Stature Estimation: Evaluating Regression Formulae for Different Population Groups in South Africa

by

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For my Sister

Carmen Sidzumo

I am because you are.

Umuntu Ngumuntu Ngabatu

"A person is a person through other persons. None of us comes into the world fully formed. We would not know how to think, or walk, or speak, or behave as human beings unless we learned it from other human beings. We need other human beings in order to be human."
Tutu (2004)

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List of Abbreviations

LS	Living stature
LSwA	Calculated living stature with age correction
LSr	Estimated living stature (Feldesman *et al*. (1990) generic femur/stature ratio)
LSf	Estimated living stature (Lundy and Feldesman (1987) femur regression)
TSH	Total skeletal height
TSH_{Calc}	Calculated total skeletal height (from full anatomical method)
TSH_{Est}	Estimated total skeletal height (from regression formula)
SA	South Africa
AD	South Africans of African Descent
ED	South Africans of European Descent
MA	South Africans of Mixed Ancestry
SEE	Standard error of estimate
Stats SA	Statistics South Africa
CS	Community Survey
pppm	Per person per month
ICT	Infancy-childhood transitional age

Abstract

Stature estimations from regression formulae are used by forensic anthropologists in constructing a biological profile from unidentified human remains. Regression formulae are used to calculate total skeletal height or living stature when incomplete, fragmentary or burned human remains are recovered. This study aimed to evaluate the reliability of the total skeletal height regression formulae from (1) Lundy and Feldesman (1987), and (2) Dayal *et al.* (2008) when compared to total skeletal height from the full anatomical method (Fully's method), in a contemporary South African population. The use of these regression formulae to estimate total skeletal height of South Africans of Mixed Ancestry was investigated as no population-specific standards exist for this group. Additionally, the reliability of the generic femur/stature ratio (Feldesman *et al*., 1990) to estimate living stature for all three population groups was investigated.

Measurements were taken from 229 individuals comprising of South Africans of Mixed Ancestry, African Descent and European Descent from South African skeletal collections. ANOVA's and paired *t*-tests were used to determined if there was a significant difference ($p<0.05$) between (1) estimated total skeletal height from regression formulae and that from Fully's method, and (2) the estimated living stature from the femur/stature ratio and a calculated living stature from Fully's total skeletal height with soft tissue and age correction factors.

No significant difference ($p>0.05$) was found between South Africans of African Descent and Mixed Ancestry's calculated total skeletal height, but both were significantly different ($p<0.000$) to individuals of European Descent. Results indicate that the Lundy and Feldesman (1987) regression formulae should be re-assessed for contemporary South Africans of African Descent and results from the Dayal *et al*. (2008) regression formulae indicate that the formulae are still relevant for contemporary South Africans of European Descent. Additionally, new regression formulae should be developed to enable forensic or physical anthropologists to estimate total skeletal height of Mixed Ancestry individuals. The femur/stature ratio's living stature were significantly different ($p<0.000$) from the calculated living stature, and generally overestimated it for maximum femur lengths greater than 50cm.

Chapter 1: Introduction

The archaeological, historical or forensic discovery of unidentifiable human remains requires the composition of a biological profile for each recovered individual found (Snow, 1982). A forensic discovery requires robust scientific methodology as the biological profile can be used in a medico-legal investigation. A basic biological profile of an individual consists of population affinity, sex, age and living stature. The first three components can be morphologically ascertained (Scheuer, 2002; Bidmos *et al*., 2010).

Living stature (LS) must be measured either directly from an individual (forensic or cadaveric height) or calculated from the individual's stature contributing skeletal elements. Fully (1956) developed the full anatomical method (Fully's method) to calculate total skeletal height (TSH) based on the summed total height of all the skeletal elements that contribute to it; *i.e*. the complete skull, the 2nd cervical to 1st sacral vertebrae, the physiological femur and tibia lengths, and the articulated talus-calcaneus bones in the foot. Determining LS from TSH, a soft-tissue correction factor (Fully, 1956) and an age correction factor (Trotter and Gleser, 1952) must be added to TSH. Trotter and Gleser (1952) noted that stature loss occur after age 30 due to thinning of the cartilaginous disks between vertebrae, anterior compression of the vertebral bodies themselves (causing increased curvature of the spine) and general wear on weight-bearing cartilage.

The full anatomical method is not always possible when fragmentary or incomplete human skeletal remains are found. The use of indirect methods such as the regression formulae formulated by Pearson (1899) can then be used to estimate TSH or LS. Regression formulae enable physical anthropologists to use either a single bone or multiple bone measurement(s) to estimate TSH or LS.

