CFH	87	24.29	1.82	21.15	28.71
BH	87	34.29	2.45	29.03	41.37
MINB	87	23.48	1.90	19.37	30.70
LAL	87	44.15	2.48	38.16	49.40
MIDB	87	37.08	2.16	31.93	44.14
DAFB	87	26.02	1.76	21.83	30.96
DAFL	87	25.80	1.78	21.54	31.66
Talus					
Male					
MTAL	86	56.38	3.52	48.20	67.08
Female					
MTAL	87	50.02	3.13	44.22	59.27

4.4   Analysis of Sexual Dimorphism in the Thai Population

Each of the nine calcaneal measurement variables and the one talar measurement variable were tested to assess whether statistically significant sexually dimorphic differences existed between male and female calcanei, as well as between male and female tali, in the Chiang Mai skeletal collection. The data were normally distributed, which allowed for the use of two-sample t-tests. Due to the large number of measurement variables being analyzed ($N_{variables} = 10$) a statistical significance level of 5% error rate ($\alpha = 0.05$) was adjusted using a Bonferroni correction of $\alpha = 0.005$. Therefore, if a measurement variable had a p-value that was less than, or equal to, 0.005 ($p \leq 0.005$), this indicated a statistically significant difference between the male and female calcaneal and talar measurement values (Table 4.3). The results of the statistical analyses indicated that all calcaneal and talar measurement variables were sexually dimorphic within this population ($p < 0.005$).

Table 4.3 Two-sample t-tests evaluating sexual dimorphism of males and females for each calcaneal and talar measurement variable.

Measurement variable	Male (N)	Female (N)	t-value	p-value
Calcaneus				
MAXL	86	87	10.32	0.00*
MAXH	86	87	7.55	0.00*
CFH	86	87	8.17	0.00*
BH	86	87	11.68	0.00*
MINB	86	87	7.76	0.00*
LAL	86	87	11.23	0.00*
MIDB	86	87	11.72	0.00*
DAFB	86	87	12.12	0.00*
DAFL	86	87	12.21	0.00*
Talus				
MTAL	86	87	12.56	0.00*

* Significant difference at $p < 0.005$

4.5   Intra- and Inter-Observer Error

Intra-observer and inter-observer error were evaluated separately for each of the nine calcaneal measurement variables (Maximum Length, Maximum Height, Cuboidal Facet Height, Body Height, Minimum Breadth, Load Arm Length, Middle Breadth, Dorsal Articular Facet Breadth, and Dorsal Articular Facet Length) and the one talar measurement variable (Maximum Length of the Talus) to measure the repeatability and accuracy of the calcaneal and talar measurements. Intra-observer error evaluates differences between measurements collected by a single individual on the same sample. Intra- observer error was assessed by the current author by re-measuring a randomly selected sample of 60 skeletonized individuals ($N_{total\ individuals} = 60; N_{males} = 30, N_{females} = 30$) consisting of 60 left calcanei and 60 left tali ($N_{total\ bones} = 120; N_{calcaneus} = 60, N_{talus} =$

60) from the Chiang Mai skeletal collection. Each of the nine calcaneal measurement variables and the one talar measurement variable were re-measured by the current author. The data were normally distributed and, therefore, statistically analyzed using paired t-tests and the concordance correlation of reproducibility method (Lin, 1989). This was done for males and females separately.

A statistical significance level of 5% error rate ($\alpha = 0.05$) is used in this research and was adjusted by dividing the Bonferroni correction ($\alpha = 0.05$) by the number of testable variables ($N_{variables} = 10$) to give a Bonferroni correction of $\alpha = 0.005$. The measurements were considered to be repeatable, with no error bias, when the original data set and the re-measured sub-sample were compared and no significant difference ($p \geq 0.005$) was found. The resulting p-values showed no statistically significant difference between the original sample and the re-measured sub-sample ($p > 0.005$). This indicates that each of the nine calcaneal measurements and one talar measurement were accurately repeated for both males and females. As well, each of the nine calcanei measurement variables and one talus measurement variable from the Thai sample were statistically analyzed using Lin's (1989) concordance correlation in order to evaluate intra-observer agreement. Each measurement variable of the calcaneus and the talus was considered to be repeatable if the values of concordance correlation coefficients fell within the internationally accepted standard range of 0.90 to 0.99 (Cameron, 1984; Lin, 1989). Of all the calcaneal and talar measurement variables, only the male DAFB (0.742) measurement and the female CFH (0.806), BH (0.896), MINB (0.819), DAFB (0.813) measurements did not fall within the internationally accepted standard range of 0.90 to 0.99 (Cameron, 1984; Lin, 1989). Table 4.4 shows the results of the statistical analyses performed for assessing intra-observer error rates for both the calcaneus and the talus.

Table 4.4 Statistical analyses of the intra-observer error rates and concordance correlation coefficients of reproducibility (Rc) for the calcaneus and talus of individuals in the Chiang Mai skeletal collection.

Measurement	n	Test statistic	p-value	Rc-value
Calcaneus				
Male				
MAXL	30	- 0.307	0.761	0.978
MAXH	30	0.139	0.752	0.956
CFH	30	- 1.599	0.121	0.958
BH	30	- 0.743	0.464	0.957
MINB	30	- 0.006	0.995	0.927
LAL	30	- 1.391	0.175	0.961
MIDB	30	- 0.206	0.838	0.933
DAFB	30	1.661	0.108	0.742
DAFL	30	- 0.930	0.360	0.909
Female				
MAXL	30	0.869	0.392	0.997
MAXH	30	- 1.976	0.058	0.971
CFH	30	- 1.413	0.168	0.806
BH	30	- 0.705	0.487	0.896
MINB	30	- 1.027	0.313	0.819
LAL	30	- 1.177	0.249	0.982
MIDB	30	- 1.559	0.130	0.963
DAFB	30	0.159	0.875	0.813
DAFL	30	- 1.002	0.324	0.923
Talus				
Male				
MTAL	30	- 1.726	0.095	0.982
Female				
MTAL	30	- 1.879	0.070	0.937

Inter-observer error evaluates potential differences between measurements that are collected by two or more individuals on the same sample. Inter- observer error was assessed with the aid of a research assistant from the University of Central Lancashire (UCLan). A randomly selected sample of 60 skeletonized individuals ($N_{total\ individuals} = 60$; $N_{males} = 30$, $N_{females} = 30$) consisting of 60 left calcanei and 60 left tali ($N_{total\ bones} = 120$; $N_{calcaneus} = 60$, $N_{talus} = 60$) was used to evaluate inter-observer error. Each of the nine calcaneal measurement variables and the one talar measurement variable were re-measured and recorded into an Excel spreadsheet by the research assistant. This was done separately for males and females. The data were normally distributed and, therefore, paired t-tests were used to examine statistical differences between the original data collected by the current author and the data re-measured by the research assistant.

A statistical significance level of 5% error rate ($α = 0.05$) was used in this research and was adjusted by dividing the Bonferroni correction ($α = 0.05$) by the number of testable variables ($N_{variables} = 10$) to give a Bonferroni correction of $α = 0.005$. The measurements were considered to be repeatable, and free of error bias, when there was no significant difference ($p > 0.005$) when the original dataset and the re-measured sub-sample were compared. The resulting p-values showed no statistically significant difference in males, or in females, between the original sample and the re-measured sample. This indicates that all measurements were accurately repeated for both males and females between researchers. As well, each of the nine calcanei measurement variables and one talus measurement variable from the Thai sample were statistically analyzed using Lin's (1989) concordance correlation in order to evaluate inter-observer agreement. Each measurement variable of the calcaneus and the talus was considered to be repeatable if the values of concordance correlation coefficients fell within the internationally

accepted standard range of 0.90 to 0.99 (Cameron, 1984; Lin, 1989). Of all the calcaneal and talar measurement variables, only the male DAFB (0.796) measurement, and the female BH (0.659) and MINB (0.896) measurements did not fall within the internationally accepted standard range of 0.90 to 0.99 (Cameron, 1984; Lin, 1989). Table 4.5 shows the results of the statistical analyses performed for assessing inter-observer error for both the calcaneus and the talus.

Table 4.5 Statistical analyses of the inter-observer error rates and concordance correlation coefficients of reproducibility (Rc) for the calcaneus and talus of individuals in the Chiang Mai skeletal collection.

Measurement	n	Test statistic	p-value	Rc-value
Calcaneus				
Male				
MAXL	30	1.255	0.220	0.999
MAXH	30	1.065	0.296	0.989
CFH	30	- 1.993	0.056	0.994
BH	30	- 1.354	0.186	0.987
MINB	30	0.012	0.991	0.987
LAL	30	- 1.483	0.149	0.992
MIDB	30	- 0.517	0.609	0.986
DAFB	30	0.272	0.788	0.769
DAFL	30	- 1.597	0.121	0.987
Female				
MAXL	30	- 0.219	0.829	0.990
MAXH	30	- 0.465	0.645	0.997
CFH	30	- 1.442	0.160	0.999
BH	30	- 0.219	0.828	0.659
MINB	30	0.358	0.723	0.896
LAL	30	- 1.898	0.068	0.994
MIDB	30	- 0.111	0.912	0.971
DAFB	30	- 0.670	0.508	0.937
DAFL	30	- 1.079	0.289	0.989
Talus				
Male				
MTAL	30	- 1.897	0.068	0.915
Female				
MTAL	30	0.496	0.623	0.999

4.6 <u>Simple and Multiple Regression Analyses</u>

4.6.1 Accuracy of the Bidmos and Asala (2005) Calcaneal Regression Equations

The first objective of the current research was to investigate whether regression equations for the calcaneus, which were developed on a Black South African population (Bidmos and Asala, 2005), and regression equations for the talus, which were developed on a Black American population (Holland, 1995), can accurately predict the living stature of individuals from a Thai population. To fulfill this objective, each of the simple and multiple regression equations for the calcaneus that were generated from a Black South African population (Bidmos and Asala, 2005) were tested on the Thai sample data. However, simple regression equations using the Cuboidal Facet Height (CFH) calcaneal measurement variable could not be tested on the Thai sample data because Bidmos and Asala (2005) do not provide simple regression equations that use the CFH calcaneal measurement variable. The accuracy of each calcaneal simple and multiple regression equation that were generated from a Black South African population (Bidmos and Asala, 2005) and tested on the Thai sample data is determined by the strength of the Pearson correlation value (r-value), also known as the correlation coefficient (r-value). The correlation coefficient (r-value) indicates the strength and direction of the relationship between measurement variables.

Table 4.6 shows the results of the male Black South African calcaneal regression equations (Bidmos and Asala, 2005) when applied to the Thai population. The regression equations are shown in decreasing order of the value (strength) of the correlation coefficient. A Bonferroni correction of $\alpha = 0.005$ is used in this research study. For Thai males, with the exception of the Dorsal Articular Facet Breadth (DAFB) and Dorsal

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Articular Facet Length (DAFL), all simple regression equations of the calcaneus have a p-

value less than 0.005 ($p < 0.005$).

Table 4.6 Accuracies of the male Black South African (Bidmos and Asala, 2005) regression equations for the calcaneus when applied to the Thai population.

Simple Regression Equations **	Correlation (*r*-value)	*p*-value
0.63(MAXL) + 100.87	0.63	0.000*
0.50(LAL) + 128.47	0.49	0.000*
0.51(MINB) + 138.53	0.48	0.000*
0.75(BH) + 123.63	0.47	0.000*
0.75(MAXH) + 118.67	0.46	0.000*
1.07(MIDB) + 105.67	0.42	0.000*
1.15(DAFB) + 124.80	0.28	0.011
0.96(DAFL) + 122.48	0.28	0.010
**Multiple Regression Equations ** **		
0.44(MAXL) + 0.37(MAXH) + 0.69(MIDB) + 70.86	0.63	0.000*
0.46(MAXL) + 0.85(MIDB) +78.37	0.62	0.000*
0.55(MAXL) + 0.59(MAXH) + 81.91	0.61	0.000*
0.38(MAXL) + 0.35(MAXH) + 0.59(MIDB) + 0.56(DAFB) + 68.17	0.59	0.000*

* p < 0.005
** (y/predicted living stature =)

This means that for each calcaneal measurement variable, excluding DAFB and DAFL, there was a statistically significant relationship between the documented living stature and the predicted living stature for each Thai male using the male Black South African (Bidmos and Asala, 2005) regression equations for the calcaneus. Of the male calcaneal regression equations that show a statistically significant relationship ($p < 0.005$), the simple regression equation using the Maximum Length (MAXL) calcaneal measurement variable and the multiple regression equation using the Maximum Length (MAXL), Maximum Height (MAXH), and Middle Breadth (MIDB) calcaneal measurement variables show the strongest relationship between documented living stature and predicted living stature ($r = 0.63$). Overall, the male Black South African (Bidmos and Asala, 2005) multiple regression equations for the calcaneus demonstrate a stronger relationship (i.e. higher correlation coefficients) than the male Black South African (Bidmos and Asala, 2005) simple regression equations for the calcaneus, indicating that they are better predictors of living stature for males in the Thai population.

Table 4.7 shows the results of the female Black South African (Bidmos and Asala, 2005) calcaneal regression equations when applied to the Thai population. The regression equations are shown in decreasing order of the value (strength) of the correlation coefficient. A Bonferroni correction of α= 0.005 is used in this research. For females, with the exception of the Minimum Breadth (MINB) equation, all simple regression equations for the calcaneus have a p-value less than 0.005 ($p < 0.005$). This means that for all calcaneal measurement variables, excluding MINB, there was a statistically significant relationship between the documented living stature and the predicted living stature for each Thai female using the female Black South African (Bidmos and Asala, 2005) simple regression equations. Of the female regression equations for the calcaneus

that show a statistically significant relationship ($p < 0.005$), the simple regression equation using the Maximum Length (MAXL) calcaneal measurement variable and the multiple regression equation using the Maximum Length (MAXL), Maximum Height (MAXH), and Dorsal Articular Facet Length (DAFL) calcaneal measurement variables show the strongest relationship between documented living stature and predicted living stature ($r = 0.54$). Overall, the female Black South African (Bidmos and Asala, 2005) multiple regression equations for the calcaneus demonstrate a stronger relationship (i.e. higher correlation coefficients) than the female Black South African (Bidmos and Asala, 2005) simple regression equations for the calcaneus, indicating that they are better predictors of living stature for females in the Thai population.

Table 4.7 Accuracies of the female Black South African (Bidmos and Asala, 2005) regression equations for the calcaneus when applied to the Thai population.

Simple Regression Equations**	Correlation (*r*-value)	*p*-value
0.82(MAXL) + 82.49	0.54	0.000*
0.64(LAL) + 115.80	0.53	0.000*
1.03(MAXH) + 100.97	0.47	0.000*
1.08(BH) + 105.81	0.41	0.000*
1.54(DAFB) + 110.72	0.40	0.000*
1.76(DAFL) + 94.48	0.39	0.000*
1.16(MIDB) + 97.24	0.35	0.001*
1.17(MINB) + 117.46	0.23	0.034
Multiple Regression Equations*		
0.30(MAXL) + 0.51(MAXH) + 1.16(DAFL) + 68.11	0.54	0.000*
0.69(MAXL) − 0.67(LAL) + 0.37(BH) + 1.27(DAFL) + 72.24	0.49	0.000*
0.71(MAXH) + 1.43(DAFL) + 74.88	0.49	0.000*
0.81(MAXL) − 0.73(LAL) + 1.41(DAFL) + 75.22	0.47	0.000*

* $p < 0.005$
** (y/predicted living stature =)

Overall, for both males and females, the Black South African (Bidmos and Asala, 2005) MAXL simple regression equation for the calcaneus displays the highest correlation coefficient value (and is thus the most accurate for stature estimation in a Thai population) between documented living stature and predicted living stature for Thai individuals ($r = 0.63$ in males, $r = 0.54$ in females). Documented living stature and predicted living stature, when using these calcaneal regression equations, show a statistically significant relationship ($p < 0.005$). However, the correlation value (*r*-value) indicates that this relationship is not strong ($r = 0.63$ in males, $r = 0.54$ in females).

Similarly, the multiple regression equations for the calcaneus (for both Thai males and Thai females), have r-values ranging from 0.47 to 0.63.

The strength and direction of the relationship between documented living stature and the predicted living stature, when using the Black South African (Bidmos and Asala, 2005) calcaneal regression equations, was illustrated through simple scatterplots. A scatterplot is a figure that assists in the visualization of a relationship between two variables in two-dimensional space. Simple scatterplots were created to analyze the correlation between measurement variables for each Black South African (Bidmos and Asala, 2005) simple and multiple regression equation for the calcaneus that was tested on the Thai sample data. A strong relationship between variables is depicted in a scatterplot as a tight cluster in which data points are close together and show a clear linear relationship. The correlation coefficient is a numerical indication of the strength of this relationship of linearity. Therefore, while the majority of the simple and multiple regression equations for the calcaneus that were developed from the Black South African population (Bidmos and Asala, 2005) show a statistically significant relationship with the documented living statures of the Thai individuals, these relationships are not strong and are not accurate when estimating stature in a Thai population. Figure 4.2 is an example of a simple scatterplot when the male Black South African Maximum Length (MAXL) simple regression equation (Bidmos and Asala, 2005) is applied to the Thai sample data. Appendix D shows simple scatterplots when male and female Black South African (Bidmos and Asala, 2005) calcaneal simple and multiple regression equations are applied to the Thai population.
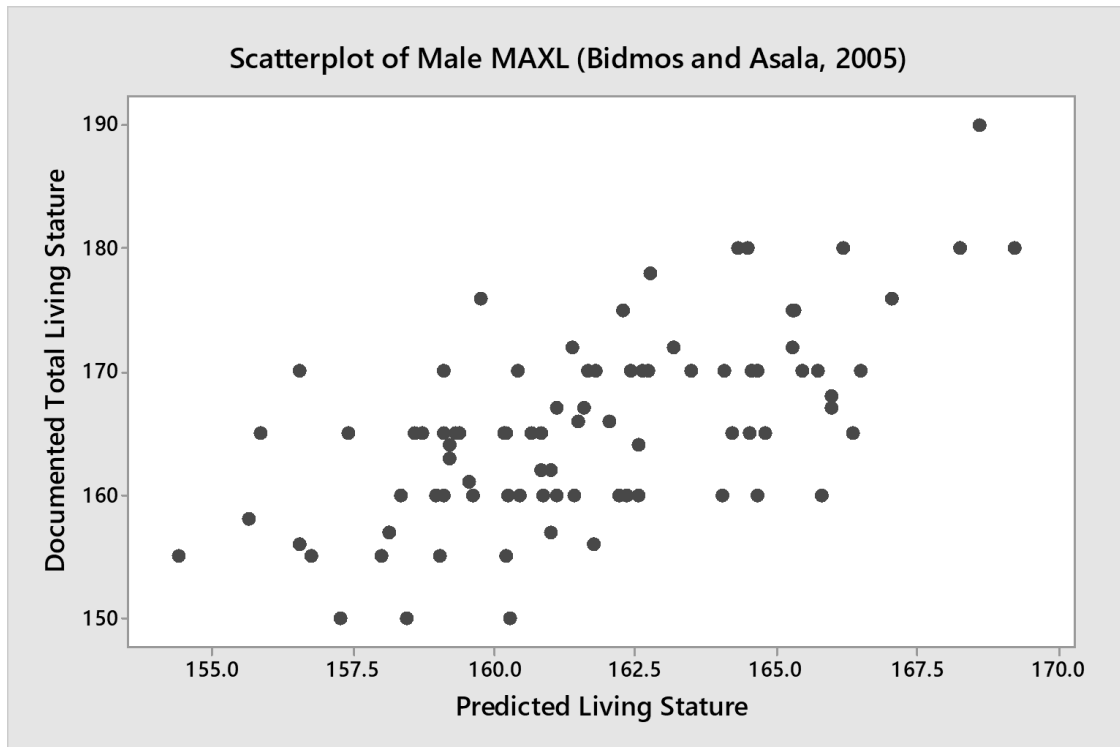
Figure 4.2 Simple scatterplot illustrating the correlation between documented and predicted living stature in the Thai male population using the male Black South African Maximum Length (MAXL) simple regression equation for the calcaneus (Bidmos and Asala, 2005).

4.6.2 Accuracy of the Holland (1995) Talar Regression Equations

The Thai data were also entered into the Black American (Holland, 1995) talar simple regression equations for the estimation of living stature (Table 4.8). The accuracy of each simple regression equation for the talus that was tested on the Thai sample data, is determined by the strength of the correlation coefficient. Holland (1995) did not provide multiple regression equations for the talus and therefore multiple regression equations for the talus could not be tested on the Thai sample data. For both Thai males and Thai females, the Holland (1995) simple regression equations for the talus show a statistically significant relationship between the documented living stature and predicted living stature. A Bonferroni correction of $\alpha = 0.005$ is used in this research and the p-values for

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both male and female talar regression equations are less than 0.005 ($p < 0.005$). The

correlation coefficient however, indicates that this relationship is not strong ($r = 0.56$

males, $r = 0.55$ females). Simple scatterplots were created to analyze the correlation

between talar measurement variables for the talar simple regression equations tested on

the Thai sample data. A scatterplot is a figure that assists in the visualization of a

relationship between two variables in two-dimensional space. A strong relationship

between variables is depicted in a scatterplot as a tight cluster in which data points are

close together and show a clear linear relationship. The correlation coefficient is a

numerical indication of the strength of this relationship of linearity. Therefore, while both

male and female simple regression equations for the talus, developed from the Black

American population (Holland, 1995), show a statistically significant relationship with

the documented living statures of the Thai individuals, these relationships are not strong

and are not accurate predictors of stature in a Thai population. Figure 4.3 is an example of

a simple scatterplot when the male Black American (Holland, 1995) MTAL simple

regression equation is applied to the Thai sample data. Appendix D shows simple

scatterplots when male and female Black American (Holland, 1995) simple and multiple

regression equations for the talus are applied to the Thai population.

Table 4.8 Accuracies of the male and female Black American (Holland, 1995) regression equations for the talus when applied to the Thai population.

Simple Regression Equations**	Correlation (*r*-value)	*p*-value
Male		
1.046(MTAL) + 112.26	0.56	0.000*
Female		
1.046(MTAL) + 97.55	0.55	0.000*

* $p < 0.005$
** (y/predicted living stature=)
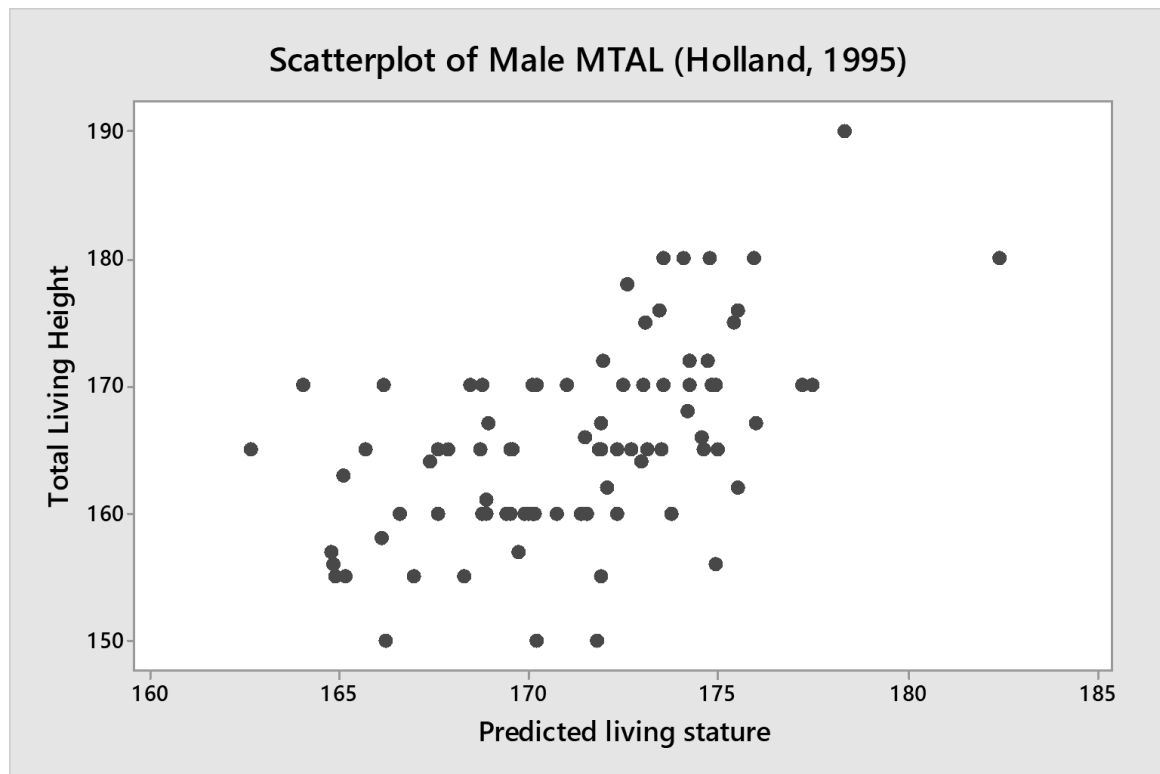
Figure 4.3 Simple scatterplot illustrating the correlation between documented and predicted living stature in the Thai male population using the male Black American (Holland, 1995) Maximum Length of the Talus (MTAL) simple regression equation.

4.6.3 Accuracy of Simple and Multiple Regression Equations for the Thai Population

The calcaneus, the talus, and a combination of the two foot bones were used to create simple and multiple regression equations for living stature estimation in the Thai population. To develop the regression equations, simple and multiple regression analyses were performed using individuals from Sample 1. Unstandardized coefficients, constant values, correlation coefficients (*r*-values), *p*-values, *f*-statistics, and the Standard Error of the Estimate (SEE) were obtained for each simple and multiple regression equation that was developed. Nine simple regression equations were calculated for each calcaneal measurement variable following Bidmos and Asala (2005). One simple regression equation was calculated for the talar measurement variable following Holland (1995). This was done for males and females separately. A total of 18 simple regression equations were generated from the calcaneus ($N_{\text{total calcaneal simple regression equations}} = 18$; $N_{\text{male calcaneal simple regression equations}} = 9$, $N_{\text{female calcaneal simple regression equations}} = 9$), and a total of two simple regression equations were generated from the talus ($N_{\text{total talar simple regression equations}} = 2$; $N_{\text{male talar simple regression equations}} = 1$, $N_{\text{female talar simple regression equations}} = 1$) to estimate living stature in the Thai population. Simple regression equations for the calcaneus and the talus, for both sexes, are shown in Table 4.9. They are arranged in decreasing order of the value (strength) of the correlation coefficient (*r*-value). and increasing magnitude of Standard Error of the Estimate (SEE). The accuracy of the estimation of stature (i.e. how close the estimate is to the documented living stature) for each simple regression equation is measured by the Standard Error of the Estimate (SEE); the lower the SEE as presented by a regression equation, the more accurate the estimate of stature.

Table 4.9 Calcaneal and talar simple regression equations for male and female living stature estimation (in cm) in a Thai population.

Regression Equations**	Correlation (*r*-value)	*p*-value	*f*-statistics	SEE
Calcaneus				
Male				
1.02 (MAXL) + 83.59	0.63	0.000	55.44	5.95
1.35 (LAL) + 99.56	0.50	0.000	28.50	6.99
1.26 (BH) + 116.32	0.48	0.000	25.16	6.73
1.42 (MIDB) + 107.33	0.46	0.000	17.12	6.64
0.97 (MAXH) + 123.18	0.45	0.000	21.61	6.84
1.87 (MINB) + 117.43	0.41	0.000	22.66	6.81
1.38 (CFH) + 128.53	0.40	0.000	15.65	7.04
1.12 (DAFB) + 132.55	0.28	0.010*	06.99	7.37
1.09 (DAFL) + 133.53	0.28	0.009*	07.09	7.36
Female				
0.90 (MAXL) + 86.94	0.54	0.000	34.54	3.06
1.53 (LAL) + 85.77	0.53	0.000	33.26	6.09
0.94 (MAXH) + 115.94	0.47	0.000	24.18	6.34
1.19 (BH) + 112.27	0.41	0.000	16.98	6.56
1.62 (DAFB) + 111.07	0.40	0.000	16.03	6.59
1.55 (DAFL) + 113.08	0.39	0.000	14.89	6.63
1.16 (MIDB) + 110.13	0.35	0.001	11.91	6.73
0.97 (CFH) + 129.58	0.25	0.021*	05.49	6.96
0.86 (MINB) + 133	0.23	0.034*	04.65	6.99
Talus				
Male				
1.22 (MTAL) + 96.73	0.56	0.000	38.91	6.34
Female				
1.25 (MTAL) + 90.62	0.55	0.000	36.48	6.01

* $p > 0.005$
** (y/predicted living stature =)

Using both direct and stepwise statistical methods, multiple regression equations were developed for males and females separately using only calcaneal measurement variables, as well as by using a combination of calcaneal and talar measurement variables. Using the direct statistical method, a multiple regression equation was generated using all nine calcaneal measurement variables to determine whether accuracy rates are enhanced when utilizing all available calcaneal measurement variables. Using a stepwise statistical method, calcaneal multiple regression equations were generated for males and females in order to determine which combination of calcaneal measurement variables produced the most accurate estimation of living stature. Multiple regression function 5 (Table 4.10) was developed using a stepwise method for both males and females. The MTAL talar measurement variable was added to each male and female calcaneal multiple regression equation that was developed, thus creating additional multiple regression equations. In total, 10 multiple regression equations were generated for living stature estimation using calcaneal and talar measurement variables ($N_{total\ multiple\ regression\ equations} = 10$; $N_{male\ multiple\ regression\ equations} = 5$, $N_{female\ multiple\ regression\ equations} = 5$). Refer to Table 4.10 for the multiple regression equations generated for both sexes. As with the simple regression equations generated in this study, the accuracy of the estimation of stature (i.e. how close the estimate is to the documented living stature) for each multiple regression equation is measured by the Standard Error of the Estimate (SEE); the lower the SEE as presented by a regression equation, the more accurate the estimate of stature.

Table 4.10 Direct and stepwise multiple regression equations for male and female living stature estimation (in cm).

Regression Equations**	Correlation (r - value)	p-value	f- statistic	SEE
Male				
Direct multiple regression equations				
1 0.66 (MAXL) – 0.13 (MAXH) + 0.30 (CFH) + 0.68 (BH) + 1.10 (MINB) – 0.38 (LAL) + 0.12 (MIDB) + 0.27 (DAFB) – 0.85 (DAFL) + 0.42 (MTAL) + 65.94	0.71	0.000*	7.71	5.70
2 0.79 (MAXL) – 0.05 (MAXH) + 0.28 (CFH) + 0.61 (BH) + 1.04 (MINB) – 0.30 (LAL) + 0.24 (MIDB) + 0.30 (DAFB) – 0.85 (DAFL) + 66.58	0.70	0.000*	8.25	5.74
3 0.62 (MAXL) + 0.88 (MINB) + 0.42 (MTAL) + 68.92	0.67	0.000*	22.64	5.74
4 0.77 (MAXL) + 0.44 (MTAL) + 78.56	0.65	0.000*	29.53	5.90
Stepwise multiple regression equations				
5 0.86 (MAXL) + 0.90 (MINB) + 73.55	0.66	0.000*	32.12	5.79
Female				
Direct multiple regression equations				
1 0.67 (MAXL) + 0.25 (MAXH) – 0.56 (CFH) + 0.21 (BH) – 0.22 (MINB) + 0.19 (LAL) – 0.61 (MIDB) + 0.63 (DAFB) – 0.16 (DAFL) + 0.71 (MTAL) + 72.37	0.66	0.000*	5.97	5.68
2 0.62 (MAXL) + 0.43 (MAXH) – 0.57 (CFH) + 0.28 (BH) – 0.14 (MINB) + 0.49 (LAL) – 0.50 (MIDB) + 0.83 (DAFB) – 0.15 (DAFL) + 76.95	0.63	0.000*	5.71	5.84
3 0.53 (MAXL) + 0.21(MAXH) + 0.71 (MTAL) + 70.09	0.63	0.000*	17.79	5.67
4 0.58 (MAXL) + 0.83 (MTAL) + 69.06	0.62	0.000*	26.33	5.66
Stepwise multiple regression equations				
5 0.67 (MAXL) + 0.53 (MAXH) + 82.91	0.58	0.000*	21.60	5.87

* $p < 0.005$
** (y/predicted living stature =)

The unstandardized coefficients and constant values are used in developing both calcaneal and talar simple and multiple regression equations for stature estimation in the Thai population. The estimate of living stature is the sum of the products of the unstandardized coefficient and the magnitude of the corresponding measurement variables (in mm) and the constant value, or intercept. For example, individual 31 (ID no. 31) from the Thai sample has a maximum calcaneal length (MAXL) of 70.81 mm. Using the associated calcaneal simple regression equation (Table 4.9), this individual would have a predicted living stature of:

Predicted living stature = 1.02 (MAXL) + 83.58

Predicted living stature = 1.02 (70.81) + 83.58

Predicted living stature = 155.81 cm

Following the protocol of Bidmos and Asala (2005), the current author obtained a predicted range for living stature. To do this, the Standard Error of the Estimate (SEE) is either added to, or subtracted from, the final estimate of living stature as predicted by the calcaneal simple regression equation. In this case, the Standard Error of the Estimate (SEE) was 5.93 cm. Therefore, the value of 1SEE is 5.93 cm and the value of 2SEEs is 11.86cm. As a 2SEE interval provides a more accurate estimate of total living stature, the current author recommends that a 2SEE interval is utilized for all predicted living stature ranges (Giles and Klepinger, 1988). Therefore, the range of predicted living stature at 2SEE is:

Predicted living stature range = 155.81 cm ± 11.86 cm

Predicted living stature range = 143.95cm – 167.67 cm

This means that the predicted living stature for the calcaneus of individual (ID no. 31) ranged from 143.95 cm to 167.67 cm. All calcaneal and talar simple and multiple

regression equations developed (Table 4.9 and Table 4.10) can be used this way for future practical applications.

Nine simple regression equations were calculated for each calcaneal measurement variable following Bidmos and Asala (2005). This was done for males and females separately. A total of 18 simple regression equations were generated to estimate living stature from the calcaneus for the Thai population ($N_{\text{total calcaneal simple regression equations}} = 18$; $N_{\text{male calcaneal simple regression equations}} = 9$, $N_{\text{female calcaneal simple regression equations}} = 9$) (Table 4.9). P-values were obtained to determine whether a statistically significant relationship existed between documented living stature and the living stature of an individual as predicted by the corresponding calcaneal regression equation. A statistical significance level of 5% error rate ($\alpha = 0.05$) is used in this research and was adjusted by dividing the Bonferroni correction by the number of testable measurement variables ($\alpha = 0.05/10$) to give a Bonferroni correction of $\alpha = 0.005$. Therefore, if the p-value is less than, or equal to, 0.005 ($p \leq 0.005$), a statistically significant relationship exists between documented living stature and predicted living stature for the Thai individual.

For Thai males, all calcaneal measurement variables showed a statistically significant positive correlation with documented living stature except the Dorsal Articular Facet Breadth (DAFB) and the Dorsal Articular Facet Length (DAFL) calcaneal measurement variables. In other words, DAFB and DAFL did not show statistically significant correlations with documented living stature when individual calcaneal measurement variables were analyzed using a Bonferroni correction of $\alpha = 0.005$. For the male calcaneal simple regression equations, the correlation coefficients (*r*-values) ranged from 0.28 to 0.63 and the Standard Error of the Estimate (SEE) ranged from 5.95 to 7.36 (Table 4.9). The male Maximum Length (MAXL) calcaneal measurement variable

showed the highest correlation with documented living stature ($r = 0.63$) and the lowest

SEE (5.95) (Table 4.9), which indicates that this measurement variable is the most

accurate predictor of stature for Thai males.

For Thai females, seven of the nine calcaneal measurement variables showed a

significant positive correlation with documented living stature; the Cuboidal Facet Height

(CFH) and Minimum Breadth (MINB) calcaneal measurement variables did not display a

significant positive correlation with documented living stature. Overall, for the female

calcaneal simple regression equations, the correlation coefficients (r-values) range from

0.23 to 0.54. The Standard Error of the Estimate (SEE) values range from 3.06 to 6.99,

which is lower than the Standard Error of the Estimate (SEE) values observed in the male

calcaneal simple regression equations. For the calcaneus, this indicates that the female

simple regression equations provide a more accurate estimate of living stature than the

male equations. Similar to males, the highest correlation with documented living stature

was shown by the MAXL calcaneal measurement variable ($r = 0.54$). The Standard Error

of the Estimate (SEE) for the female MAXL calcaneal simple regression equation

however, is notably lower than that presented in the male MAXL calcaneal simple

regression equation (SEE = 3.06 in females, SEE = 5.95 in males). This indicates that the

female MAXL simple regression equation provides a more accurate estimate of living

stature than the male MAXL simple regression equation.

Following Holland (1995), two simple regression equations were calculated using

the Maximum Length of the Talus (MTAL) talar measurement variable. This was done

separately for both males and females, which resulted in the generation of two talar

simple regression equations for the estimation of living stature for the Thai population

($N_{\text{total talar simple regression equations}} = 2$; $N_{\text{male talar simple regression equations}} = 1$, $N_{\text{female talar simple regression}}$

equations= 1) (Table 4.9). As with the simple regression equations generated from the calcaneus, p-values were obtained and a Bonferonni correction of α= 0.005 was utilized (p = 0.005). The MTAL talar measurement variable showed a significant positive correlation with documented living stature in both Thai males and Thai females. The male (r = 0.56) and female (r = 0.55) correlation coefficient values were similar. The Standard Error of the Estimate (SEE) was lower in Thai females (SEE = 6.01) than in Thai males (SEE = 6.34). This indicates that although males show a slightly higher correlation coefficient, the female talar simple regression equations may provide a more accurate estimate of living stature.

Multiple regression equations were also developed for living stature estimation in a Thai population. Using both direct and stepwise statistical methods, five multiple regression equations were developed for Thai males, and five multiple regression equations were developed for Thai females using calcaneal measurement variables, as well as a combination of calcaneal and talar measurement variables ($N_{total\ multiple\ regression\ equations}$ = 10; $N_{male\ multiple\ regression\ equations}$ = 5, $N_{female\ multiple\ regression\ equations}$= 5) (Table 4.10). All multiple regression equations show a significant positive correlation with documented living stature ($p < 0.005$) for the Thai population. For both males and females, the correlation coefficient values (r-values) from the multiple regression equations range from 0.58 to 0.71, which is higher than those obtained from the use of individual measurement variables (i.e. simple regression equations). This indicates that the multiple regression equations are more accurate predictors for stature estimation than the simple regression equations in the Thai population. Standard Error of the Estimate (SEE) values were also obtained for each multiple regression equation. The Standard Error of the Estimate (SEE), for each multiple regression equation, ranged from 5.70 to 5.90 for Thai

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males and 5.68 to 5.87 for Thai females. Overall, the Standard Error of the Estimate

(SEE) values are lower than those obtained from the use of individual measurements.

This indicates that the multiple regression equations are more accurate predictors of living

stature than the simple regression equations in the Thai population.

Using a direct statistical method, a multiple regression equation was generated

using all nine calcaneal measurement variables for males ($r = 0.70$, SEE $= 5.74$) and

females ($r = 0.63$, SEE $= 5.84$) (Table 4.10). Using a stepwise statistical method, a

multiple regression equation was produced for males and for females using only calcaneal

measurement variables. For males, the stepwise multiple regression equation (male

multiple regression equation 5) was generated using the Maximum Length (MAXL) and

Minimum Breadth (MINB) calcaneal measurement variables ($r = 0.66$, SEE $= 5.79$)

(Table 4.10). For females, the stepwise multiple regression equation (female multiple

regression equation 5) was generated using the Maximum Length (MAXL) and

Maximum Height (MAXH) calcaneal measurement variables ($r = 0.58$, SEE $= 5.87$)

(Table 4.10).

To determine whether the talus added to the utility of the regression equations (i.e.

if using both the calcaneus and the talus produced more accurate regression equations for

the estimation of living stature in a Thai population), comparisons were made between

regression equations that utilized the MTAL talar variable and those that did not (Table

4.10). Using a direct statistical method, the MTAL talar measurement variable was added

to the calcaneal simple regression equation that most accurately predicted living stature in

the Thai population, for both males and females. The MAXL simple regression equation

for the calcaneus demonstrated the highest correlation and lowest Standard Error of the

Estimate (SEE) for both sexes and thus is the most accurate predictor of living stature for

the Thai population (Table 4.9). When the male MTAL talar measurement variable was added to the male MAXL calcaneal simple regression equation, the correlation coefficient increased from 0.63 (Table 4.9) to 0.65 (Table 4.10), and the Standard Error of the Estimate (SEE) decreased from 5.95 (Table 4.9) to 5.90 (Table 4.10). When the female MTAL talar measurement variable was added to the female MAXL calcaneal simple regression equation, the correlation coefficient increased from 0.54 (Table 4.9) to 0.62 (Table 4.10), but the Standard Error of the Estimate (SEE) increased from 3.06 (Table 4.9) to 5.66 (Table 4.10). This indicates that calcaneal multiple regression equations, which include the MTAL talar measurement variable, may not be as accurate for the estimation of stature in a Thai population as the simple regression equations that utilize only the MAXL measurement of the calcaneus.

Using a direct statistical method, the MTAL talar measurement variable was also added to the multiple regression equations generated solely from calcaneal measurement variables to determine if the talus added to the utility of the multiple regression equations for a Thai population (Table 4.10). When the male MTAL talar measurement variable was added to the male multiple regression equation, which utilized all nine calcaneal variables, the correlation coefficient increased from 0.70 (male multiple regression equation 2) to 0.71 (male multiple regression equation 1) in the Thai population, and the Standard Error of the Estimate (SEE) decreased from 5.74 (male multiple regression equation 2) to 5.70 (male multiple regression equation 1). When the male MTAL talar measurement variable was added to the male multiple regression equation, which utilized the MAXL and MINB calcaneal measurement variables, the correlation coefficient (r-value) increased from 0.66 (male multiple regression equation 5) to 0.67 (male multiple regression equation 3) in the Thai population, and the Standard Error of the Estimate

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(SEE) decreased from 5.79 (male multiple regression equation 5) to 5.74 (male multiple

regression equation 3). When the female MTAL talar measurement variable was added to

the female multiple regression equation, which utilized all nine calcaneal variables, the

correlation coefficient values (r-values) increased 0.63 (female multiple regression

equation 2) to 0.66 (female multiple regression equation 1) in the Thai population, and the

Standard Error of the Estimate (SEE) decreased from 5.84 (female multiple regression

equation 2) to 5.68 (female multiple regression equation 1). When the female MTAL talar

measurement variable was added to the female multiple regression equation, which

utilized the MAXL and MAXH calcaneal measurement variables, the correlation

coefficient (r-value) increased to from 0.58 (female multiple regression equation 5) to

0.63 (female multiple regression equation 3) in the Thai population, and the Standard

Error of the Estimate (SEE) decreased from 5.87 (female multiple regression equation 5)

to 5.67 (female multiple regression equation 3).

Overall, for both males and females, regression equation correlation coefficients

increased and Standard Error of the Estimate (SEE) values decreased when the MTAL

talar measurement variable was added to the multiple regression equations (Table 4.10).

The highest correlation coefficient (r-value) and the lowest Standard Error of the Estimate

(SEE) value for males was shown in multiple regression equation 1 that uses all calcaneal

and talar measurement variables to predict living stature ($r = 0.71$ for males, SEE $= 5.70$).

This indicates a stronger relationship between documented living stature and predicted

living stature for males in the Thai collection when the talus is utilized. It also shows that

the inclusion of the talus provides a more accurate estimation of living stature. While

multiple regression equation 1 (using all calcaneal and talar measurements) for females

also shows the highest correlation coefficient ($r = 0.68$), this regression equation does not

demonstrate the lowest Standard Error of the Estimate (SEE) value. The female multiple

regression equation with the lowest Standard Error of the Estimate (SEE) (i.e. the female

multiple regression equation which is the most accurate) is female multiple regression

equation 4, which uses the MAXL and MTAL measurement variables (SEE = 5.66).

However, this equation also utilizes the talar measurement variable, which indicates that,

overall, the inclusion of the talus is beneficial for stature estimation.

4.7 Cross-Validation of the Thai Regression Equations

Sample 1 was used to derive calcaneal and talar simple and multiple regression

equations for the Thai population. Sample 2 is an independent sample, which was used to

test the accuracy of the calcaneal and talar simple and multiple regression equations from

Sample 1. Only simple and multiple regression equations of the calcaneus and talus that

showed a significant positive correlation with documented living stature ($p < 0.005$) in the

Thai population were tested on Sample 2. The predicted living stature ranges, obtained

from the calcaneal and talar simple and multiple regression equations from Sample 1,

were correlated with documented living stature in the Thai population. P-values were

calculated from the calcaneal and talar simple and multiple regression equations

generated from Sample 1 to determine if there was a statistically significant relationship

between documented living stature and the predicted living stature of a Thai individual.