Pearson (1899) demonstrated how regression formulae would represent a mathematical correlation between a known variable, *e.g*. long bone length(s), and an unknown variable, *e.g*. TSH or LS. He illustrated how the correlation of long bone length(s) and TSH or LS would be expressed as a mathematical linear formula. He explained that the regression formula would be derived from the mean size and standard deviation for both TSH or LS and the long bone length(s) in question and their coefficients of correlation. However he cautioned that in order to determine an individual's stature using regression formulae it must first be ascertained if the individual in question stems from the same population group from which the regression coefficients have been derived.

Developing TSH regression formulae researchers require access to cadaveric-derived skeletal remains, ensuring the availability of all stature contributing skeletal elements to calculate TSH and to determine the correlation coefficients of a specific bone length(s) to TSH or LS. In the first half of the 20th century many published regression formulae were based on European and North American population groups where bone collections at universities or government institutes made it possible. Unfortunately such accessibility was limited for many researchers in other parts of the world.

Since the late 20th to early 21st century more bone collections were established and expanded on in different countries enabling researchers to test the statistical robustness of non-population-specific versus population-specific regression formulae. Consequently many researchers have advocated development of population- and/or sex-specific regression formulae (Lundy and Feldesman, 1987; Feldesman and Fountain, 1996; Raxter *et al*., 2008; Cardosa, 2016). Others have cautioned using sex- and/or population-specific regression formulae when either population affinity and/or sex cannot be ascertained with certainty (Feldesman and Fountain, 1996; Albanese *et al*., 2016).

Furthermore, various researchers have noted the importance of regularly updating regression formulae to account for temporal osteological modifications in a population group (Steyn and Işcan, 1997; Mall *et al.*, 2001).

In South Africa (SA) in the latter half of the 20th century, anthropometric and regression formulae stature research were conducted on two of SA's population groups by many researchers at various points in time (Lundy and Feldesman, 1987; Bidmos and Asala, 2005, Bidmos, 2006; Chibba and Bidmos, 2007; Ryan and Bidmos; 2007; Bidmos, 2008; Dayal *et al*., 2008; Bidmos, 2008; Bidmos, 2009; Pininski and Brits, 2014; Brits *et al*., 2017). The first focus population group, and SA's largest (80.6%), consisted of South Africans of African Descent (AD) (2016 Community Survey (CS), Statistics South Africa). The second focus population group, and currently third largest (8.1%), consisted of South Africans of European Descent (ED).

In the last decade anthropometric research (Steyn and Smith, 2007) has also included the second largest (8.8%) South African population group (2016 CS, Stats SA). This population group consist of individuals with a highly mixed ancestral lineage from West and Central Africa (Bantu-speaking people) (Petersen *et al*., 2013; Montinaro *et al.*, 2017), Europe, the Middle/Far East, and population groups indigenous to Southern Africa (*i.e.* the Khoesan people). Henceforth, these individuals will be referred to as South Africans of Mixed Ancestry (MA) for the purpose of this study. Until very recently population-specific regression formulae for MA have been lacking.

Composition of a biological profile by a forensic anthropologist aids the South African Police Service (SAPS) with investigations concerning missing persons or for victim identification. Due to the legal importance and possible ramifications of such medico-legal investigations, it is imperative that all scientific evidence for admission in a court case is in alignment with Act 37 of 2013: Criminal Law (Forensic Procedures) Amendment Act, 2013 (No. 37268, Government Gazette, Republic of South Africa, 27 January 2014). Hence the estimated stature from regression formulae should be within an acceptable statistical range (95% confidence interval) from the sex- and/or population-specific stature ranges the individual was assigned to.

The aim of the current study was to first calculate TSH (TSH_{Calc}) and then to statistically compare it to the estimated TSH (TSH_{Est}) results from various stature regression formulae. Similarly, the current study's second aim was to first calculate living stature (LSwA) from TSH_{Calc} and then to statistically compare it to the estimated living stature results (LSr) from Feldesman *et al*.'s (1990) generic femur/stature ratio.

The objectives of the current study were:

(1) To create an unbiased reference stature, *i.e*. TSH_{Calc}, to which TSH_{Est} from stature regression formulae could be compared.

(2) To test the current applicability of existing stature regression formulae on a subsample of contemporary AD and ED population groups. Regression formulae tested were (1) Lundy and Feldesman's 1987 AD-derived and (2) Dayal *et al*.'s 2008 ED-derived univariate and multivariate stature regression formulae.

(3) To determine if AD- and/or ED-derived regression formulae could estimate MA's TSH_{Est} within a 95% confidence interval of TSH_{Calc}.

(4) To test the statistical robustness (within a 95% confidence interval) of Feldesman *et al*.'s (1990) generic femur/stature ratio's estimated LS (LSr) to the calculated LS (LSwA).

The key foci of the study were:

(1) To evaluate the continued use of population-specific stature regression formulae developed for AD and ED on a contemporary population.

(2) To determine if the use of other South African population-specific regression formulae could yield TSH_{Est} of MA within a 95% confidence interval of the TSH_{Calc} or if MA's TSH_{Est} would be under- or overestimated.

(3) Whether or not the generic femur/stature ratio could estimate LS of MA, AD and ED within a 95% confidence interval or if any of the population groups' LSr would be under- or overestimated.

Chapter 2: Literature Review

Since the mid-19th century scientists have researched the stature of various population groups (Humphry, 1858; Rollet, 1889; Manouvrier, 1893). Their research involved stature ranges (means and standard deviations) and mathematical relationships between stature and various long bones. It was not until 1899 when Professor Karl Pearson fundamentally explored the mathematical linear relationship of correlation between stature and different skeletal elements. Consequently, his mathematical scrutiny, and subsequent divergent findings, of many previous stature researchers' conclusions places his research as the proper commencement of stature regression formulae.

2.1 Sample size, outliers and individual variation

Pearson (1899) was first to draw attention to sample size as a factor which should not be disregarded. He said that if the correlation between the known, *i.e*. long bone length(s), and the unknown, *i.e*. stature, variables was high "...fifty to a hundred individuals may be sufficient..." (Pearson, 1899: 170). When considering the methodology for deriving regression formulae (Pearson, 1899; Bidmos, 2008) and that approximately 85% of human variation occurs within a population group (Lewontin, 1972 *cited in* Ousley *et al.*, 2009), a large sample size would incorporate most individual variation within a population group.

Stature regressions are adjusted linear formulae:

$$\text{Total skeletal height } (\mathbf{y}) = [\text{slope } (\mathbf{m}) \text{ x bone length in cm } (x)] + \text{intercept } (\mathbf{c}) \pm \textbf{SEE}$$

where the standard error of estimate (SEE) represents the difference between the actual (or calculated) stature of an individual and the predicted stature by the regression formula. SEE values should thus be low (Bidmos, 2008) as most of the variation between individuals of a specific population group should have been incorporated in the mean, standard deviation and coefficients of correlation used to devise the regression formulae (Pearson, 1899). Both the mean and the standard deviation of any variable depend on the data points in a data set and therefore outliers in a data set may adversely influence both these statistical variables (Jackson and Chen, 2004; Ben-Gal, 2005; Hair *et al*., 2010).

Nonconforming or "atypical" data points that are three (3) or more standard deviations from the mean of the sample may be considered an outlier (Jackson and Chen, 2004). It may be easier to identify 'true' outliers in a larger sample size as both the mean and standard deviation would not be radically influenced by such outliers.

2.2 Population-specific stature and influencing factors

Several different reasons have been researched to explain the stature differences between historic and/or modern intra- and inter-population groups. Stature is not merely a consequence of genetic influence (Weedon and Frayling, 2008; Petersen *et al*., 2013; German *et al*., 2015), but external factors such as infancy-childhood transitional age (Gawlik *et al.*, 2011), environment (Cowgill *et al*., 2012; Wells, 2012), nutrition (Akachi and Canning, 2007; Victora *et al*., 2008), pathogens (Walker, 1995; Deaton, 2007; Limony *et al*., 2013), economy (Steckel, 1995; Inwood and Masakure, 2013; Stulp and Barrett, 2016) and even business cycles (Sunder and Woitek, 2005) can significantly affect stature. Combined, these factors influence human growth patterns and growth rates, and have contributed to stature differences between the population groups in South Africa (SA).

Population groups in SA are genetically diverse due to different genetic ancestral input, the past socio-political landscape and the consequential economic circumstances (Petrus and Isaacs-Martin, 2012; Inwood and Masakure, 2013; Petersen *et al*., 2013; Montinaro *et al*., 2017). The current study will only be focusing on the three largest population groups. First, and foremost, are the individuals that make up more than 80% of SA's population (2016 Community Survey (CS), Statistics SA). These individuals are referred to as 'Black' by the South African government and this is the term used by Stats SA. For the purpose of this study, and in accordance with policy at the University of Cape Town (UCT), hereafter they will be referred to as South Africans of African Descent (AD). Modern AD are the descendants of agro-pastoral Bantu-speaking (in reference to the Niger-Kordofanian phylum of African languages) African people who migrated south from West and Central Africa (Petersen *et al*., 2013; Liebenberg *et al*., 2015). During their migration process *circa* 1 500 years ago genetic research has shown admixture with people from Niger-Congo, East Africa, the rainforest Pygmies and finally the Khoesan in Southern Africa (Montinaro *et al*., 2017). Several different tribes exist in SA and the surrounding countries with each tribe showing evidence of different percentage genetic contribution from these four main groups depending on their geographic location. For the purpose of this study, the AmaXhosa, AmaZulu, AmaNdebele, Basotho and all other tribes are grouped as AD.