Correlation coefficients (r-values) were also calculated. Following the protocol of

Bidmos and Asala (2005) for the calcaneus and Holland (1995) for the talus, the accuracy

of the estimation of living stature for each of the calcaneal and talar simple and multiple

regression equations was assessed. This was done by calculating in what percent of cases,

from Sample 2, did the Thai predicted living stature fall within 1 Standard Error of the Estimate (1SEE) and 2 Standard Errors of the Estimate (2SEE) of the Thai documented living stature. Table 4.11 shows the male and female simple regression equations derived from the calcaneus and the talus (tested on Sample 2) and the associated accuracy rates. The male and female multiple regression equations that were tested on Sample 2 and their associated accuracy rates are available in Table 4.12.

Table 4.11 Cross validation results of calcaneal and talar simple regression equations for the Thai population.

Regression Equations	Correlation (*r*-value)	*p*-value	1SEE	2SEE
Calcaneus				
Male				
1.35 (LAL) + 99.56	0.56	0.001*	67 %	97 %
1.02 (MAXL) + 83.59	0.55	0.002*	50 %	90 %
1.26 (BH) + 116.32	0.52	0.003*	53 %	90 %
0.97 (MAXH) + 123.18	0.34	0.063	53 %	93 %
1.87 (MINB) + 117.43	0.29	0.122	53 %	90 %
1.42 (MIDB) + 107.33	0.23	0.216	53 %	90 %
1.38 (CFH) + 128.53	0.08	0.672	57 %	87 %
Female				
1.55 (DAFL) + 113.08	0.52	0.003*	67 %	97 %
0.90 (MAXL) + 86.94	0.50	0.004*	33 %	67 %
1.19 (BH) + 112.27	0.38	0.036	70 %	93 %
1.53 (LAL) + 85.77	0.35	0.061	63 %	93 %
0.94 (MAXH) + 115.94	0.35	0.061	53 %	90 %
1.16 (MIDB) + 110.13	0.30	0.102	63 %	97 %
1.62 (DAFB) + 111.07	0.09	0.624	63 %	93 %
Talus				
Male				
1.22 (MTAL) + 96.73	0.44	0.016	53%	90%
Female				
1.25 (MTAL) + 90.62	0.42	0.021	70 %	93 %

* $p < 0.005$
** (y/predicted living stature =)

Table 4.12 Cross validation results of calcaneal and talar multiple regression equations for the Thai population.

Regression Equations**	Correlation (*r*-value)	*p*-value	1SEE	2SEE
Male				
Direct multiple regression equations				
1 0.66 (MAXL) − 0.13 (MAXH) + 0.30 (CFH) + 0.68 (BH) + 1.10 (MINB) − 0.38 (LAL) + 0.12 (MIDB) + 0.27 (DAFB) − 0.85 (DAFL) + 0.42 (MTAL) + 65.94	0.45	0.013	47%	83%
2 0.79 (MAXL) − 0.05 (MAXH) + 0.28 (CFH) + 0.61 (BH) + 1.04 (MINB) − 0.30 (LAL) + 0.24 (MIDB) + 0.30 (DAFB) − 0.85 (DAFL) + 66.58	0.44	0.015	57%	83%
3 0.62 (MAXL) + 0.88 (MINB) + 0.42 (MTAL) + 68.92	0.59	0.001*	53%	87%
4 0.77 (MAXL) + 0.44 (MTAL) + 78.56	0.57	0.001*	57%	87%
Stepwise multiple regression equations				
5 0.86 (MAXL) + 0.90 (MINB) + 73.55	0.57	0.001*	53%	90%
Female				
Direct multiple regression equations				
1 0.67 (MAXL) + 0.25 (MAXH) − 0.56 (CFH) + 0.21 (BH) − 0.22 (MINB) + 0.19 (LAL) − 0.61 (MIDB) + 0.63 (DAFB) − 0.16 (DAFL) + 0.71 (MTAL) + 72.37	0.46	0.010	67%	87%
2 0.62 (MAXL) + 0.43 (MAXH) − 0.57 (CFH) + 0.28 (BH) − 0.14 (MINB) + 0.49 (LAL) − 0.50 (MIDB) + 0.83 (DAFB) − 0.15 (DAFL) + 76.95	0.41	0.024	63%	90%
3 0.53 (MAXL) + 0.21(MAXH) + 0.71 (MTAL) + 70.09	0.48	0.007	70%	93%
4 0.58 (MAXL) + 0.83 (MTAL) + 69.06	0.50	0.005*	63%	93%
Stepwise multiple regression equations				
5 0.67 (MAXL) + 0.53 (MAXH) + 82.91	0.48	0.015	67%	93%

* $p < 0.005$

** (y/predicted living stature =)

Simple scatterplots were created for each calcaneal and talar simple and multiple regression equation. A scatterplot is a figure that assists in the visualization of a relationship between two variables in two-dimensional space. These scatterplots illustrate the strength of the relationship between documented living stature and the predicted living stature in the Thai population. A strong relationship between variables is illustrated in a scatterplot as a tight cluster in which data points are close together and show a clear linear relationship. Figure 4.4 is an example of a simple scatterplot, illustrating the cross-validation correlation for the Thai male Maximum Length (MAXL) calcaneal simple regression equation. Refer to Appendix E for the simple scatterplots for each Thai calcaneal and talar simple and multiple regression equation tested on Sample 2.
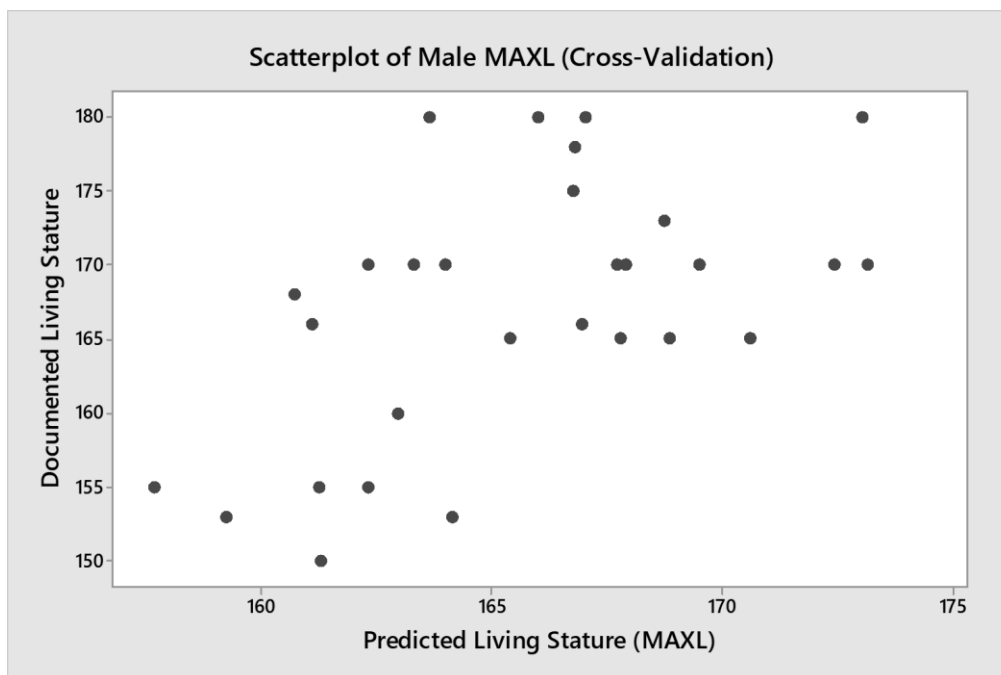
Figure 4.4 Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the Maximum Length (MAXL) calcaneal simple regression equation.

For the calcaneus, fourteen of the simple regression equations generated from Sample 1 were tested on Sample 2 ($N_{\text{total calcaneal simple regression equations}} = 14$; $N_{\text{male calcaneal simple regression equations}} = 7$, $N_{\text{female calcaneal simple regression equations}} = 7$). This was done for males and females separately. Only simple regression equations for the calcaneus that showed a significant positive correlation with documented living stature ($p < 0.005$) were tested on Sample 2. P-values were obtained to determine whether a statistically significant relationship existed between documented living stature and predicted living stature of a Thai individual. A statistical significance level of 5% error rate ($\alpha = 0.05$) was used in this research and was adjusted by dividing the Bonferroni correction by the number of testable measurement variables ($\alpha = 0.05/10$) to give a Bonferroni correction of $\alpha = 0.005$. Therefore, if the p-value is less than, or equal to, 0.005 ($p \leq 0.005$), a statistically significant relationship exists between documented living stature and predicted living stature.

For Thai males, only the Load Arm Length (LAL), Maximum Length (MAXL), and Body Height (BH) calcaneal measurement variables showed a significant positive correlation with documented living stature. The highest correlation was shown by the LAL calcaneal measurement variable (Table 4.11). For Thai females, only the Dorsal Articular Facet Length (DAFL) and Maximum Length (MAXL) calcaneal measurement variables showed a significant positive correlation with documented living stature. The highest correlation was shown by the DAFL calcaneal measurement variable (Table 4.11). Table 4.11 also shows the results of the accuracy of stature estimation using calcaneal simple regression equations at 1 and 2 Standard Errors of the Estimate (SEE). In males, the estimated living stature fell within 1SEE in 50% to 67% of cases while the

accuracy was higher at 2SEE (87% to 97%). For Thai females, living stature estimates fell within 1SEE in 53% to 70% of cases and within 2SEE in 90% to 97% of cases.

Two talar simple regression equations that were generated from Sample 1 were tested on Sample 2. This was done separately for both males and females ($N_{\text{total talar simple regression equations}} = 2$; $N_{\text{male talar simple regression equations}} = 1$, $N_{\text{female talar simple regression equations}} = 1$) (Table 4.11). As with the calcaneal simple regression equations, p-values were obtained and a Bonferonni correction of $\alpha = 0.005$ was utilized. Neither the male or female talar simple regression equations demonstrated a significant positive correlation with documented living stature when tested on Sample 2. The accuracy of the living stature estimation for each of the talar simple regression equations was assessed by calculating in what percentage of cases did predicted living stature fall within 1 Standard Error of the Estimate (1SEE) and 2 Standard Errors of the Estimate (2SEE) of documented living stature in the Thai population. In males, the living stature estimate generated from the MTAL simple regression equation for the talus fell within 1SEE in 53% of cases and within 2SEE in 90% of cases. For Thai females, the living stature estimations generated from the MTAL simple regression equation for the talus fell within 1SEE in 70% of cases and within 2SEE in 93% of cases.

Ten multiple regression equations were generated from Sample 1 using calcaneal measurement variables as well as a combination of calcaneal and talar measurement variables ($N_{\text{total multiple regression equations}} = 10$; $N_{\text{male multiple regression equations}} = 5$, $N_{\text{female multiple regression equations}} = 5$). These equations were tested on Sample 2 (Table 4.12). In order to determine whether a statistically significant relationship existed between documented living stature and the predicted living stature of a Thai individual, p-values were obtained. A statistical significance level of 5% error rate ($\alpha = 0.05$) is used in this research and was

adjusted by dividing the Bonferroni correction by the number of testable variables ($\alpha =$ 0.05/10) to give a Bonferroni correction of $\alpha = 0.005$. Therefore, if the p-value is less than, or equal to, 0.005 ($p \leq 0.005$), a statistically significant relationship exists between documented living stature and predicted living stature.

For Thai males, multiple regression equations 3, 4, and 5 show a statistically significant positive correlation between living stature and predicted stature in the Thai population ($p = 0.001$). Multiple regression equations 1 and 2 do not show a statistically significant positive correlation between living stature and predicted stature in the Thai population. The highest correlation between documented living stature and predicted living stature is shown by the multiple regression equation 3 which uses the Maximum Length (MAXL), Minimum Breadth (MINB), and Maximum Length of the Talus (MTAL) calcaneal measurement variables (Table 4.12).

For Thai females, only multiple regression equation 4 shows a significant positive correlation between documented living stature and predicted living stature ($p = 0.005$). For females, the highest correlation between documented living stature and predicted living stature is also shown by multiple regression equation 4. Multiple regression equation 4 was generated using the Maximum Length (MAXL) calcaneal measurement variable and the Maximum Length of the Talus (MTAL) talar measurement variable (Table 4.12).

The accuracy of living stature estimation for each of the multiple regression equations was assessed by calculating in what percent of cases did predicted living stature fall within 1 Standard Error of the Estimate (1SEE) and 2 Standard Errors of the Estimate (2SEE) of the documented living stature in the Thai population. For Thai males, the predicted living stature fell within 1 SEE in 47% to 57% of cases while the accuracy was

higher at 2SEE (83% to 90%). Thai females however, showed a higher percentage accuracy as the predicted living stature fell within 1SEE in 63% to 70% of cases and within 2SEE in 87% to 93% of cases.

4.8 <u>Statistical Population Comparison</u>

The measurements from the Thai sample were compared to Black South African (Bidmos and Asala, 2005), White South African (Bidmos, 2006), and Black American (Holland, 1995) populations. Two-sample t-tests were completed in order to determine if there was a difference between the total number of individuals *(N),* mean measurement values, and the standard deviation for each calcaneal and talar measurement variable. This was done for both males (Table 4.13) and females (Table 4.14).

Table 4.13 Comparison of male Thai mean measurements to a Black South African (Bidmos and Asala, 2005), White South African (Bidmos, 2006), and Black American (Holland, 1995) population.

	Current Study			Bidmos and Asala (2005)			Bidmos (2006)			Holland (1995)		
Measurement variables	Thai			Black South African			White South African			Black American		
	n	Mean (mm)	SD	n	Mean (mm)	SD	n	Mean (mm)	SD	n	Mean (mm)	SD
Male												
MAXL	86	80.49	4.72	59	79.71	3.99	41	84.02*	5.40	-	-	-
MAXH	86	43.62	3.56	60	43.71	2.86	41	47.67*	4.11	-	-	-
CFH	86	26.79	2.19	54	23.91*	1.94	41	25.46*	2.21	-	-	-
BH	86	39.06	2.91	60	37.18*	2.86	41	39.15	2.79	-	-	-
MINB	86	25.71	1.88	58	25.48	3.17	41	26.56	2.23	-	-	-
LAL	86	48.68	2.82	60	46.18*	3.36	41	47.20	3.80	-	-	-
MIDB	86	40.97	2.21	59	42.61*	2.56	41	42.10	2.29	-	-	-
DAFB	86	29.37	1.88	60	23.11*	1.85	41	23.50*	1.91	-	-	-
DAFL	86	29.25	1.95	60	30.12	1.85	41	31.40*	2.63	-	-	-
MTAL	86	56.38	3.52	-	-	-	-	-	-	25	61.96*	3.59

* $p < 0.005$

Table 4.14 Comparison of female Thai mean measurements to a Black South African (Bidmos and Asala, 2005), White South African (Bidmos, 2005), and Black American (Holland, 1995) population.

	Current Study			Bidmos and Asala (2005)			Bidmos (2006)			Holland (1995)		
Measurement variables	Thai			Black South African			White South African			Black American		
	n	Mean (mm)	SD	*n*	Mean (mm)	SD	*n*	Mean (mm)	SD	*n*	Mean (mm)	SD
Female												
MAXL	87	73.44	4.26	56	73.38	4.61	44	75.45	4.08	-	-	-
MAXH	87	39.53	3.57	55	40.36	2.94	44	42.95*	3.37	-	-	-
CFH	87	24.29	1.82	53	20.73*	1.79	44	22.88*	1.96	-	-	-
BH	87	34.29	2.45	56	33.69	2.83	44	35.30	3.01	-	-	-
MINB	87	23.48	1.90	56	21.18*	2.65	44	23.28	2.15	-	-	-
LAL	87	44.15	2.82	56	41.65*	3.36	44	41.96*	2.82	-	-	-
MIDB	87	37.08	2.16	55	39.00*	2.62	44	37.66	2.29	-	-	-
DAFB	87	26.06	1.76	53	20.61*	1.60	44	19.96*	1.77	-	-	-
DAFL	87	25.80	1.78	54	27.42*	2.24	44	27.31*	1.52	-	-	-
MTAL	87	50.12	3.13	-	-	-	-	-	-	25	53.67*	3.09

* $p < 0.005$

The study by Bidmos and Asala (2005) utilized 116 complete skeletons of Black South Africans ($N_{individuals}$ = 116; N_{male} = 60, N_{female} = 56) from the Raymond A. Dart Collection of Human Skeletons. The Thai data were compared to the study by Bidmos and Asala (2005) in order to create regression equations for living stature estimation from the calcaneus. The mean values (in millimeters) of each calcaneal measurement variable were compared between the Thai population and the Black South African population (Bidmos and Asala, 2005) using descriptive statistics (Table 4.15).

Table 4.15 Comparison of male and female Thai measurements of the calcaneus to a Black South African population (Bidmos and Asala, 2005).

	Current Study			Bidmos and Asala (2005)				
	Thai			Black South African				
Measurement variable							*t*-value	*p*-value
	N	Mean	SD	*N*	Mean	SD		
Male								
MAXL	86	80.49	4.72	59		3.99	1.08	0.284
MAXH	86	43.62	3.56	60	79.71	2.86	0.16	0.872
CFH	86	26.79	2.19	54	43.71	1.94	8.12	0.000*
BH	86	39.06	2.91	60	23.91	2.86	3.89	0.000*
MINB	86	25.71	1.88	58	37.18	3.17	0.50	0.619
LAL	86	48.68	2.82	60	25.48	3.36	4.73	0.000*
MIDB	86	40.97	2.21	59	46.18	2.56	- 4.00	0.000*
DAFB	86	29.37	1.88	60	42.61	1.85	19.99	0.000*
DAFL	86	29.25	1.95	60	23.11	1.85	- 2.73	0.007
					30.12			
Female								
MAXL	87	73.44	4.26	56	73.38	4.61	0.08	0.939
MAXH	87	39.53	3.57	55	40.36	2.94	- 1.50	0.135
CFH	87	24.29	1.82	53	20.73	1.79	11.34	0.000*
BH	87	34.29	2.45	56	33.69	2.83	1.31	0.194
MINB	87	23.48	1.90	56	21.18	2.65	5.63	0.000*
LAL	87	44.15	2.82	56	41.65	3.36	4.62	0.000*
MIDB	87	37.08	2.16	55	39.00	2.62	- 4.55	0.000*
DAFB	87	26.02	1.76	53	20.61	1.60	18.66	0.000*
DAFL	87	25.80	1.78	54	27.42	2.24	- 4.52	0.000*

* $p < 0.005$

A statistical significance level of 5% error rate ($\alpha = 0.05$) is used in this research and was adjusted by dividing the Bonferroni correction ($\alpha = 0.05$) by the number of testable measurement variables to give a Bonferroni correction of $\alpha = 0.005$. A p-value

that is less than, or equal to, 0.005 ($p \leq 0.005$) indicated a statistically significant difference in the mean measurement values. A p-value greater than 0.005 ($p > 0.005$) indicated that there was no statistically significant difference in mean measurement variable values between populations.

For males, the means of all calcaneal measurement variables are larger in the Thai sample than in the Black South African sample (Bidmos and Asala, 2005) with the exception of Maximum Height (MAXH) and Middle Breadth (MIDB). The male Cuboidal Facet Height (CFH), Body Height (BH), Load Arm Length (LAL), Middle Breadth (MIDB), and Dorsal Articular Facet Breadth (DAFB) calcaneal measurement variables have p-values of 0.000 ($p = 0.000$), which means that there is a statistically significant difference in these values between the Thai population and the Black South African population (Bidmos and Asala, 2005). In contrast, there is no statistically significant difference between the male Maximum Length (MAXL), Maximum Height (MAXH), and Minimum Breadth (MINB) calcaneal measurement variables. The p-value of the Dorsal Articular Facet Length (DAFL) calcaneal measurement variable was p = 0.007. While there was no "statistically significant" difference in the DAFL calcaneal measurement variable between Thai males and Black South African males (Bidmos and Asala, 2005), this measurement variable shows a higher degree of difference between these populations than the male MAXL, MAXH and MINB calcaneal measurement variables.

For females, the mean values for the Maximum Height (MAXH), Middle Breadth (MIDB), and Dorsal Articular Facet Length (DAFL) calcaneal measurement variables are larger in the Black South African population (Bidmos and Asala, 2005) than in the Thai

population. The mean values for the Maximum Length (MAXL), Cuboidal Facet Height (CFH), Body Height (BH), Minimum Breadth (MINB), Load Arm Length (LAL), and Dorsal Articular Facet Breadth (DAFB) calcaneal measurement variables are larger in the Thai population than in the Black South African population (Bidmos and Asala, 2005). The MAXL, MAXH, and BH calcaneal measurement variables have p-values greater than 0.005 ($p > 0.005$), which means that there is no statistically significant difference between the Thai population and the Black South African population (Bidmos and Asala, 2005). All other female calcaneal measurement variables (Cuboidal Facet Height, Minimum Breadth, Load Arm Length, Middle Breadth, Dorsal Articular Facet Breadth, and Dorsal Articular Facet Length) have a p-value of 0.000, indicating a statistically significant difference in these calcaneal measurement variable values between the Thai population and the Black South African population (Bidmos and Asala, 2005) (Table 4.15).

The Thai measurements were also compared with a White South African population (Bidmos, 2006) using descriptive statistics. The study by Bidmos (2006) utilized 85 complete skeletons ($N_{individuals} = 85$; $N_{male} = 41$, $N_{female} = 44$) from the Raymond A. Dart Collection of Human Skeletons, in order to create regression equations for living stature estimation from the calcaneus. The mean values (in millimeters) of each calcaneal measurement variable were compared between the Thai population and a White South African population (Bidmos, 2006) (Table 4.16).

Table 4.16 Comparison of male and female Thai measurements of the calcaneus to a White South African population (Bidmos, 2006).

	Current Study Thai			Bidmos (2006) White South African			*t*-value	*p*-value
Measurement variable	*N*	Mean	SD	*N*	Mean	SD		
Male								
MAXL	86	80.49	4.72	41		5.40	- 3.58	0.001*
MAXH	86	43.62	3.56	41	84.02	4.11	- 5.41	0.000*
CFH	86	26.79	2.19	41	47.67	2.21	3.17	0.002*
BH	86	39.06	2.91	41	25.46	2.79	- 0.16	0.870
MINB	86	25.71	1.88	41	39.15	2.23	- 2.11	0.039
LAL	86	48.68	2.82	41	26.56	3.80	2.23	0.030
MIDB	86	40.97	2.21	41	47.20	2.29	- 2.63	0.010
DAFB	86	29.37	1.88	41	42.10	1.91	16.28	0.000*
DAFL	86	29.25	1.95	41	23.50	2.63	- 4.66	0.000*
					31.40			
Female								
MAXL	87	73.44	4.26	44	75.45	4.08	- 2.62	0.010
MAXH	87	39.53	3.57	44	42.95	3.37	- 5.37	0.000*
CFH	87	24.29	1.82	44	22.88	1.96	3.98	0.000*
BH	87	34.29	2.45	44	35.30	3.01	- 1.93	0.058
MINB	87	23.48	1.90	44	23.28	2.15	0.53	0.601
LAL	87	44.15	2.82	44	41.96	2.82	4.20	0.000*
MIDB	87	37.08	2.16	44	37.66	2.29	- 1.40	0.166
DAFB	87	26.02	1.76	44	19.96	1.77	20.40	0.000*
DAFL	87	25.80	1.78	44	27.31	1.52	- 4.62	0.000*

* $p < 0.005$

For males, the mean Maximum Length (MAXL), Maximum Height (MAXH), Body Height (BH), Minimum Breadth (MINB), Middle Breadth (MIDB), and Dorsal Articular Facet Length (DAFL) calcaneal measurement variables were larger in the White

South African population (Bidmos, 2006) than in the Thai population. In contrast, the mean values of the Cuboidal Facet Height (CFH) Load Arm Length (LAL), and Dorsal Articular Facet Breadth (DAFB) calcaneal measurement variables were larger in the Thai population than in the White South African population (Bidmos, 2006). The male MAXL, MAXH, CFH, DAFB, and DAFL calcaneal measurement variables had p-values that were less than 0.005 ($p < 0.005$) which means that there is a statistically significant difference in these calcaneal measurement variable values between the Thai population and the White South African population (Bidmos, 2006). The male BH, MINB, and LAL calcaneal measurement variables had p-values that were greater than 0.005 ($p > 0.005$), which means that there is no statistically significant difference in these calcaneal measurement variable values between the Thai and White South African populations (Bidmos, 2006). The p-value of the male MIDB calcaneal measurement variable was p = 0.010. While there was no "statistically significant" difference in the male MIDB calcaneal measurement variable between Thai males and White South African males (Bidmos, 2006), this measurement variable shows a higher degree of difference between these populations than the male BH, MINB, and LAL calcaneal measurement variables.

For females, the mean values for the Maximum Length (MAXL), Maximum Height (MAXH), Body Height (BH), Middle Breadth (MIDB), and Dorsal Articular Length (DAFL) calcaneal measurement variables were larger in the White South African population (Bidmos, 2006) than in the Thai population. The Cuboidal Facet Height (CFH), Minimum Breadth (MINB), Load Arm Length (LAL), and Dorsal Articular Facet Breadth (DAFB) calcaneal measurement variable values were larger in the Thai population. The female MAXH, CFH, LAL, DAFB, and DAFL calcaneal measurement

variables had p-values of less than 0.005 ($p \leq 0.005$) which means that there is a statistically significant difference in these calcaneal measurement variables between the Thai population and the White South African population (Bidmos, 2006). The female BH, MINB, and MIDB calcaneal measurement variables had p-values that were greater than 0.005 ($p > 0.005$), which means there is no statistically significant difference in these calcaneal measurement variables between the Thai and White South African population (Bidmos, 2006) The p-value of the female MAXL calcaneal measurement variable was p = 0.010. While there was no "statistically significant" difference in the female MAXL calcaneal measurement variable between Thai females and White South African females (Bidmos, 2006), this measurement variable shows a higher degree of difference between these populations than the female BH, MINB, and MIDB calcaneal measurement variables.

The Thai data were also compared to the results from Holland (1995), who utilized 100 tali ($N_{individuals} = 100$) from the Hamann-Todd Collection at the Cleveland Museum of Natural History in order to derive regression equations for living stature estimation. The results of the study by Holland (1995) provide regression equations for Maximum Length of the Talus (MTAL) for Black males and Black females ($N_{individuals} = 50$; $N_{male} = 25$, $N_{female} = 25$). The mean values (in millimeters) of each talar measurement variable were compared between the Thai population and the Black American population (Holland, 1995) using descriptive statistics (Table 4.17).

Table 4.17 Comparison of male and female Thai measurements of the talus to a Black American population (Holland, 1995).

Measurement variable	Current Study Thai			Holland (1995) Black American			t-value	p-value
	N	Mean	SD	N	Mean	SD		
Male MTAL	86	56.38	3.52	25	61.96	3.59	- 6.88	0.000*
Female MTAL	87	50.12	3.13	25	53.67	3.09	- 5.19	0.000*

* $p < 0.005$

The mean MTAL talar measurement variable value was larger for both males and females in the Black American population (Holland, 1995) than in the Thai population. The p-values for both males and females was 0.000, which indicates that there is a statistically significant difference in the mean MTAL talar measurement variable values between the Thai population and the Black American population (Holland, 1995) (Table 4.17).

CHAPTER 5: DISCUSSION

5.1   Context of the Current Research

When unknown skeletal remains are recovered, the goal of the forensic

anthropologist is to assist in the identification through the creation of a biological profile.

Previous authors have shown that osteometric differences exist between different

populations and have suggested that methods derived from one specific population should

not be used for other populations (Bidmos, 2006; Bidmos and Asala, 2005; Holland,

1995; King et al., 1998; Lundy, 1983; Steyn and Işcan, 1997; Trotter and Gleser, 1958).

There is an urgent need for the development of population-specific osteometric

methodologies for contemporary Thai populations. The impact of climate change is

estimated to be particularly severe in Thailand; recent studies have shown that the effects

of climate change will continue to impact Thailand as flooding and natural disasters will

multiply in both frequency and severity, which will have negative impacts in terms of

death and destruction (Arunrat and Pumijumnong, 2015; Jinsart et al., 2014;

Jothityangkoon et al., 2013; Thavorntam and Tantemsapya, 2013; Wang et al., 2014).

However, these methodologies must prove high levels of reliability, accuracy, and

precision to be admissible in a court of law (Berg et al., 2007; Christensen and Crowder,

2009; Lesciotto, 2015).

Research has shown that preservationally favoured and/or complete skeletal elements,

such as the calcaneus and the talus, are suitable for the identification of unknown human

remains, and are often recovered at forensic scenes as they are protected inside shoes

(Bidmos and Asala, 2003; Pickering, 1986; Saul and Saul, 2005; Scott et al., 2017).

Studies have shown that the calcaneus and the talus can be used for the estimation sex

(Abd-elaleem et al., 2012; Barrett et al., 2001; Bidmos, 2006; Bidmos and Asala 2003, 2004, 2005; Bidmos and Dayal, 2003, 2004; DiMichele and Spradley, 2012; Ekizoglu et al., 2017; Gualdi-Russo, 2007; Holland, 1995; Introna et al., 1997; Kim et al., 2013; Lee et al., 2012; Mahakkanukrauh et al., 2014; Moore et al., 2016; Murphy, 2002a,b, 2005; Nathena et al., 2017; Otong et al., 2016; Peckmann et al., 2015a,b; Riepert et al., 1996; Scott et al., 2017; Silva, 1995; Steele, 1976; Wilbur, 1998; Zakaria et al., 2010; Zhang et al., 2016). However, there are limited published studies, which investigate the accuracy of the calcaneus and the talus for the estimation of stature (Bidmos and Asala, 2005; Bidmos, 2006; Holland, 1995; Pablos et al., 2013). Thus far, the calcaneus has been used for living stature estimation in a Black South African population (Bidmos and Asala, 2005) and White South African population (Bidmos, 2006), and the talus has been used for living stature estimation in a Black American population (Holland, 1995). To date, neither the calcaneus nor the talus has been used to estimate stature in an Asian population, specifically a contemporary Thai population. The current research study aims to fill this gap in the literature.

The current research study focuses on nine measurements of the calcaneus (Maximum Length, Maximum Height, Cuboidal Facet Height, Body Height, Minimum Breadth, Load Arm Length, Middle Breadth, Dorsal Articular Facet Breadth, and Dorsal Articular Facet Length) and one measurement of the talus (Maximum Length of the Talus) to establish an accurate method for estimating living stature in a contemporary Thai population. The objectives of this research are to:

1. investigate whether regression equations for the calcaneus, which were developed on a Black South African population (Bidmos and Asala, 2005), and regression equations

for the talus, which were developed on a Black American population (Holland, 1995),

can accurately predict the living stature of individuals from a contemporary Thai

population.

2. develop population-specific simple regression and multiple regression equations

for the calcaneus and the talus of the contemporary Thai population should the Black

South African (Bidmos and Asala, 2005) and Black American (Holland, 1995) equations

not accurately predict the living stature of the Thai individuals.

3. compare the results from the contemporary Thai population to other populations.

5.2 <u>Analysis of Sexual Dimorphism in the Thai Population</u>

The results of the current research show that all measurement variables of the

calcaneus and the talus exhibit sexual dimorphism in the contemporary Thai population.

These results are consistent with those of other researchers who have shown that the

calcaneus and the talus are sexually dimorphic (Abd-elaleem et al., 2012; Barrett et al.,

2001; Bidmos, 2006; Bidmos and Asala 2003, 2004, 2005; Bidmos and Dayal, 2003,

2004; DiMichele and Spradley, 2012; Ekizoglu et al., 2017; Gualdi-Russo, 2007;

Holland, 1995; Introna et al., 1997; Kim et al., 2013; Lee et al., 2012; Mahakkanukrauh

et al., 2014; Moore et al., 2016; Murphy, 2002a,b, 2005; Nathena et al., 2017; Otong et

al., 2016; Peckmann et al., 2015a,b; Riepert et al., 1996; Scott et al., 2017; Silva, 1995;

Steele, 1976; Wilbur, 1998; Zakaria et al., 2010; Zhang et al., 2016).

For the calcaneus, all measurement variables (i.e. MAXL, MAXH, BH, CFH,

MINB, LAL, MIDB, DAFL, DAFB) were larger in contemporary Thai males than in

contemporary Thai females (Table 4.2). In the current research, the most dimorphic

measurement variable of the calcaneus was the MAXL measurement variable, with a mean difference of 7.05 mm between the maximum length of the contemporary Thai male calcanei and the contemporary Thai female calcanei. These results are consistent with the published literature (Bidmos, 2006; Bidmos and Asala 2003, 2004, 2005; Ekizoglu et al., 2017; Gualdi-Russo, 2007; Holland, 1995; Introna et al., 1997; Kim et al., 2013; Moore et al., 2016; Murphy, 2002a; Nathena et al., 2017; Peckmann et al., 2015a; Riepert et al., 1996; Scott et al., 2017; Silva, 1995; Steele, 1976; Wilbur, 1998; Zakaria et al., 2010; Zhang et al., 2016). Overall, the literature shows that the maximum length of the calcaneus (i.e. the MAXL measurement variable) exhibits more dimorphism than any other measurement variable of the calcaneus, with mean differences between males and females ranging from 5.60 mm to 10.67 mm. Table 5.1 shows the mean differences between the male maximum length of the calcaneus (MAXL) measurement variable and the female maximum length of the calcaneus (MAXL) measurement variable for different studies, and is organized from most dimorphic to least dimorphic by the mean difference in relation to the size of the calcaneus (i.e. % difference). DiMichele and Spradley (2012) however, found that the posterior circumference (PCF) of the calcaneus, a measurement variable newly introduced for their research study, was the most dimorphic measurement variable of the calcaneus and MAXL was the second most dimorphic measurement variable.

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

Investigator	Population	% difference[a]	Mean difference (mm)
Zakaria et al. (2010)	Egyptian	13.5	10.67
Ekizoglu et al. (2017)	Turkish	12.1	9.79
Murphy (2002a)	Prehistoric New Zealand Polynesian	11.9	8.99
Bidmos and Asala (2003)	White South African	11.1	8.91
Bidmos (2006)	White South African	10.8	8.57
Peckmann et al. (2015a)	Greek	10.7	8.27
Wilbur (1998)	Prehistoric West Central Illinois	10.6	7.90
Gualdi-Russo (2007)	Italian	10.4	8.25
Zhang et al. (2016)	Chinese	9.9	6.78
Moore et al. (2016)	Colombian	9.4	6.78
Current research study	**Thai**	**9.2**	**7.05**
Silva (1995)	Portuguese	9.2	6.95
Riepert et al. (1996)	German	9.1	7.80
Kim et al. (2013)	Korean	8.9	6.70
Steele (1976)	Black American	8.7	6.90
Introna et al. (1997)	Southern Italian	8.7	6.60
Scott et al. (2017)	Thai	8.4	6.47
Bidmos and Asala (2005)	Black South African	8.3	6.33
Bidmos and Asala (2004)	Black South African	8.0	6.14
Nathena et al. (2017)	Cretan	7.8	6.05
Steele (1976)	White American	7.2	5.60

[a] The mean difference in relation to the size of the calcaneus

For the talus, the MTAL measurement variable was larger in contemporary Thai males than in contemporary Thai females (Table 4.2). The mean difference in the MTAL measurement variable between contemporary Thai male tali and contemporary Thai female tali was 6.36 mm. This result is consistent with the existing published literature (Abd-elaleem et al., 2012; Barrett et al., 2001; Bidmos and Dayal, 2003, 2004; Gualdi-Russo, 2007; Holland, 1995; Lee et al., 2012; Mahakkanukrauh et al., 2014; Murphy, 2002b; Otong et al., 2016; Peckmann et al., 2015b; Silva, 1995; Steele, 1976; Wilbur, 1998).

For the current research study, only the maximum length of the talus (i.e. MTAL measurement variable) was examined following the protocol of other stature estimation literature (i.e. Holland, 1995). However, an earlier study by Mahakkanukrauh et al. (2014) examined sexual dimorphism of the talus using the same skeletal collection as the current research study (i.e. the Chiang Mai Skeletal Collection). Mahakkanukrauh et al. (2014) examined ten talar measurements, including: maximum talar length (MaxLg), maximum talar breadth (MaxBr), maximum talar height (MaxHt), maximum trochlear length (MaxTrLg), maximum trochlear breadth (MaxTrBr), maximum length of the inferior articular surface (MaxIASLg), maximum breadth of the inferior articular surface (MaxIASBr), minimum inferior interarticular distance (MinIID), maximum lateral malleolar surface height (MaxLMSHt), and minimum interarticular distance across the neck (MinIDNk). Of these, Mahakkanukrauh and colleagues (2014) found that the maximum length of the talus was the most sexually dimorphism measurement variable. As Mahakkanukrauh and colleagues (2014) utilized the same skeletal collection as the current research study, it can be suggested that the maximum length of the talus (i.e. the

MTAL measurement variable) is the most sexually dimorphic measurement variable of the talus in a contemporary Thai population. This is consistent with the existing published literature, which has consistently shown that the maximum length of the talus exhibits more dimorphism than other measurement variables of the talus, with mean differences between male and female maximum talar length ranging from 3.71 mm to 8.29 mm. Table 5.2 shows the mean difference between the male maximum length of the talus (MTAL) measurement variable and the female maximum length of the talus (MTAL) measurement variable for different studies, and is organized from most dimorphic to least dimorphic by the mean difference in relation to the size of the talus (i.e. % difference). Abd-elhakim and colleagues (2012) however, found that the neck length (NL) of the talus was the most dimorphic measurement variable of the talus in an Egyptian population. The NL measurement is defined as the distance between the most distant point of the navicular articular facet to the anterior end of the middle sagittal curvature of the trochlea (Abd-elhakim et al., 2012; Martin and Knuβmann, 1988). Future studies should utilize the NL measurement variable when assessing sexual dimorphism of the talus in other populations.

Table 5.2 Comparison of the mean difference between the male maximum length of the talus (MTAL) measurement variable and the female maximum length of the talus (MTAL) measurement variable between different studies.

Investigator	Population	% difference[a]	Mean difference (mm)
Holland (1995)	Black American	14.3	8.29
Peckmann et al. (2015b)	Greek	12.4	7.10
Gualdi-Russo (2007)	Northern Italian	13.0	6.85
Current research study	**Thai**	**11.9**	**6.36**
Mahakkanukrauh et al. (2014)	Thai	11.5	6.13
Steele (1976)	Black American	11.5	6.00
Wilbur (1998)	Prehistoric West Central Illinois	10.9	5.40
Steele (1976)	White American	10.7	5.60
Barrett et al. (2001)	Prehistoric Native American	10.6	5.77
Murphy (2002b)	Prehistoric New Zealand Polynesian	10.4	5.24
Silva (1995)	Portuguese	10.3	5.23
Bidmos and Dayal (2004)	Black South African	9.3	4.61
Holland (1995)	White American	9.2	5.42
Bidmos and Dayal (2003)	White South African	8.4	4.50
Lee et al. (2012)	Korean	6.9	3.71

[a] The mean difference in relation to the size of the talus.

The size and shape of the calcaneus and the talus may vary between sexes and populations due to differences in genetics, socioeconomic status, and habitual or occupational behaviours (Abd-elhakim, 2012; Ekizoglu et al., 2017; Kim et al., 2013; Lee et al., 2012; Mahakkanukrauh et al., 2014). These influences may explain why certain

populations show larger mean differences, or exhibit more sexual dimorphism, in the MAXL and MTAL measurement variables than other populations.

Genetic factors and the genetically controlled release of hormones have been shown to influence pubertal timing, skeletal development, and growth rates in males and females (Bailey and Garn, 1986; Gajdos et al., 2009, 2010; Humphrey, 1998). Growth hormones (GH and IGH-1), and sex and adrenal steroids, are responsible for the timing of growth spurts and attainment of maturity. Females experience growth spurts and maturation, on average, two years prior to males (Eckes and Trautner, 2000; Humphrey, 1998; Loesch et al., 1995). The earlier commencement of puberty for females is associated with an earlier secretion of estrogen, the effect of which is to increase bone maturation at the cost of reducing pubertal gain in stature (Bourguignon, 1988). As a result, males reach a greater overall size prior to their final growth spurt in puberty than females (Loesch et al., 1995; Parent et al., 2003). Furthermore, the genetic regulation of pubertal timing, and thus skeletal development and growth rates, has been shown to vary among populations (Gajdos et al., 2009, 2010; Parent et al., 2003). For example, Stavrou and colleagues (2002) found that two polymorphisms of the estrogen receptor α gene were associated with delayed menarche in Greek adolescent females. However, in a study of Japanese adolescent girls, Gorai and colleagues (2003) found that menarcheal age was not associated with the estrogen receptor α gene, but rather was linked to the A2 polymorphism of CYP17 gene. These findings suggest that the involvement of genetics in controlling female pubertal timing is variable between populations.

The mean age at menarche in a contemporary Thai population is 11.8 years (Noipayak et al., 2017). As earlier commencement of menarche is associated with a

reduction in female stature and thus an increase in dimorphism between the sexes, the current author suggests that populations that exhibit less sexual dimorphism of the calcaneus and the talus may demonstrate a mean age at menarche that is later than that which occurs in the contemporary Thai population. The mean age at menarche for populations that exhibit less sexual dimorphism of the calcaneus and the talus when compared to the contemporary Thai population (according to Table 5.1 and Table 5.2) is as follows: 11.86 years (Portuguese; Reis et al., 2016), 15.0 (historic Black American, Trussell and Steckle, 1978), 12.70 (Korean; Lee et al., 2016), 12.17 (Southern Italian; De Sanctis et al., 2014), 12.8 (German; Bau et al., 2009), 14.11 (Black South African; Anderson, 2015), and 12.50 (White American; Reagan et al., 2012). As these populations show a later mean age at menarche than the contemporary Thai population, it is possible that they did not experience the same reduction of pubertal gain in stature as shown in the contemporary Thai population.

Socioeconomic status has also been shown to influence skeletal development and overall growth in males and females, thus contributing to expressions of sexual dimorphism (Danubio and Sanna, 2008; Figueroa-Soto, 2012; Parent et al., 2003). Previous studies have demonstrated that populations exposed to environmental stressors, such as low socioeconomic status, will exhibit less sexual dimorphism than populations not exposed to such stressors (Figueroa-Soto, 2012; Hamilton, 1975; Malina et al., 1981; Rickland and Tobias, 1986; Stini, 1969, 1972). The Female Buffering Hypothesis for example, suggests that the growth and development of males in a low socioeconomic status is more affected than that of females, in the same environment, during times of nutritional shortage and poverty (Frayer and Wolpoff, 1985; Stinson, 1985). In 1951,

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Greulich found that food deprivation and poverty retarded the skeletal development of

Guamanian males (i.e. low socioeconomic status) during the Japanese occupation, which

resulted in females being larger and more robust than males in this population. These

results are supported by Stini (1969) who also found that the long-term effects of

malnutrition (i.e. growth retardation) in a Heliconia population were more pronounced in

males than in females, thus reducing the degree of sexual dimorphism.

The Chiang Mai Skeletal Collection, utilized for the current research study,

consists of individuals from Chiang Mai and adjacent villages in northern Thailand with

recorded occupations consistent with middle and low socioeconomic status, including

farmers and public servants (King et al., 1998; Traithepchanapai et al., 2016). While only

10.5% of the total contemporary Thai population live below national poverty lines,

poverty in Thailand does exist as a mainly rural phenomenon. As of 2014, over 80% of

the country's poor live in rural areas, and pockets of poverty remain in the North and

Northeast regions (World Bank, 2017). Therefore, the contemporary Thai population is of

lower-middle-socioeconomic status. The current author suggests that populations with a

higher socioeconomic status than the contemporary Thai population, will exhibit more

sexual dimorphism.

The World Bank (2017) lists Italy, Greece, and Central Europe as high-income

countries, and lists Turkey, South Africa, China, and Colombia as upper-middle-income

countries. These populations are likely to have improved nutrition, clean water, and

sanitation, increased economic activity (i.e. more job opportunities), and greater access to

administrative structures and services such as health care and education. As a result, these

populations will have better overall health, growth, and development, which may explain

the higher expression of sexual dimorphism in these populations in comparison to populations of lower socioeconomic status, such as the contemporary Thai population (Figueroa-Soto, 2012; Hamilton, 1975; Leon, 2008; Malina et al., 1981; Paciorek et al., 2013; Rickland and Tobias, 1986; Stini, 1969, 1972).

The Egyptian population (Zakaria et al., 2010) is representative of an urban population. Research has shown that children living in cities are taller and have enhanced growth and development in comparison to their rural counterparts in many low-middle-income countries (Black et al., 2013; Fox and Heaton, 2012; Heaton and Forste, 2003; Paciorek et al., 2013; Panter-Brick et al., 1996; Peckmann et al., 2017; Smith et al., 2005). Panter-Brick et al. (1996) for example compared the heights of children from Nepal and Pakistan living in rural villages with those living in an urban environment, and found that children living in urban environments showed better overall growth and development than children living in rural villages. Overall, cities offer access to services (e.g. healthcare and education) and infrastructure (e.g. sanitation, clean water), which may increase the quality of life for those in a lower socioeconomic bracket (Fox and Heaton, 2012; Paciorek et al., 2013; Panter-Brick et al., 1996; Peckmann et al., 2017). Therefore, it is likely that the Egyptian population (Zakaria et al., 2010) had better overall health, growth, and development than the contemporary Thai population, which may explain the higher expression of sexual dimorphism in this population, despite the similarities in cited socioeconomic status (Figueroa-Soto, 2012; Hamilton, 1975; Malina et al., 1981; Rickland and Tobias, 1986; Stini, 1969, 1972).