The second largest, approximately 8.8% (2016 CS, Stats SA), population group in SA consists of individuals with the highest (30%) heterozygosity in the world (Petersen *et al*., 2013; Montinaro *et al*., 2017). Stats SA uses the term 'Coloured' to identify these individuals and more than 90% of individuals self-identify as 'Coloured' (2016 CS, Stats SA). For the purpose of this study, and in accordance with policy at UCT, henceforth they will be referred to as South Africans of Mixed Ancestry (MA). The term 'Mixed Ancestry' was decided upon as this genetic heterogeneity is far more recent than that of AD, *circa* 360 years ago (Petrus and Isaacs-Martin, 2012; Inwood and Masakure, 2013; Petersen *et al*., 2013; Montinaro *et al*., 2017). In addition to the Khoesan and African non-Khoesan genetic input, as with AD, these individuals contain genetic contributions from Eurasia including clusters from the Netherlands, France, Germany, Britain, India, Indonesia and Han-China to name but a few (Petersen *et al*., 2013; Montinaro *et al*., 2017). Similar to AD, MA's ancestral genetic input varies according to geographic location. For example, Mixed Ancestry individuals in Cape Town, Western Cape Province (WC), have a greater Asian input than those in the Eastern Cape Province (EC) and less Khoesan input than those in the Northern Cape Province (NC) (Petersen *et al.*, 2013). The EC's MAs have the highest genetic contribution of African non-Khoesan than either those in the Western or Northern Cape Provinces and the lowest Asian input overall (Petersen *et al.*, 2013). Petersen *et al.* (2013) describes it as "...the largest within population and regional-associated variability".

The third largest, approximately 8.1% (2016 CS, Stats SA), population group in SA are descendants of mainly European settlers (Steyn and Işcan, 1997; Steyn and Işcan, 1999; Quintana-Murci *et al*., 2010; Montinaro *et al*., 2017). The Dutch East India Company (Vereenigde Oost-Indische Compagnie or VOC) established a replenishing station along the maritime route between Europe and the East (Middle and Far East) at the Cape Colony around the southern tip of Africa (Quintana-Murci *et al*., 2010). The initial influx of Dutch and later French, British and German settlers started *circa* 365 years ago (Petersen *et al*., 2013). These individuals will be referred to as South Africans of European Descent (ED) for the purpose of the current study although they are more commonly described as 'White' by the South African government and Stats SA. Founder's effect (term coined by Ernst Mayr in 1942), ecogeographic changes and limited admixture with other more established population groups in SA have rendered this group of individuals as the most homogeneous in SA (Petersen *et al*., 2013) yet osteologically distinct from their ancestral gene pool (Liebenberg *et al*., 2013; L`Abbé *et al*., 2013; Liebenberg *et al*., 2015). The remaining 2.5% of the South African population consist of Indian/Asian, 2.47% (2016 CS, Stats SA), and Other (Census 2011, Stats SA).

Many osteological and anthropometric studies have been conducted on AD and ED with the recent (last decade) addition of MA. These studies include osteological (L'Abbé *et al*., 2013) or anthropometric (Feldesman and Fountain, 1996; Steyn and Smith, 2007; Stulp and Barrett, 2016; accepted manuscript Myburgh *et al*., 2017) comparisons with other common ancestral groups such as North Americans, Europeans or other African nations. African descendants in SA may be osteologically diverse from African-Americans due to the unique genetic input of the Khoesan. For example the AmaXhosa contain 35.4% Khoesan and 4.4% Sandawe-related genetic input in addition to the 63.6% African non-Khoesan (Petersen *et al*., 2013). L`Abbé *et al*. (2013) did an ancestry estimation of AD using Howell's database from the Forensic Anthropology Databank at the University of Tennessee, Knoxville, United States of America, and interestingly they classified 62% more accurately as 'Bushmen', *i.e*. Khoesan, than the 48% for AmaZulu. The Khoesan themselves have three distinct groups namely Northern, Central and Southern Khoesan (Petersen *et al*., 2013; Busby *et al*., 2016; Montinaro *et al*., 2017). In South Africa African Descent individuals show mainly Central Khoesan lineage whereas Mixed Ancestry individuals show only Southern Khoesan lineage (Montinaro *et al.,* 2017). The osteological consequences due to this diverse genetic input between these two South African population groups have as yet remained unexplored. In comparison, ED's osteological distinction from their ancestral genetic lineage is mainly based on limited genetic admixture among settlers from the European continent (Steyn and Işcan, 1997) with very little to no admixture with more established population groups prior to and during racial segregation in South Africa (Petrus and Isaacs-Martin, 2012; Inwood and Masakure, 2013). Furthermore it may possibly be attributed to environmental factors such as a harsher climate compared to the European continent affecting growth and development (Steckel, 1995; Steckel, 2008; Hochberg, 2009; Gawlik *et al*., 2011; Hochberg, 2011; German *et al*., 2015).

Aside from the genetic diversity or lack thereof political circumstances and the subsequent socio-economic conditions intensified existing anthropometric and/or osteological features due to limited gene flow between population groups (Petrus and Isaacs-Martin, 2012). In 1948 a new political party took over governance in SA and 'racial' (population group) segregation laws were introduced. These laws, *i.e*. the Prohibition of Mixed Marriages Act of 1949 and the Immorality Act of 1950, legally prevented admixture between those classified as 'White' and those classified as 'Non-White' (Petrus and Isaacs-Martin, 2012; Inwood and Masakure, 2013). The political hierarchy of population groups had employment, medical care and residential consequences causing severe and adverse socio-economic discrepancies for AD and MA from their ED counterparts (Keswell, 2004).

Basic income levels reduced AD and MA's power of purchase for both food (sustainable nutrition) and medical care. Steckel (1995; 2008) said living stature was a function of access to resources and research on developmental growth rates has shown that human growth is a net measure of nutrient input (food) versus metabolic output (physical activity) (Balogun *et al*., 2015; Martorell and Zongrone, 2012). Furthermore, modern medical science has determined that the infancy-childhood transitional (ICT) age is deferred in a hostile (nutrient-deficient, disease prone, high metabolic output) environment, which can lead to shorter stature (Hochberg, 2009; Gawlik *et al*., 2011; Hochberg 2011; German *et al*., 2015). Both AD and MA were subjected to such harsh environments which may possibly account for their shorter stature compared to ED (Gawlik *et al.*, 2011; Petrus and Isaacs-Martin, 2012; Inwood and Masakure, 2013; Liebenberg *et al*., 2015).

In addition nutrient-deficient disorders and increased pathogen, *e.g*. tuberculosis (TB) and diarrhoea, exposure in urban areas may contribute to stunting in various phases of human growth due to a much higher metabolic output compared to nutrient intake (Labadarios and Steyn, 2005; Akachi and Canning, 2007). Gastroenteritis combined with protein-energy malnutrition is classified as a “Group I” cause of death by Global Burden of Diseases (Statistical Release P0309.3, Stats SA, 2017). This combination is one of the most common medical causes young African Descent children are admitted to hospital (Walker, 1995). In the last century urbanisation especially amongst AD males, and more recently females, has increased considerably. Urbanised AD’s diet contains more fat and protein with far less unrefined carbohydrates, fibre and vitamins compared to their rural counterparts which has translated into an increased prevalence of “Group II” causes of death (non-communicable diseases classification; Global Burden of Diseases) in an urbanised environment (Labadarios and Steyn, 2005; Stats SA, 2017). Although nutrient-rich food and medical facilities are more readily available in urban areas, two in three (66.6%) South Africans lived below the R992 per person per month (pppm) upper-bound poverty line in 2015 (Stats SA, 2017). Of the 40.0% of South Africans that lived below the lower-bound poverty line of R647pppm in 2015, 47.1% were AD, 23.3% were MA and <1.0% were ED (Stats SA, 2017). Urbanisation of AD may have increased their accessibility to readily available nutrient-rich food and/or medical facilities, but income levels promoting power of purchase have not.

Both nutrition and pathogen exposure correlate with socio-economic circumstances and could possibly provide reasons, other than genetics, for living stature differences amongst SA’s population groups (Deaton, 2007; German *et al*., 2015).