Sexual dimorphism may also be influenced by divisions of labour. This hypothesis can be traced back to Darwin (1874), who suggested that sexual dimorphism

evolves through natural selection in species where males and females occupy different ecological niches, or have different foraging strategies. Human societies are characterized by marked sexual divisions of labour in subsistence strategies, which is the equivalent of animal foraging strategies (Murdock and Provost, 1973). This hypothesis has been developed in paleoanthropology; Brace and Ryan (1980) and Frayer (1980, 1981) suggested that changes in male and female subsistence activities may explain the decline in sexual dimorphism since the Late Paleolithic. The results of more recent studies support this; Carlson and colleagues (2007) for example studied Australian aborigine hunter-gatherer groups and found that sexual dimorphism was greater in groups, which practiced a division of labour. Groups that had adopted agriculture, and in which both males and females were involved in similar food production and preparation tasks, exhibited a low degree of sexual dimorphism (Carlson et al., 2007). Holden and Mace (1999) conducted a similar study and found that when females were involved with food production and preparation, they were taller and more robust, and thus sexual dimorphism at the population level was reduced. Overall, the published literature has demonstrated that divisions of labour vary across populations, which may explain differences in the expression of sexual dimorphism between contemporary populations for the calcaneus and the talus (Abd-elhakim et al., 2012; Carlson et al., 2007; Ekizoglu et al., 2017; Holden and Mace, 1999; Nathena et al., 2017; Scott et al., 2017).

The individuals represented in the current research study are from the northern region of Thailand, an area in which rice farming is popular (Arunrat and Pumijumnong, 2015; Isvilanonda and Bunyasiri, 2009). Rice farming involves the navigation of uneven terrain and hard manual labour and is traditionally considered men's work. While women

are involved in some aspects of rice production, their participation is limited to peak seasons of land preparation and they are often only assigned to production tasks when time constraints are imposed (e.g. by weather) or when the need is dire (Coyle and Kwong, 2000). Furthermore, women are often excluded when machines replace physical labour and the status of the job is raised. Coyle and Kwong (2000) cite that traditionally, women were responsible for grain transportation, but contemporary Thai men have since taken over this task with the introduction of the truck, which bestows prestige and mobility on the operator. Overall, contemporary Thai women are more involved in child rearing, housework, and entrepreneurial activities (e.g. selling surplus rice or vegetables at a local market or in their home) than contemporary Thai men, resulting in a division of labour between the sexes, and thus increasing sexual dimorphism at the population level.

In contrast, Cretan females of rural regions are more involved in manual labour; Nathena and colleagues (2017) compared expressions of sexual dimorphism of the calcaneus between a Cretan population and a Greek population and found that the increased sexual dimorphism in the Greek population may be the result of differences in female activity patterns between the two populations. The Greek population can be described as "urban", whereas the Cretan population can be described as "rural". Cretan females of rural regions tend to be more involved in manual labour, thus increasing their bone size and decreasing the level of sexual dimorphism in the Cretan population (Nathena et al., 2017). Overall, divisions of labour between males and females are different between the contemporary Thai and Cretan (Nathena et al., 2017) populations, with the contemporary Thai population showing a more sexually dimorphic division of labour in which males are more involved with food production and manual labour than

contemporary Thai females (Coyle and Kwong, 2000). Therefore, differences in divisions of labour may be responsible for differences in the expression of sexual dimorphism between the current research study and other population studies.

Lastly, some studies (Barrett et al., 2001; Murphy, 2002a,b, 2005; Wilbur, 1998) have utilized prehistoric skeletal samples to examine sexual dimorphism; thus, secular change may also be a reason for differences in the expression of sexual dimorphism between populations. Secular change in a non-genetic response to sociocultural and environmental pressures, which causes an increase in overall body dimensions and earlier onset of menarche over several decades or generations (Danubio and Sanna, 2008; Roche, 1979). Positive secular change (i.e. increases in body dimensions and earlier onset of menarche) can be attributed to enhanced population health (e.g. the creation of modern medicine or the advancement of medical technologies for treatment and diagnosis), improved nutrition, and an increase in quality of living conditions (Albanese, 2010; Chan, 2011; Danubio and Sanna, 2008). Malina (1981) for example, showed that improvements in sociocultural and environmental pressures such as the improvement of water and sanitation, or the elimination of infectious disease over time may lead to increased maturation/earlier onset of menarche, which has been shown to influence the expression of sexual dimorphism at the population level (Bourguignon, 1988; Gajdos et al., 2004; Loesch et al., 1995; Parent et al., 2003).

The individuals examined in the current research study represent a contemporary Thai population; these individuals lived during the 20th and 21st centuries and have had access to more contemporary diets and medical treatments. In contrast, Barrett and colleagues (2001) examined prehistoric Ohio Valley Native Americans from three Late

Archaic hunting-gathering populations, Murphy (2002a,b) examined New Zealand

Polynesian skeletal remains from the prehistoric (pre-European settlement) period, and

Wilbur (1998) examined prehistoric Native Americans from West-Central Illinois,

spanning the Middle Woodland to Mississippian periods (AD 1-1100). As prehistoric

Native American populations began to develop and depend upon agriculture, populations

would have aggregated into sedentary settlements (Boyd, 1996). Similarly, prehistoric

New Zealand Polynesians were settling into transient, short-term villages and specialized

sites for subsistence activities (Kinaston et al., 2013). These types of settlements would

have had poor sanitation and waste disposal, factors that increased the frequency of

infection and disease (e.g. diarrheal infections and iron deficiency anemia), which would

have been exacerbated by the fact that prehistoric populations did not have access to

modern medicine or medical technologies for treatment (Boyd, 1996; Lewis, 1998). As a

result, these populations would have had poorer population health, higher susceptibility to

disease and lack of modern medicine/medical care, higher nutritional stress, and lower

quality of living conditions than the contemporary Thai population (Barrett et al., 2001;

Murphy, 2002a,b; Wilbur, 1998). This may be one reason that the expression of sexual

dimorphism observed in the prehistoric Native American (Barrett et al., 2001), prehistoric

New Zealand Polynesian (Murphy, 2002b), and prehistoric West-Central Illinois (Wilbur,

1998) populations is lower than that observed in the contemporary Thai population.

Table 5.1 however, indicates that the amount of sexual dimorphism expressed in

the calcaneus is higher in the prehistoric New Zealand Polynesian (Murphy, 2002b), and

prehistoric West-Central Illinois (Wilbur, 1998) populations than in the contemporary

Thai population. This may be because the calcaneus is a weight-bearing bone, and

subsistence strategies associated with hunter-gatherer populations may have placed strain on this bone, causing it to become more robust. In most hunter-gatherer and foraging societies, males are often responsible for large game hunting that requires high terrestrial mobility and habitual loading associated with tracking, hunting, and carrying large game animals (Marlowe, 2007; Ruff, 2008; Stock and Macintosh, 2016). These activities are likely to have the greatest influence on the morphology of weight-bearing bones among prehistoric populations and may have resulted in larger male calcanei (Stock and Macintonish, 2016). Therefore, the subsistence strategies of the prehistoric New Zealand Polynesian (Murphy, 2002b) and prehistoric West-Central Illinois (Wilbur, 1998) populations may have caused a higher expression of sexual dimorphism in the weight-bearing calcaneus than that exhibited in the contemporary Thai population, despite the influence of positive secular change.

5.3 Analysis of Observer Error and Reproducibility

In recent years, and particularly since the 1993 Supreme Court *Daubert* decision that addressed the standard of admissibility for expert testimony, the forensic community has become increasingly concerned with the reliability of methods from which scientific conclusions are drawn (Berg et al., 2007; Lesciotto, 2015). Reliability can be defined as "how frequently a method yields the same results between successive trials" (i.e. its repeatability) (Berg et al., 2007: 1020) In forensic anthropology, methods and measurements must be well defined so that future researchers are able to accurately repeat the measurements. Without accurate repeatability, methods and measurements are considered unreliable (Berg et al., 2007). To ensure high accuracy and repeatability of the

calcaneus and the talus measurements, the current research study calculates intra-observer and inter-observer error rates using paired t-tests to evaluate error bias, following the protocol of Holland (1995), and also utilizes the concordance correlation of reproducibility method (Lin, 1989), following the protocol of Bidmos and Asala (2005).

For the current research study, intra-observer error was assessed by calculating the error associated with repeated measurements of calcaneal and talar measurement variables by the current author. When examining the calcaneal and talar measurements, the results showed that accuracy and repeatability were maintained for all variables when the current author remeasured a subsample at a different time, which indicates consistency between the first and second data sets. However, the male DAFB measurement variable and the female CFH, MINB, and DAFB measurement variables showed concordance correlation coefficient values below the internationally accepted standard range. This indicates that these measurement variables are not highly reproducible, and may not be accurately repeated in future studies. Therefore, these measurements should be used with caution during future studies and practical application.

Inter-observer error was assessed by calculating the error associated with repeated measurements of calcaneal and talar variables by two different observers (i.e. the current author and a research assistant). The results showed no statistically significant differences between the current author and the research assistant, which indicates that all measurement variables were accurately repeated between observers. However, the male DAFB and the female BH measurement variables showed concordance correlation coefficient values below the internationally accepted standard range, which suggests that these measurement variables are not highly repeatable. The research assistant had no

previous experience or familiarity with the measurements of the current research study. Therefore, the low concordance correlation coefficient values may have resulted from inexperience or lack of familiarity with the DAFB and BH measurement variables. Previous studies have shown that investigator experience and familiarity with a method may be a potential source of observer error (Berg et al., 2007). To enhance the familiarity of a user with these measurement variables, and thus the repeatability of these measurement variables, training with theoretical discussions and practical activities is recommended prior to application (Lopez et al., 2017).

Overall, the results of intra-and-inter-observer error analyses demonstrate discrepancies within or between observers for the male DAFB measurement variable and the female CFH, MINB, DAFB, and BH measurement variables. This indicates that these measurements may not be accurately repeated in future studies and as such may be considered unreliable (Berg et al., 2007). Since the 1993 Supreme Court *Daubert* decision and the 1994 Canadian Supreme Court *Mohan* decision, the forensic community has emphasized the need for anthropological research and testimony to conform to certain standards; namely the methods and techniques used during forensic assessment must be based on reliable principles and methodologies (Berg et al., 2007; Christensen, 2004; Holobinko, 2012; Lesciotto, 2015; Williams and Rogers, 2006). If the techniques (i.e. the measurements) utilized during forensic assessment are considered unreliable or are not based on reliable principles and methodologies, the credibility of the expert witness and their professional reputation could be damaged, and testimony may be considered inadmissible (Williams and Rogers, 2006). Given the results of the current research study, the current author suggests that forensic practitioners utilize the male DAFB

measurement variable and the female CFH, MINB, DAFB, and BH measurement variables during anthropological assessment only when other, more reliable (i.e. those with more accurate repeatability) measurement variables are unavailable for examination, in order to best satisfy admissibility criteria.

5.4   <u>Simple and Multiple Regression Equations</u>

Previous research has demonstrated that osteometric differences exist between populations and suggests that the methods and standards derived for victim identification be population-specific (Bidmos, 2006; Bidmos and Asala, 2005; Holland, 1995; King et al., 1998; Lundy, 1983; Steyn and Işcan, 1997; Trotter and Gleser, 1952a, b, 1958). The first objective of the current research study was to investigate whether regression equations for the calcaneus and the talus that were developed on a Black South African population (Bidmos and Asala, 2005) and a Black American population (Holland, 1995) could accurately classify individuals from a contemporary Thai population. The second objective of the current research study was to develop population-specific simple regression and multiple regression equations for the calcaneus and the talus of the contemporary Thai population should the Black South African (Bidmos and Asala, 2005) and Black American (Holland, 1995) equations not accurately predict the living stature of the Thai individuals.

5.4.1 Accuracy of the Bidmos and Asala (2005) calcaneal regression equations

Bidmos and Asala (2005) used nine measurements of the calcaneus (i.e. MAXL, MAXH, BH, CFH, MINB, LAL, MIDB, DAL, DAFB) to derive regression equations for

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estimation of living stature in a Black South African population. They presented

correlation coefficients (r-values) ranging from 0.27 to 0.47 between individual calcaneal

measurements and living stature (i.e. simple regression analyses) for Black South African

males. The range of values obtained for Black South African females was higher than that

obtained from males (from 0.35 to 0.65). Combinations of variables (i.e. multiple

regression analyses) showed correlation coefficients (r-values) that were higher than

those obtained from the use of individual variables, ranging from 0.52 to 0.60 in Black

South African males and from 0.72 to 0.77 in Black South African females.

To determine whether regression equations developed by Bidmos and Asala

(2005) would accurately estimate living stature for a contemporary Thai population, each

of the simple and multiple regression equations developed by Bidmos and Asala (2005)

were tested on the Thai data. Simple regression equations using the CFH calcaneal

measurement variable could not be tested on the Thai sample data because Bidmos and

Asala (2005) did not provide simple regression equations that used the CFH calcaneal

measurement variable. Overall, when the male Black South African (Bidmos and Asala,

2005) simple regression equations were applied to the contemporary Thai population

correlation coefficient values (r-values) decreased. The lowered accuracy rates for the

Bidmos and Asala (2005) calcaneal regression formulae when applied to the

contemporary Thai population suggest that regression formulae are population-specific

and that there is variation in skeletal features of the calcaneus between populations. This

supports the observations of previous authors that forensic anthropologists should limit

the application of regression equations to the population from which they were derived

(Bidmos, 2006; Bidmos and Asala, 2005; Holland, 1995; King et al., 1998; Lundy, 1983; Steyn and Işcan, 1997; Trotter and Gleser, 1952a,b, 1958).

5.4.2 Accuracy of the Holland (1995) talar regression equations

Holland (1995) used one measurement of the talus (i.e. MTAL) to derive a simple regression equation for estimation of living stature in a Black American population. He utilized Black American individuals from the Hamann-Todd Collection at the Cleveland Museum of Natural History. These individuals are representative of a mixed temporal population, i.e. an historic Black American population and a modern early 20th century Black American population. The population shows birth dates ranging from 1823 to 1924 and death dates ranging from 1908 to 1939 (personal communication, LM Jellema, Collections Manager, Cleveland Museum of Natural History, January 2017). Holland (1995) presented a correlation coefficient (*r*-value) of 0.723 between MTAL and living stature (i.e. simple regression analyses), though Holland (1995) does not specify if this correlation coefficient (*r*-value) is the same for males and females, or if this value is the average of the subgroups. Correlation coefficients (*r*-values) were not available for males and females separately, though male and female regression equations were presented individually (Holland, 1995).

To determine whether regression equation developed by Holland (1995) would accurately estimate living stature for a contemporary Thai population, the Black American simple regression equations developed by Holland (1995) were tested on the Thai sample data. Overall, correlation coefficient values (*r*-values) decreased from when Black American (Holland, 1995) regression equations were applied to the contemporary

Thai population. The lowered accuracy rates for Holland (1995) talar regression formulae when applied to the contemporary Thai population suggest that regression formulae are population-specific, and that there is variation in skeletal features of the talus between populations. These results are similar to those achieved in the current research study when testing the Black South African (Bidmos and Asala, 2005) regression equations on the contemporary Thai population, and thus support the notion that forensic anthropologists should limit the application of regression equations to the population from which they were derived (Bidmos, 2006; Bidmos and Asala, 2005; Holland, 1995; King et al., 1998; Lundy, 1983; Steyn and Işcan, 1997; Trotter and Gleser, 1952a,b, 1958).

5.4.3 Accuracy of simple and multiple regression equations for the contemporary Thai population

The application of the Bidmos and Asala (2005) and Holland (1995) regression equations on the contemporary Thai population demonstrated that methods derived from a specific population should not be used for other populations. Although the calcaneus and the talus have been used for stature estimation in Black American, White American, Black South African, and South African populations (Bidmos, 2006; Bidmos and Asala, 2005; Holland, 1995; Pablos et al., 2013), these bones have not yet been used for stature estimation in Thailand. Therefore, the second objective of the current research study was to develop population-specific simple regression and multiple regression equations for the calcaneus and the talus of the contemporary Thai population.

The accuracy of stature estimation from bones using regression equations is measured by the Standard Error of the Estimate (SEE); the lower the SEE as presented by a regression equation, the more accurate is the estimate of stature. For contemporary Thai males, the lowest SEE is observed when utilizing all ten measurement variables of the calcaneus and the talus. This suggests that all measurement variables of the calcaneus and the talus should be utilized when estimating stature for contemporary Thai males, in order to provide the most accurate results. For contemporary Thai females, the lowest SEE is observed when utilizing only the MAXL calcaneal measurement variable. This suggests that utilizing combinations of measurement variables, or including the talus in the analysis, does not increase the accuracy of stature estimation in a contemporary female Thai population. Therefore, when estimating stature for contemporary Thai females, only the MAXL measurement variable should be used in order to obtain the most accurate results.

To date, there has only been one study completed on stature estimation in a contemporary Thai population (Mahakkanukrauh et al., 2011). However, this research used long bones (i.e. humeri, radii, ulnae, femora, tibiae, fibulae) and not foot bones (Mahakkanukrauh et al., 2011). Therefore, in order to determine how accurately the calcaneus and the talus estimate stature in comparison to other skeletal elements, the SEE range from the current research study is compared to the SEE ranges from previous research (Table 5.3). For consistency, the SEE range from the current research study (i.e. 3.06 to 7.36) has been rounded to the nearest tenth (i.e. 3.1 to 7.4).

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Table 5.3 Comparison of Standard Error of the Estimate (SEE) ranges for the current research study and previous studies by different authors.

Investigator	Population	Skeletal element	SEE
Jason and Taylor (1995)	American*	Vertebrae	2.6 – 7.1
Trotter and Gleser (1952a)	American*	Humerus, radius, ulna, femur, tibia, fibula	3.0 – 5.1
Current research study	**Thai**	**Calcaneus, talus**	**3.1 – 7.4**
Torimitsu et al. (2017)	Japanese	Clavicle	3.4 – 4.9
Shintaku and Furuya (1990)	Japanese	Phalanges	3.6 - 4.3
Torimitsu et al. (2015)	Japanese	Scapula	3.8 – 6.3
Bidmos and Asala (2005)	Black South African	Calcaneus	4.0 – 5.9
Byers et al. (1989)	American*	Metatarsals	4.0 – 7.6
Menezes (2009, 2011)	South Indian	Sternum	4.1 – 5.6
Bidmos (2006)	White South African	Calcaneus	4.2 – 5.5
Holland (1995)	Black American	Talus	4.7 – 5.5
Mahakkanukrauh et al. (2011)	Thai	Humerus, radius, ulna, femur, tibia, fibula	4.9 – 6.1
Meadows and Jantz (1992)	White American	Metacarpals	5.1 – 5.7
Zhang et al. (2016)	Chinese	Calcaneus	5.1 –10.5
Torimitsu et al. (2016)	Japanese	Skull	5.4 – 9.1
Simmons et al. (1990)	American*	Fragmentary femur	5.5 – 7.2
Torimitsu et al. (2014)	Japanese	Sacrum	5.8 – 8.3

*White American and Black American populations (combined ancestral sample)

A comparison of the SEE range from the current research study and the SEE

range from the study by Mahakkanukrauh et al. (2011), suggests that in a contemporary

Thai population, the calcaneus and the talus are more accurate when compared to intact

long bones (i.e. intact humeri, radii, ulnae, femora, tibiae, fibulae). This seems to indicate

that when the calcaneus and the talus are recovered in a forensic context, these bones

should be used for the estimation of stature instead intact humeri, radii, ulnae, femora,

tibiae, fibulae, because these bones may provide a more accurate estimation of stature in

a contemporary Thai population. However, if the SEE value from the female simple

regression equation using the MAXL measurement variable (i.e. 3.06, Table 4.9) is

excluded, the SEE range from the current research study becomes 5.95 to 7.36. This

indicates that overall, long bones provide a more accurate estimate of stature than the

calcaneus and the talus in the contemporary Thai population. Therefore, if available in a

forensic context, intact humeri, radii, ulnae, femora, tibiae, and fibulae should be used for

stature estimation.

Overall, the SEE range from the current research study (3.06 to 7.36) suggests

that the calcaneus and the talus may be less accurate when compared to the vertebral

column (Jason and Taylor, 1995) and intact long bones (i.e. humeri, radii, ulnae, femora,

tibiae, fibulae) (Trotter and Gleser, 1952a). Furthermore, the SEE ranges from studies by

Shintaku and Furuya (1990) and Torimitsu and colleagues (2015) are, overall, lower than

the SEE range from the current research study. This suggests that the calcaneus and the

talus may also be less accurate when compared to the clavicle (Torimitsu et al., 2015) and

the phalanges (Shintaku and Furuya, 1990). However, as regression equations for the

estimation of stature are population-specific, the SEE ranges are only accurate for stature

estimation in the population from which they were derived (i.e. White American, Black

American, and Japanese populations; Jason and Taylor, 1995; Shintaku and Furuya,

1990; Torimitsu et al., 2015; Trotter and Gleser, 1952a). Future studies should investigate the accuracy of these skeletal elements, particularly the vertebrae, for stature estimation in a contemporary Thai population.

While the results of the current research study demonstrate that the calcaneus and the talus may be accurate predictors of stature in a Thai population, previous studies have found contrasting results in other populations. For example, Zhang and colleagues (2016) found a high SEE range (i.e. SEE values from 5.05 to 10.5) in their study of stature estimation from the calcaneus in a Han Chinese population. Based on these results, Zhang and colleagues (2016) concluded that the calcaneus is not an accurate predictor of stature in the Han Chinese population. This study further demonstrates the necessity for population-specific regression formulae for stature estimation. However, the data utilized in the study by Zhang et al. (2016) were obtained from computed radiography (CR) technology, and thus, the results may not be as accurate as those obtained directly from bone (as in the current research study).

Studies have shown that projection, landmark identification, and measurement errors may occur using radiographic imaging technologies (Guenoun et al., 2012; Lagravère et al., 2010). Radiographic projection errors may be the result of magnification or distortion. Magnification occurs because the x-ray beams originate from a source that is not parallel to all points of the object (i.e. the bone) being examined. Distortion may occur because of unequal magnifications between different planes; skeletal landmarks may be affected by distortion because of their locations at different depth fields. Landmark identification error is influenced by factors such as quality of the radiographic image, which may in turn be influenced by the density and sharpness of images,

superimposition of bone and other soft tissues, or differences in specimen orientation/positioning (Berg et al., 2007; Guenoun et al., 2012; Lagravère et al., 2010; Major et al., 1994; Spoor et al., 2000). These factors may influence the accuracy and reliability of measurements and result in measurement error. These factors may explain why Zhang and colleagues (2016) received such high SEE values for the calcaneus.

5.5 <u>Statistical Population Comparison</u>

The current research study has identified the need for population-specific regression formulae for the estimation of stature in unknown Thai skeletal remains. The third objective of this research was to compare the results from the contemporary Thai population to other populations. The contemporary Thai descriptive statistics were compared to the descriptive statistics of: Black South African (Bidmos and Asala, 2005), White South African (Bidmos, 2006), and Black American (Holland, 1995) populations.

5.5.1 Comparison of contemporary Thai and Black South African (Bidmos and Asala, 2005) descriptive statistics

Bidmos and Asala (2005) found that the calcaneus could be used to accurately estimate stature in a Black South African population. The descriptive statistics from the Black South African (Bidmos and Asala, 2005) population and the contemporary Thai population were compared (Table 4.15). Overall, the mean values of the calcaneal measurement variables, for both males and females, were larger in the contemporary Thai population than in the Black South African (Bidmos and Asala, 2005) population, with the exception of the male and female MAXH, MIDB, and DAFL measurement variables.

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The larger overall calcanei of the contemporary Thais when compared to the Black South

Africans may be related to differences in their socioeconomic status or psychosocial

stress.

During the South African apartheid (1948-1994), individuals were identified as

Black (predominately of Bantu ancestry), White (of European ancestry), or Coloured (a

heterogenous group comprised of individuals of Khoesan, Bantu, European, South

Indian, and/or East Indian ancestry). There was a strong association between 'race'

classification and socioeconomic status, which has continued during the country's

transition to democracy (1994 to present day) (Christopher, 2001; Das-Munshi et al.,

2016; Pfeiffer et al., 2016). The apartheid regime (1948-1994) led to a 'racially'

segregated society in which Black South Africans were at a socioeconomic disadvantage

to Whites and Coloureds (Das-Munshi et al., 2016). Overall, Black South Africans have

experienced dietary deficiencies, inadequate state-subsidized health services,

unemployment, inadequate, and often crowded accommodation/shelter, under-education,

and general poverty (De Beer, 1984; Kark, 1974; Turton and Chalmers, 1990). Overall,

lower socioeconomic status, marked by factors such as nutritional deficiencies, higher

incidence of disease, and inadequate access to medical care, is correlated with decreased

skeletal growth and development (Inwood and Roberts, 2010). These factors may have

had a negative impact on the health and growth of Black South Africans and, thus, may

be responsible for the smaller calcaneal dimensions observed in the Black South African

(Bidmos and Asala, 2005) population.

Dietary information for Black South Africans during the apartheid era is limited,

although it has been suggested that approximately 30% (and up to 75% in rural areas) of

all Black South African children were malnourished (World Health Organization, 2005). Stupar (2007) states that, traditionally, the rural Black South African diet was not diverse or nutrient dense; staples of the Black South African diet included maize, vegetables, such as sweet potato or cabbage, and few meat products. Overall, studies have suggested that the nutritional status of Black South Africans was poor, with inadequate intake of calcium, vitamin D, and protein (Karaand and Myburgh, 1992; Naude et al., 2012, Pfeiffer et al., 2016; Stupar, 2007). Studies have shown that inadequate intake of calcium and vitamin D may compromise bone (specifically calcaneal) growth and development (Babaroutsi et al., 2005; Nathena et al., 2017; Naude et al., 2012; Stini, 1969). Furthermore, studies have shown that excessive alcohol use is correlated with calcium and vitamin D deficiencies. Excessive alcohol consumption has been known to negatively affect bone health by disturbing osteoblast activity and decreasing bone mass and strength (Naude et al., 2012). During the apartheid era, alcohol abuse was a common issue in many impoverished regions, and in many Black South African townships, very heavy alcohol use is still reported today (Kalichman et al., 2007, 2008; Pfeiffer et al., 2016; Schneider et al., 2007; Suliman et al., 2010). Poor nutrition in combination with heavy alcohol use may have compromised bone growth and skeletal development in the Black South African (Bidmos and Asala, 2005) population. Therefore, this may be the reason for the smaller calcaneal measurements in the Black South African population when compared to the Thai population.

The prevalence of alcohol use is relatively low in Thailand (especially in women), with consumption rates of only 21.6% to 22.22% among those aged 15 to 24 years (The National Statistics Office, 2008). The overall low prevalence of alcohol use and abuse

among the general Thai population is likely the result of religious affiliations. Approximately 95% of the population in Thailand declare themselves Buddhist, which is the state religion in Thailand; Buddhism has a significant influence on Thai lifestyle and culture (Assanangkornchai et al., 2000, 2002; Limaye et al., 2013). Buddhists are expected to conform to certain moral injunctions known as the Five Precepts (Silas Ha), one of which is "the avoidance of distilled and fermented intoxicants causing carelessness" (Assanangkornchai et al., 2002: 193.) As a result, the Thai population shows enhanced bone growth and skeletal development when compared to the Black South African (Bidmos and Asala, 2005) population, which may explain the smaller calcaneal dimensions in the Black South African (Bidmos and Asala, 2005) population.

Differences in calcaneal dimensions between the Black South African (Bidmos and Asala, 2005) population and the contemporary Thai population may also be the result of socioeconomic differences related to living conditions, exposure to infectious disease and access to medical care (Dearden et al., 2017; Doak et al., 2002; Hong et al., 2006; Inwood and Roberts, 2010; Magnani et al., 1993; Merchant et al., 2003; Pongou et al., 2006).

Black South Africans, in the apartheid and post-apartheid eras, lived in often unsanitary and crowded conditions, which may have increased exposure to toxins and pollutants and thus increased their risk of disease (Dearden et al., 2017; Doak et al., 2002; Hong et al., 2006; Inwood and Roberts, 2010; Magnani et al., 1993; Merchant et al., 2003; Pongou et al., 2006). Turok and Borel-Saladin (2016) describe the conditions of squatter settlements inhabited by Black South Africans, citing that shacks of one to two rooms were often built by residents from materials such as wood or pieces of zinc or tin,

and had no outdoor toilets or indoor running water. This type of accommodation is typical of many of the larger squatter settlements and townships South Africa (De Beer, 1984; Kark, 1974; Turok and Borel-Saladin, 2015; Turton and Chalmers, 1990). Studies have shown that individuals in households with a lack of sewage connection and indoor water connection were more likely to contract infectious diseases such as diarrhea, polio, or cholera, and parasites, and thus suffer growth and development deficits (Checkley et al., 2004; Haque, 2007; Hathi et al., 2017). Disease exposure and incidence can retard growth by diverting energy to fighting disease or by causing inadequate absorption of the nutrients consumed (Dearden et al., 2017; Doak et al., 2002; Hong et al., 2006; Inwood and Roberts, 2010; Magnani et al., 1993; Merchant et al., 2003; Pongou et al., 2006).

The incidence of such infectious diseases may be enhanced by high population density, facilitated by crowded living conditions, which provides more opportunities for disease transmission (Haque, 2007; Hathi et al., 2017). Overcrowding was common in many Black South African communities in the apartheid and post-apartheid eras, with an average of 17 people per household (De Beer, 1984; Kark, 1974; Turton and Chalmers, 1990).

Disease incidence may also be exacerbated by inadequate access to medical care. Access to health care has been limited for Black South Africans (De Beer, 1984; Kark, 1974; Turton and Chalmers, 1990). According to the American Association for the Advancement of Science and Physicians for Human Rights Organization (1998), the South African health care system has not only limited access to health care for Black South Africans, but facilitated an environment in which refusal of emergency treatment, denial or limitation of access of ongoing medical care, and mistreatment of the ill occurs.

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Overall, the inadequate living conditions, exposure to disease, and lack of access to proper medical care for Black South Africans may explain their smaller calcaneal dimensions when compared to the Thai population.

Research has also demonstrated that psychosocial stress during life may cause a decline in growth rates (Gilmour and Skuse, 1999; Peckmann et al., 2017; Ranabir and Reetu, 2011; Talbot et al., 1947; Turton and Chalmers, 1990) and therefore may be related to the calcaneal size differences between the Black South African (Bidmos and Asala, 2005) and Thai populations. Psychosocial stress is defined as the relationship between a person and the environment that is appraised by the person as taxing or exceeding their resources and endangering their well being (Lazarus and Folkman, 1984:19). In response to stress, hormone levels change; reactions to stress are associated with defects in the secretion of hormones such as glucocorticoids, catecholamines, growth hormone and prolactin (Ranabir and Reetu, 2011).

Turton and Chalmers (1990) state that discrimination may act as a stimulant to psychosocial stress, and studies have shown that the systemic 'racial' discrimination experienced by Black South Africans during the apartheid and post-apartheid eras have contributed to psychosocial distress among Black South Africans (Das-Munshi et al., 2016; Turton and Chalmers, 1990). Black South Africans, during the apartheid and post-apartheid eras, were made to carry 'race' classification documentation and endured prejudicial practices such as the banning of 'inter-racial' marriage, residential segregation, forced removal from White-only residential areas, and required to use separate railway carriages and separate entrances at stations, post offices, and other business establishments (Seekings, 2008; Turton and Chalmers, 1990). Such

discrimination may have contributed to psychosocial stress among Black South Africans, and thus negatively impacted hormone production causing stunted bone growth in the contemporary Black South African population. Therefore, psychosocial stresses may be responsible for the smaller calcaneal measurements illustrated by the Black South African (Bidmos and Asala, 2005) population when compared to the Thai population.

5.5.2 Comparison of contemporary Thai and White South African (Bidmos, 2006)
 descriptive statistics

Bidmos (2006) found that the calcaneus could also accurately estimate stature in a White South African population. The descriptive statistics from the White South African (Bidmos, 2006) population and the contemporary Thai population were compared (Table 4.16). Overall, the mean values of the calcaneal measurement variables, for both males and females, were smaller in the contemporary Thai population than in the White South African (Bidmos, 2006) population, with the exception of the male and female CFH, LAL, and DAFB measurement variables, and the female MINB measurement variable. The larger calcaneal dimensions of the White South African population may be the result of differences in genotype, socioeconomic factors, and occupational stressors.

Studies have demonstrated the effect of genotype and genetic factors on skeletal growth; twin and family studies have suggested that as much as 90% of variation in human growth is genetically determined (Knight et al., 2005; Lettre et al., 2008; Macgregor et al., 2006; Perola et al., 2007; Preece, 1996; Rappold et al., 2007; Silventoinen et al., 2000, 2001; Weedon et al., 2007, 2008; Zhao et al., 2010). There have been many genome wide association (GWA) studies that have identified a number of

genes and genetic loci influencing skeletal growth (Carty et al., 2012; Estrada et al., 2009; Johansson et al., 2009; Lettre et al., 2008; Liu et al., 2010; Sanna et al., 2008; Soranzo et al., 2009; Tönjes et al., 2009; Weedon et al., 2007, 2008). Although, very few studies have been conducted in Asian populations. One study, however, by Lei and colleagues (2009) found that the genomic region containing the *ZNP510* and *ZNP782* genes is an "ethnic-specific" locus associated with bone growth in Asian individuals. Similarly, Hao and colleagues (2013) identified three novel loci for bone growth, which mapped in or near *ZNF638* (rs12612930)*, MAML2* (rs11021504)*,* and *C18orf12* (rs11082671). These loci were found in a Han Chinese population but not identified individuals of other ancestral backgrounds, indicating that these loci may be specific to Asian individuals (Hao et al., 2013).

Contemporary Thai populations show genetic contributions from South Asians, Southeast Asians, Northwest Asians, and Polynesians (Peckmann et al., 2017; Xing et al., 2010). The genetic composition of the White South African (Bidmos, 2006) population group includes contributions from migrants of the Netherlands, United Kingdom, France, Germany, Portugal and other European groups, as well as admixture with local (i.e. South African) groups (Bidmos, 2006; Bidmos and Asala, 2003; Pfeiffer et al., 2016; Steyn and Işcan, 1997). As the genetic composition of the contemporary Thai population and the White South African (Bidmos, 2006) population is different, and given that previous authors have identified many Asian-specific loci associated with skeletal growth and development, genotype may be the reason for the mean calcaneal differences observed between the contemporary Thai and the White South African (Bidmos, 2006) population.

Calcaneal growth and development may also be affected by socioeconomic conditions (Bogin et al., 2002; Dangour, 2001; Inwood and Roberts, 2010; Nyati et al., 2006). The individuals utilized for the current research study were from Chiang Mai and adjacent villages in northern Thailand and were of middle and low socioeconomic status (King et al., 1998; Traithepchanapai et al., 2016). Poverty in Thailand exists as a mainly rural phenomenon; as of 2014, over 80% of the country's poor live in rural areas and pockets of poverty remain in the North and Northeast regions (World Bank, 2017). Many of the White South African individuals in the Bidmos (2006) study lived during the apartheid era (1948-1994) (Steyn and Işcan, 1997). During this time, White South Africans experienced a higher socioeconomic status when compared to other groups in the country, including better living conditions and limited overall poverty (Kon and Lackan, 2008; Turton and Chalmers, 1990; van der Berg et al., 2006). Therefore, the differences in living conditions may be responsible for the larger calcaneal dimensions observed in the White South African (Bidmos, 2006) population when compared to the Thai population.

Nutritional deficiencies may comprise bone growth and development (Babaroutsi et al., 2005; Nathena et al., 2017; Naude et al., 2012; Stini, 1969). Food intake and proper nutrition may be compromised when food is in short supply (in instances such as war or famine), or because the price of food groups important to growth, such as protein, increases above what some individuals are able to pay (Bogin, 1999; Inwood and Roberts, 2010). The Food and Agricultural Organization of the United Nations (2012) has reported that there is a high level of undernourishment in Thailand. In particular, studies have shown that the habitual diet among rural Northern Thai individuals does not meet

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recommended calcium, protein, zinc, vitamin A or vitamin C intake levels, thus resulting in stunted growth (Pongchaiyakul et al., 2008; Rojroongwasinkul et al., 2013). In a study by Pongchaiyakul and colleagues (2008), it was observed that 67% of contemporary Thai men and 87% of contemporary Thai women had a dietary calcium intake of less than half the recommended level (<400 milligrams per day). As calcium is the dominant mineral in bone, the authors' note that such deficiencies may result in an acceleration of bone loss, increased risk of osteoporosis, increased risk of bone fracture, and overall impaired bone growth and development (Pongchaiyakul et al., 2008).

In contrast, the White South African population experienced adequate nutrition with minimal nutritional deficiencies or diet-related growth impairments (Kon and Lackan, 2008; Turton and Chalmers, 1990; van der Berg et al., 2006). Overall, studies have shown that White South Africans during the apartheid and post-apartheid eras were food secure (i.e. did not experience hunger) and experienced high dietary diversity (Kon and Lackan, 2008; Stupar, 2007; Turton and Chalmers, 1990; van der Berg et al., 2006). Dietary diversity can be used as a proxy measure of the nutritional quality of a population's diet (Kennedy et al., 2009). The high dietary diversity of the White South African population thus indicates adequate intake of essential nutrients. Therefore, the nutritional deficiencies and inadequate calcium intake in contemporary Thai populations may have caused impaired bone growth and development, which may explain the larger calcaneal dimensions observed in the White South African (Bidmos, 2006) population when compared to the Thai population.

Differences in the mean calcaneal dimensions between the White South African (Bidmos, 2006) population and the contemporary Thai population may also be the result

of socioeconomic differences related to exposure to toxins and/or pollutants, risk of disease, and access to medical care (Dearden et al., 2017; Doak et al., 2002; Hong et al., 2006; Inwood and Roberts, 2010; Magnani et al., 1993; Merchant et al., 2003; Pongou et al., 2006). During apartheid, areas with higher living standards were designated "White-only" (Turton and Chalmers, 1990). The high socioeconomic status of White South Africans (Bidmos, 2006) means that this group benefitted from more affluent living conditions, proper sanitation, clean water access, and low population density. These conditions may also reduce exposure to toxins or pollutants and reduce the risk of disease in the White South African (Bidmos, 2006) population (Dearden et al., 2017; Doak et al., 2002; Hong et al., 2006; Inwood and Roberts, 2010; Magnani et al., 1993; Merchant et al., 2003; Pongou et al., 2006). Therefore, greater socioeconomic conditions may be responsible for the larger calcaneal dimensions observed in the White South African (Bidmos, 2006) population when compared to the Thai population.

Finally, increases in the intensity or the volume of physical activity without increasing caloric intake may decrease the calories available for bone growth, thus retarding bone growth and influencing final bone size (Steckel, 2008). The individuals represented in the contemporary Thai population are from the northern region of Thailand, and area in which rice farming is popular (Arunrat and Pumijumnong, 2015; Isvilanonda and Bunyasiri, 2009). Rice farming involves the navigation of uneven terrain and hard manual labour, which requires high caloric expenditure. The diet of the contemporary Thai population has been shown to be nutritionally deficient, resulting in high levels of undernourishment in Thailand (Pongchaiyakul et al., 2008; Rojroongwasinkul et al., 2013). The high intensity and volume of physical activity (i.e.

the high caloric expenditure) experienced by the contemporary Thai population, in combination with the compromised caloric intake of contemporary Thais, would have decreased calories available for growth and may have contributed to deficiencies in bone growth in the contemporary Thai population.

The White South African (Bidmos, 2006) population is more urban than the contemporary Thai population, with higher levels of education and as a result, has enhanced economic and urban labour market opportunities (Kon and Lackan, 2008; Turton and Chalmers, 1990; van der Berg et al., 2006). Many of the White South African individuals in the Bidmos (2006) study lived during the apartheid era (1948-1994) (Steyn and Işcan, 1997). Employment data demonstrate that during this time, the majority of White South Africans during the apartheid were employed "skilled" occupations (i.e. managerial, professional, and technician positions), specifically in positions that are considered "white collar", such as administration, management, executive, and clerical positions (Mariotti, 2012; van Wyk, 1968). As a result of these labour activities, the White South African (Bidmos, 2006) population likely experienced low caloric expenditure, as the physical intensity of daily activities would have been low. Furthermore, as discussed earlier in this chapter, the White South African (Bidmos, 2006) population experienced adequate nutrition with minimal nutritional deficiencies and substantial caloric intake (Kon and Lackan, 2008; Turton and Chalmers, 1990; van der Berg et al., 2006). The low caloric expenditure and high caloric intake experienced by the White South African (Bidmos, 2006) population would have been conducive to bone growth. This may explain the larger calcaneal dimensions observed in the White South African (Bidmos, 2006) population in comparison to the contemporary Thai population.

5.5.3 Comparison of contemporary Thai and Black American (Holland, 1995) descriptive

statistics

Holland (1995) found that the talus may be used to accurately estimate stature in a

Black American population. The descriptive statistics from the Black American

population (Holland, 1995) and the contemporary Thai population were compared (Table

4.17). Overall, the mean values of the one talar measurement variable, for both males and

females, were larger in the Black American (Holland, 1995) population than the

contemporary Thai population.

The individuals utilized for the current research study were from Chiang Mai and

adjacent villages in northern Thailand and were of middle and low socioeconomic status

(King et al., 1998; Traithepchanapai et al., 2016). Holland (1995) utilized Black

American individuals from the Hamann-Todd Collection at the Cleveland Museum of

Natural History. These individuals are representative of a mixed temporal population, i.e.

an historic Black American population and a modern early 20th century Black American

population. The population shows dates of birth ranging from 1823 to 1924 and dates of

death ranging from 1908 to 1939 (personal communication, LM Jellema, Collections

Manager, Cleveland Museum of Natural History, January 2017). As this population is

representative of an enslaved African and early historic Black American population, this

population was also of low socioeconomic status (Blonigen, 2004; Carson, 2010;

Spradley, 2006). Overall, both the Black American (Holland, 1995) population and the

contemporary Thai population were of depressed backgrounds, with poor nutrition, poor

sanitation and high exposure to toxins and/or pollutants, increased risk of disease, and

inadequate access to medical care. Therefore, differences in socioeconomic status cannot

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account for differences in talar dimensions observed between the Black American

(Holland, 1995) population and the contemporary Thai population.

Furthermore, the Thai individuals are from the Northern region of Thailand, an

area in which rice farming is popular (Arunrat and Pumijumnong, 2015; Isvilanonda and

Bunyasiri, 2009). Rice farming involves the navigation of uneven terrain and hard

manual labour. Specifically, rice farming requires individuals to bear large amounts of

weight on the head, shoulders, or back during seed transplantation and harvesting

(Barton, 1960). The individuals utilized by Holland (1995) (i.e. enslaved Africans and

early historic Black Americans) were mainly unskilled workers involved in domestic or

agricultural positions, which also required hard manual labour (Blonigen, 2004; Carson,

2010). Black Americans working on plantations, for example, were responsible for tasks

such as chopping trees, repairing cabins, tending gardens, and harvesting, which may

include specific tasks such as vigorous hoeing, weed pulling, thrashing, and sifting

(Blonigen, 2004). As both populations were engaged in similar occupational activites,

which required hard manual labour and intense physical activity, therefore differences in

occupational activities cannot account for the differences in talar dimensions observed

between the Black American (Holland, 1995) population and the contemporary Thai

population.

Overall, the larger tali of Black Americans (Holland, 1995), in comparison to the

contemporary Thai population, may be the result of differences in genotype. Studies have

demonstrated the effect of genotype and genetic factors on skeletal growth (Knight et al.,

2005; Lettre, 2008; Macgregor et al., 2006; Perola et al., 2007; Preece, 1996; Rappold et

al., 2007; Silventoinen et al., 2000, 2001; Weedon et al., 2007, 2008; Zhao et al., 2010).

As well, the published literature has demonstrated the existence of genetic variants associated with bone growth, which are specific to Asian individuals (Hao et al., 2013; Lei et al., 2009). For example, Hao and colleagues (2013) identified three novel loci that mapped in or near *ZNF638* (rs12612930)*, MAML2* (rs11021504)*,* and *C18orf12* (rs11082671), which were found in a Han Chinese population but not identified individuals of other ancestral backgrounds. These results demonstrate that there are differences in the genetic variants associated with bone growth between populations of different ancestral backgrounds.