2.3 Sex-specific stature regression formulae

The intricacies surrounding sexual dimorphism is beyond the scope of the current study. Frayer and Wolpoff (1985) provided an extensive review on sexual dimorphism. Gustafsson and Lindenfors (2009) attempted to provide reasons for the differential growth rate and development between the sexes. Hochberg (2011) described the developmental plasticity and adaptive capacity of human beings in changing, advantageous or adverse, environments. Bogin (2012) described the differences in development rates and high velocity growth spurts between the sexes especially in the infancy-childhood transitional age (ICT), childhood and adolescent phases. Stulp and Barrett (2016) explained the patriarchal influence on society with regard to social hierarchy, economic developments and many other factors which could possibly affect differential growth rate and development between sexes. Combined these studies and many others have attempted to describe and explain sexual size dimorphism within the human species. What is of importance is the fact that there are definite differences between the sexes regarding mean living stature. As with many other attributes living stature varies greatly between individuals but on the whole females tend to be shorter than their male intra-population counterparts (Steyn and Smith, 2007; Bogin, 2012; Stulp and Barrett, 2016).

Contrary evolutionary studies such as Frayer and Wolpoff (1985) show the convergence of sexual stature dimorphism across time. Osteological studies have shown the decrease of sexual dimorphism within a specific population group when compared to an ancestral genetically and phenotypically similar population group, for example South Africans of African Descent compared to African-Americans (L`Abbé *et al*., 2013). Cranial results (length and height) from L`Abbé *et al*. (2013) showed less sexual dimorphism between the sexes of AD than in males and females of European descent. When sex estimation was performed for AD using the Forensic Anthropology Databank and Howell's database in FORDISC 3.0, incorrect sex estimation was high (AD females only 48% accurate) though population affinity estimations were moderately good.

Notwithstanding this possible prospect of sexual dimorphism convergence, stature research has shown a distinct sexual dimorphism of post cranial skeletal elements within population groups. Although Albanese and his various co-authors (2008; 2016; 2016) have consistently advocated for a non-population- or group-specific approach regarding stature regression formulae, their estimated stature results of females when using male stature regression formulae, and vice versa, indicate a discrepancy with their final conclusion. Male mean differences between the 'documented' and estimated statures from female regression formulae were relatively high at +6.2cm (underestimated) and female mean differences were slightly less at -4.3cm (overestimated) (Table 4, page 63, Albanese *et al*., 2016). Both these values would report ANOVA *p*-values of significant differences ($p<0.000$).

Whether or not sex-specific regression formulae were used to estimate stature of an individual, it is the responsibility of the scientific expert in a medico-legal investigation and court case to justify the specific methodology used with regard to the case and its evidentiary circumstances (Act 37 of 2013: Criminal Law (Forensic Procedures) Amendment Act, 2013, Government Gazette, Republic of South Africa, Volume 583, 27 January 2014).

2.4 Long bone lengths and proportionality

2.4.1 Long bone lengths

Allen's rule states that long bones are lengthier in warmer climates than in colder climates to increase surface area to volume ratio enabling improved thermoregulation (Allen, 1877, *cited in* Frelat and Mittereocker, 2011). Frelat and Mittereocker (2011) further states that this elongation of the long bones may not be as noticeable due to the effect environmental stressors may have on the growth rate and development of limb bones. Mahakkanukrauh *et al*. (2011) noted that the growth rate and development of the distal long bones (tibia, fibula, ulna and radius) are more susceptible to environmental stressors compared to the proximal limb bones (femur and humerus). Jantz and Meadows Jantz (2017) reiterated the plasticity of long bone development in modern society and secular changes that have occurred over the last 150 years. Considering the climatic changes ED have had to adapt to they may be osteologically distinct from their ancestral lineage yet due to the limited admixture and the short timeframe for such adaptations (*circa* 350 years) their limb growth rate and development may still be in line with their ancestral lineage and not that of their new climatic environment (Liebenberg *et al*., 2015). It might just be masked by the environmental stressors as suggested by Frelat and Mittereocker (2011).

Albanese *et al*. (2016) noted that for either sex-specific or population-specific regression formulae the femur without fail performed better with the highest correlation to stature and the lowest standard error of estimates. The ulna and radius consistently had the lowest correlation with stature and the highest standard error of estimates. This is evident for the Lundy and Feldesman (1987) (Table 3.4, page 23) and Dayal *et al*. (2008) (Table 3.5, page 24) regression formulae. The correlation coefficient, constant and standard error of estimates of the regression formulae are much higher for the upper limb bones than those of the lower limb bones. Albanese *et al*. (2016) noted that the femur-tibia-humerus combination performed the best of all sex-specific or even generic multivariate regression formulae. They found that although the tibia performed better than the humerus for univariate formulae, a multivariate combination of any two of the femur, tibia and/or humerus outperformed all the univariate regression formulae.

Liebenberg *et al*. (2015) found that MA overall had shorter limbs than AD although much overlap occurred between these population groups. They also noted that ED on average had longer limb bones.

2.4.2 Proportionality of long bones to stature

Raxter *et al*. (2008) and Bogin (2012) both noted that population groups with similar phenotypic features have different body proportions, and therefore the correlation between certain body regions, for example torso to lower limb, will differ. Feldesman and Fountain (1996) found that African-Americans (‘Blacks’) had the highest femur/stature ratio of all the population groups in their study. Liebenberg *et al*. (2015) found that ED consistently had longer limb bones, but whether or not the proportion of the lower limb bones to stature were greater for this population group compared to MA and AD were not investigated. Myburgh (2016) focused on limb proportion differences and secular trends between ED and AD specifically and compared them to ‘white’ and ‘black’ North Americans and Europeans.

Although many South African studies have dealt with univariate and multivariate stature regression formulae (Table 2.1) and others with specific skeletal lengths (L`Abbé *et al.*, 2013; Liebenberg *et al*., 2015), none have focused on differences of limb proportions to stature between the three focus population groups of the current study.

2.5 Regression formulae

Multiple methods have been formulated to determine stature. First there is the full anatomical method (commonly known as Fully’s method) as described by Fully (1956) which requires all stature contributing skeletal elements to be available, measured and summed to provide total skeletal height (TSH). To determine living stature (LS) from TSH a soft tissue (Fully, 1956) and age correction factor (Trotter and Gleser, 1952) must be added and subtracted, respectively. Raxter *et al*. (2006; 2007) questioned and revised Fully’s anatomical method whereas Bidmos and Manger (2012) revised both Fully and Raxter *et al*.’s soft tissue correction factor for South Africans of African Descent. Soft-tissue correction factors between TSH and LS vary between 10cm – 11cm (Fully, 1956) and 12.4cm (Raxter *et al*., 2006) depending on the reference source. Presently consensus regarding the soft tissue correction factor is yet to be finalised.

Secondly, the mathematical method is used to determine stature when incomplete or fragmentary unidentified skeletal remains are discovered and/or due to time constraints (*i.e.* a limited time period in which to compose the overall biological profile of the unidentified individual). The full anatomical method is more laborious than measuring a single skeletal element. Mathematical methods include generic ratios such as the femur/stature ratio (Feldesman *et al*., 1990), generic regression formulae (Feldesman and Fountain, 1996; Albanese *et al*., 2016) or sex- and/or population-specific regression formulae. Feldesman, Kleckner and Lundy's (1990) advocated the use of a generic femur/stature ratio for hominid fossils or when "race" and sex cannot be established with certainty. Similarly, Albanese *et al*. (2016; 2016) stated exactly the same reasons for developing generic regression formulae. In 1996 Feldesman and Fountain showed that for modern population groups their generic regression formula performed better than the generic femur/stature ratio designed by Feldesman *et al*. in 1990. Furthermore they acknowledge the statistical error from the generic ratio in comparison to either a population-specific regression formula or the generic regression formula.

The femur/stature ratio determines LS directly from a 'dry' (no soft tissue) femur length. The regression formulae which the current study will test derives TSH from the various univariate (single bone length) and multivariate (two or more combined bone lengths) regression formulae. Subsequently LS can then be calculated by adding the soft tissue correction factor from Fully (1956) to the estimated TSH from the regression formula and then subtracting the age correction factor from Trotter and Gleser (1952) from the answer. Fully (1956) suggested a soft tissue addition of 10.0cm for TSH equal to or less than 153,5cm; a 10.5cm addition for TSH between 153.5 – 165.4cm; and an 11.0cm addition for TSH greater than 165.5cm. Trotter and Gleser (1952) calculated an annual 0.06cm decrease in adult height after age 30, *i.e*. age of individual – 30 x 0.06cm.

Regression formulae are derived from the coefficients of correlation, mean and standard deviations of skeletal dimensions in relation to TSH or LS. These statistical variables are then used to formulate an adjusted linear formula, *i.e*. $y = mx + c \pm \text{SEE}$, with the added standard error of estimate (SEE) (Pearson, 1899; Hess and Hess, 2017).

Stature regression formulae have been derived from various sources available to researchers for more than a hundred years. Sources include anthropometric data from living populations (Özaslan *et al*., 2003, Didia *et al.*, 2009), military personnel (Steyn and Smith, 2007; Rühli *et al.*, 2008) and cadavers before autopsy (Radoinova *et al*., 2002) or after autopsy (Singh *et al*., 2010, Chandran and Kumar, 2012). Osteometric data sources may stem from cemeteries (Kozak, 2009), historical museums (De Groote and Humphrey, 2011), archaeological skeletal material (Formicola and Francheschi, 1996; Pomeroy and Stock, 2012; Vercellotti *et al*., 2014), deceased World War military personnel (Trotter and Gleser, 1952), repatriation (Ousley *et al*., 2005), cadaveric-derived skeletal bone collections (Trotter and Gleser, 1952; Maijanen, 2009; and all publications as set out in Table 2.1) and databases (Wilson *et al*., 2010). The final source of data may be found on databases contained within FORDISC 3.0 for example such as the Forensic Anthropology Databank, Howells' database and a custom South African database (L`Abbé *et al*., 2013).