Contemporary Thai populations show genetic contributions from South Asians, Southeast Asians, Northwest Asians, and Polynesians (Peckmann et al., 2017; Xing et al., 2010). As discussed previously in this chapter, Holland (1995) utilized Black American individuals representative of a mixed temporal population, i.e. an historic Black American population and a modern early 20th century Black American population. The genotype of this Black American (Holland, 1995) population was influenced by varying levels of African and White European ancestry (Spradley, 2006). As the genetic composition of the contemporary Thai population and the Black American (Holland, 1995) population is different, and given that previous authors have identified many Asian-specific loci associated with skeletal growth and development, genotype may be the reason for the mean talar differences observed between the contemporary Thai and the Black American (Holland, 1995) populations.

CHAPTER 6: CONCLUSIONS

Within the current body of literature for stature estimation, Thai populations are underrepresented; prior to the current project, there has only been one study completed on stature estimation in a contemporary Thai population (Mahakkanukrauh et al., 2011). In Thailand, the 2004 tsunami disaster highlighted the lack of forensic anthropology expertise in the country and the lack of population-specific methods in the region (Traithepchanapai et al., 2016). The current research study addresses this need, and focuses on the calcaneus and the talus to establish an accurate method of living stature estimation for a contemporary Thai population. The objectives of this research are to:

1. investigate whether regression equations for the calcaneus, which were developed on a Black South African population (Bidmos and Asala, 2005), and regression equations for the talus, which were developed on a Black American population (Holland, 1995), can accurately predict the living stature of individuals from a contemporary Thai population.

2. develop population-specific simple regression and multiple regression equations for the calcaneus and the talus of the contemporary Thai population should the Black South African (Bidmos and Asala, 2005) and Black American (Holland, 1995) equations not accurately predict the living stature of the Thai individuals.

3. compare the results from the contemporary Thai population to other populations.

This study examined the calcaneus and the talus as they are small, compact bones with dense trabeculae and small surface area, and are often encased in socks and/or shoes, which serve as protection for the feet (Bidmos and Asala, 2005; Peckmann et al., 2017;

Pickering, 1986; Saul and Saul, 2005). These factors result in resiliency to taphonomic stresses, leading to enhanced preservation for stature estimation in forensic cases.

In the current research study, the paired calcaneus and talus of 232 adult skeletonized individuals (115 males, 117 females) of Thai ancestry were examined for their potential in estimating stature. In total, 464 individual bones ($N^{total\ bones} = 464$; $N^{calcaneus} = 232$, $N^{talus} = 232$) were examined from the Chiang Mai skeletal collection, which represents a contemporary population. Only calcanei and tali of skeletally adult individuals (between 19 years and 96 years of age) were studied to ensure that the calcaneus and the talus are skeletally mature and have reached their maximum size. Individuals were excluded from this study if both the calcaneus and the talus (from an individual pair) were not present for analysis, or if the bones exhibited any form of taphonomic damage, post mortem trauma, or extreme pathologic remodeling of the morphometric characteristics which would inhibit the collection of accurate measurements. The vast majority of skeletons in the Chiang Mai skeletal collection exhibited some osteoarthritic bone remodeling. Therefore, calcanei and tali exhibiting mild osteoarthritis, in which measured morphometric traits of the calcaneus and the talus were not affected, were included in this study because excluding these individuals would bias the sample from accurately representing the Thai population as a whole.

Following the protocol of Bidmos and Asala (2005), nine measurements (i.e. "measurement variables") were collected from the calcaneus: Maximum Length (MAXL), Maximum Height (MAXH), Cuboidal Facet Height (CFH), Body Height (BH), Minimum Breadth (MINB), Load Arm Length (LAL), Middle Breadth (MIDB), Dorsal Articular Facet Breadth (DAFB), and Dorsal Articular Facet Length (DAFL). Following

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the protocol of Holland (1995), one measurement variable was collected for the talus: Maximum Length of the Talus (MTAL). A total of ten measurement variables were collected for each individual, i.e. nine measurements of the calcaneus and one measurement of the talus.

Sexual dimorphism was statistically analyzed using two-sample t-tests. All calcaneal and talar measurement variables were found to be sexually dimorphic ($p < 0.005$), which indicates that these measurement variables have good predictive value for estimating living stature for both contemporary Thai males and contemporary Thai females. For the calcaneus, the MAXL measurement variable exhibited the greatest dimorphic variation between males and females. For the talus, the MTAL measurement variable exhibited the greatest dimorphic variation between males and females. The variations of sexually dimorphic expression exhibited in the MAXL and MTAL measurement variables, between populations, may be due to differences in genetics, socioeconomic status, and habitual or occupational behaviours.

Intra-observer and inter-observer error were statistically analyzed using paired t-tests and concordance correlation of reproducibility method (Lin, 1989). Intra-observer error showed no statistically significant difference between the original sample and the re-measured sub-sample ($p > 0.005$). However, when statistically analyzed using Lin's (1989) concordance correlation, four of the nine measurement variables (male DAFB, female CFH, BH, MINB, and DAFB) did not fall within the internationally accepted standard range of 0.90 to 0.99 (Cameron, 1984; Lin, 1989). Inter-observer error also showed no statistically significant difference between the original sample and the re-measured sub-sample ($p > 0.005$). However, when statistically analyzed using Lin's

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(1989) concordance correlation, three of the nine measurement variables (male DAFB, female BH and MINB) did not fall within the internationally accepted standard range of 0.90 to 0.99 (Cameron, 1984; Lin, 1989). This indicates that these measurements may not be accurately repeated and as such caution must be taken when including these variables in future studies (Berg et al., 2007). Given the results of the current research study, the current author suggests that forensic practitioners utilize the male DAFB measurement variable and the female CFH, MINB, DAFB, and BH measurement variables during anthropological assessment only when other, more reliable (i.e. those with more accurate repeatability) measurement variables are unavailable for examination, in order to best satisfy the *Mohan* and *Daubert* admissibility criteria.

To determine whether published regression equations for the calcaneus can accurately predict the living stature of individuals from a contemporary Thai population, each of the simple and multiple regression equations for the calcaneus and for the talus, that were generated from a Black South African (Bidmos and Asala, 2005) and Black American (Holland, 1995) population, respectively, were tested on the Thai sample data. Overall, correlation coefficient values (*r*-values) decreased when Black South African (Bidmos and Asala, 2005) and Black American (Holland, 1995) regression equations were applied to the contemporary Thai population. The lowered accuracy rates for the Bidmos and Asala (2005) calcaneal regression formulae and the Holland (1995) talar regression formulae when applied to the contemporary Thai population suggest that regression formulae are population-specific and that there is variation in skeletal features of the calcaneus and the talus between populations.

To date, no study has used the calcaneus and/or the talus for the estimation of stature in a contemporary Thai population. The calcaneus, the talus, and a combination of the two foot bones, were used to create simple and multiple regression equations for living stature estimation in the contemporary Thai population. A total of 18 simple regression equations were generated from the calcaneus ($N^{\text{total calcaneal simple regression equations}} = 18$; N^{male} $^{\text{calcaneal simple regression equations}} = 9$, $N^{\text{female calcaneal simple regression equations}} = 9$), a total of two simple regression equations were generated from the talus ($N^{\text{total talar simple regression equations}} = 2$; N^{male} $^{\text{talar simple regression equations}} = 1$, $N^{\text{female talar simple regression equations}} = 1$), and a total of 10 multiple regression equations were generated from a combination of calcaneal and talar measurement variables ($N^{\text{total multiple regression equations}} = 10$; $N^{\text{male multiple regression equations}} = 5$, $N^{\text{female multiple regression equations}} = 5$).

The accuracy of stature estimation from bones using regression equations is measured by the Standard Error of the Estimate (SEE); the lower the SEE as presented by a regression equation, the more accurate is the estimate of stature. For contemporary Thai males, the lowest SEE is observed when utilizing all ten measurement variables of the calcaneus and the talus (Function 1; SEE = 5.70). This suggests that all measurement variables of the calcaneus and the talus should be utilized when estimating stature for contemporary Thai males, in order to provide the most accurate results. For contemporary Thai females, the lowest SEE is observed when utilizing only the MAXL calcaneal measurement variable (SEE = 3.06). This suggests that utilizing combinations of measurement variables, or including the talus in the analysis, does not increase the accuracy of stature estimation in a contemporary female Thai population. Therefore,

when estimating stature for contemporary Thai females, only the MAXL measurement variable should be used in order to obtain the most accurate results.

A cross-validation study evaluated the accuracy of the simple and multiple regression equations for the estimation of stature by testing the predictive performance of each simple and multiple regression equation on an independent sample (Sample 2), which was not used to generate the simple and multiple regression equations. Following the protocol of Bidmos and Asala (2005) for the calcaneus and Holland (1995) for the talus, the accuracy of the estimation of living stature for each of the calcaneal and talar simple and multiple regression equations was assessed by calculating in what percent of cases, from Sample 2, did the Thai predicted living stature fall within 1 Standard Error of the Estimate (1SEE) and 2 Standard Errors of the Estimate (2SEE) of the Thai documented living stature. Using calcaneal simple regression equations, the estimated living stature fell within 1SEE in 50% to 67% of cases for contemporary Thai males, while the accuracy was higher at 2SEE (87% to 97%). For Thai females, living stature estimates fell within 1SEE in 53% to 70% of cases and within 2SEE in 90% to 97% of cases using calcaneal simple regression equations. Using talar simple regression equations, the estimated living stature fell within 1SEE in 53% of cases and within 2SEE in 90% of cases for contemporary Thai males. For contemporary Thai females, the living stature estimations generated from the MTAL simple regression equation for the talus fell within 1SEE in 70% of cases and within 2SEE in 93% of cases. Using multiple regression equations, the predicted living stature fell within 1 SEE in 47% to 57% of cases for contemporary Thai males, while the accuracy was higher at 2SEE (83% to 90%). Contemporary Thai females however, showed a higher percentage accuracy as the

predicted living stature fell within 1SEE in 63% to 70% of cases and within 2SEE in 87% to 93% of cases when utilizing multiple regression equations.

The contemporary Thai descriptive statistics were compared to the descriptive statistics of: Black South African (Bidmos and Asala, 2005), White South African (Bidmos, 2006) and Black American (Holland, 1995) populations. Statistical analyses indicated that that all measurement variables of the calcaneus show statistically significant differences between the contemporary Thai population and the Black South African population (Bidmos and Asala, 2005), except the male MAXL, MAXH, MINB and the female MAXL, MAXH, BH. Overall, the mean values of the calcaneal measurement variables, for both males and females, were larger in the contemporary Thai population than in the Black South African population (Bidmos and Asala, 2005) with the exception of the male and female MAXH, MIDB, and DAFL measurement variables. When compared to a White South African population (Bidmos, 2006), statistical analyses indicated that that all measurement variables of the calcaneus show statistically significant differences between the contemporary Thai population and the White South African population (Bidmos, 2006), except the male BH, MINB, LAL, and female BH, MINB, and MIDB measurement variables. Overall, the mean values of the calcaneal measurement variables, for both males and females, were smaller in the contemporary Thai population than in the White South African population (Bidmos, 2006), with the exception of the male and female CFH, LAL, and DAFB measurement variables, and the female MINB measurement variable. For the talus, statistical analyses indicated that all measurement variables of the talus showed a statistically significant difference between the contemporary Thai population and the Black American population (Holland, 1995).

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Overall, the mean values of the one talar measurement variable, for both males and females, were larger in the Black American population (Holland, 1995) than the contemporary Thai population. The variations in calcaneal and talar morphology between populations may be due to differences in socioeconomic status, psychosocial stress, genotype, or occupational stressors.

Overall, the results of the current research study demonstrate that regression equations for the calcaneus, which were developed on a Black South African population (Bidmos and Asala, 2005), and regression equations for the talus, which were developed on a Black American population (Holland, 1995), do not provide high enough accuracy rates for the estimation of stature in a contemporary Thai population. This finding, in addition to the comparison of descriptive statistics, further supports the notion that regression formulae for the estimation of stature are population-specific. The methods of stature estimation generated in the current research study should only be used for the Thai population and not be applied to other Southeast Asian populations.

Future research should continue to expand the data on available calcaneal and talar dimensions for the estimation of stature for contemporary Thais by collecting data across the country. The population-specific regression equations generated in the current research study would need to be tested using samples from different geographic regions in Thailand. It would be especially important to evaluate the regression equations generated in the current research study using an urban contemporary Thai population, in order to better examine the role of genetic, socioeconomic, and environmental factors on calcaneal and talar morphology. Furthermore, future studies should test the regression formulae generated in the current research study on geographically distinct populations of

Thai ancestry, as well as other Southeast Asian populations; this would help determine if these data would accurately predict stature for other Southeast Asian populations.

Lastly, future studies should aim to generate regression formulae for the estimation of stature, in the Thai population, using other skeletal elements. To date, there has only been one study completed on stature estimation in a contemporary Thai population, which used long bones (i.e. humeri, radii, ulnae, femora, tibiae, fibulae) (Mahakkanukrauh et al., 2011). The creation of regression formulae from other skeletal elements will help to determine if there are other skeletal elements that may be more accurate for the estimation of stature in a contemporary Thai population. Given that climate change events such as flooding and natural disasters are predicted to increase in both frequency and severity in Thailand, resulting in a higher number of deaths, it is crucial that population-specific methods of victim identification be derived for a Thai population. Ultimately, the creation of new regression formulae for the estimation of stature will help forensic practitioners accurately identify the remains of contemporary Thais in mass disaster contexts, and also in cases of missing persons unrelated to mass disaster scenarios.

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APPENDIX A:
CHIANG MAI SKELETAL COLLECTION RAW DATA

Catalogue No.	ID	Date of Birth	Date of Death	Age (years)	Age Group (years)	Sex	Living Height (cm)	MAXL (mm)	MAXH (mm)	CFH (mm)	BH (mm)	MINB (mm)	LAL (mm)	MIDB (mm)	DAFB (mm)	DAFL (mm)	MTAL (mm)
110/57	1	1995	2014	19	19-25	F	160	74.47	41.91	23.75	35.53	23.45	47.9	36.8	26.08	28.48	55.09
3/50	2	1981	2007	26	26-30	F	172	79.04	45.95	24.47	41.37	21.94	45.97	38.43	29.68	27.06	57.47
81/54	3	1989	2011	22	19-25	F	150	66.47	39.11	23.35	36.08	22.9	42.66	36.17	25.62	25.03	47.57
30/55	4	1982	2012	30	26-30	F	165	80.82	41.49	24.92	35.53	26.4	45.85	38.82	24.75	25.55	53.55
342/56	5	1983	2013	30	26-30	F	150	65.18	35.87	22.97	31.2	22.96	43.62	37.86	24.86	24.44	49.05
131/50	6	1976	2007	31	31-35	F	170	78.72	42.17	26.36	39.73	26.72	49.19	41.46	27.47	27.03	55.35
28/56	7	1977	2013	36	36-40	F	155	67.06	41.04	21.57	32.07	22.23	43.09	35.88	25.85	25.9	49.7
312/56	8	1976	2013	37	36-40	F	158	77.03	41.04	24.99	36.74	22.33	45.32	36.83	28.5	27.03	50.39
122/51	9	1968	2008	40	36-40	F	150	66.76	39.51	21.55	30.09	21.59	38.16	34.77	23.49	21.68	46.44
157/50	10	1963	2007	44	41-45	F	155	69.7	38.95	26.72	34.48	23.94	41.31	38.33	24.39	23.59	50.86
50/50	11	1961	2007	46	46-50	F	165	75.33	41.78	24.85	33.94	22.62	46.15	38.46	28.32	25.5	52.35
61/52	12	1960	2009	49	46-50	F	150	69.36	36.02	23	34.95	24.8	43.77	34.68	24.85	22.9	50.94
23/50	13	1957	2007	50	46-50	F	158	76.88	41.45	25.16	37.72	25.36	45.13	37.9	26.51	27.25	53.88
108/49	14	1955	2006	51	51-55	F	167	77.57	40.34	23.62	34.59	23.55	48.2	37.63	26.53	26.76	54.1
163/52	15	1955	2009	54	51-55	F	148	66.78	39.03	23.3	31.5	25.35	41.52	38.37	25.52	27.04	50.47
119/49	16	1949	2006	57	56-60	F	155	81.06	40.45	26.99	36.1	26.37	48.13	39.93	30.81	26.95	54.28
60/52	17	1950	2009	59	56-60	F	155	73.75	44.58	24.5	38.74	23	47.1	37.61	27.33	25.79	51.02
120/50	18	1947	2007	60	56-60	F	150	72.01	38.24	23.6	34.38	23.67	43.28	36.52	27.41	25.57	50.7
90/50	19	1945	2007	62	61-65	F	150	69.53	41.52	23.68	33.41	25.29	41.58	34.18	24.26	23.82	48.84
1/56	20	1949	2013	64	61-65	F	158	63.81	34.67	25.3	30.8	22.54	38.2	34.51	26.53	23.88	44.33
166/52	21	1943	2009	66	66-70	F	150	68.5	37.2	22.37	33.49	22.65	40.97	34.75	25.67	24.79	51.49
130/50	22	1938	2007	69	66-70	F	163	77.63	39.29	24.67	34.29	24.68	45.92	38.92	29.39	29.52	53.41
17/50	23	1937	2007	70	66-70	F	153	74.36	44.76	24.85	33.48	23.32	46.06	37.55	25.91	28.33	51.37
19/52	24	1936	2009	73	71-75	F	145	70.95	38.24	21.96	30.58	21.46	42.7	36.15	25.15	25.83	46.62
1/53	25	1936	2010	74	71-75	F	155	74.36	50.41	27.19	35.44	21.73	46.34	38.43	28.47	26.17	52.03
91/51	26	1930	2008	78	76-80	F	135	67.57	40.98	24.96	32.99	22.12	42.14	36.16	26.46	23.83	46.83

Catalogue No.	ID	Date of Birth	Date of Death	Age (years)	Age Group (years)	Sex	Living Height (cm)	MAXL (mm)	MAXH (mm)	CFH (mm)	BH (mm)	MINB (mm)	LAL (mm)	MIDB (mm)	DAFB (mm)	DAFL (mm)	MTAL (mm)
22/50	27	1921	2007	86	86-90	F	150	66.54	38.04	24.87	33.16	21.79	43.3	35.83	26.09	24.51	54.22
14/53	28	1923	2010	87	86-90	F	150	75.87	43.57	28.61	32.49	26.82	44.86	39.78	28.52	26.47	53.46
5408145	29	1922	2011	89	86-90	F	150	70.81	38.76	21.67	34.39	21.77	39.82	34.61	24.71	24.88	50.08
185/52	30	1987	2009	22	19-25	M	158	71.1	40.82	27.84	35.41	25.3	45.43	40.86	31.48	28.85	51.51
142/57	31	1986	2014	28	26-30	M	180	78.49	44.55	27.46	38.9	24.08	49.01	42.11	31.1	30.02	55.71
120/53	32	1981	2010	29	26-30	M	170	83.66	46.71	29.88	41.49	24.94	48.93	44.05	32.05	29.11	57.61
5310183	33	1976	2010	34	31-35	M	163	76.74	40.39	29.2	36.43	25.49	46.09	37.67	29.57	27.11	50.52
122/50	34	1971	2007	36	36-40	M	180	87.02	48.12	29.13	40.5	26.23	50.14	45.12	30.01	29.47	59.12
131/52	35	1973	2009	36	36-40	M	165	78.25	44.25	25.92	34.25	28.14	49.59	39.62	31.05	31.57	53.98
184/53	36	1974	2010	36	36-40	M	190	90.87	47.52	31.86	49.14	29.75	57.35	45	32.84	31.24	63.17
341/56	37	1975	2013	38	36-40	M	155	72.68	42.3	25.52	39.39	25.51	44.79	39.27	31.12	28.72	52.6
299/56	38	1973	2013	40	36-40	M	160	77.84	44.47	24.5	36.84	23.94	47.91	38.08	30.14	29.25	53.48
109/53	39	1967	2010	43	41-45	M	150	73.69	38.7	25.28	32.45	25.83	43.55	40.08	26.12	26.36	51.62
1/50	40	1963	2007	44	41-45	M	156	80.81	44.5	24.89	38.02	25.21	49.06	39.23	27.51	26.43	59.92
95/50	41	1958	2007	49	46-50	M	165	76.57	40.41	21.69	40.13	26.27	45.12	39.91	30.81	31.4	51.1
35/52	42	1954	2009	55	51-55	M	170	87.48	42.25	28.61	40.77	28.29	54.01	44.37	30.05	31.96	62.38
113/52	43	1953	2009	56	56-60	M	172	85.57	41.08	31.15	38.21	29.15	50.65	43.98	27.47	32.23	59.72
69/50	44	1950	2007	57	56-60	M	170	82.49	41.63	27.47	39.7	25.56	50.91	43.55	31.2	30.08	57.66
70/56	45	1955	2013	58	56-60	M	170	76.59	43.17	27.52	36.46	26.46	47.89	40.6	28.51	27.25	55.42
182/52	46	1950	2009	59	56-60	M	160	83.63	47.12	25.58	41.7	29.1	51.43	41.04	30.91	28.95	54.64
47/50	47	1946	2007	61	61-65	M	172	80.18	42.31	26.59	40.85	24.51	48.85	40.29	29.7	29.99	57.06
43/51	48	1946	2008	62	61-65	M	155	76.44	42.64	24.42	41.65	23.23	47.15	38.19	29.6	27.76	57.05
64/50	49	1943	2007	64	61-65	M	162	79.59	40.06	27.53	39.89	25.31	49.23	39.97	30.48	29.49	57.16
21/52	50	1943	2009	66	66-70	M	165	84.4	43.58	28.66	42.24	27.67	47.27	41.61	27.17	32.25	57
12/50	51	1938	2007	69	66-70	M	160	84.6	42.83	26.25	38.78	28.47	48.45	41.96	31.03	30.97	55.92
17/52	52	1939	2009	70	66-70	M	166	76.03	44.66	27.41	37.57	26.92	49.73	39.95	28.4	31.16	57.18

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| Catalogue No.	ID	Date of Birth	Date of Death	Age (years)	Age Group (years)	Sex	Living Height (cm)	MAXL (mm)	MAXH (mm)	CFH (mm)	BH (mm)	MINB (mm)	LAL (mm)	MIDB (mm)	DAFB (mm)	DAFL (mm)	MTAL (mm)
186/55	53	1936	2012	76	76-80	M	157	75.03	40.33	24.92	37.85	24.96	47.67	42.67	29.93	27.96	50.24
70/50	54	1928	2007	79	76-80	M	170	84.23	44.92	27.41	41.66	25.98	51	42.7	27.45	28.17	59.54
33/50	55	1927	2007	80	76-80	M	173	83.5	49.47	29.1	39.64	26.39	48.11	41.1	30.3	30.23	56.43
14/50	56	1924	2007	83	81-85	M	178	81.58	43.18	21.5	40.07	26.97	48.21	40.01	29.29	28.98	51.68
140/57	57	1925	2014	89	86-90	M	155	74.83	39.18	25.85	36.57	22.13	47.01	36.9	27.74	28.09	52.34
116/53	58	1914	2010	96	96-100	M	150	78.45	40.66	26.41	36.96	23.12	49.78	41.4	29.34	29.25	56.94
5405075	59	1968	2011	43	41-45	F	160	78.17	42.35	27.42	36.62	21.78	48.03	39.4	27.69	26.64	50.66
5405067	60	1968	2011	43	41-45	F	157	72.32	38.41	24.43	34.19	23.57	42.77	35.43	26.39	23.1	48.93
5408150	61	1966	2011	45	41-45	F	170	79.5	50.16	25.34	37.47	26.38	49.26	41.13	27.6	28.64	57.32
160/52	62	1963	2009	46	46-50	F	165	79.39	44.7	25.37	35.14	23.17	45.86	36.5	24.01	25.81	54.68
153/52	63	1962	2009	47	46-50	F	165	79.33	38.67	26.31	33.06	23.09	46.27	37.87	28.16	25.94	48.34
25/52	64	1961	2009	48	46-50	F	155	73.22	42.12	22.14	38.5	20.9	45.69	35.8	57.5	26.14	51.78
70/53	65	1961	2010	49	46-50	F	140	64.27	36.13	22.9	34.99	22.6	40.88	36.16	29.62	23.28	44.19
224/53	66	1961	2010	49	46-50	F	155	74.29	43.53	27.63	38.15	22.83	43.17	34.56	27.44	24.83	48.35
5305098	67	1960	2010	50	46-50	F	160	68.36	37.72	23.95	33.13	24.98	43.57	38.96	25.36	26.01	50.04
9/54	68	1961	2011	50	46-50	F	160	79.62	42.37	26.11	35.53	25.47	47.43	39.74	27.83	28.49	53.69
138/57	69	1963	2014	51	51-55	F	160	71.61	38.86	24.6	35.38	23.64	44.75	37.46	28.27	25.3	53.99
109/57	70	1964	2014	50	46-50	F	150	67.52	37.48	23.36	34.24	20.37	43.11	35.89	23.36	25.05	49.08
95/51	71	1956	2008	52	51-55	F	150	68.72	39.91	24.51	31.38	23.96	42.23	34.75	25.55	24.51	47.1
6/52	72	1954	2009	55	51-55	F	160	71.02	39.95	23.96	34.83	22.02	44.49	33.99	26.35	27.75	49.28
5401017	73	1956	2011	55	51-55	F	155	70.99	39.21	24.09	34.11	24.16	42.76	36.29	21.83	23.92	45.13
184/52	74	1954	2009	55	51-55	F	159	78.01	44.15	22.79	34.9	26.13	44.87	37.69	27.73	25.22	51.64
5407110	75	1955	2011	56	56-60	F	150	75.18	37.47	23.98	33.16	23.72	43.53	35.25	25.51	23.77	50.42
38/52	76	1951	2009	58	56-60	F	150	69.25	36.15	21.15	32.22	22.04	41.13	34.46	24.24	23.26	44.22
289/55	77	1953	2012	59	56-60	F	150	71.36	40.01	26.25	32.73	22.89	43.08	35.22	27.64	25.8	46.47
5305094	78	1951	2010	59	56-60	F	155	72.81	35.44	23.66	31.63	21.06	46.47	35.05	26.82	27.61	51.49

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48/53	79	1949	2010	61	61-65	F	150	73.96	35.48	21.53	31.94	21.1	45.83	34.83	24.86	23.7	47.66
271/56	80	1952	2013	61	61-65	F	155	71.91	37.66	22.89	32.23	20.85	44.07	36.49	24.06	25.03	52.63
74/52	81	1947	2009	62	61-65	F	155	70.79	40.81	21.21	31.19	23.84	42.7	38.45	27.42	24.48	48.01
77/50	82	1945	2007	62	61-65	F	160	78.34	41.07	23.31	32.94	23.05	47.02	36.21	24.89	26.3	49.64
5407126	83	1949	2011	62	61-65	F	150	73.66	36.69	25.49	29.7	22.89	43.97	34.86	23.78	25.47	47.7
5402023	84	1958	2011	53	51-55	F	165	82.38	43.07	28.47	41.21	30.7	46.71	44.14	30.96	31.66	59.27
133/52	85	1947	2009	62	61-65	F	150	72.38	37.48	22.53	32.56	22.68	41.65	37.62	26.01	22.6	44.55
108/50	86	1944	2007	63	61-65	F	145	68.49	38.08	22.12	29.03	21.72	39.7	36.67	23.25	23.56	47.25
40/51	87	1945	2008	63	61-65	F	150	76.55	40.88	27.27	38.18	26.86	47.06	38.19	26.79	28.35	56.49
199/51	88	1945	2008	63	61-65	F	150	74.11	35.01	23.29	32.23	26.09	43.29	37.65	27.19	25.95	46.69
25/56	89	1950	2013	63	61-65	F	150	68.12	35.54	22.61	34.09	21.45	43.1	34.65	25.61	26.41	46.34
5409174	90	1947	2011	64	61-65	F	160	69.93	39.84	24.55	36.85	20.88	43.72	36.24	26.61	24.42	46.58
49/50	91	1942	2007	65	61-65	F	170	84.05	45.72	24.01	35.3	25.54	47.12	38.01	26.26	29.15	52.65
31/52	92	1944	2009	65	61-65	F	146	69.9	40.3	23.58	34.52	24	42.38	35.9	22.5	24.96	49.07
53/52	93	1944	2009	65	61-65	F	155	69.97	37.25	26.34	34.57	22.99	42.42	38.41	30.59	26.59	51.31
84/50	94	1941	2007	66	66-70	F	160	73.14	43.16	25.13	30.5	20.24	45.27	37.63	25.42	25.65	51.53
151/52	95	1943	2009	66	66-70	F	140	67.01	38.04	23.24	31.08	24.07	41.28	34.12	25.18	24.1	45.28
5212188	96	1943	2009	66	66-70	F	160	75.17	39.06	25.92	33.78	24.22	44.91	36.16	28.22	27.25	50.45
5312238	97	1943	2010	67	66-70	F	150	72.05	35.13	24.41	35.72	22.9	43.58	35.55	25.13	24.27	49.46
5402033	98	1944	2011	67	66-70	F	150	76.66	38.42	28.05	33.18	21.5	43.48	36.26	26.54	25.72	48.17
5308140	99	1943	2010	67	66-70	F	145	70.4	37.42	23.47	32.45	23.57	42.63	38.63	25.96	27.52	48.17
101/51	100	1940	2008	68	66-70	F	140	75.48	37.35	27.37	34.51	21.41	41.78	37.68	23.26	24.72	47.67
159/52	101	1940	2009	69	66-70	F	150	72.89	40.41	26.52	32.05	25.15	43.49	36.83	28.08	25.65	49.92
5404056	102	1942	2011	69	66-70	F	150	70.67	36.64	19.86	31.39	21.62	45.08	38.72	25.06	26.46	50.81
61/50	103	1938	2007	69	66-70	F	158	73.83	36.85	25.85	37.74	22.64	45.37	36.55	25.42	28.27	45.69
164/52	104	1939	2009	70	66-70	F	150	71.77	38.87	24.06	30.17	19.99	42.12	34.33	26.86	25.21	49.24

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44/52	105	1938	2009	71	71-75	F	155	78.14	38.06	25.89	34.52	24	46.37	38.53	27.91	26.52	49.38
5409168	106	1940	2011	71	71-75	F	140	67.61	39.8	24.3	31.63	25.15	41.02	36.45	25.58	24.76	49.32
103/50	107	1935	2007	72	71-75	F	145	72.66	41.13	24.59	33.54	24.52	46.56	36.28	25.84	28.1	48.96
149/52	108	1937	2009	72	71-75	F	150	70.53	39.257	23.2	35.71	22.94	43.66	36.26	25.35	25.38	51.72
57/53	109	1938	2010	72	71-75	F	150	72.76	37.04	23.09	34.13	23.26	42.99	37.08	23.1	24.96	48.59
32/56	110	1941	2013	72	71-75	F	150	74.62	40.27	24.11	35.2	22.29	43.8	37.23	25.41	26.72	48.01
42/52	111	1936	2009	73	71-75	F	155	76.23	38.37	24.01	31.77	25.8	44.93	37.85	26.84	26.39	50.09
76/52	112	1936	2009	73	71-75	F	150	78.67	41.38	24.44	38.16	25.9	44.24	38.52	25.66	24.99	49.4
160/57	113	1941	2014	73	71-75	F	145	69.91	33.61	22.97	30.66	21.45	40.39	35.33	24.75	24.01	47.96
279/56	114	1939	2013	74	71-75	F	150	81.13	44.53	25.89	36.88	25.99	45.21	37.94	30.58	28.09	54.05
99/49	115	1931	2006	75	71-75	F	155	73.51	36.4	22.68	34.94	21.96	42.16	35.74	24.44	25.07	48.85
102/49	116	1931	2006	75	71-75	F	160	72.44	36.31	23.13	33.65	19.67	41.06	35.79	24.16	25.75	48.78
57/51	117	1933	2008	75	71-75	F	155	76.2	43.14	25.17	35.47	25.19	44.34	41.1	27.76	27.74	52.1
78/56	118	1937	2013	76	76-80	F	152	74.88	39.84	24.21	33.56	24.64	44.26	35.53	25.76	25.85	51.8
23/56	119	1936	2013	77	76-80	F	150	74.09	38.57	21.58	33.53	22.44	43.89	35.18	24.22	25.38	46.17
99/50	120	1930	2007	77	76-80	F	153	67.4	37.86	25.2	33.48	25.89	43.82	37.31	26.1	26.49	47.33
42/51	121	1931	2008	77	76-80	F	150	74.46	36.6	25.32	33.04	23.53	42.9	38.2	26.72	25.24	50.12
11/53	122	1932	2010	78	76-80	F	155	73.67	37.18	22.37	32.97	24.9	43.95	36.71	25.82	26.42	45.92
111/56	123	1935	2013	78	76-80	F	156	76.21	46.41	23.16	33.77	23.17	48.55	39.4	24.74	28.81	55.83
5311203	124	1930	2010	80	76-80	F	150	73.32	39.4	24.31	34.1	24.32	43.11	36.92	27.01	24.43	51.51
5402035	125	1931	2011	80	76-80	F	153	77.91	44.34	26.24	37.13	21.96	47.85	39.64	26.11	25.82	51.8
46/53	126	1928	2010	82	81-85	F	155	76.65	36.52	23.49	34.37	22.9	41.49	37.09	25.75	25.15	46.21
229/54	127	1929	2011	82	81-85	F	140	75.56	36.58	23.42	34.72	22.36	41.23	37.03	25.19	25.49	45.3
5401021	128	1929	2011	82	81-85	F	150	78.4	42.93	27.13	35.91	22.94	48.83	37.97	29.31	29.27	54.31
149/55	129	1930	2012	82	81-85	F	140	78.49	45.93	28.71	39.34	25	49.4	41.71	28.3	27.95	55.06
114/49	130	1923	2006	83	81-85	F	150	70.71	41.99	22.96	37.25	24.89	46.95	36.28	26.59	26.75	51.02

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42/53	131	1927	2010	83	81-85	F	166	80.17	43.55	23.85	39.52	25.54	45.28	40.46	28.07	28.03	52.62
5401008	132	1927	2011	84	81-85	F	150	75.39	30.14	25.59	34.43	24.83	42.27	36.53	25.88	26.24	47.67
88/56	133	1929	2013	84	81-85	F	160	74.3	37.88	24.72	36.6	25.02	41.4	36.15	24.2	27.24	51
385/56	134	1928	2013	85	81-85	F	150	68.12	27.24	21.77	31.51	19.37	40.57	31.93	23.41	22.89	47.19
115/49	135	1921	2006	85	81-85	F	150	77.06	44.01	22.73	35.16	24.66	46.73	36.99	25.35	27.27	51.26
5401020	136	1926	2011	85	81-85	F	153	76.46	41.68	22.52	37.72	21.55	48.19	39.93	27.37	27.74	53.78
197/51	137	1922	2008	86	86-90	F	145	67.18	33.47	21.28	32.27	21.98	39.31	34.93	25.6	21.54	47.58
55/52	138	1923	2009	86	86-90	F	150	69.83	37.39	24.3	32.33	22.11	42.62	35.61	25.75	25.56	48.17
5406103	139	1924	2011	87	86-90	F	140	67.41	36.41	22.71	34.16	20.65	42.66	34.66	24.09	25.72	49.64
5405072	140	1923	2011	88	86-90	F	140	69.64	33.78	23.89	32.16	24.55	41.09	37.19	24.69	24.13	45.67
3/57	141	1926	2014	88	86-90	F	145	69.5	36.13	21.36	32.24	23.57	41.73	35.51	25.59	23.76	47.73
113/49	142	1915	2006	91	91-95	F	150	77.85	39.59	24.89	34.21	23.83	45.54	41.71	27.88	28.21	48.14
191/54	143	1975	2011	36	36-40	M	165	83.59	46.16	27.95	38.78	25.89	51.23	41.29	29.53	29.84	59.16
61/56	144	1977	2013	36	36-40	M	162	79.31	46.22	25.55	43.12	25.08	51.16	42.94	31.5	28.95	60.5
181/52	145	1972	2009	37	36-40	M	165	77.03	42.52	25.88	38.06	22.4	46.49	38.35	27.96	26.74	54.73
165/52	146	1970	2009	39	36-40	M	165	82.55	42.53	26.88	38.08	26.72	48.76	41.23	28.01	28.43	58.03
55/53	147	1969	2010	41	41-45	M	170	77.22	40.93	26.75	36.72	25.81	48.1	41.46	30.78	29.77	58.3
49/53	148	1968	2010	42	41-45	M	165	75.75	42.49	24.88	39.12	21.55	45.27	37.35	28.49	27.51	52.94
328/56	149	1970	2013	43	41-45	M	160	75.36	39.8	23.69	37.24	25.63	45.81	38.99	26.94	27.69	54.02
369/56	150	1970	2013	43	41-45	M	175	81.57	43.82	22.86	37.41	25.8	47.46	39.94	27.03	28.15	54.81
35/50	151	1963	2007	44	41-45	M	176	77.59	44.88	26.09	40.18	27.01	48.06	39.15	28.59	29.09	60.47
53/50	152	1963	2007	44	41-45	M	168	86.68	49.58	29.34	39.64	27.16	52.11	40.57	30.95	31.25	59.2
145/50	153	1963	2007	44	41-45	M	160	79.39	38.7	22.16	40.91	26.1	48.94	41.6	26.65	28.53	51.95
5408137	154	1964	2011	47	46-50	M	150	75.52	41.49	26.96	39.9	23.43	45.87	38.66	30.96	28.51	55.43
67/55	155	1964	2012	48	46-50	M	170	87.09	47.15	26.41	39.73	23.44	52.42	41.4	32.49	30.9	60.14
256/55	156	1956	2012	56	56-60	M	172	83.03	43.3	25.59	41.66	24.65	51.17	40.27	30.27	29.47	59.28

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15/56	157	1956	2013	57	56-60	M	165	73.88	39.11	25.75	34.7	23.73	45.14	38.5	29.95	27.8	57.78
150/57	158	1956	2014	58	56-60	M	176	88.37	44.89	28.36	43.01	26.46	50.02	40.47	30.73	30.6	58.52
75/50	159	1949	2007	58	56-60	M	170	82.66	48.28	26.1	41.04	23.87	54.74	41.13	28.76	26.33	63.19
5404051	160	1952	2011	59	56-60	M	165	79.32	45.66	26.58	41.46	23.53	46.5	38.45	30.2	28.06	53.2
5402024	161	1951	2011	60	56-60	M	165	79.04	44.61	26.85	40.28	26.12	45.44	40.74	27.74	28.78	58.57
54/50	162	1946	2007	61	61-65	M	180	84.07	47.95	25.1	41.9	27.64	49.41	44.18	30.01	27.74	60.89
104/50	163	1946	2007	61	61-65	M	164	76.76	40.48	22.91	35.35	25.69	44.6	40.05	25.33	22.13	52.74
5409159	164	1950	2011	61	61-65	M	165	85.31	43.5	25.76	41.9	28.02	49.58	43.53	29.98	31.06	58.48
185/57	165	1953	2014	61	61-65	M	170	78.63	41.29	25.55	37.58	28.95	49.12	41.51	29.95	32.48	53.73
27/52	166	1947	2009	62	61-65	M	175	81.64	43.72	26.72	42.44	26.19	50.89	46.21	30.39	30.58	60.38
5405084	167	1949	2011	62	61-65	M	166	81.75	42.7	28.24	37.52	25.45	48.69	42.78	28.51	29.32	55.8
266/55	168	1950	2012	62	61-65	M	180	80.81	45.23	25.73	37.87	24.95	50.85	41.96	27.74	29.81	61.47
41/50	169	1944	2007	63	61-65	M	170	80.86	38.05	27.78	36.98	26.11	47.58	41.95	25.08	27.56	49.54
65/51	170	1945	2008	63	61-65	M	170	86.29	43.25	25.92	36	23.39	50.32	40.64	28.41	27.57	59.94
71/52	171	1945	2009	64	61-65	M	170	84.42	45.9	29.53	38.88	27.52	50.18	40.16	29.45	30.37	59.8
5406097	172	1947	2011	64	61-65	M	160	76.38	34.45	22	41.17	23.95	46.67	41.7	31.19	30.65	55.1
101/52	173	1945	2009	64	61-65	M	164	82.07	41.81	28.88	39.02	25.78	49.03	41.27	30.37	30.58	58.03
4/50	174	1942	2007	65	61-65	M	166	80.38	45.82	26.27	38.98	25.5	48.76	41.65	31.73	30.64	56.63
185/55	175	1947	2012	65	61-65	M	153	78.97	41.77	27	34.88	26.17	45.11	40.15	28.97	26.55	51.8
60/51	176	1943	2008	65	61-65	M	180	90.29	44.74	29.59	41.87	26.77	52.79	39.63	29.05	28.66	58.63
66/56	177	1948	2013	65	61-65	M	170	80.65	46.32	27.64	37.85	23.53	48.47	40.53	29.8	29.75	54.06
29/50	178	1940	2007	67	66-70	M	170	81.81	42.72	28.18	36.97	24.7	48.98	38.74	31.09	29.88	56.15
83/51	179	1941	2008	67	66-70	M	180	87.7	48.78	29.64	42.18	27.36	50.06	41.32	34.44	30.89	58.62
47/53	180	1943	2010	67	66-70	M	165	76.92	43.67	24.96	39.16	24.98	49.38	39.92	26.43	28.93	57.46
78/53	181	1942	2010	68	66-70	M	161	77.31	43.38	25.71	38.28	27.97	48.41	40.93	30.62	29.4	54.13
31/50	182	1938	2007	69	66-70	M	160	77.42	42.1	26.58	39.31	25.01	49.12	40.33	28.44	29.43	54.77

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81/51	183	1939	2008	69	66-70	M	180	84.34	47.16	28.05	41.74	25.68	48.83	44.61	29.71	28.81	59.75
18/53	184	1941	2010	69	66-70	M	180	91.86	51	31.57	42.39	30.26	54.26	42.38	32.06	33.07	67.08
41/54	185	1942	2011	69	66-70	M	157	79.6	45.9	29.34	39.86	24.17	48.26	41.4	29.53	28.37	54.94
110/49	186	1935	2006	71	71-75	M	165	83.88	45.18	25.5	41.35	25.71	48.88	42.66	27.59	26.11	59.61
118/49	187	1935	2006	71	71-75	M	165	71.45	31.32	23.62	34.69	24.29	42.32	35.7	26.53	27.24	48.2
13/50	188	1935	2007	72	71-75	M	170	82.14	48.67	24.78	39.03	25.62	49.08	42	32.89	29.6	55.31
62/50	189	1935	2007	72	71-75	M	170	85.89	41.43	26.6	39.15	25.8	53.62	42.32	30.55	31.55	58.08
5307124	190	1937	2010	73	71-75	M	170	78.18	47.61	24.76	35.85	23.92	51.03	40.95	26.42	28.5	53.92
5405079	191	1938	2011	73	71-75	M	160	79.75	43.89	26.28	39.78	26.32	49.37	41.19	28.57	29.13	55.22
54/56	192	1940	2013	73	71-75	M	165	87.3	47.69	28.61	42.88	28.07	53.63	42.32	31.84	33.9	58.22
43/53	193	1936	2010	74	71-75	M	170	82.31	45.99	27.78	45.48	23.84	49.93	39.96	27.5	28.46	58.61
8/53	194	1935	2010	75	71-75	M	150	76.18	41.15	22.17	36.06	24.8	45.2	39.23	25.43	26.42	51.09
18/52	195	1934	2009	75	71-75	M	160	81.74	42.12	28.97	39.57	25.01	48.37	43.83	31.73	32.57	58.82
192/52	196	1934	2009	75	71-75	M	166	81.24	44.14	27.46	37.58	22.1	49.89	41.6	24.56	28.61	59.59
5304080	197	1934	2010	76	76-80	M	153	74.19	45.62	27.22	35.56	24.08	47.76	39.11	25.77	29.15	55.19
120/56	198	1937	2013	76	76-80	M	167	86.68	51.94	32.29	38.8	27.07	51.67	40.31	28.53	28.69	57.01
63/50	199	1929	2007	78	76-80	M	165	78.32	43.42	28.35	34.33	27.45	53.58	46.57	32.31	31.95	57.01
61/53	200	1932	2010	78	76-80	M	156	72.54	37.81	23.26	35.83	23.37	44.34	35.1	27.2	26.17	50.27
134/50	201	1927	2007	80	76-80	M	160	86.42	47.81	28.89	41.21	24.14	52.78	40.56	29.62	30.64	56.67
5404066	202	1930	2011	81	81-85	M	155	72.84	43.01	26.37	32.88	25.26	45.87	37.59	26.8	27.29	50.57
5401003	203	1930	2011	81	81-85	M	165	80.22	43.18	25.69	38.81	24.77	48.6	37.34	27.73	28.02	56.85
288/55	204	1931	2012	81	81-85	M	160	76.59	43.86	26.78	40.74	24.3	47.02	40.72	28.05	29.94	52.91
2/53	205	1928	2010	82	81-85	M	160	78.7	43.98	25.1	38.08	25	45.82	39.11	27.5	31.21	54.12
48/56	206	1931	2013	82	81-85	M	155	78.33	38.73	26.56	35.34	22.92	46.76	39.16	27.39	28.05	53.57
76/50	207	1924	2007	83	81-85	M	165	75.97	41.58	27.28	36.03	26.57	46.67	41.15	31.19	29.79	54.78
5/54	208	1927	2011	84	81-85	M	167	79.74	45.2	27.71	35.91	23.86	44.82	38.39	28.06	25.46	54.17

Catalogue No.	ID	Date of Birth	Date of Death	Age (years)	Age Group (years)	Sex	Living Height (cm)	MAXL (mm)	MAXH (mm)	CFH (mm)	BH (mm)	MINB (mm)	LAL (mm)	MIDB (mm)	DAFB (mm)	DAFL (mm)	MTAL (mm)
32/50	209	1922	2007	85	81-85	M	168	75.65	42.52	26.11	36.12	24.5	48.75	40.43	28.44	29.78	50.37
24/53	210	1925	2010	85	81-85	M	167	80.53	46.33	24.53	34.81	26.81	47.86	44.21	31.58	29.05	60.93
15/50	211	1922	2007	85	81-85	M	155	69.11	42.95	25.33	38.78	24.98	42.61	40.69	26.89	26.67	50.34
5409160	212	1926	2011	85	81-85	M	170	87.79	37.29	29.13	39.54	25.27	47.18	38.97	26.82	27.42	57.33
171/55	213	1927	2012	85	81-85	M	180	81.8	42.17	27.6	38.82	27.47	49.26	37.05	23.4	31.06	53.46
347/56	214	1928	2013	85	81-85	M	155	77.22	41.07	29.62	35.54	24.77	45.85	40.57	26.12	27.25	53.79
9/52	215	1923	2009	86	86-90	M	170	78.85	41.44	26.27	37.89	29.99	47.56	45.28	29.88	27.67	57.71
62/53	216	1924	2010	86	86-90	M	155	76.16	40.12	26.67	37.5	23.43	45.23	40.33	24.47	29.49	48.98
55/56	217	1927	2013	86	86-90	M	160	81.5	44.74	27.17	38.4	27.18	50.28	42.12	30.66	29.22	55.29
143/50	218	1920	2007	87	86-90	M	160	80.23	46.47	26.97	41.06	24.26	48.24	40.02	30.02	30.94	57.46
178/51	219	1921	2008	87	86-90	M	175	85.67	46.11	31.84	39.59	28.17	48.99	42.88	29.92	30.34	58.15
5406096	220	1923	2011	88	86-90	M	165	84.84	47.18	27.06	39.34	24.63	53.24	40.71	28.53	29.06	59.95
5409180	221	1923	2011	88	86-90	M	160	82.06	43.55	25.63	39.29	25.9	49.49	39.23	27.04	29.87	55.38
25/51	222	1917	2008	91	91-95	M	170	83.51	43.66	25.68	43.03	27.28	52.53	44.67	31.19	31	59.24
21/53	223	1919	2010	91	91-95	M	178	82.41	48.57	23.02	43.64	25.91	51.82	42.02	30.31	28.72	57.7
5/50	224	1913	2007	94	91-95	M	160	78.38	41.59	25.04	35.82	26.54	46.22	43.92	30.66	28.91	56.54
230/54	225	1917	2011	94	91-95	M	175	85.58	51.98	28.69	43.24	27.32	48.84	40.08	29.4	32.25	60.36
5312243	226	1929	2010	81	81-85	F	148	68.58	41.12	22.69	36.8	22.99	41.96	35.72	25.3	25.22	48.74
41/56	227	1940	2013	73	71-75	M	170	72.54	38.84	26.33	36.05	27.77	43.83	39.65	27.95	26.1	51.56
5407117	228	1951	2011	60	56-60	F	150	67.87	39.74	23.9	34.24	22.39	42.98	37.35	24.8	25.28	48.39
89/50	229	1936	2007	71	71-75	F	150	79.74	39.9	28.11	33.92	25.6	49.4	41.93	27.16	28.79	51.52
5406095	230	1927	2011	84	81-85	M	160	82.08	44.61	27.44	35.64	22.58	46.93	41.39	28.2	29.32	55.93
39/50	231	1951	2007	56	56-60	M	170	84.63	47.75	27.52	37.24	28.91	49.83	43.33	32.43	30.62	62.1
186/52	232	1926	2009	83	81-85	F	153	76.84	38.97	24.3	33.86	23.42	45.62	37.35	28.24	27.6	50.54
121/50	233	1938	2007	69	65-70	M	170	82.66	46.7	28.27	40.19	27.1	47.78	40.16	28.36	28.82	54.78

APPENDIX B:
EXAMPLES OF CALCANEAL AND TALAR PATHOLOGIES
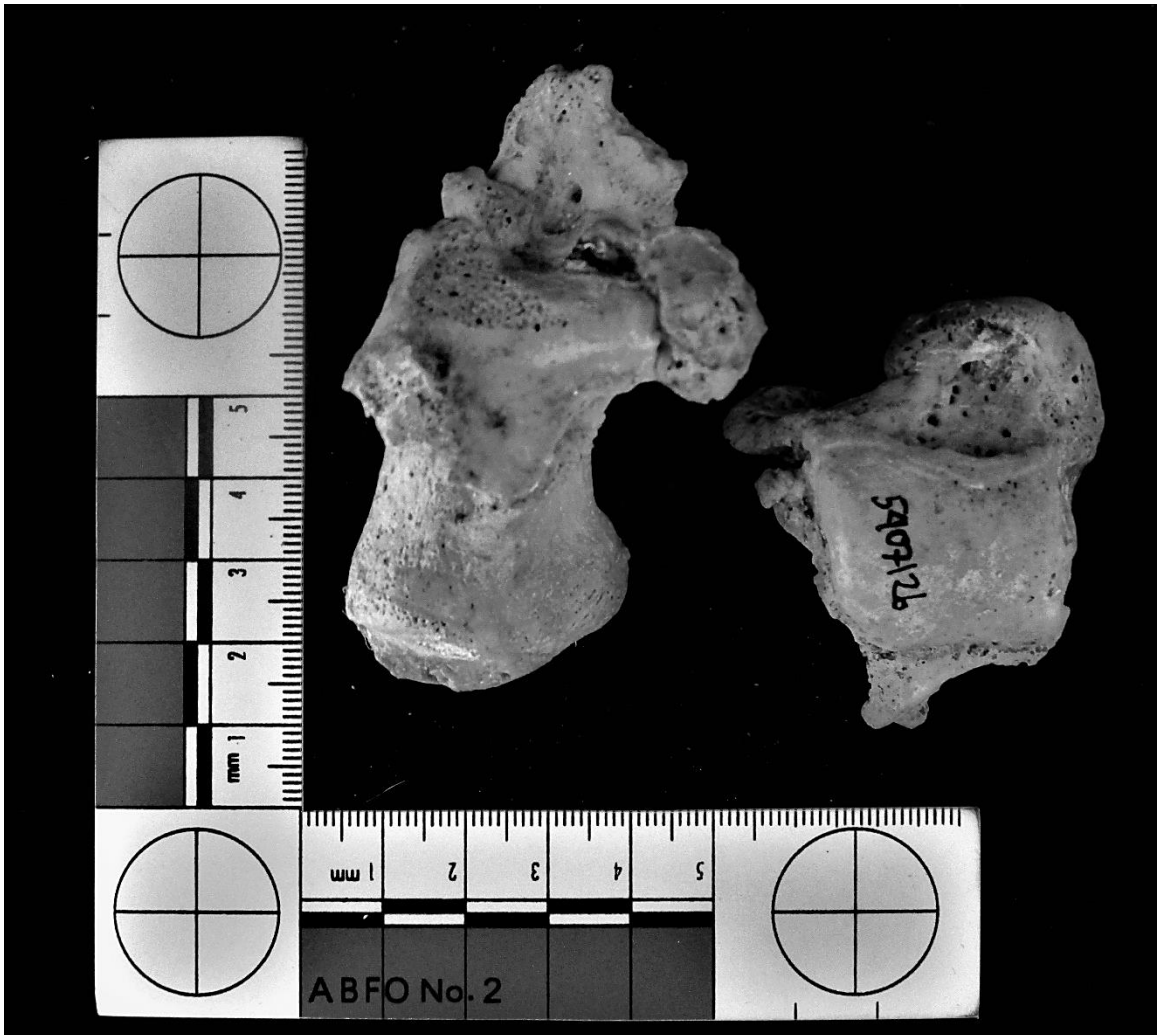
Appendix B1: Example #1 of pathological left calcaneus and left talus, excluded from analyses.
 (Catalogue number: 5407126) (Photo by: Shelby Scott)

Appendix B2: Example #2 of pathological left calcaneus and left talus, excluded from analyses.
(Catalogue number: 79-52) (Photo by: Shelby Scott)

Appendix B3: Example of degraded left calcaneus and left talus, excluded from analyses.
(Catalogue number: 271-56) (Photo by: Shelby Scott)
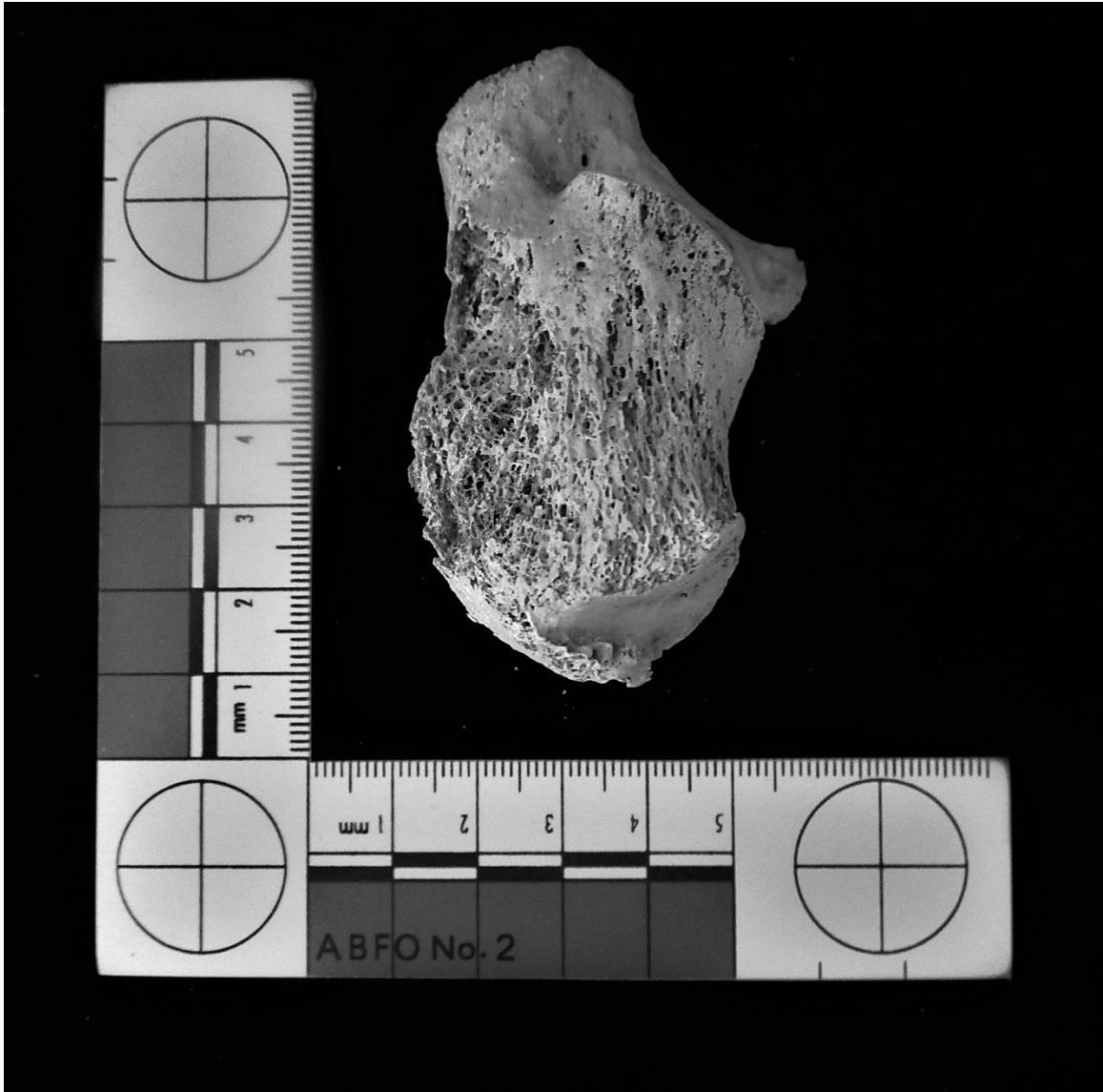
Appendix B4: Example of degraded left calcaneus, excluded from analyses.
(Catalogue number: 5301017) (Photo by: Shelby Scott)

APPENDIX C:
NORMALITY TESTS
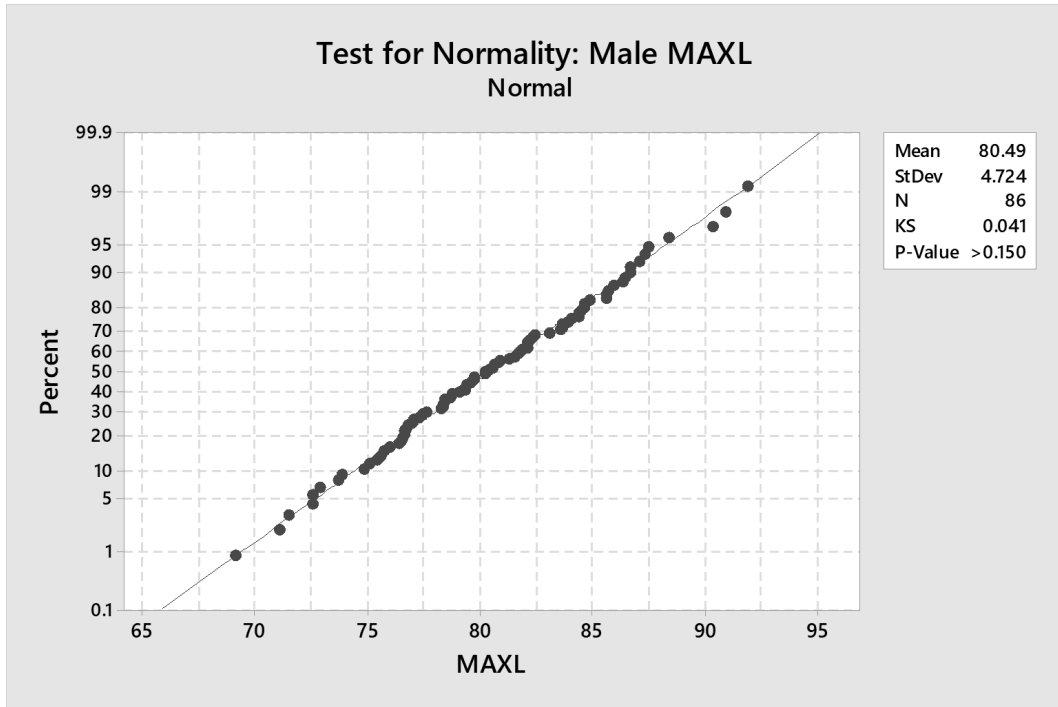
Appendix C1: Normality probability plot for male MAXL (Maximum Length) calcaneal measurements.
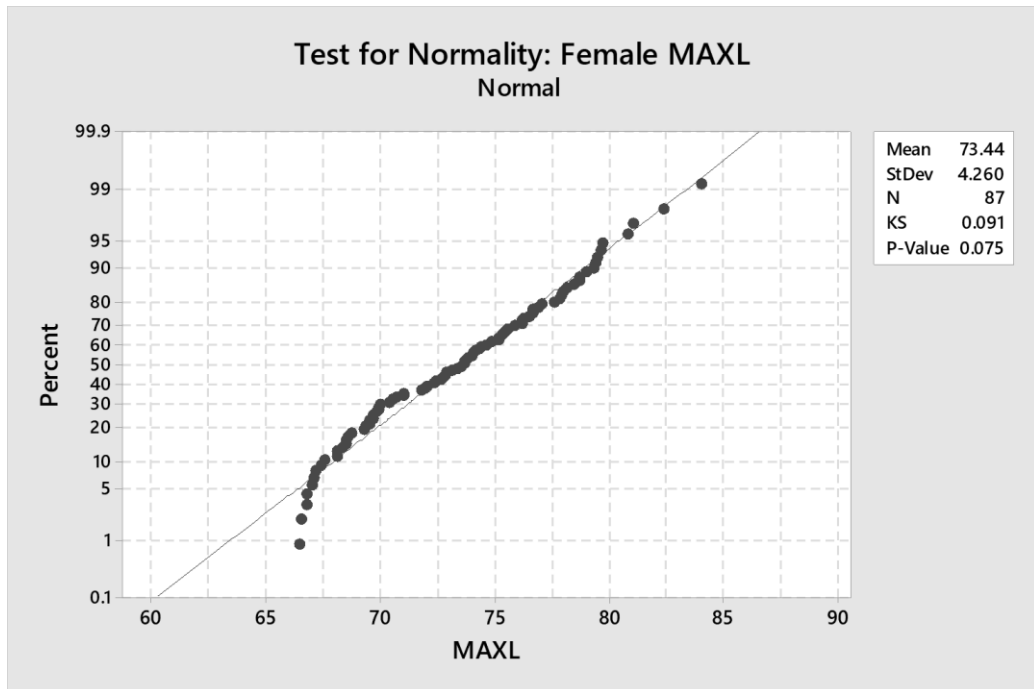
Appendix C2: Normality probability plot for female MAXL (Maximum Length) calcaneal measurements.
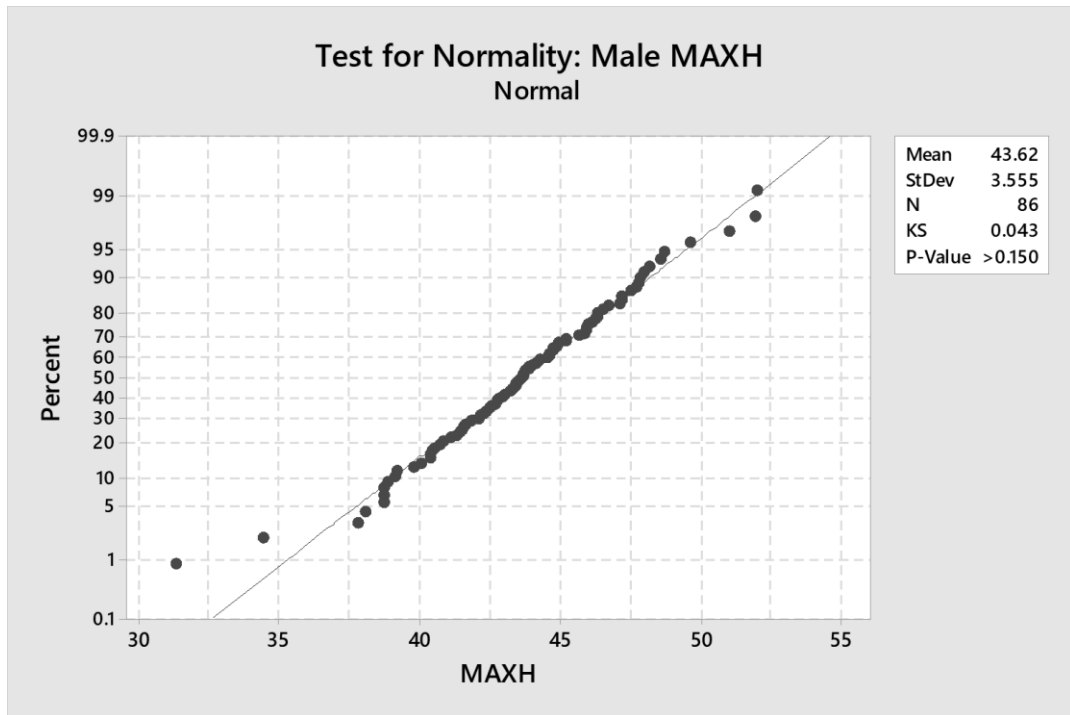
Appendix C3: Normality probability plot for male MAXH (Maximum Height) calcaneal measurements
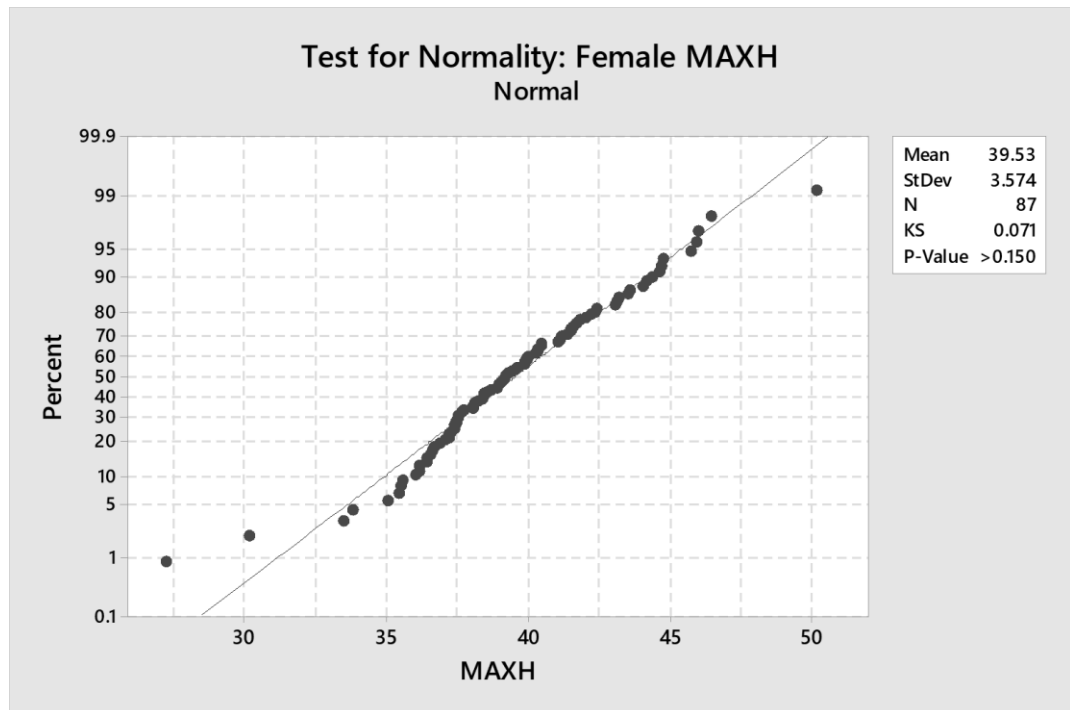
Appendix C4: Normality probability plot for female MAXH (Maximum Height) calcaneal measurements.
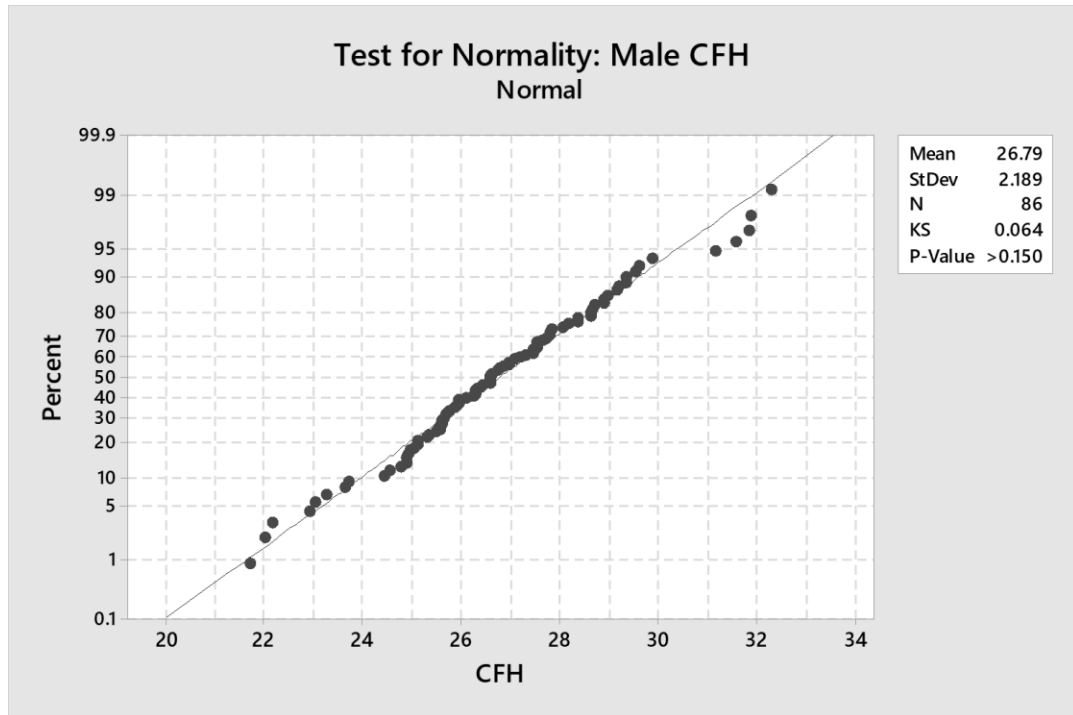
Appendix C5: Normality probability plot for male CFH (Cuboidal Facet Height) calcaneal measurements.
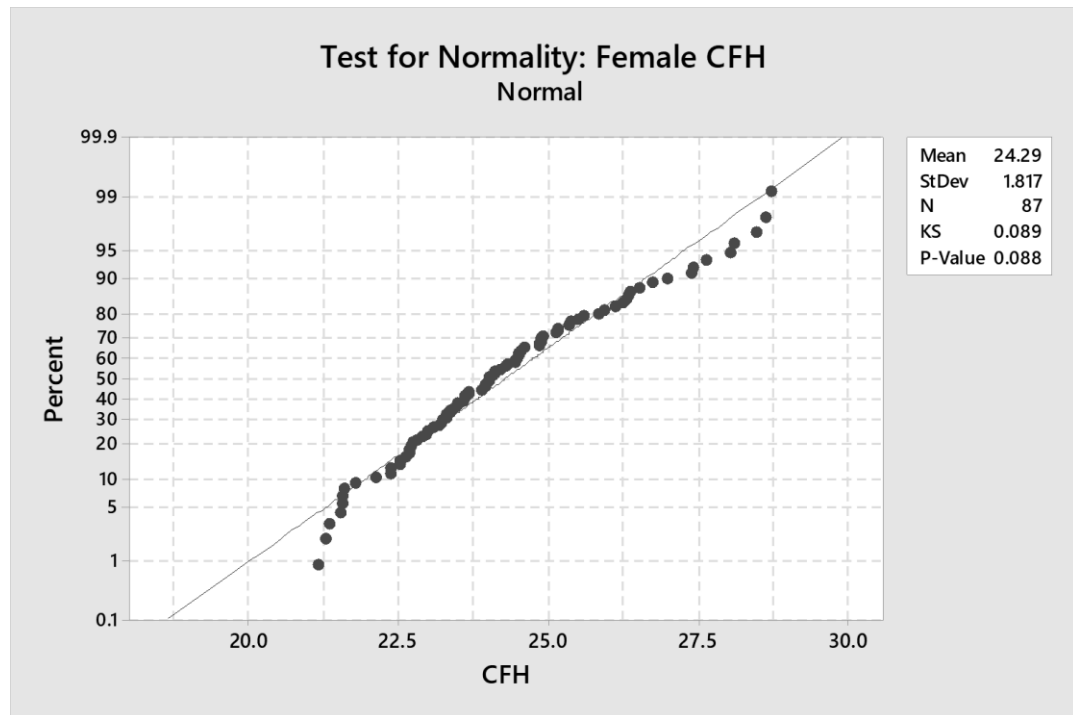
Appendix C6: Normality probability plot for female CFH (Cuboidal Facet Height) calcaneal measurements.
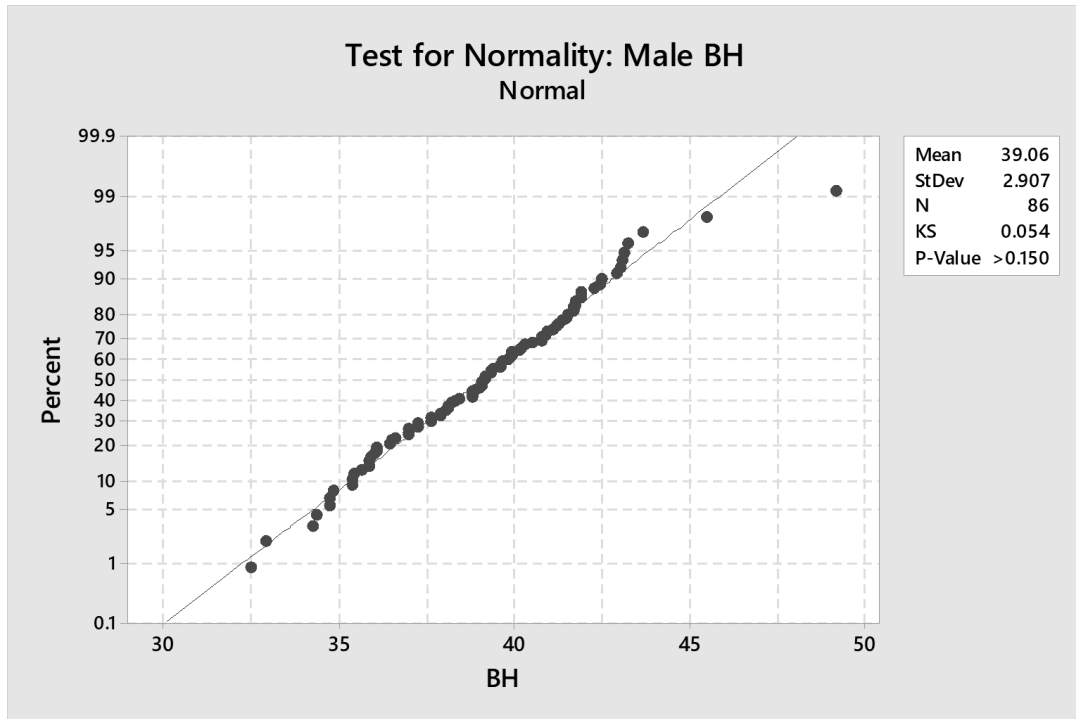
Appendix C7: Normality probability plot for male BH (Body Height) calcaneal measurements
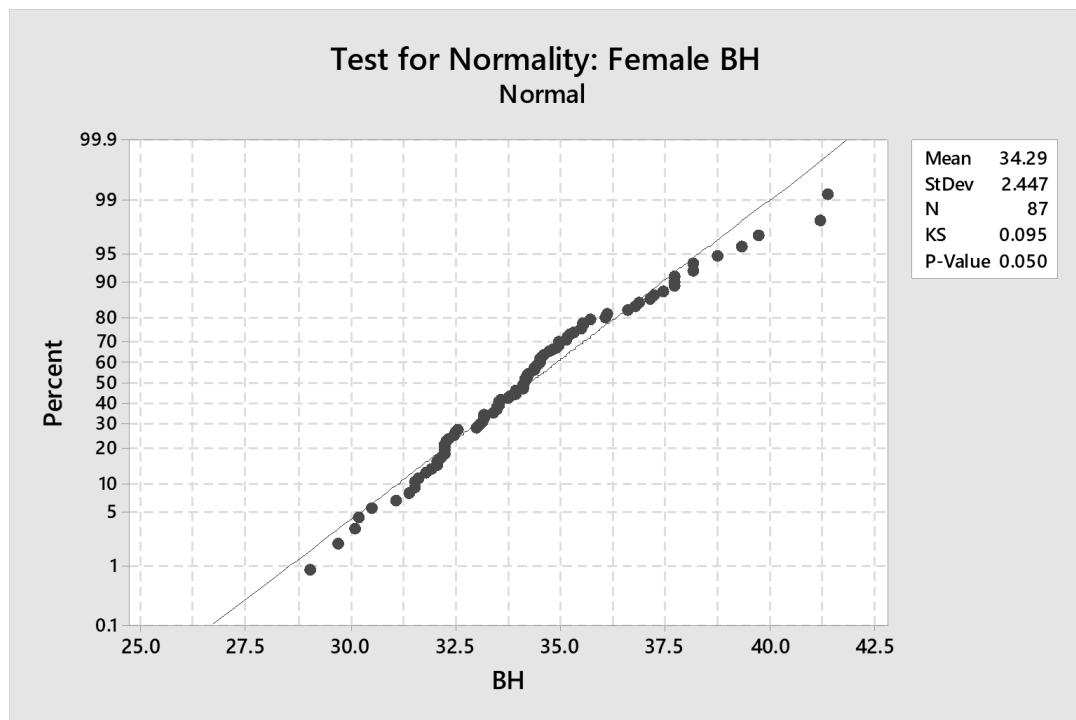
Appendix C8: Normality probability plot for female BH (Body Height) calcaneal measurements
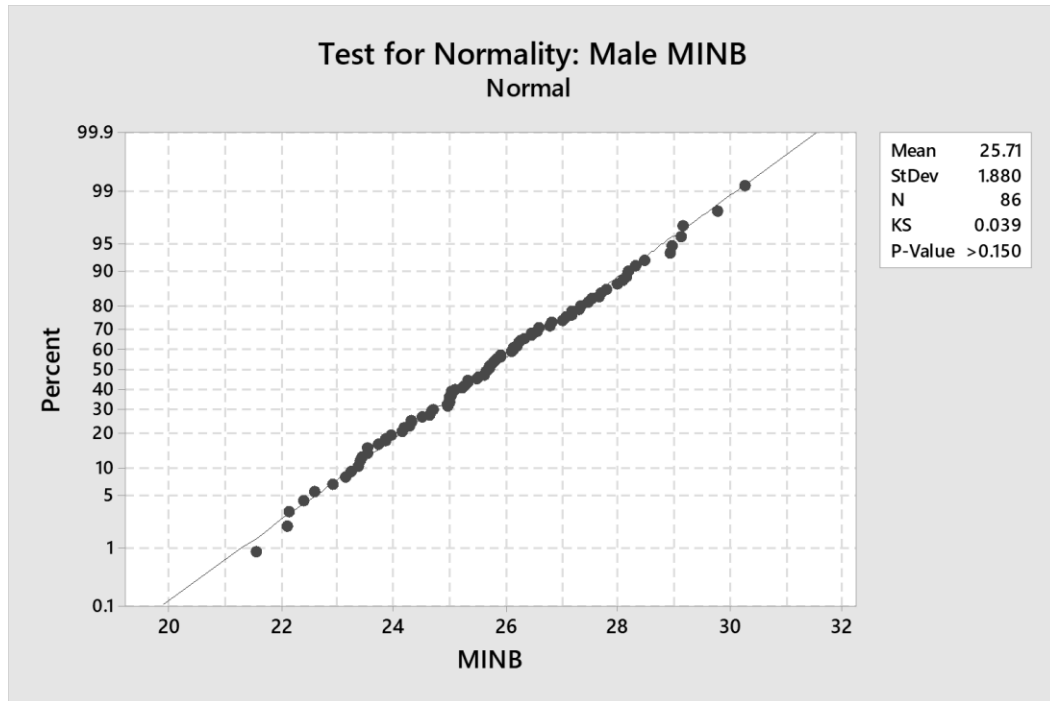
Appendix C9: Normality probability plot for male MINB (Minimum Breadth) calcaneal measurements
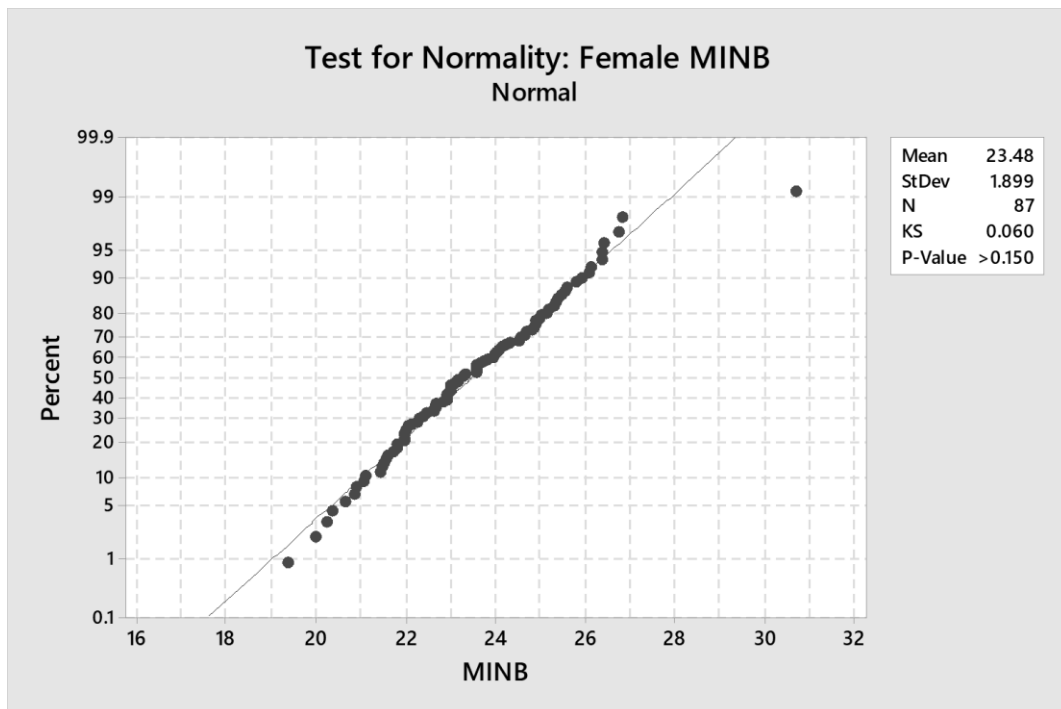
Appendix C10: Normality probability plot for female MINB (Minimum Breadth) calcaneal measurements
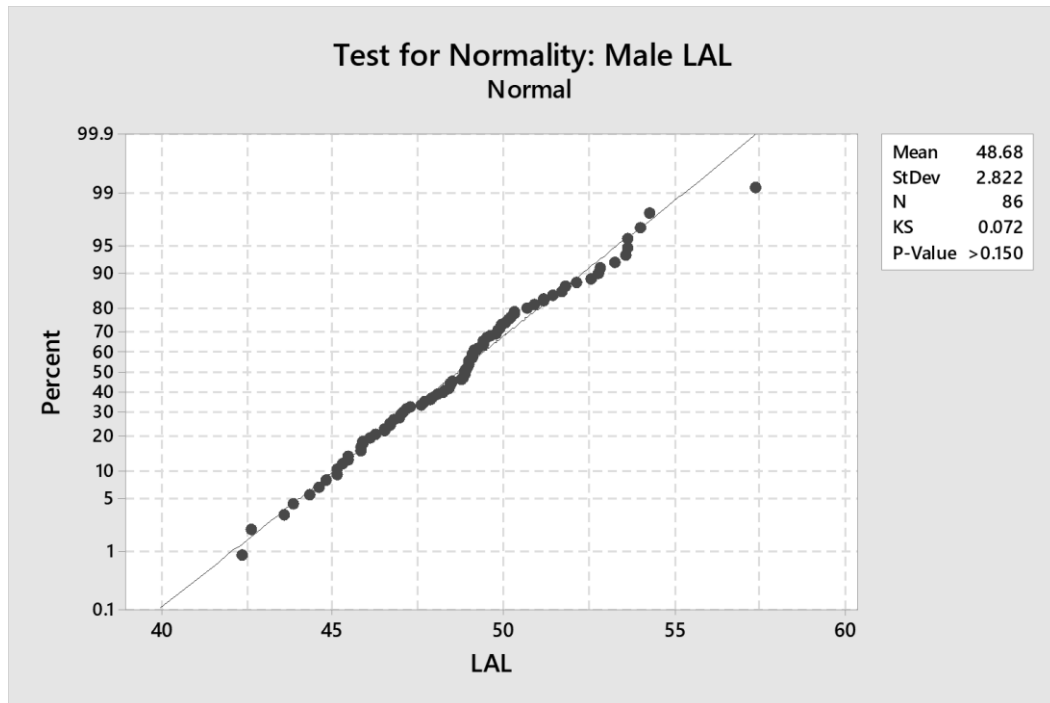
Appendix C11: Normality probability plot for male LAL (Load Arm Length) calcaneal measurements
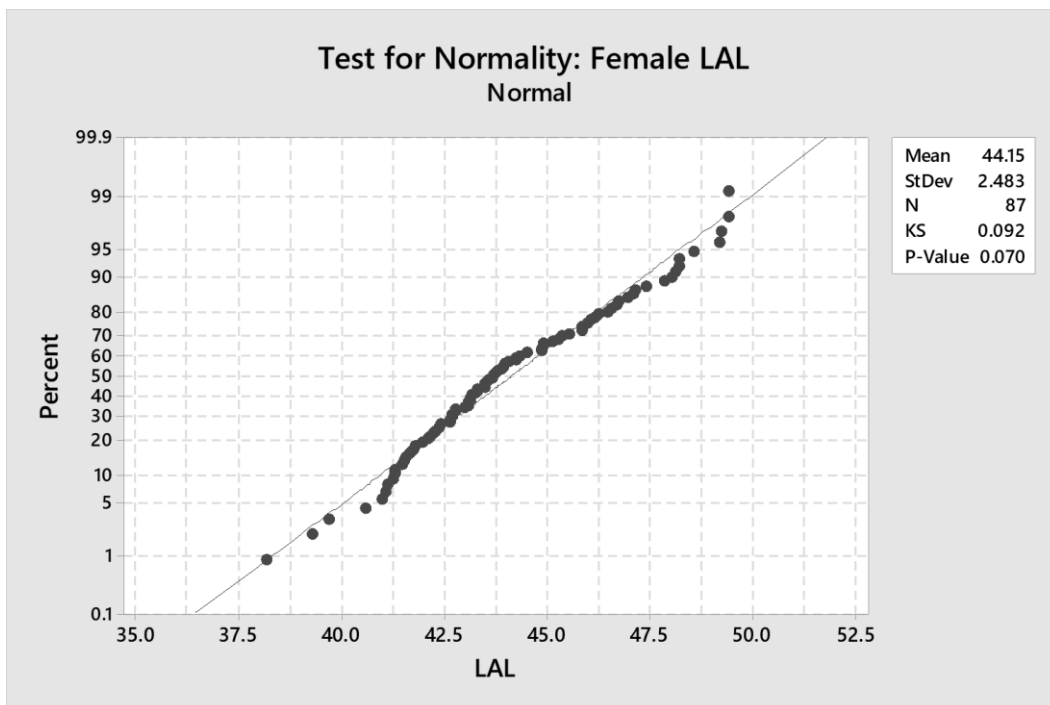
Appendix C12: Normality probability plot for female LAL (Load Arm Length) calcaneal measurements
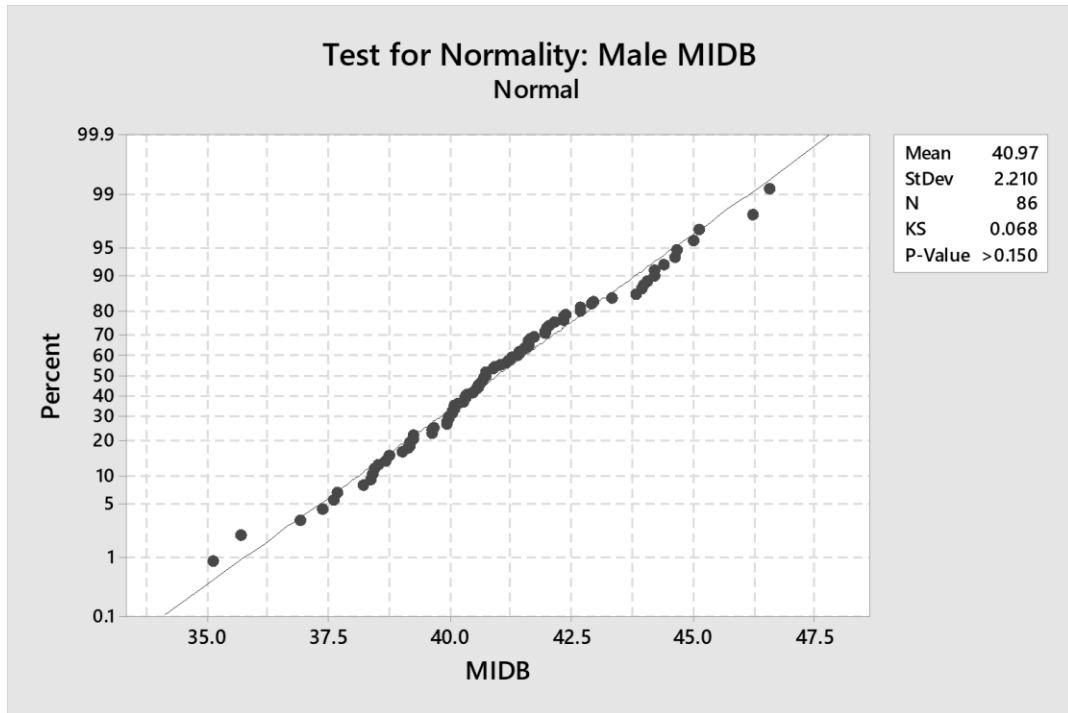
Appendix C13: Normality probability plot for male MIDB (Middle Breadth) calcaneal measurements
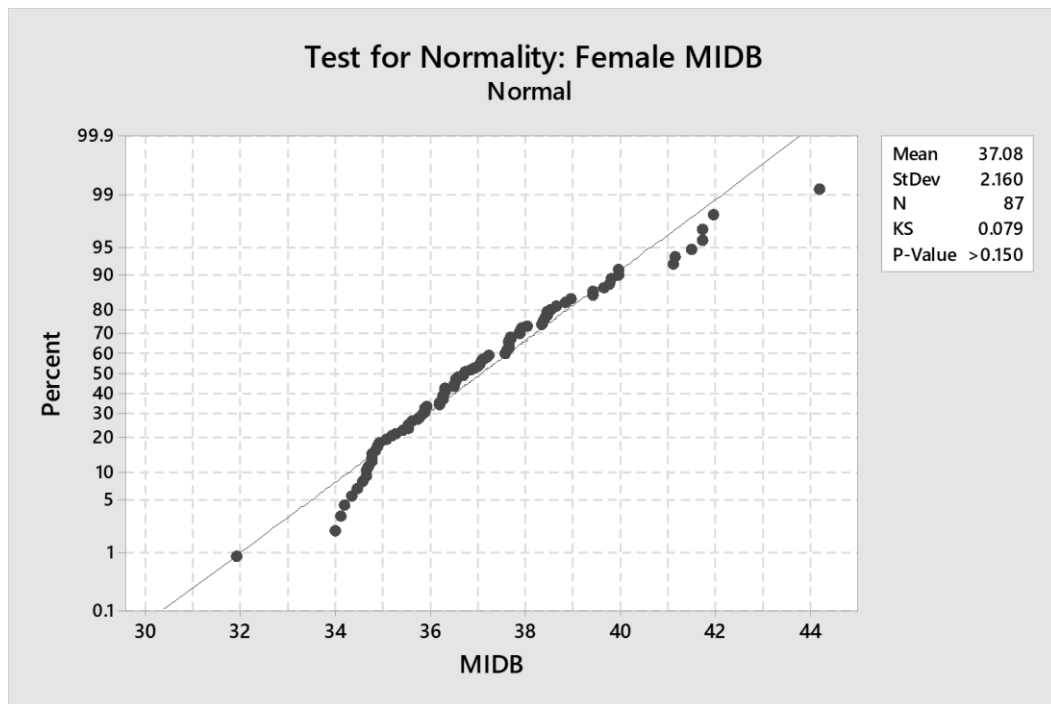
Appendix C14: Normality probability plot for female MIDB (Middle Breadth) calcaneal measurements
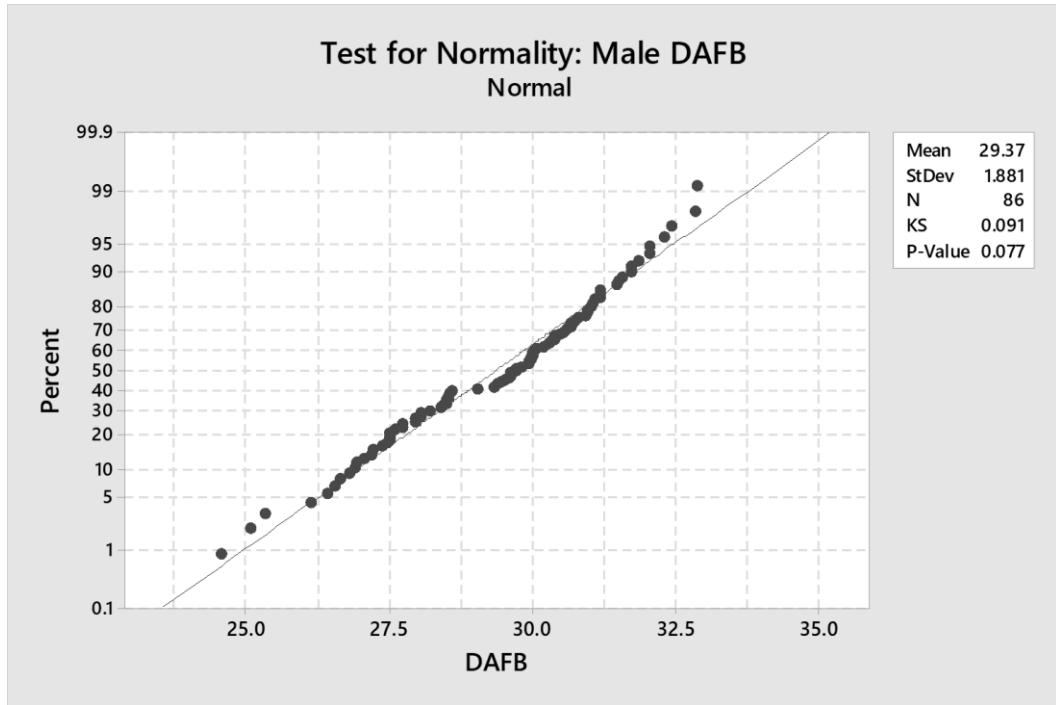
Appendix C15: Normality probability plot for male DAFB (Dorsal Articular Facet Breadth) calcaneal measurements
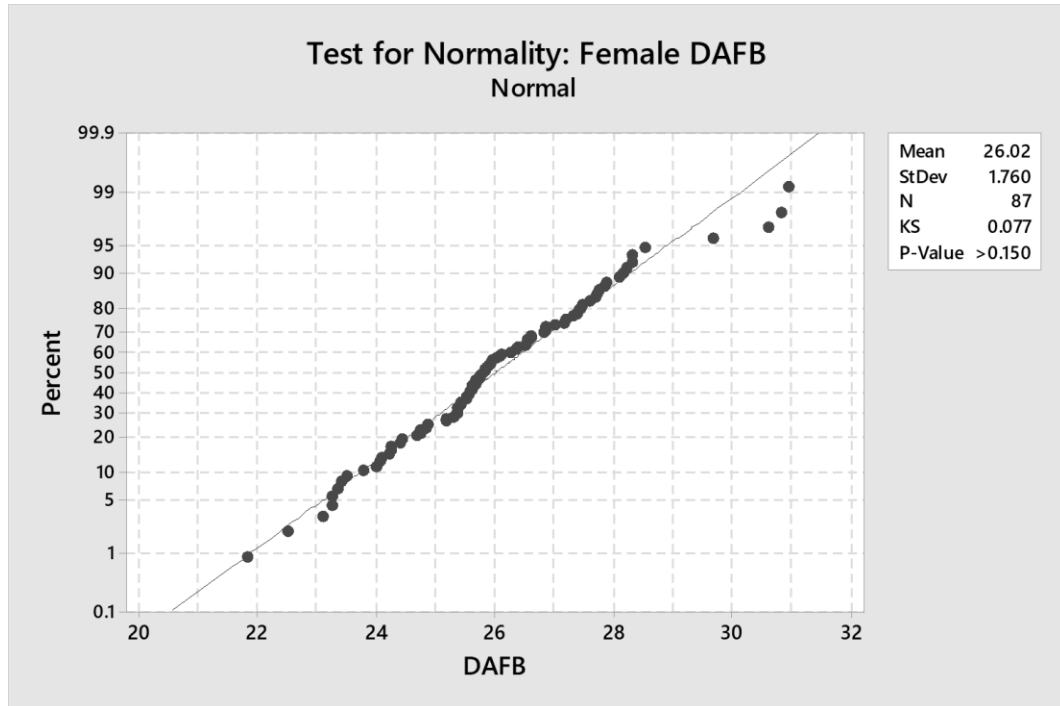
Appendix C16: Normality probability plot for female DAFB (Dorsal Articular Facet Breadth) calcaneal measurements
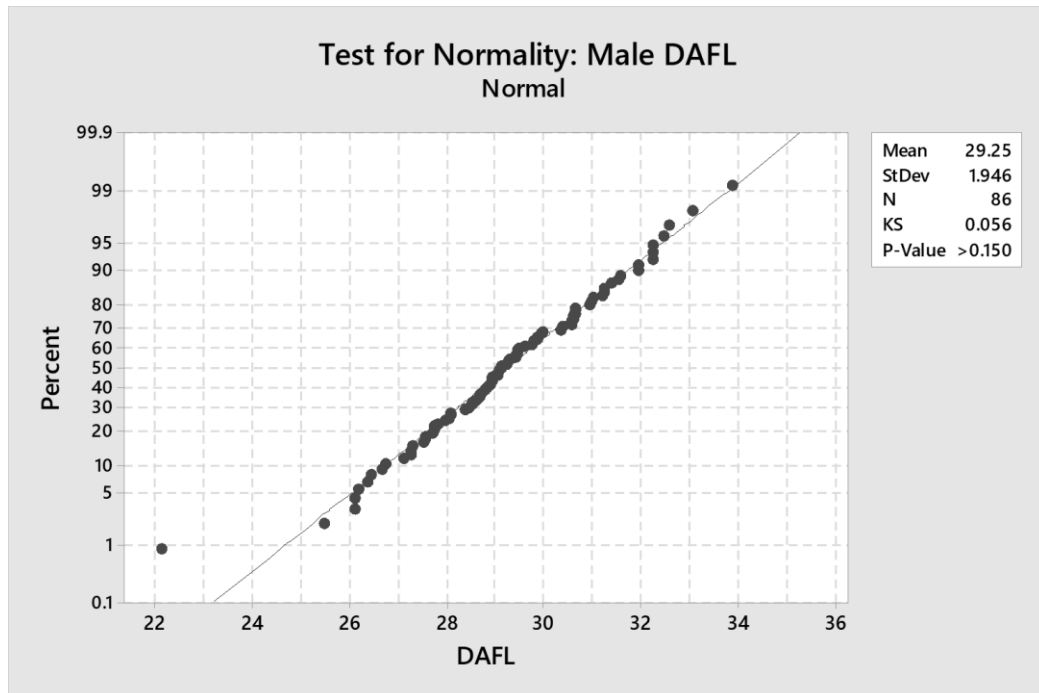
Appendix C17: Normality probability plot for male DAFL (Dorsal Articular Facet Length) calcaneal measurements
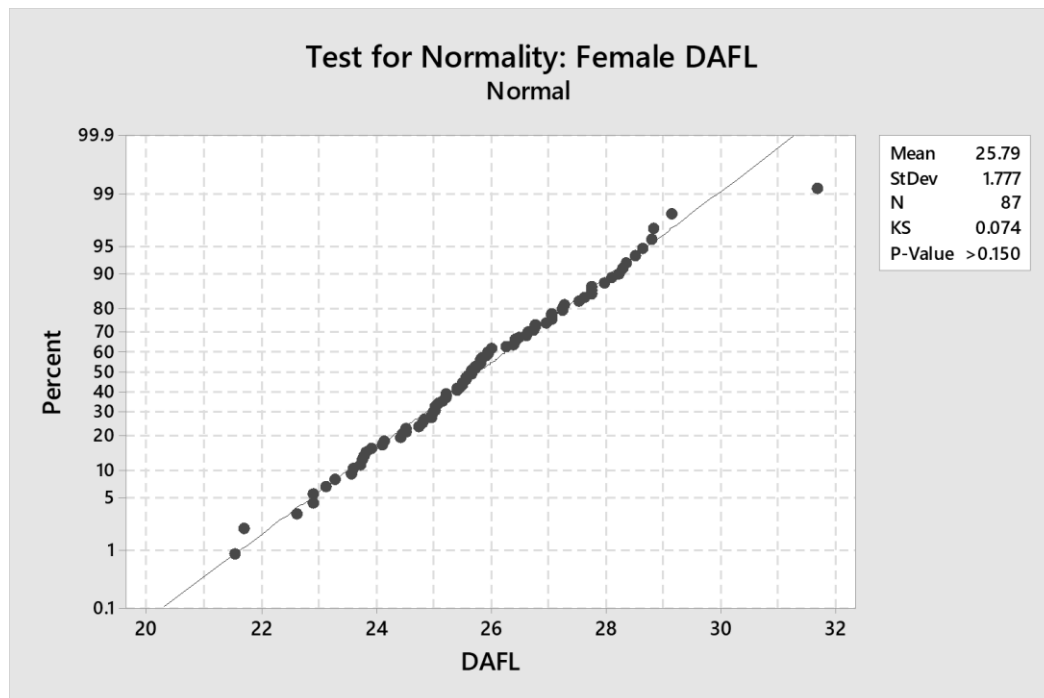
Appendix C18: Normality probability plot for female DAFL (Dorsal Articular Facet Length) calcaneal measurements
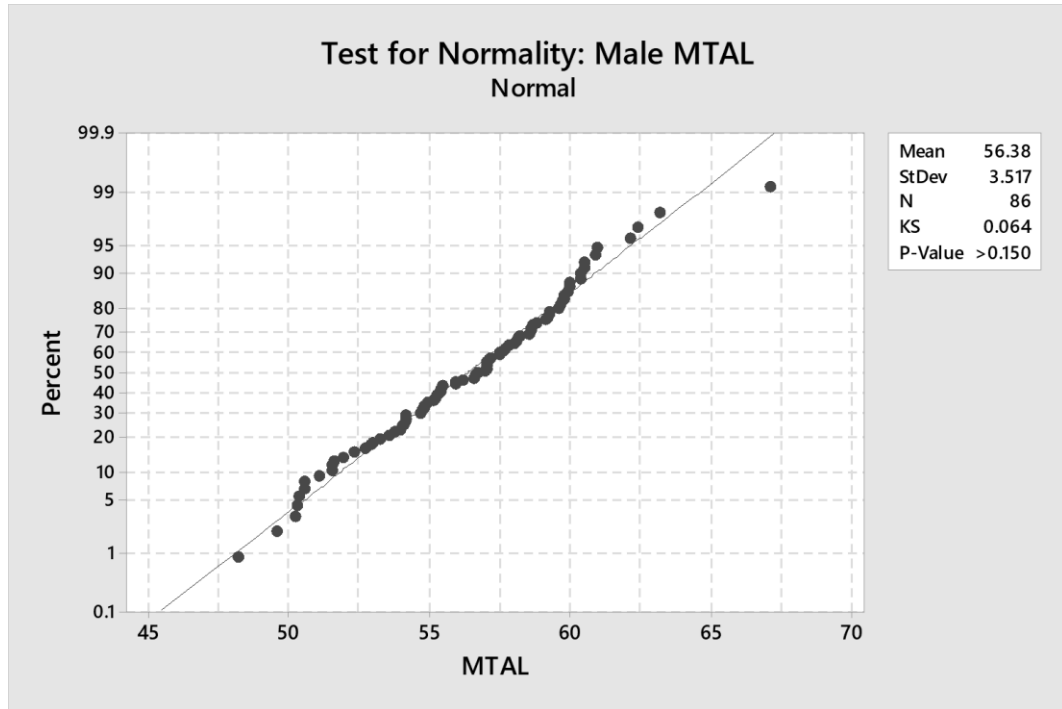
Appendix C19: Normality probability plot for male MTAL (Maximum Length of the Talus) talar measurements
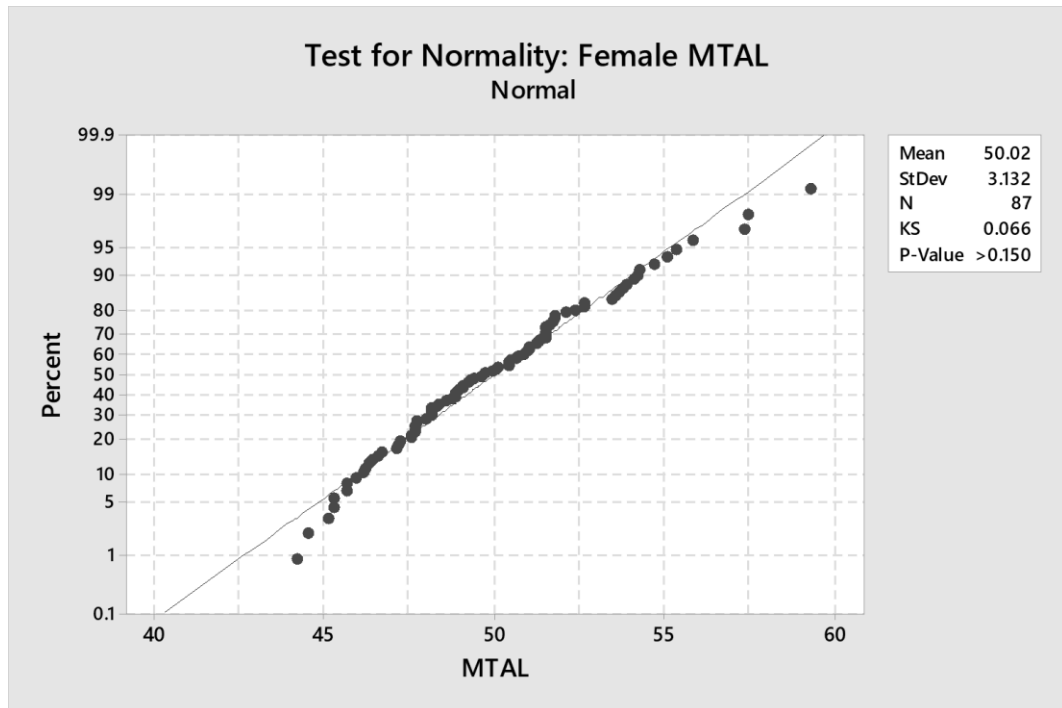
Appendix C20: Normality probability plot for female MTAL (Maximum Length of the Talus) talar measurements

APPENDIX D:
**ACCURACIES OF OTHER POPULATIONS SIMPLE AND MULTIPLE**
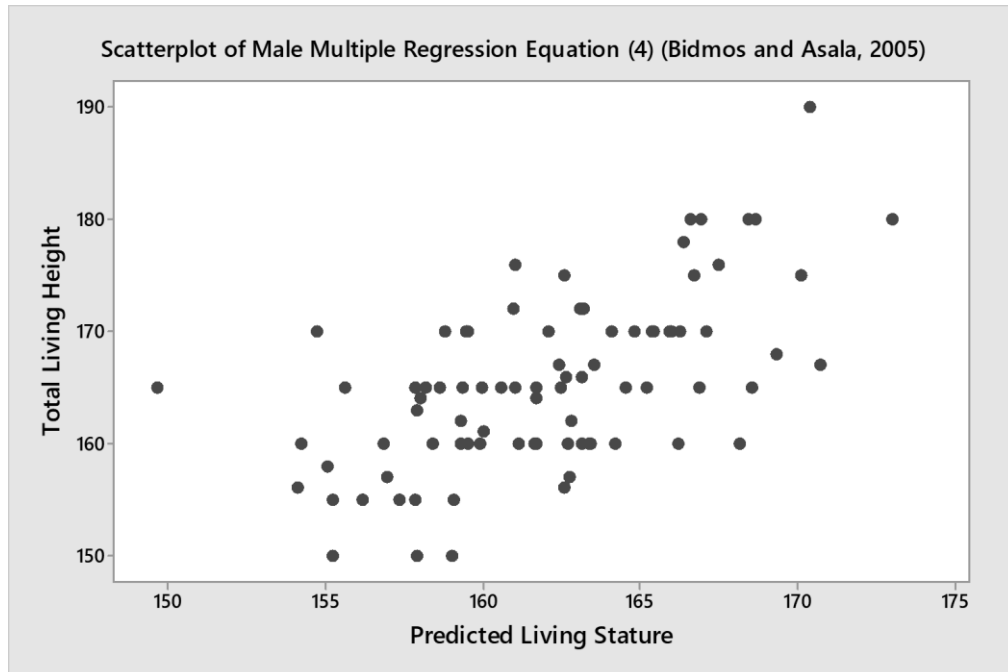**REGRESSION EQUATIONS WHEN APPLIED TO THE THAI POPULATION**
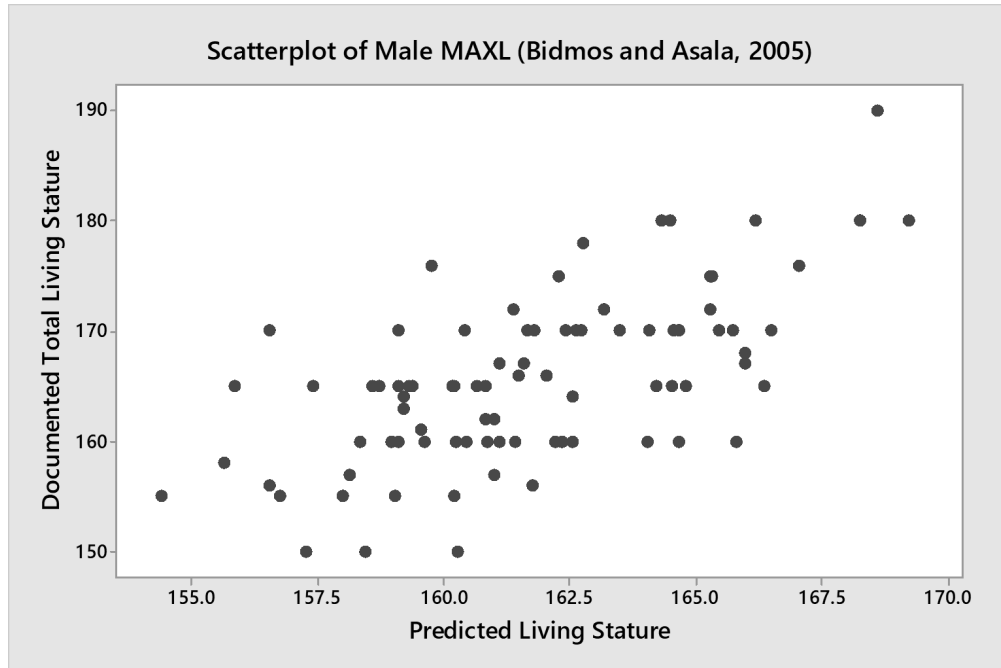
Appendix D1: Simple scatterplot showing the correlation between documented living stature and the predicted living stature, using the male Black South African (Bidmos and Asala, 2005) MAXL simple regression equation.
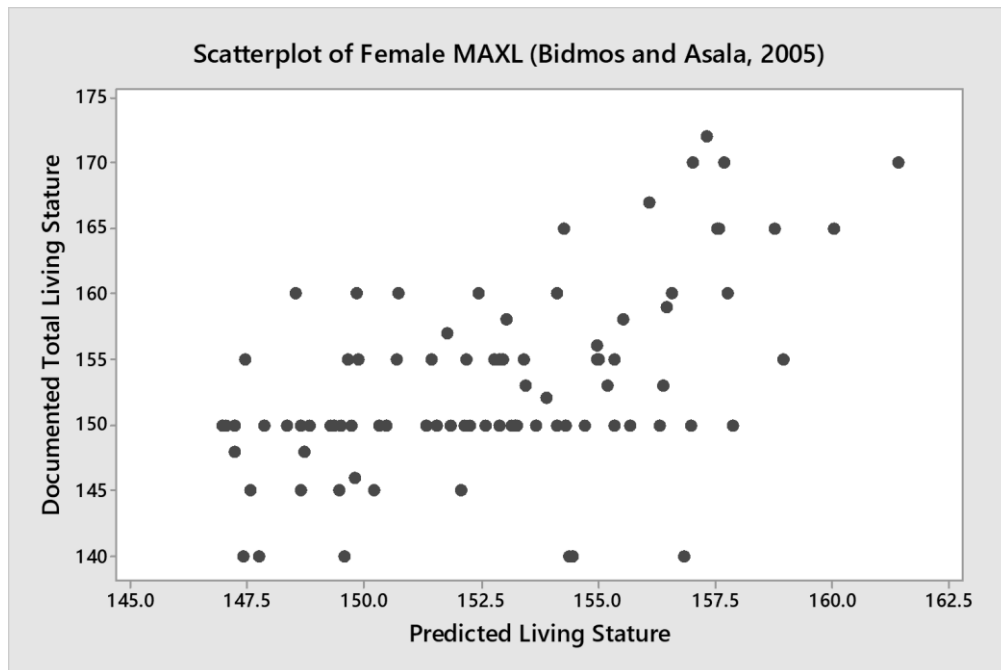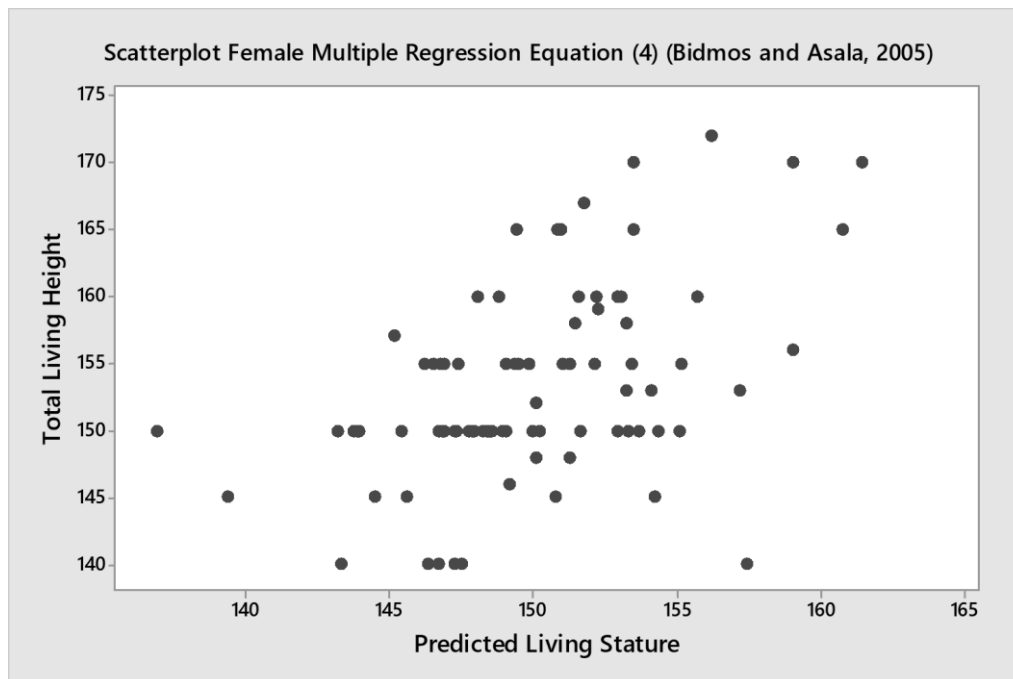

Appendix D2: Simple scatterplot showing the correlation between documented living stature and the predicted living stature, using the female Black South African (Bidmos and Asala, 2005) MAXL simple regression equation.
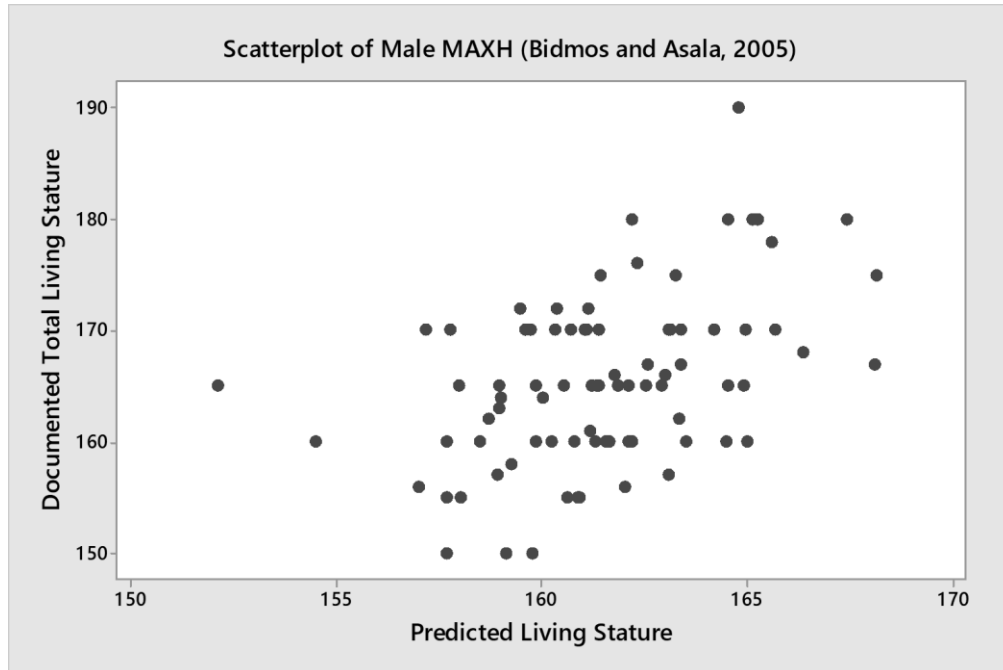
Appendix D3: Simple scatterplot showing the correlation between documented living stature and the predicted living stature, using the male Black South African (Bidmos and Asala, 2005) MAXH simple regression equation.
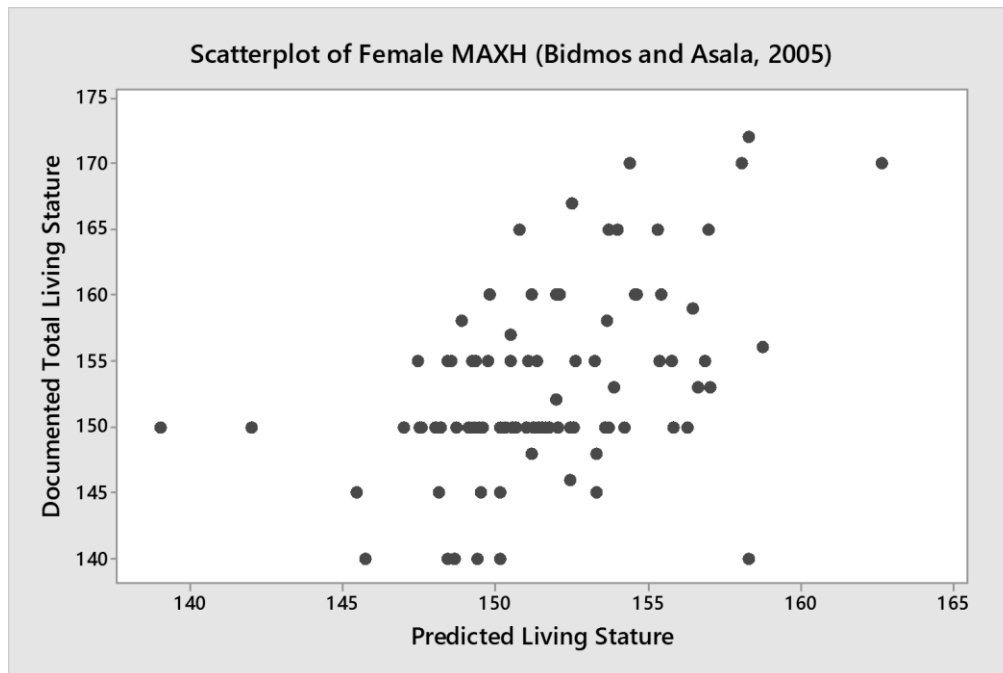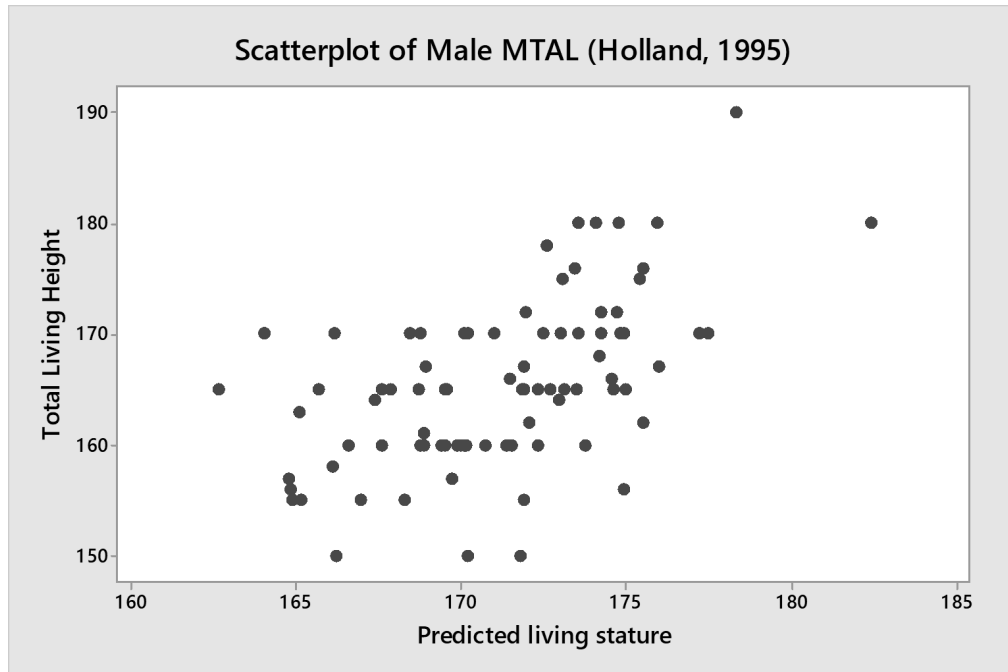

Appendix D4: Simple scatterplot showing the correlation between documented living stature and the predicted living stature, using the female Black South African (Bidmos and Asala, 2005) MAXH simple regression equation.
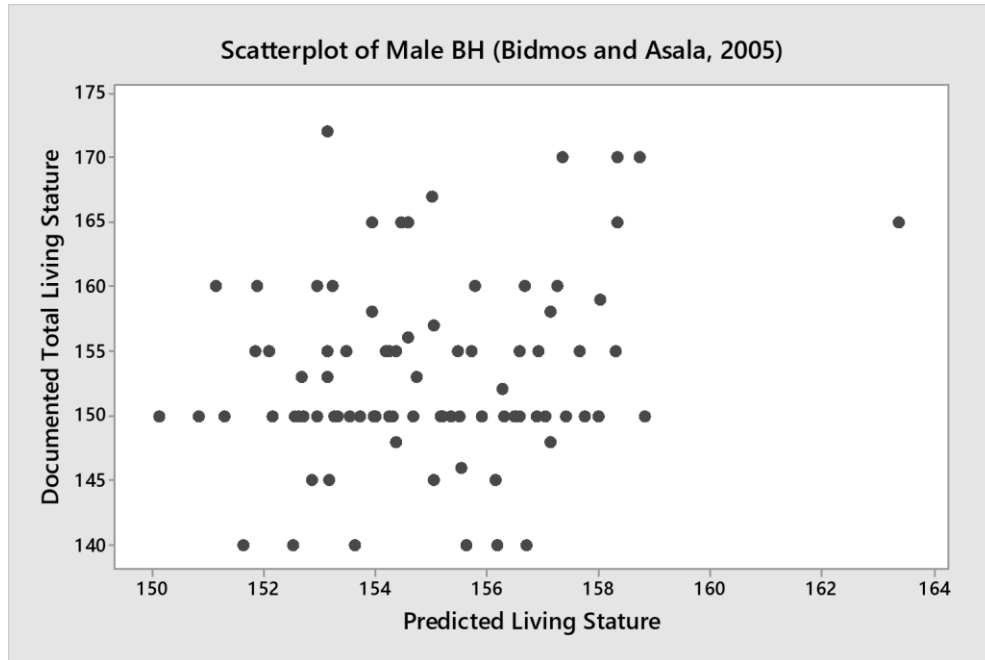
Appendix D5: Simple scatterplot showing the correlation between documented living stature and the predicted living stature, using the male Black South African (Bidmos and Asala, 2005) BH simple regression equation.
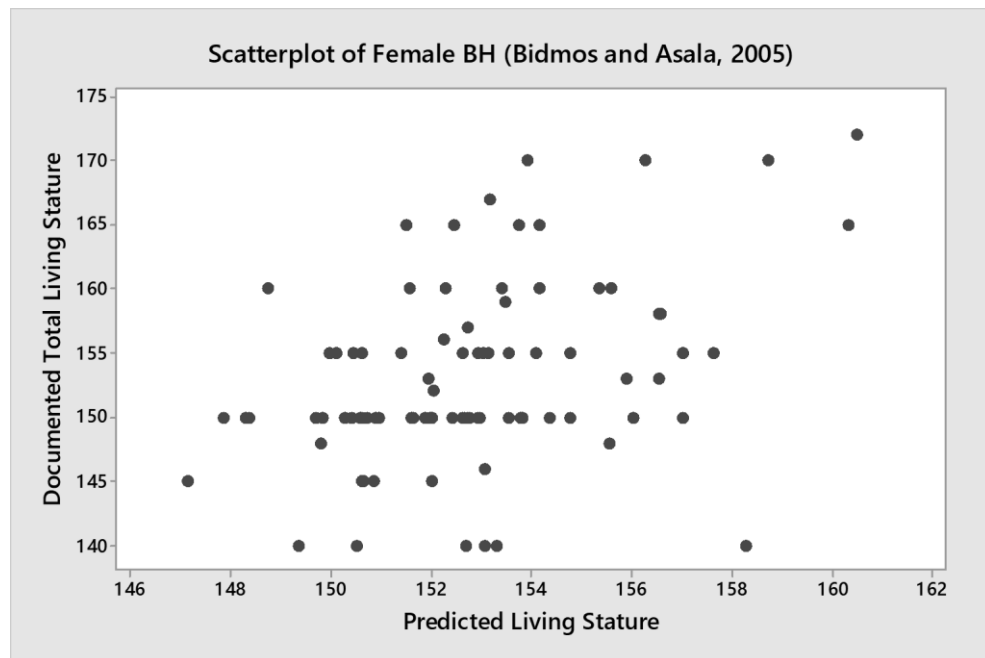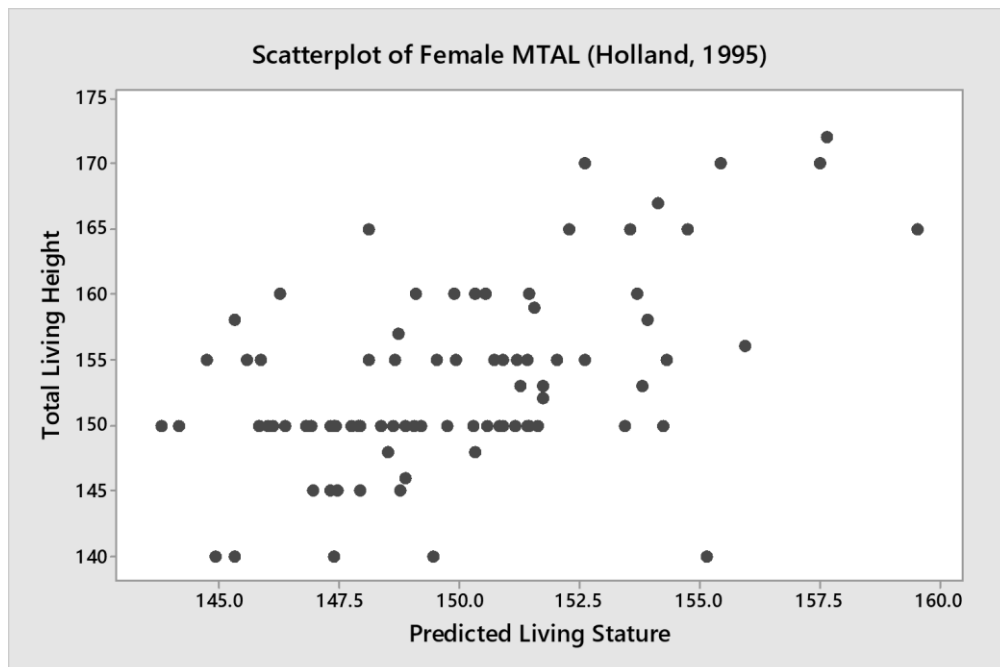

Appendix D6: Simple scatterplot showing the correlation between documented living stature and the predicted living stature, using the female Black South African (Bidmos and Asala, 2005) BH simple regression equation.
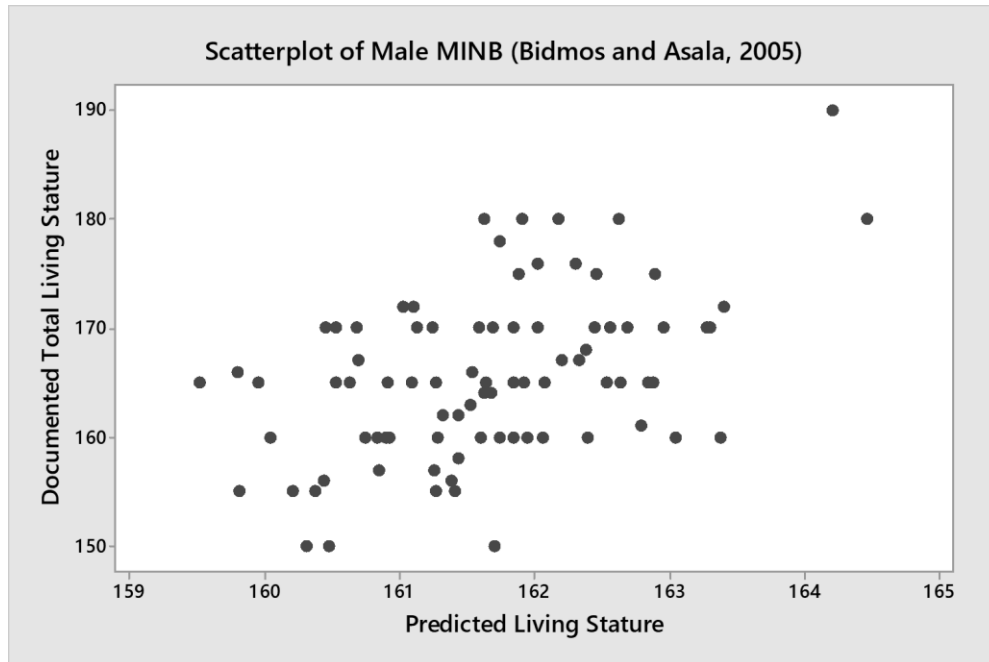
Appendix D7: Simple scatterplot showing the correlation between documented living stature and the predicted living stature, using the male Black South African (Bidmos and Asala, 2005) MINB simple regression equation.
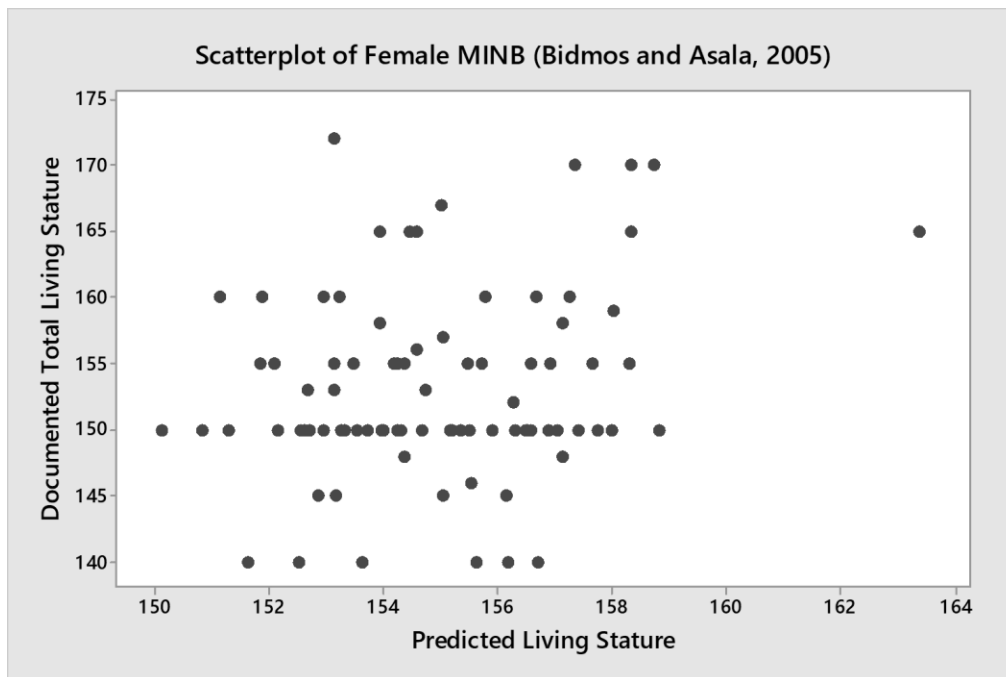
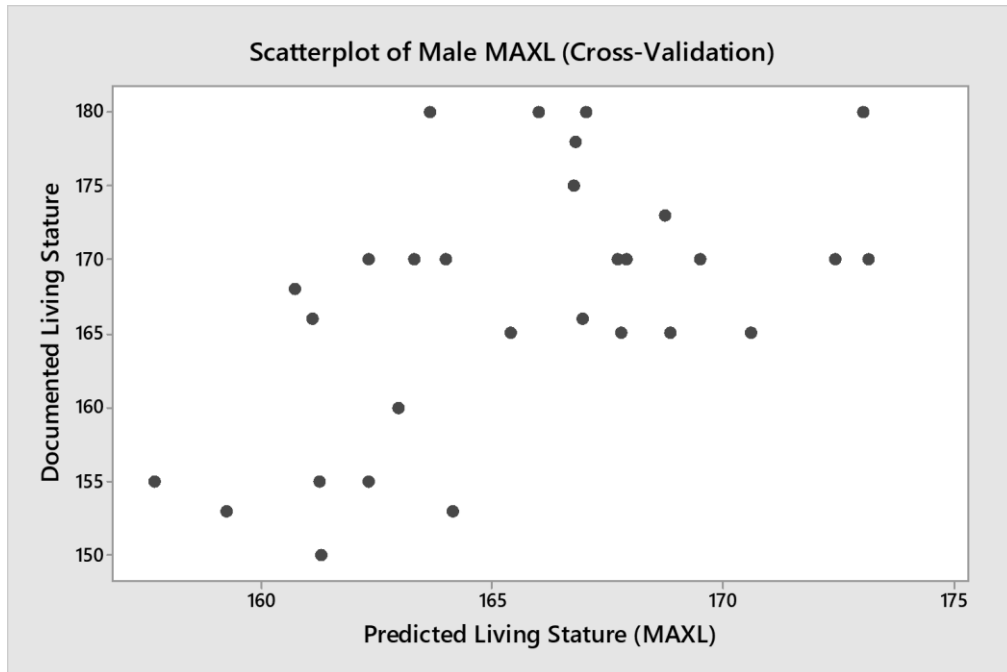**Appendix D8:** Simple scatterplot showing the correlation between documented living stature and the predicted living stature, using the female Black South African (Bidmos and Asala, 2005) MINB simple regression equation.
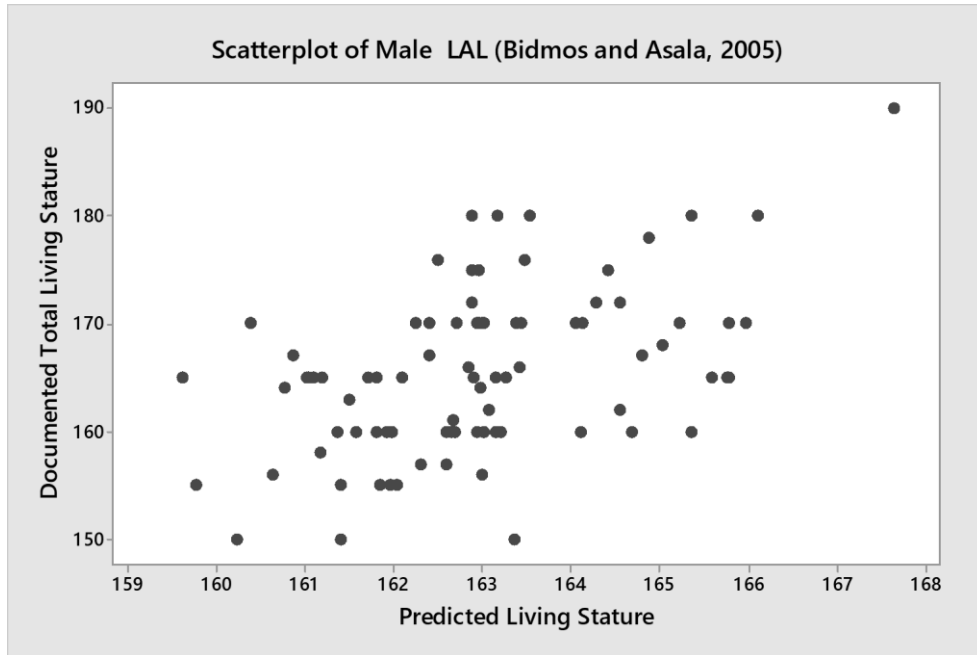
Appendix D9: Simple scatterplot showing the correlation between documented living stature and the predicted living stature, using the male Black South African (Bidmos and Asala, 2005) LAL simple regression equation.
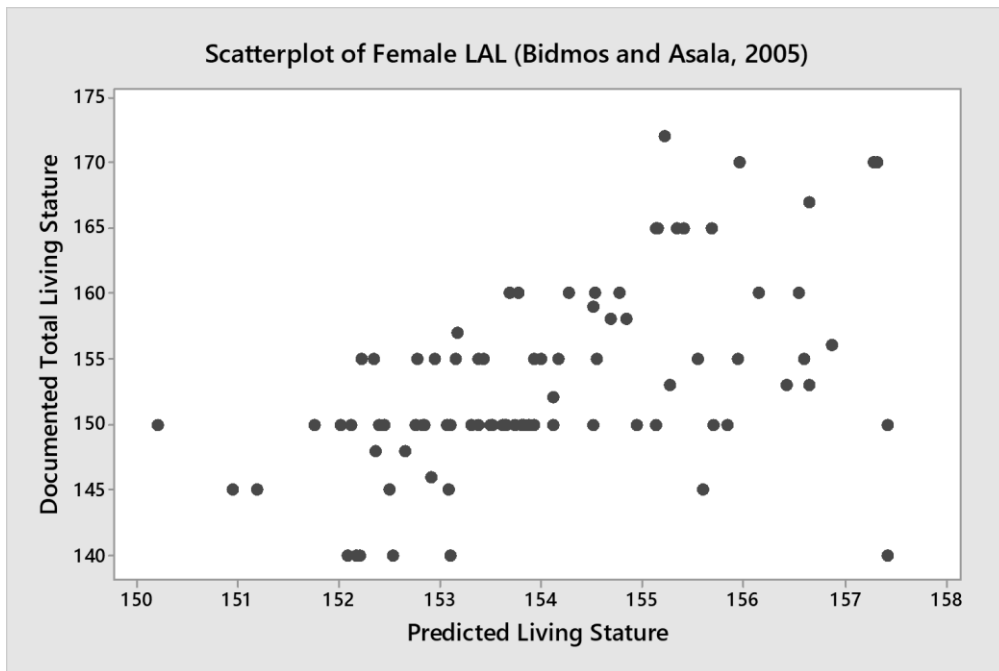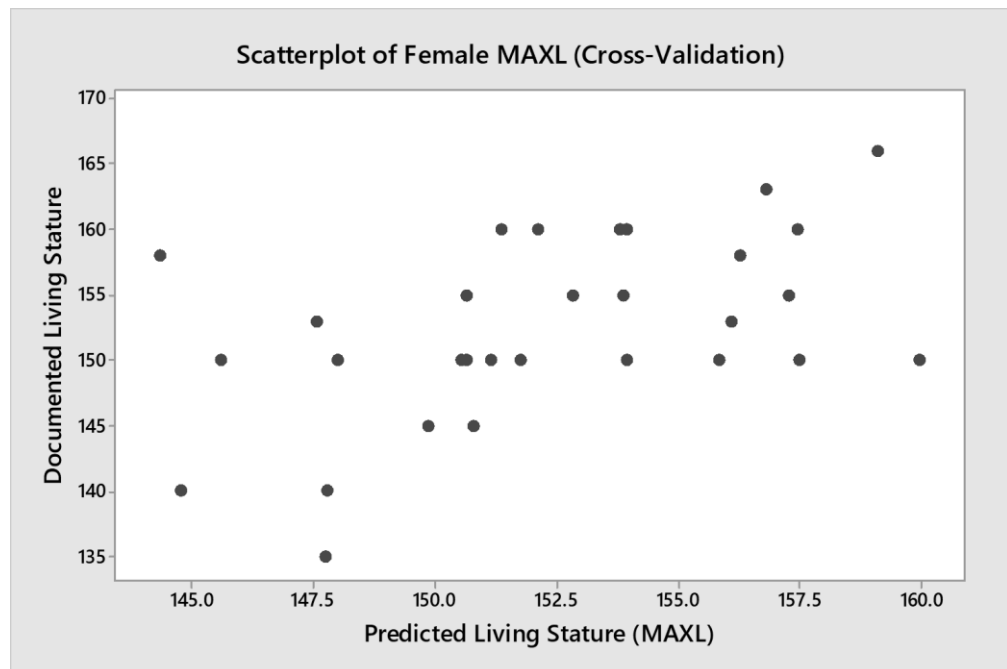

Appendix D10: Simple scatterplot showing the correlation between documented living stature and the predicted living stature, using the female Black South African (Bidmos and Asala, 2005) LAL simple regression equation.
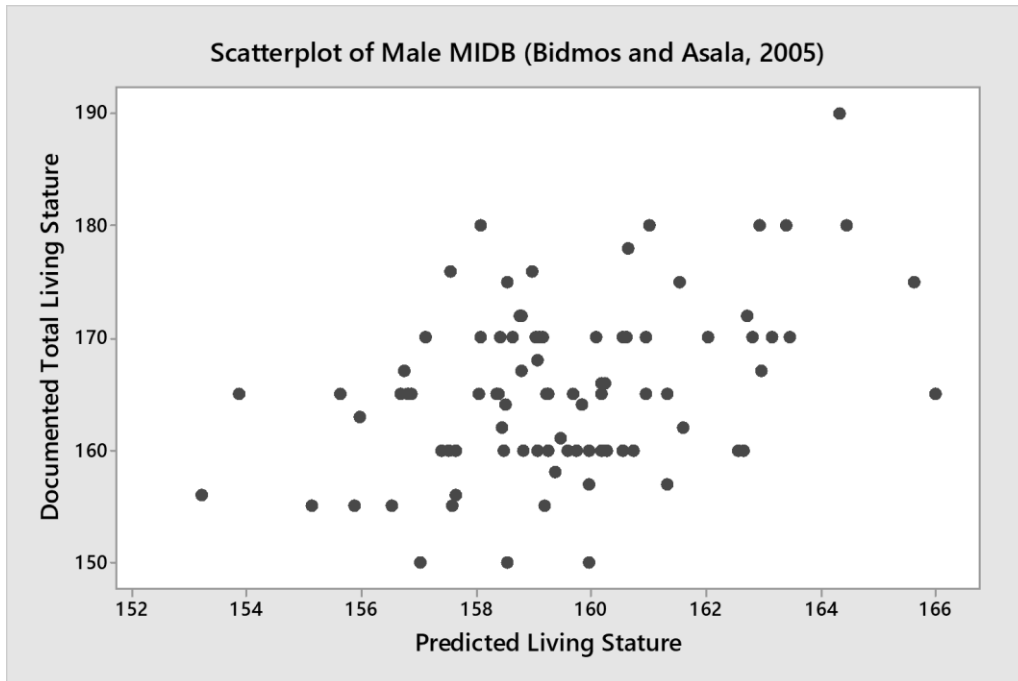
Appendix D11: Simple scatterplot showing the correlation between documented living stature and the predicted living stature, using the male Black South African (Bidmos and Asala, 2005) MIDB simple regression equation.
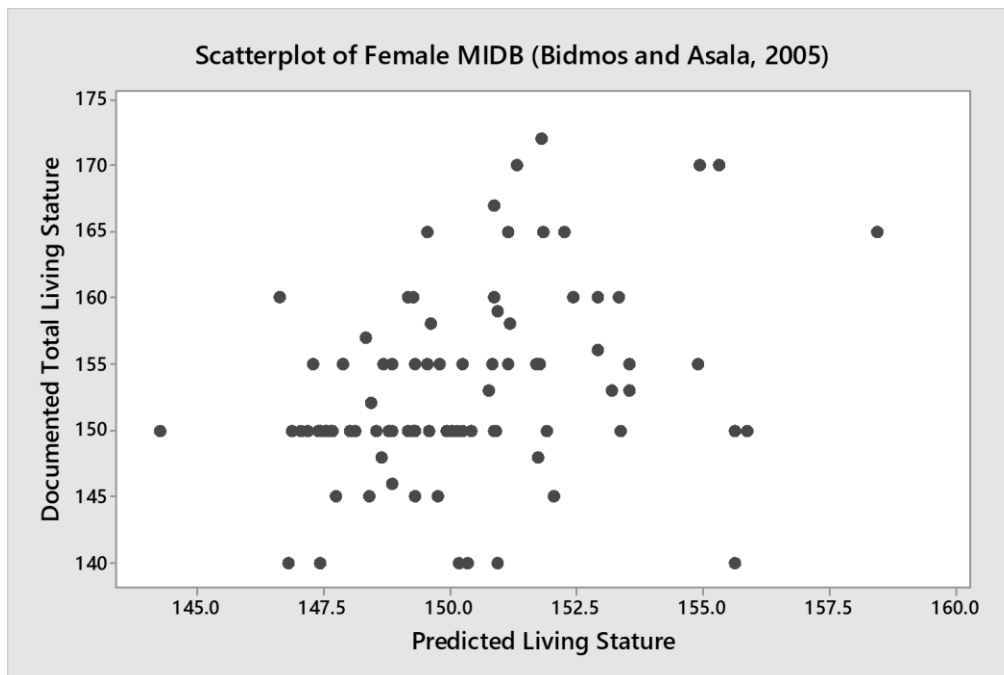
Appendix D12: Simple scatterplot showing the correlation between documented living stature and the predicted living stature, using the female Black South African (Bidmos and Asala, 2005) MIDB simple regression equation.
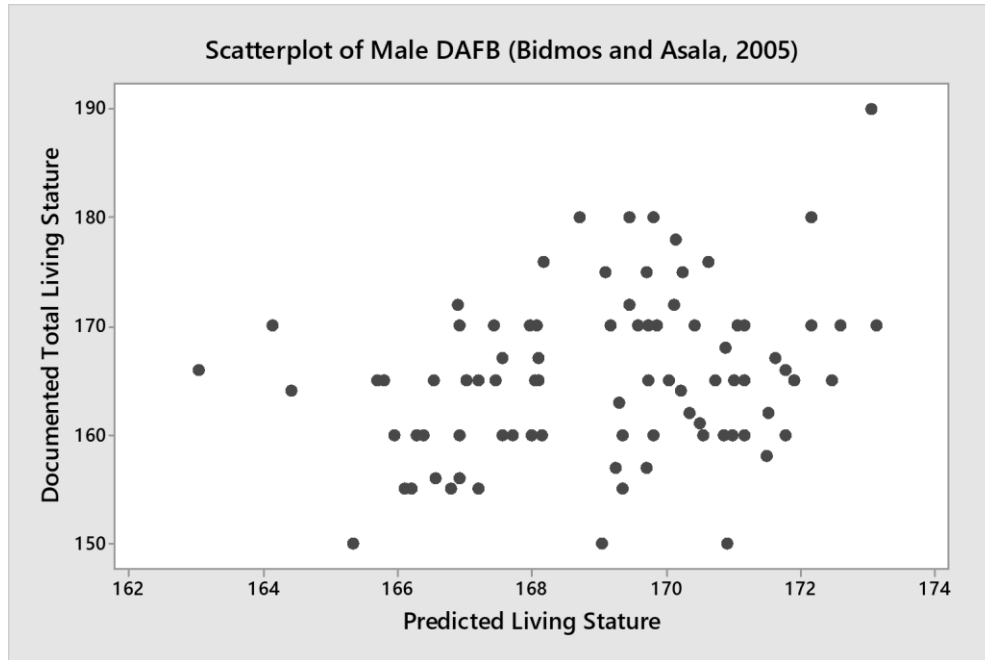
Appendix D13: Simple scatterplot showing the correlation between documented living stature and the predicted living stature, using the male Black South African (Bidmos and Asala, 2005) DAFB simple regression equation.
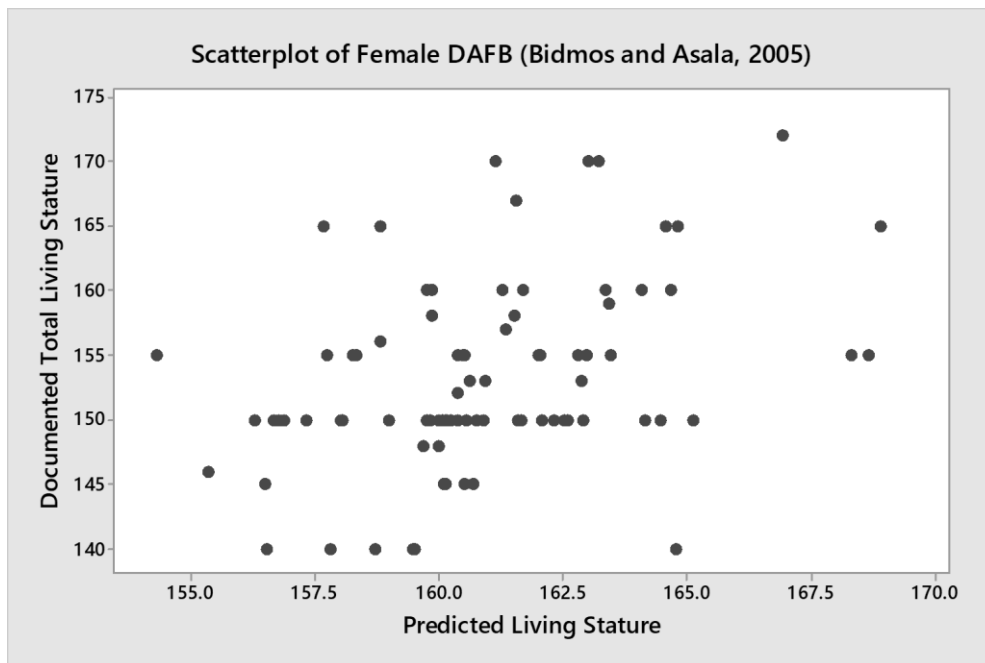
Appendix D14: Simple scatterplot showing the correlation between documented living stature and the predicted living stature, using the female Black South African (Bidmos and Asala, 2005) DAFB simple regression equation.
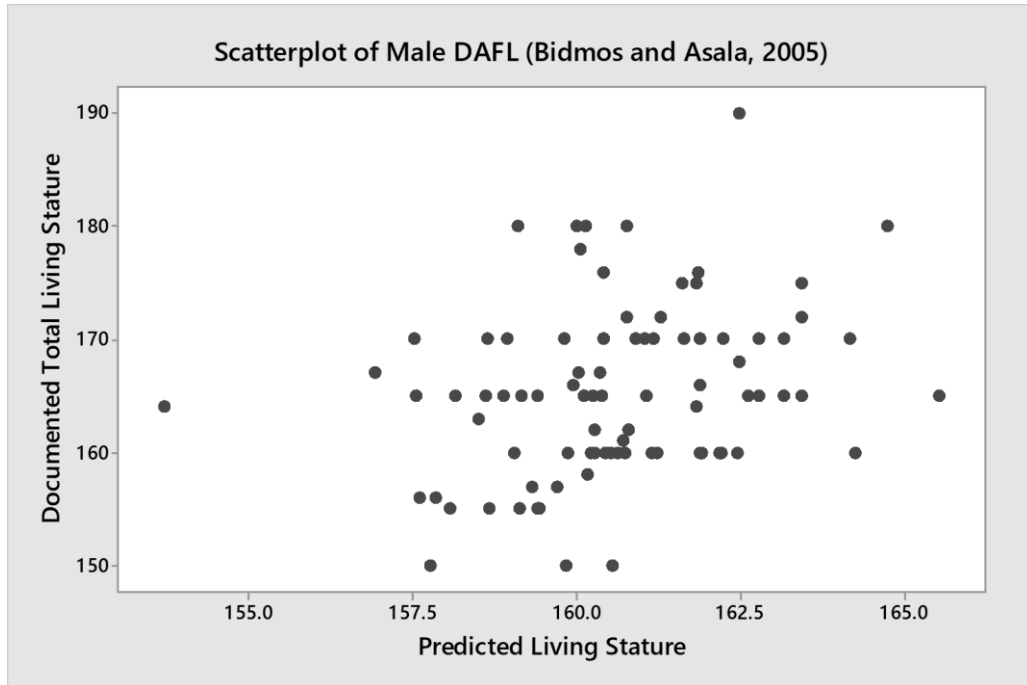
Appendix D15: Simple scatterplot showing the correlation between documented living stature and the predicted living stature, using the male Black South African (Bidmos and Asala, 2005) DAFL simple regression equation.
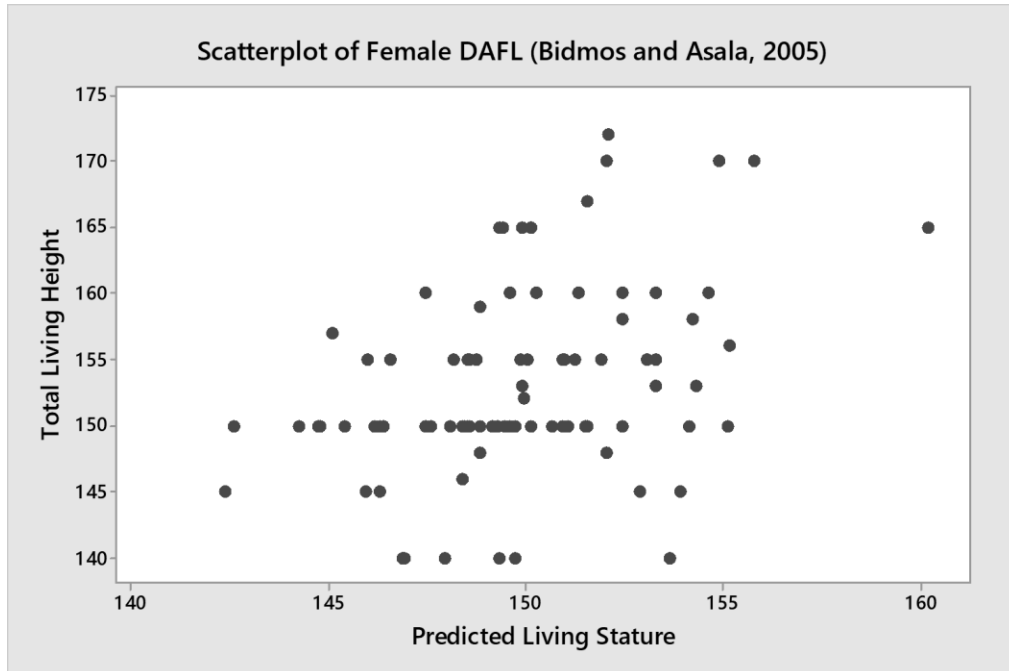
Appendix D16: Simple scatterplot showing the correlation between documented living stature and the predicted living stature, using the female Black South African (Bidmos and Asala, 2005) DAFL simple regression equation.
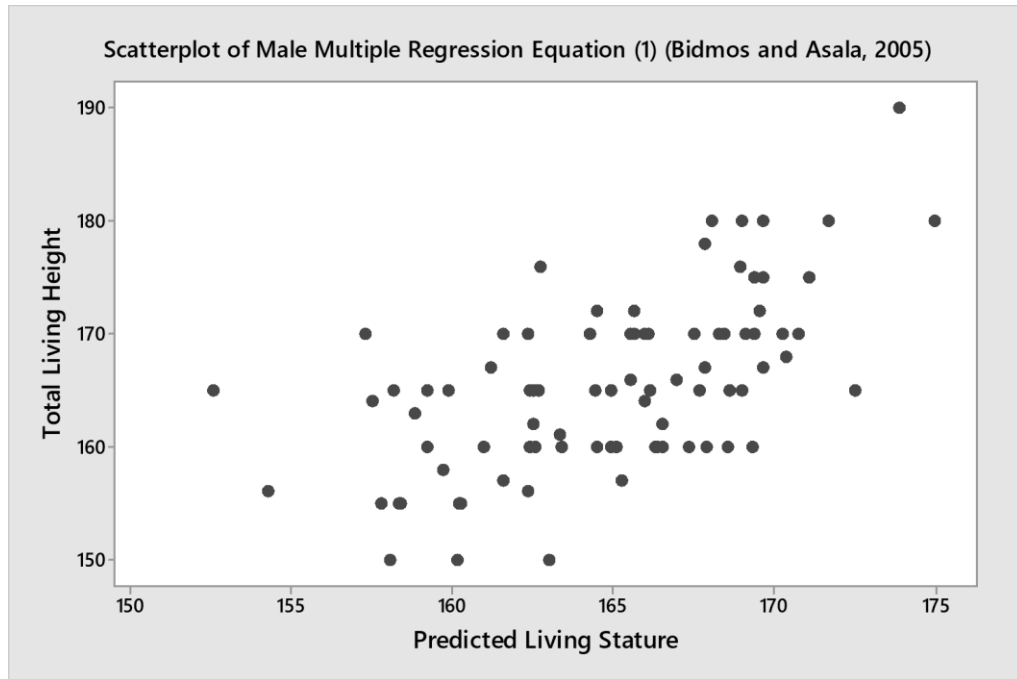
Appendix D17: Simple scatterplot showing the correlation between documented living stature and the predicted living stature, using the male Black South African (Bidmos and Asala, 2005) multiple regression equation 1 (MAXL, MAXH, MIDB, and DAFB).
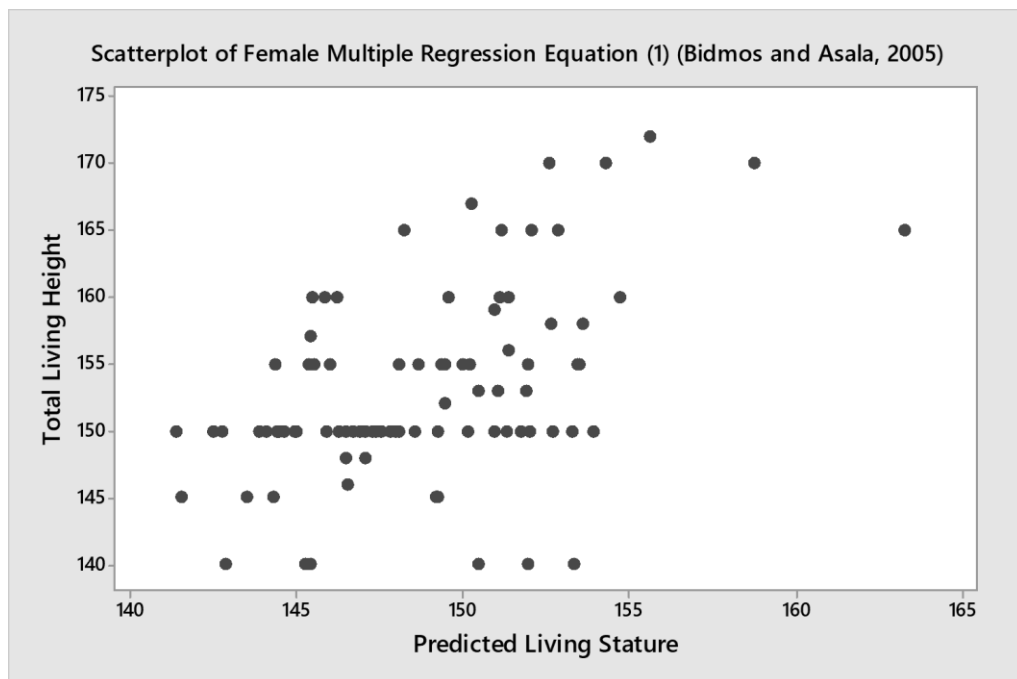
Appendix D18: Simple scatterplot showing the correlation between documented living stature and the predicted living stature, using the female Black South African (Bidmos and Asala, 2005) multiple regression equation 1 (MAXL, LAL, BH, and DAFL).
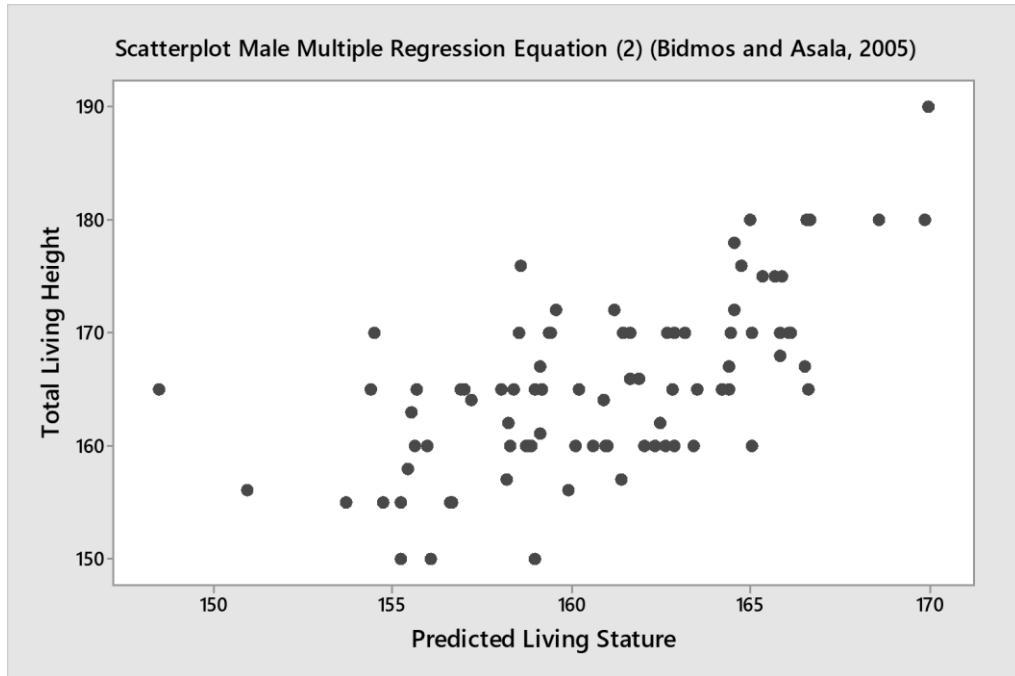
Appendix D19: Simple scatterplot showing the correlation between documented living stature and the predicted living stature, using the male Black South African (Bidmos and Asala, 2005) multiple regression equation 2 (MAXL, MAXH, and MIDB).
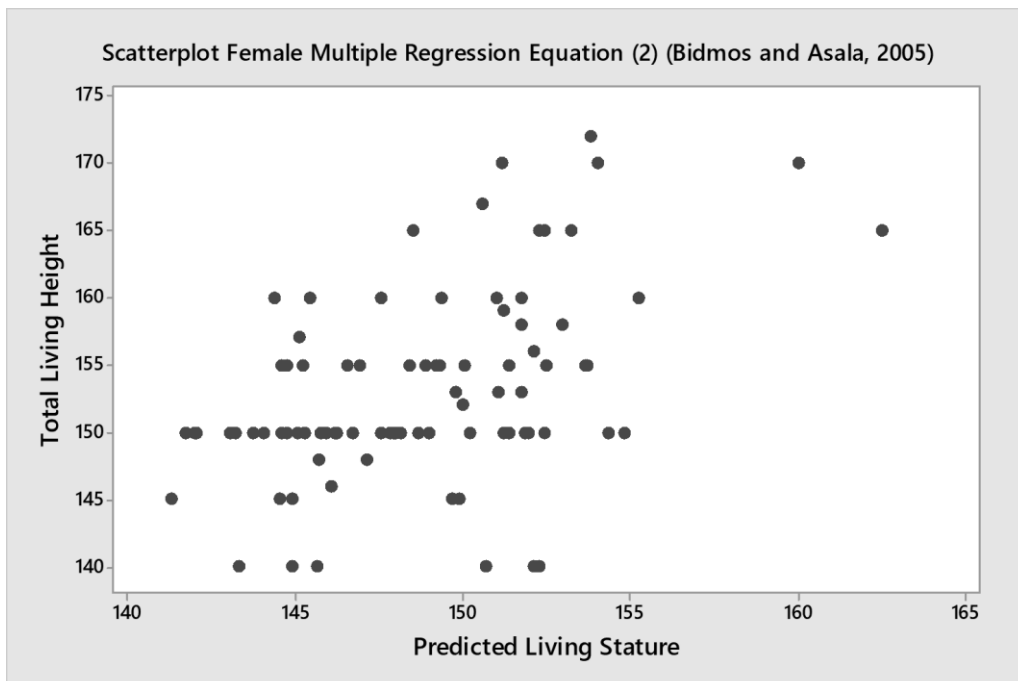
Appendix D20: Simple scatterplot showing the correlation between documented living stature and the predicted living stature, using the female Black South African (Bidmos and Asala, 2005) multiple regression equation 2 (MAXL, LAL, and DAFL).

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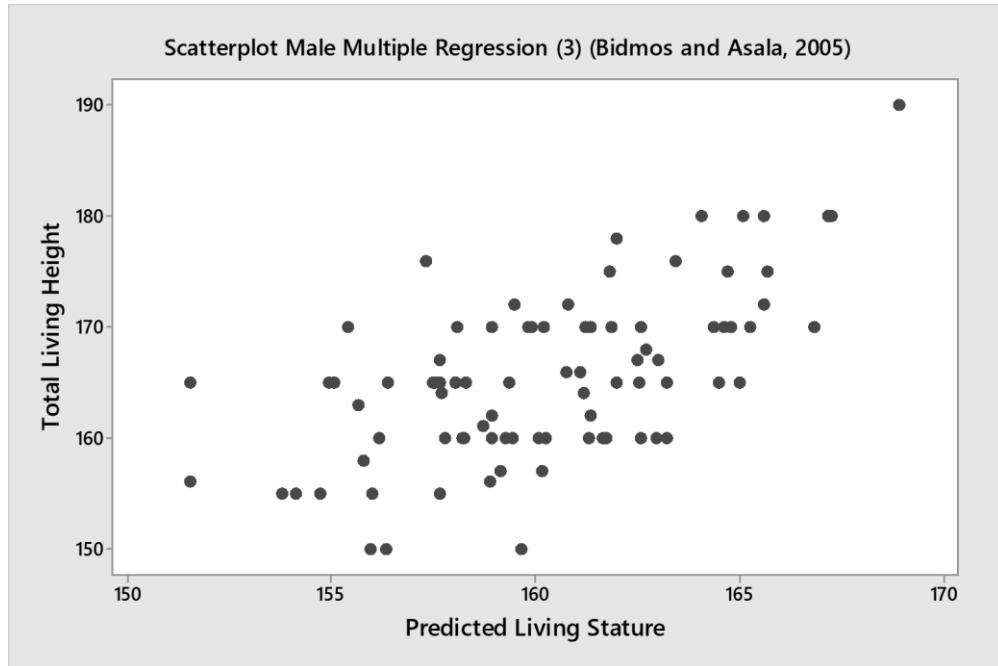
Appendix D21: Simple scatterplot showing the correlation between documented living stature and the predicted living stature, using the male Black South African (Bidmos and Asala, 2005) multiple regression equation 3 (MAXL and MIDB).
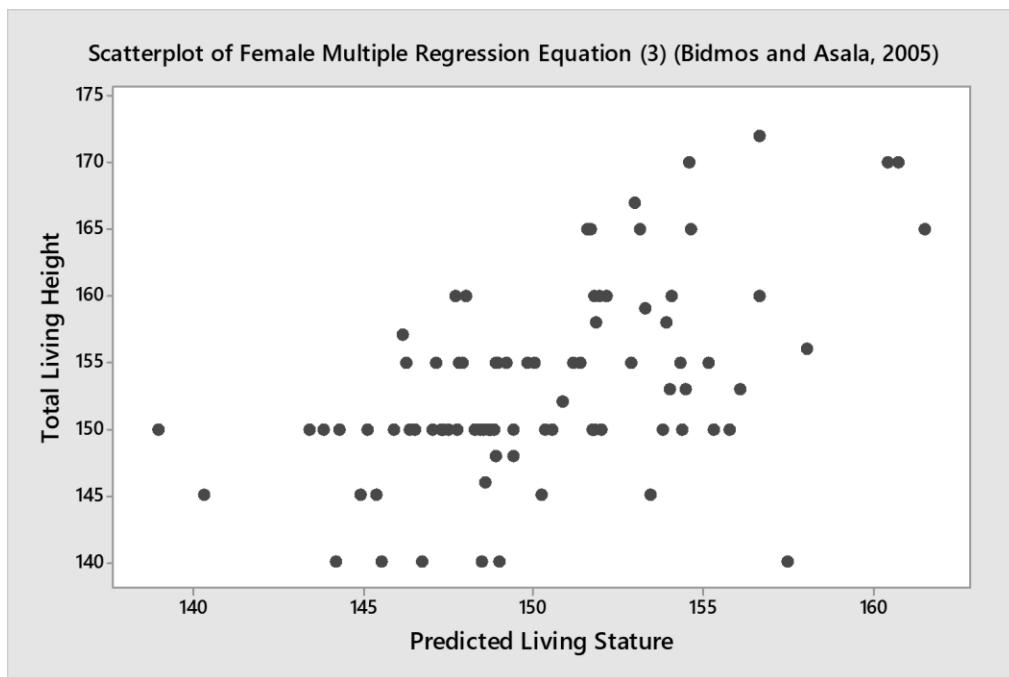
Appendix D22: Simple scatterplot showing the correlation between documented living stature and the predicted living stature, using the female Black South African (Bidmos and Asala, 2005) multiple regression equation 3 (MAXL, MAXH, and DAFL).

Appendix D23: Simple scatterplot showing the correlation between documented living stature and the predicted living stature, using the male Black South African (Bidmos and Asala, 2005) multiple regression equation 4 (MAXL and MAXH).

Appendix D24: Simple scatterplot showing the correlation between documented living stature and the predicted living stature, using the female Black South African (Bidmos and Asala, 2005) multiple regression equation 4 (MAXH and DAFL).

Appendix D25: Simple scatterplot showing the correlation between documented living stature and the predicted living stature, using the male Black American (Holland, 1995) MTAL simple regression equation.

Appendix D26: Simple scatterplot showing the correlation between documented living stature and the predicted living stature, using the female Black American (Holland, 1995) MTAL simple regression equation.

APPENDIX E:
ACCURACIES OF CROSS-VALIDATION

Appendix E1: Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the male MAXL calcaneal simple regression equation.
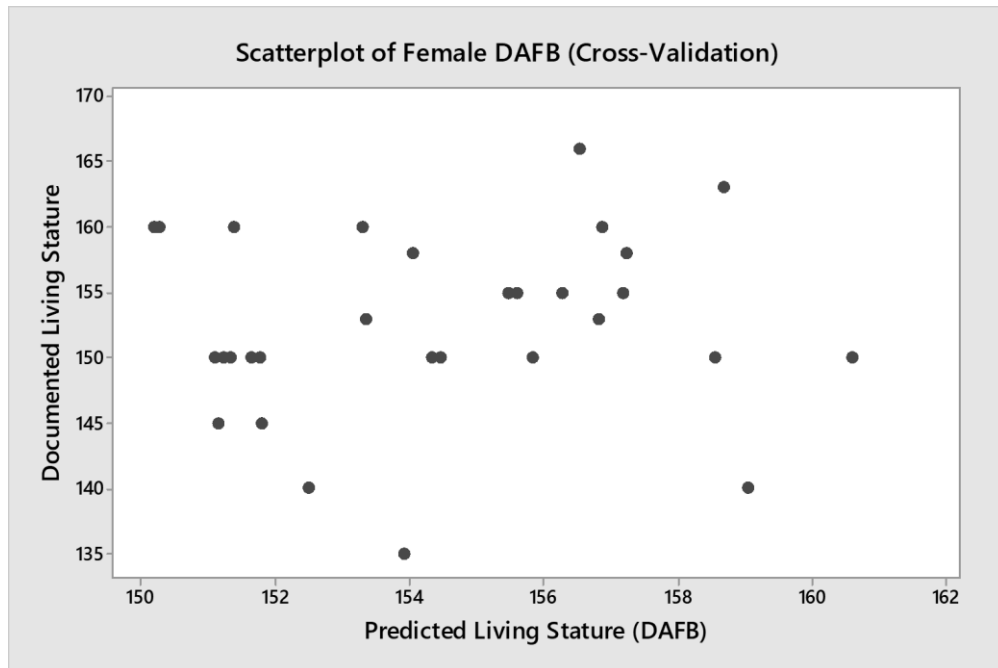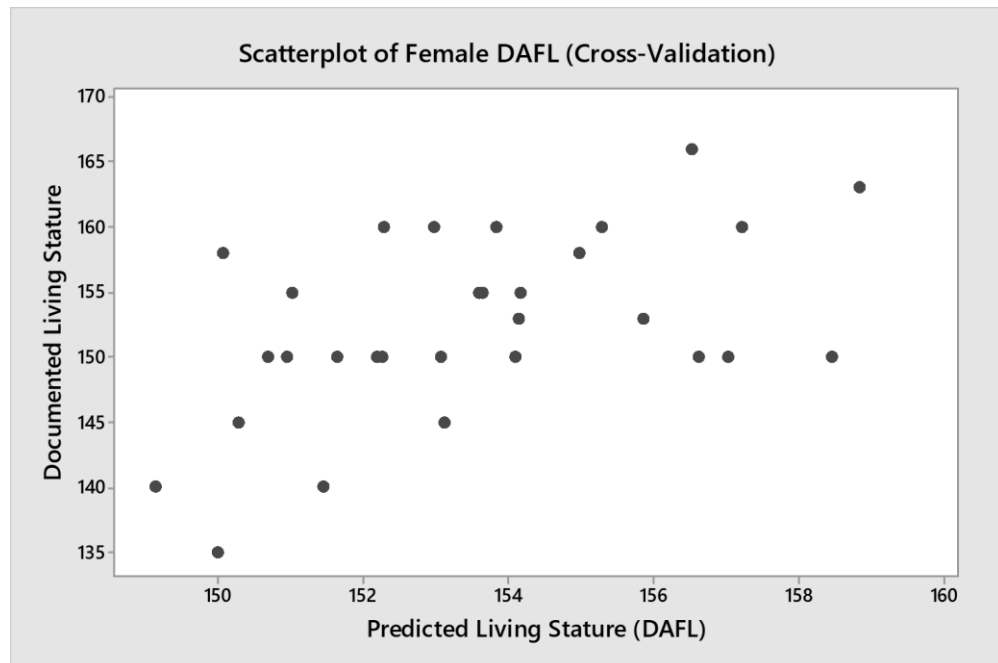

Appendix E2: Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the female MAXL calcaneal simple regression equation.
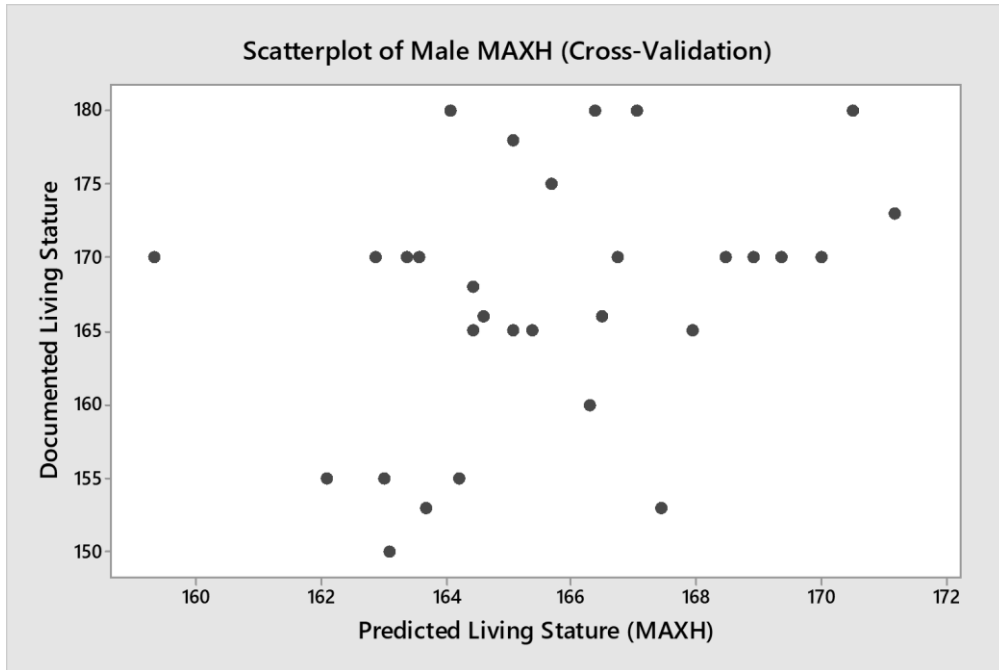
Appendix E3: Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the male MAXH calcaneal simple regression equation.
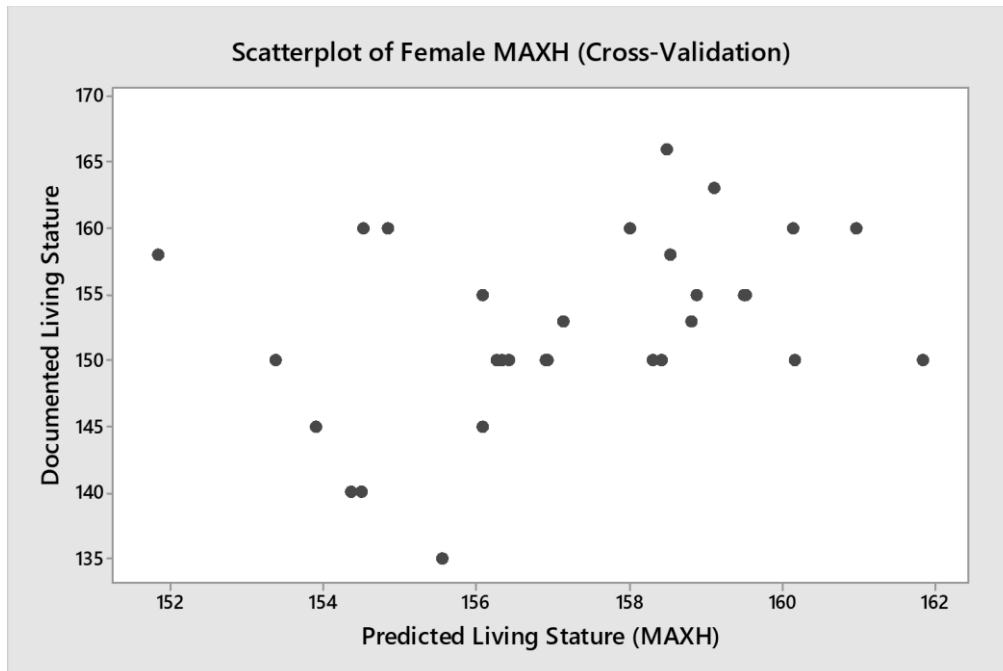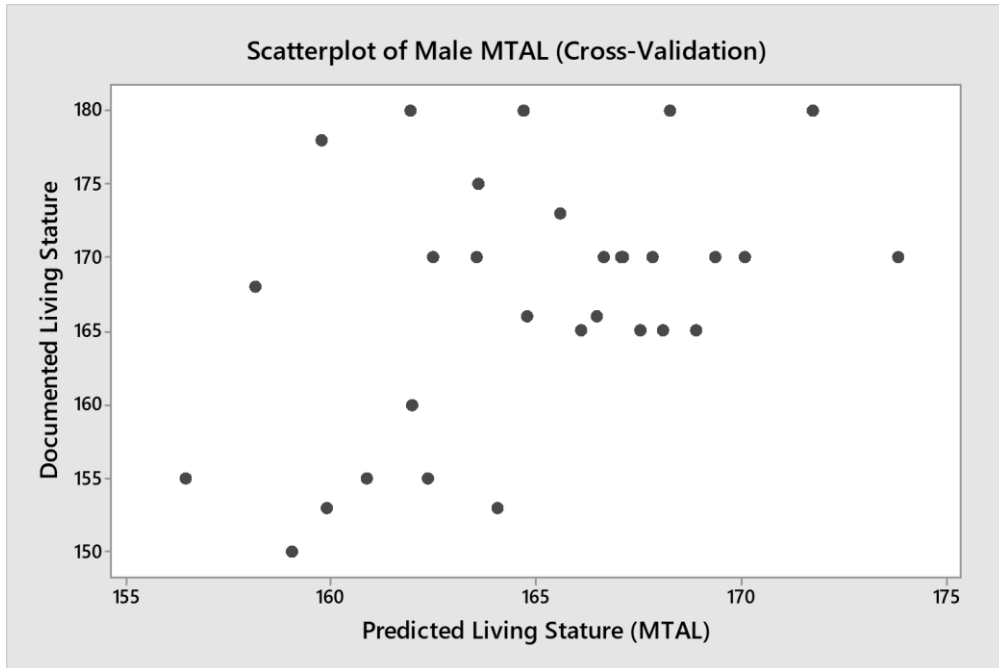

Appendix E4: Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the female MAXH calcaneal simple regression equation.
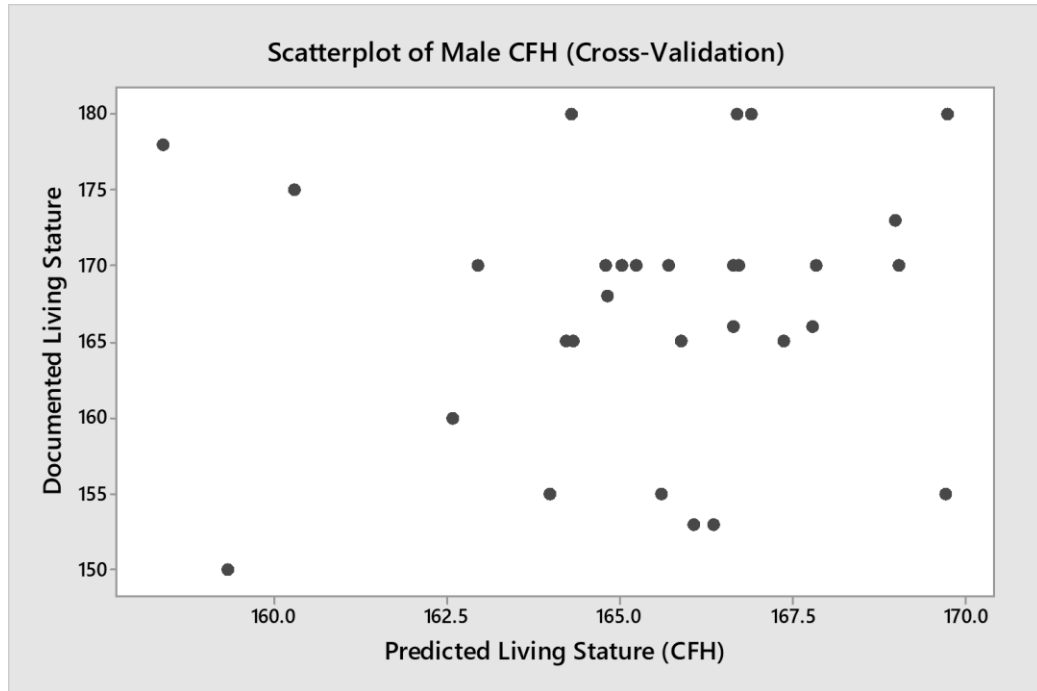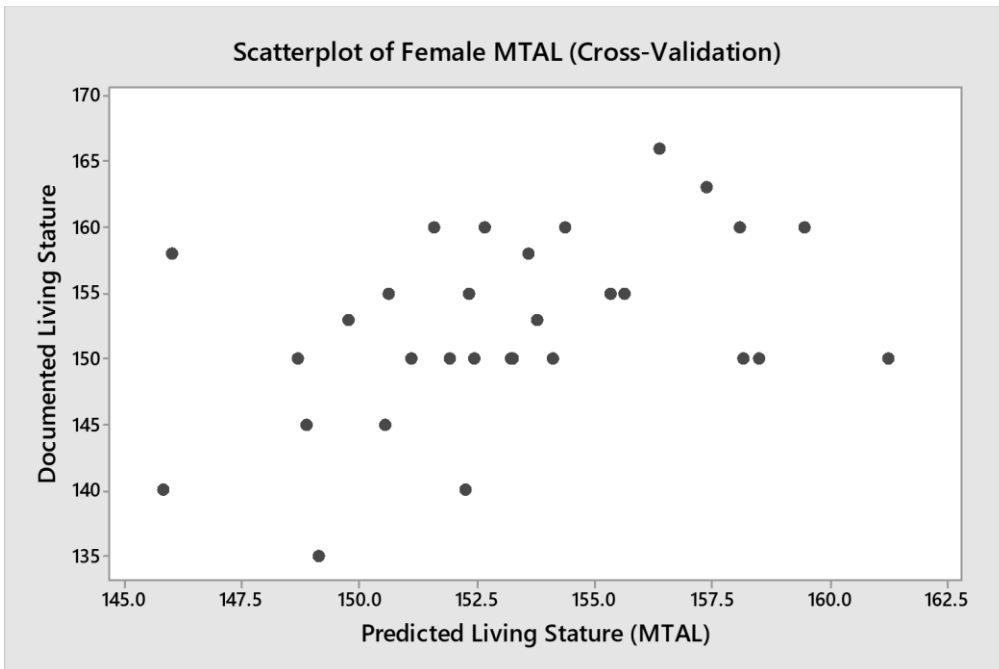
Appendix E5: Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the male CFH calcaneal simple regression equation.
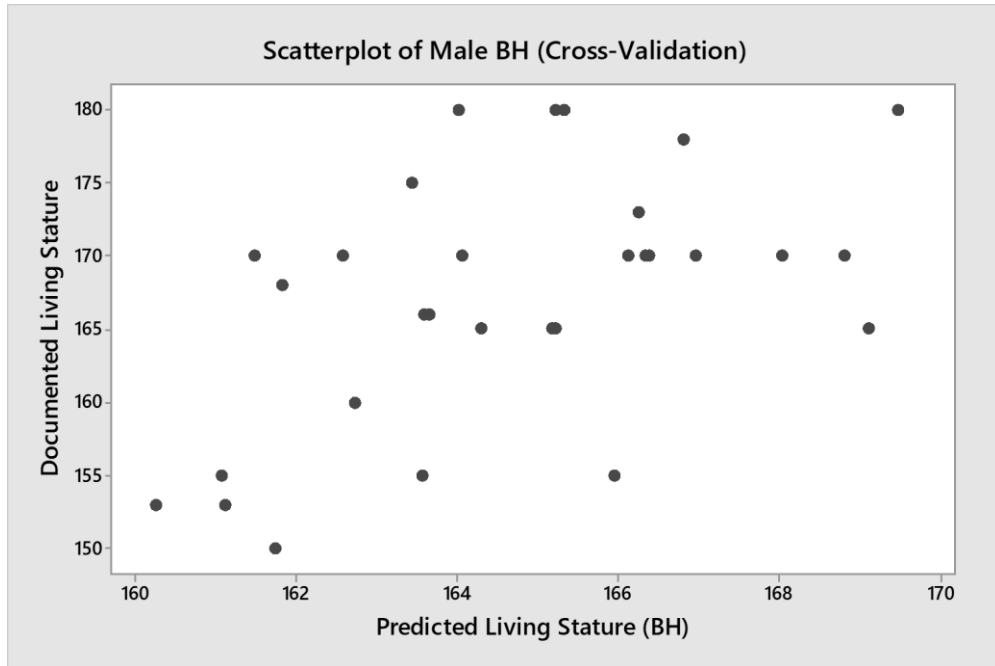
Appendix E6: Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the male BH calcaneal simple regression equation.
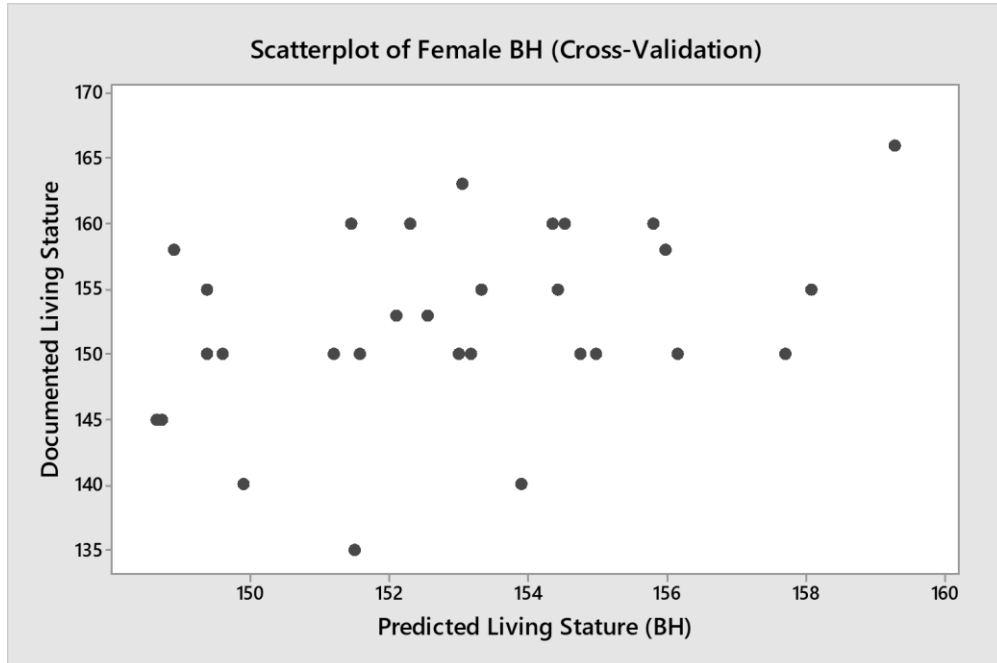
Appendix E7: Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the female BH calcaneal simple regression equation.
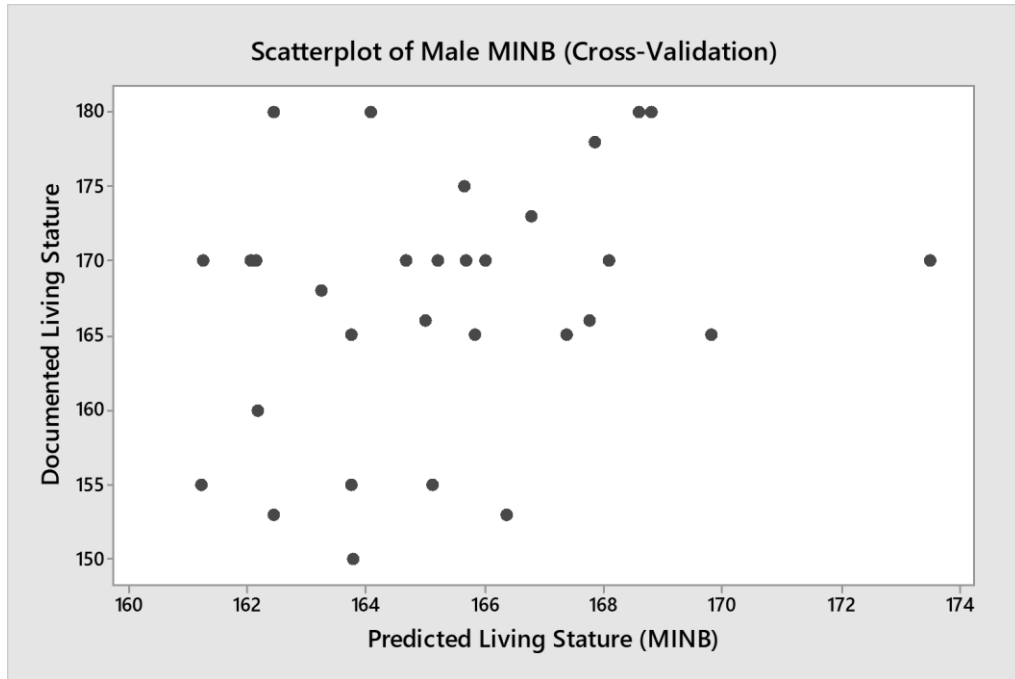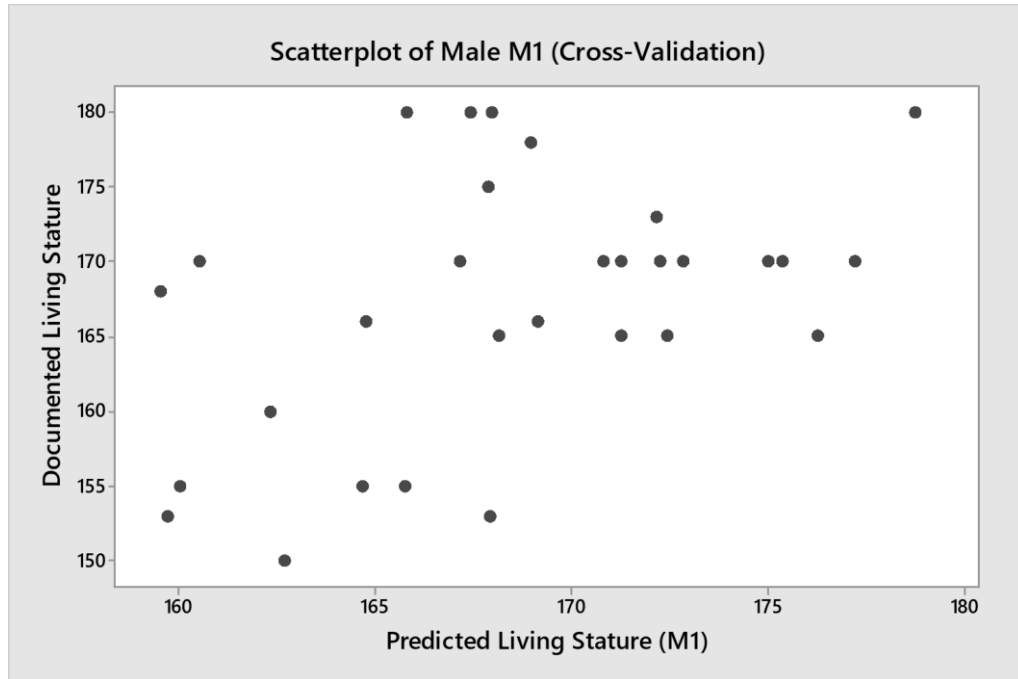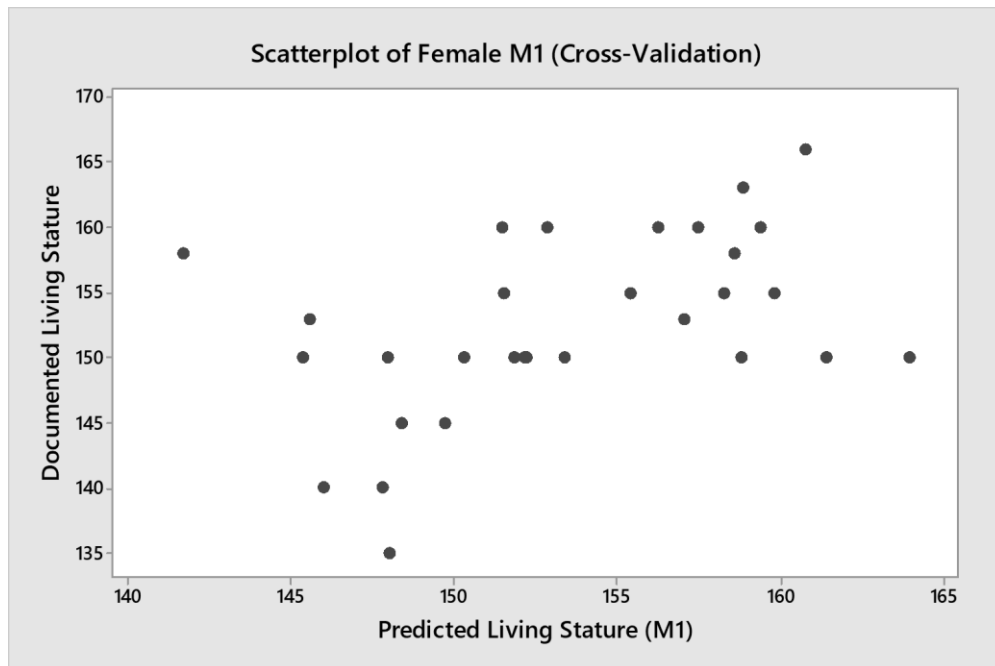
Appendix E8: Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the male MINB calcaneal simple regression equation.
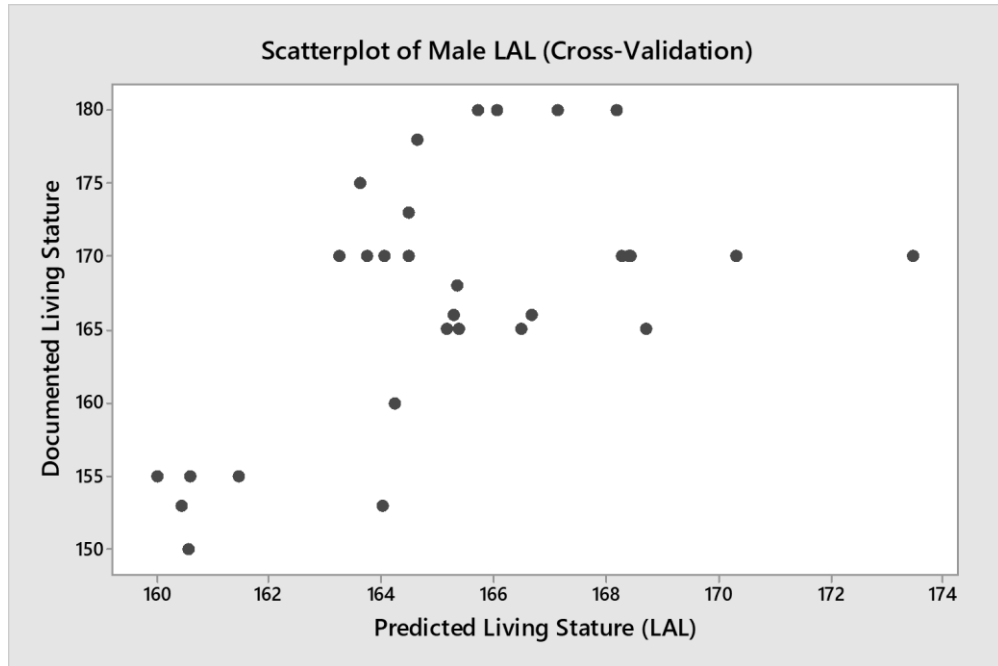
Appendix E9: Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the male LAL calcaneal simple regression equation.
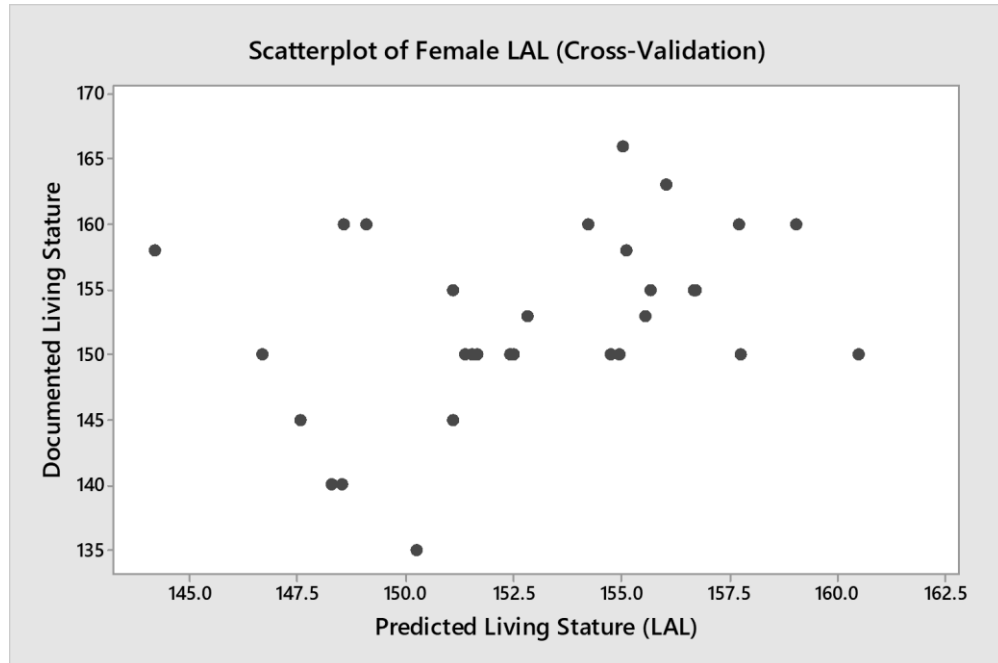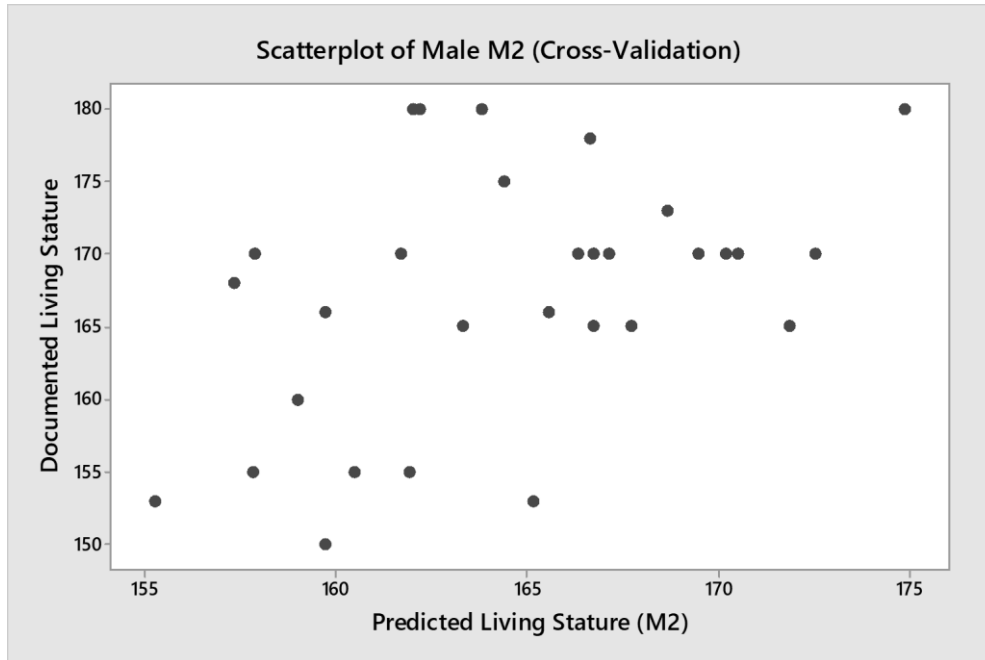

Appendix E10: Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the female LAL calcaneal simple regression equation.
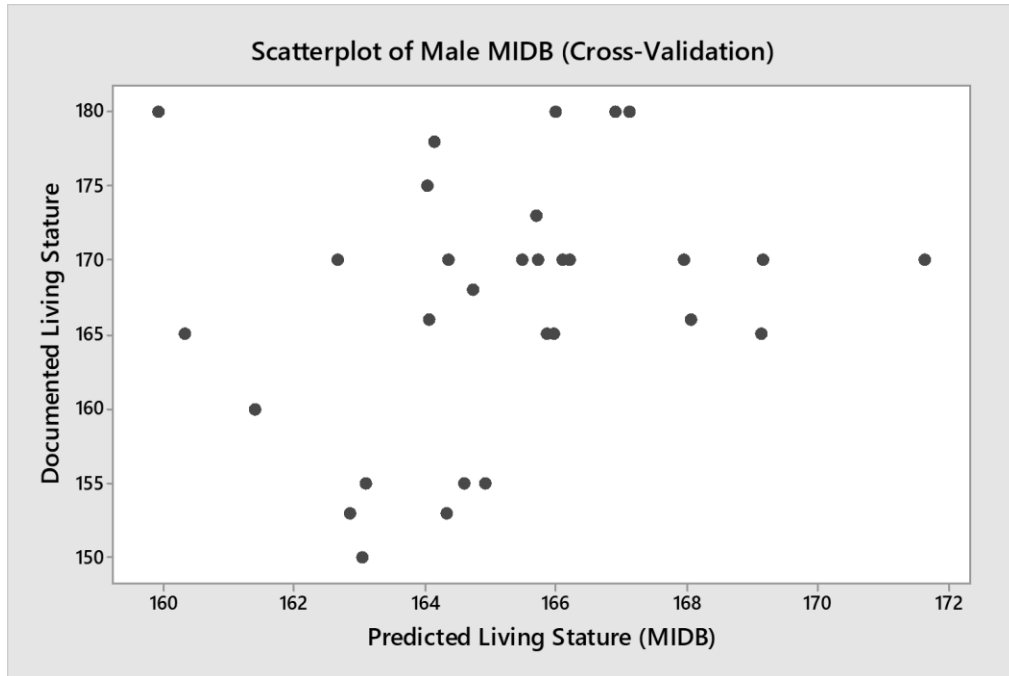
Appendix E11: Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the male MIDB calcaneal simple regression equation.
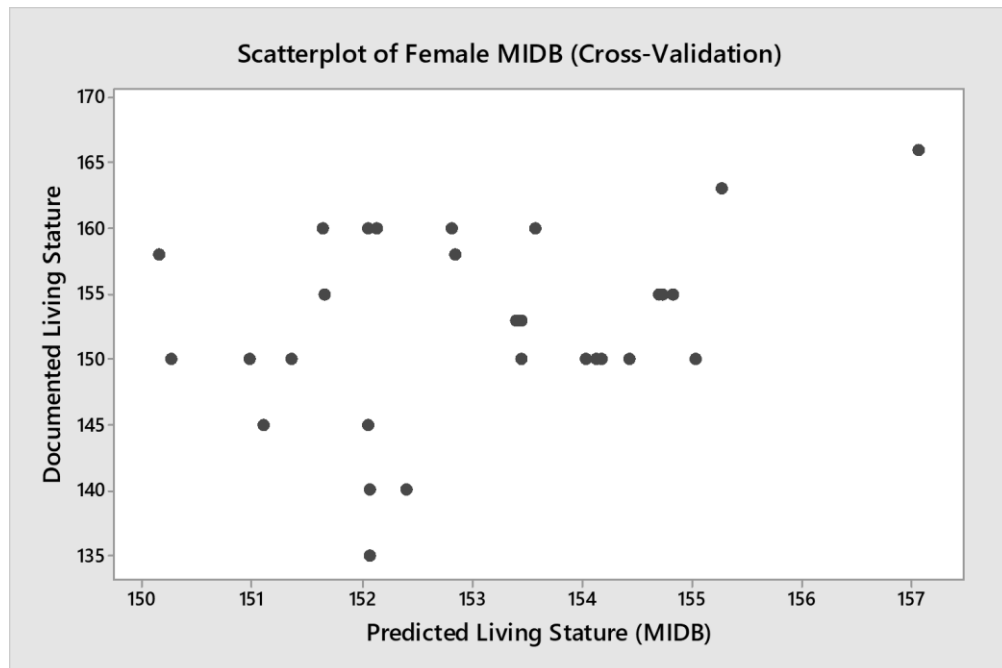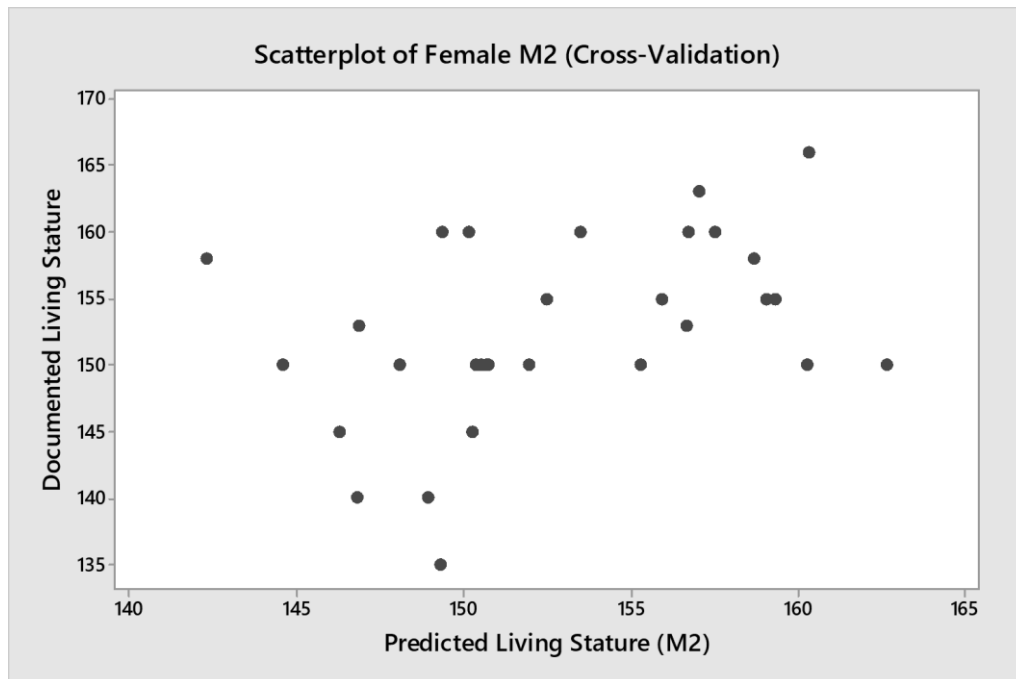

Appendix E12: Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the female MIDB calcaneal simple regression equation.

Appendix E12: Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the female DAFB calcaneal simple regression equation.
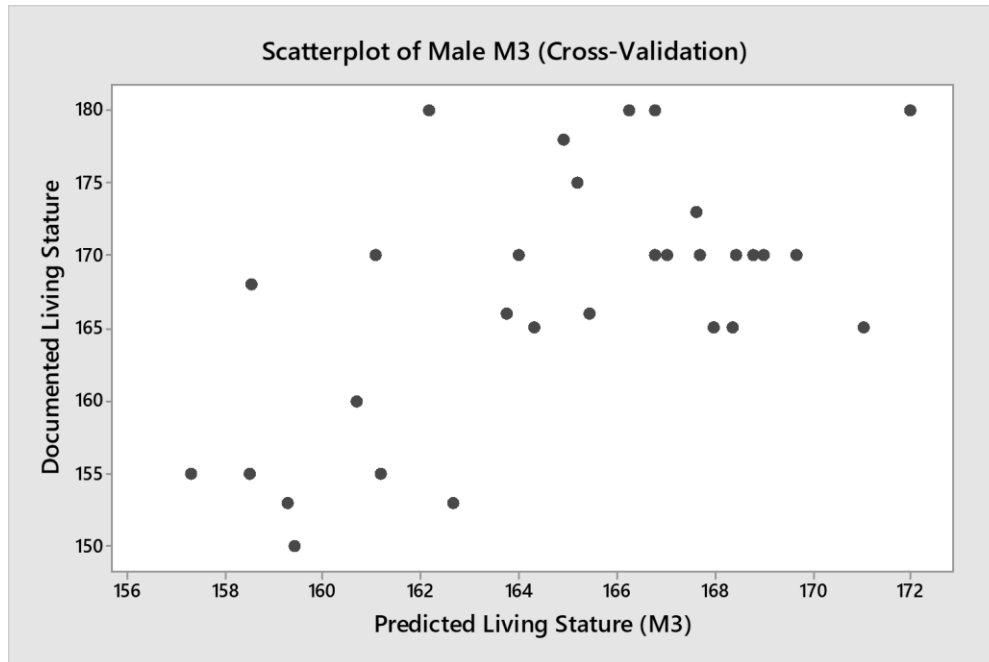

Appendix E13: Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the female DAFL calcaneal simple regression equation.

Appendix E14: Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the male MTAL talar simple regression equation.

Appendix E15: Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the female MTAL talar simple regression equation.

Appendix E16: Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the male direct multiple regression equation 1.
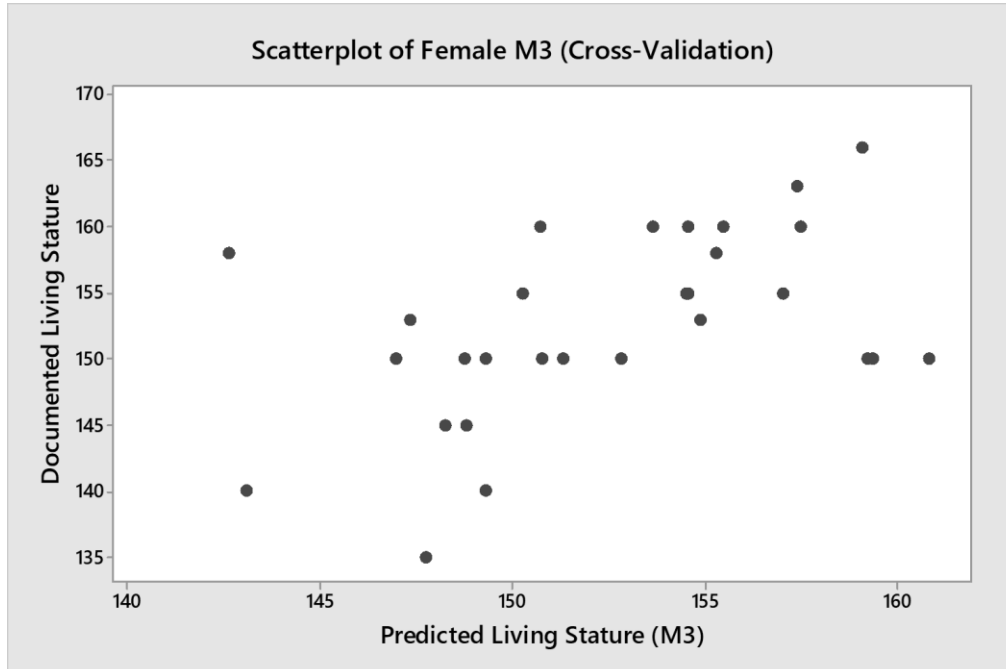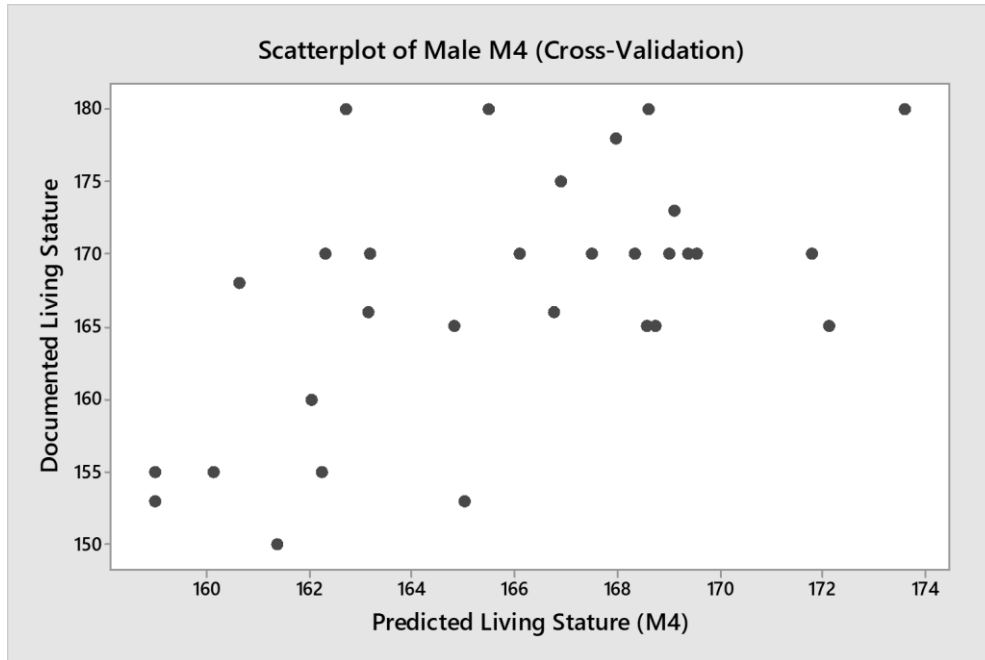

Appendix E17: Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the female direct multiple regression equation 1.
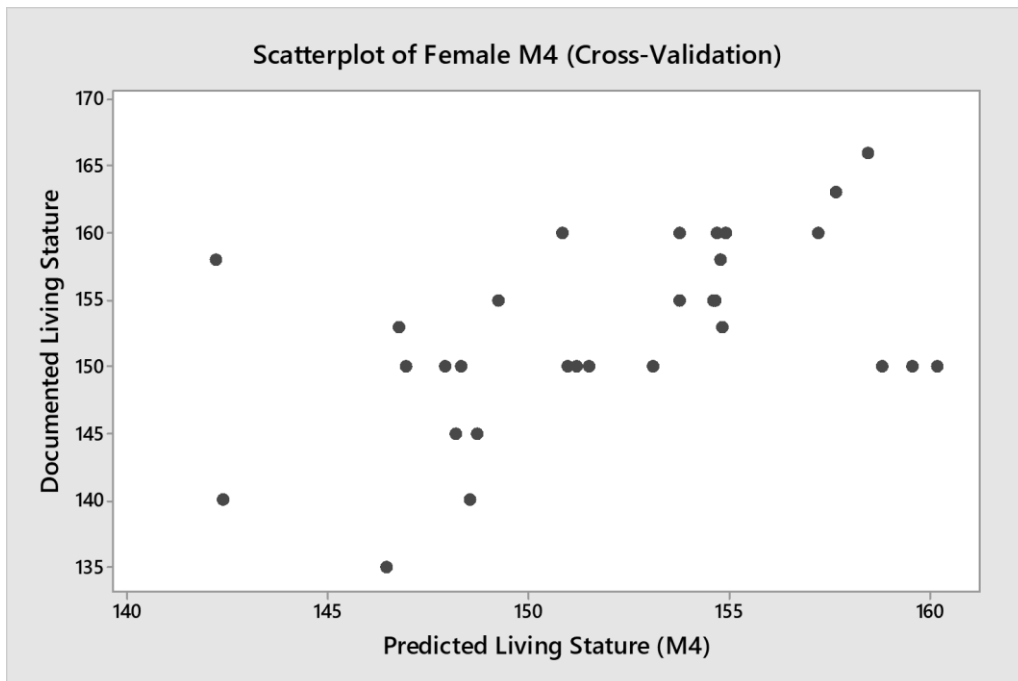
Appendix E18: Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the male direct multiple regression equation 2.

Appendix E19: Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the female direct multiple regression equation 2.

Appendix E20: Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the male direct multiple regression equation 3.
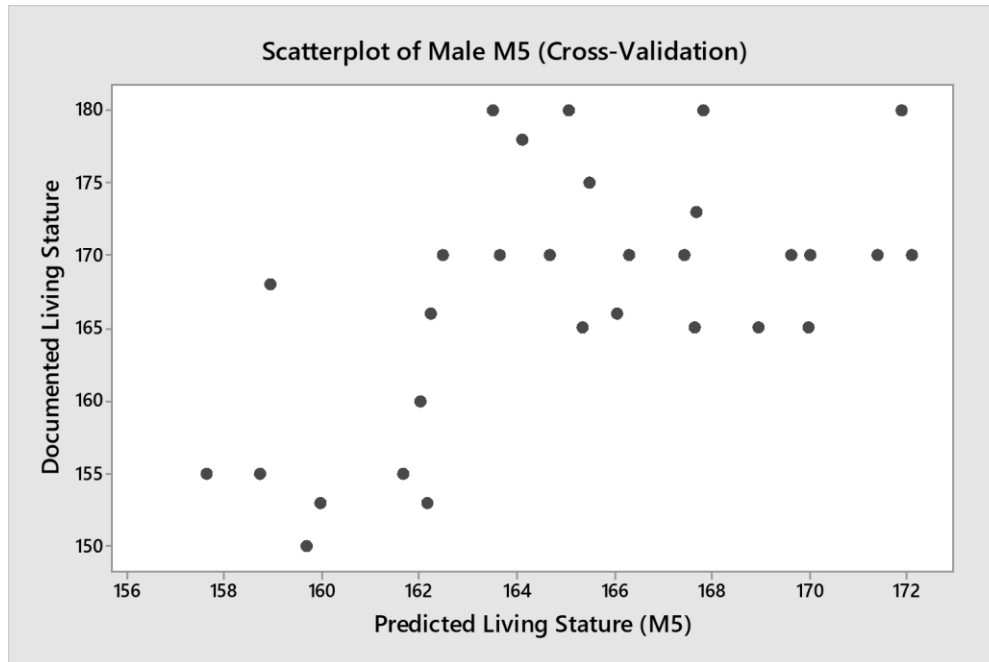

Appendix E21: Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the female direct multiple regression equation 3.
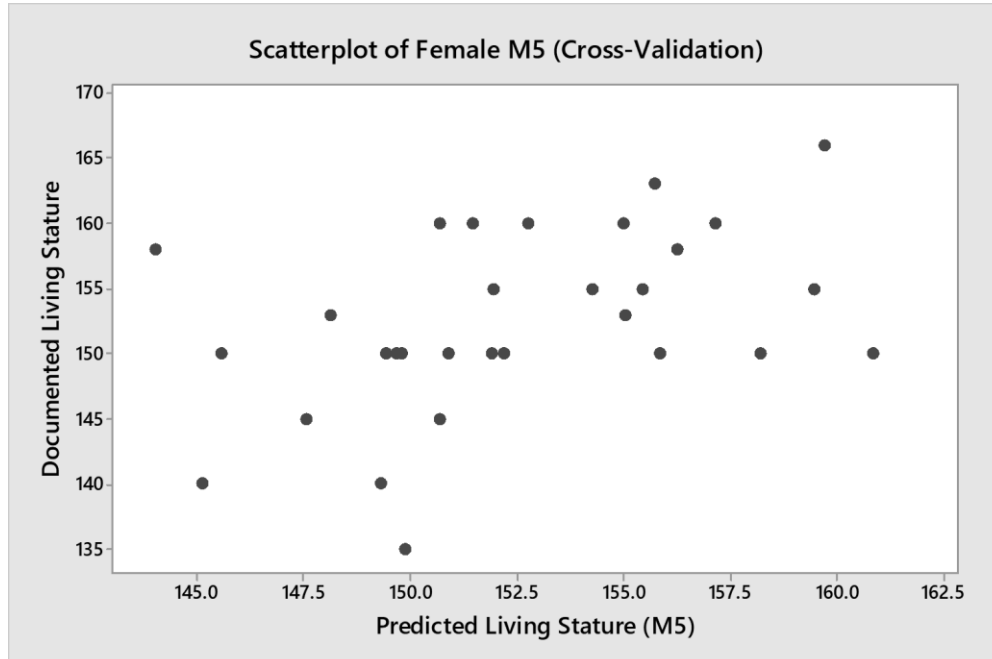
Appendix E22: Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the male direct multiple regression equation 4.

Appendix E23: Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the female direct multiple regression equation 4.

Appendix E24: Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the male stepwise multiple regression equation 5.

Appendix E25: Simple scatterplot illustrating the correlation between documented and predicted living stature, in a Thai population, using the female stepwise multiple regression equation 5.