Various skeletal elements have been used from which stature regression formulae have been derived such as the skull (Ryan and Bidmos, 2007), vertebral column (Pomeroy and Stock, 2012), sacrum (Pininski and Brits, 2014; Klein *et al*.. 2015), femur (Pearson, 1899; Trotter and Gleser, 1952; Lundy and Feldesman, 1987; Feldesman and Fountain, 1996; Hauser *et al*., 2005; Ross and Manneschi, 2011), tibia and humerus (Duyar *et al*., 2006), radius, foot bones (Bidmos, 2005) and/or various combinations of these bones (Trotter and Gleser, 1952; Dayal *et al*., 2008; Mahakkanukrauh *et al*., 2011; Mahakizadeh *et al*., 2016). Pomeroy and Stock (2012) compared specific ethnic groups in coastal and mid-altitude Andean regions. Bidmos (2009) compared ED and AD.

Dayal *et al*. (2008) and Lundy and Feldesman (1987) showed that stature for ED and AD, respectively, is generally overestimated using regression formulae derived from European and North American populations. Steyn and Smith (2007) stated that South Africans of European Descent have become osteologically distinct from their European and North American counterparts.

Table 2.1 summarises all the published studies pertaining to the testing and development of stature regression formulae for AD and ED in South Africa. Most notable from these is the lack of stature regression formulae for MA. This population group have been shown to be osteologically distinct from both AD and ED (Liebenberg *et al.*, 2015). Considering how regression formulae are derived, the coefficients of correlation, mean and standard deviations of either of these population groups' stature regression formulae would not statistically reflect stature variation within the MA population group.

Table 2.1: Previously published studies of regression formulae used for stature estimation of South African populations based on osteometric and anthropometric data

Year	Author(s)	Bone Collection	Population group	Sample size	Age range	Measurements
1987	Lundy, J.K. and Feldesman, M.R.	Raymond Dart Collection, WITS	Black (AD)	M = 175 F = 122 Total = 297	Not Specified	Femur; Tibia; Fibula; Humerus; Ulna; Radius; Lumbar vertebrae
2003	Dayal, M.R.	1. Raymond Dart Collection, WITS 2. Pretoria Bone Collection	White (ED)	M = 98 F = 71 Total = 169	25 – 70 years of age (y.o.a.)	Femur; Tibia; Fibula; Humerus; Ulna; Radius
2005	Bidmos, M.A. and Asala, S.	Raymond Dart Collection, WITS	Black (AD)	M = 60 + 8 F = 56 + 6 Total = 130	22 – 75 y.o.a.	Calcaneal measurements
2006	Bidmos, M.A.	Raymond Dart Collection, WITS	White (ED)	M = 41 F = 44 Total = 85	22 – 75 y.o.a.	Calcaneal measurements
2007	Chibba, K. and Bidmos, M.A.	Raymond Dart Collection, WITS	White (ED)	M = 50 F = 50 Total = 100	46 – 75 y.o.a.	Tibia lengths
2007	Ryan, I. and Bidmos, M.A.	Raymond Dart Collection, WITS	Black (AD)	M = 50 F = 49 Total = 99	25 – 70 y.o.a.	Cranial measurements
2008	Bidmos, M.A.	Raymond Dart Collection, WITS	Black (AD)	M = 50 + 10 F = 50 + 10 Total = 120	46 – 75 y.o.a.	Femoral lengths
2008	Dayal, M.R., Steyn, M. and Kuykendall, K.L. *_Note: only study to include_ Raxter et al. _(2006) soft tissue and age (2007) correction factors_	1. Raymond Dart Collection, WITS 2. Pretoria Bone Collection	White (ED)	M = 98 F = 71 Total = 169	25 – 70 y.o.a.	Femur; Tibia; Fibula; Humerus; Ulna; Radius; Lumbar vertebrae *_Note: the study in 2003 by Dayal did not include regression formulae for the lumbar vertebrae_
2008	Bidmos, M.A.	Raymond Dart Collection, WITS	Black or ISA (AD) White (ED)	M = 60 F = 53 Total = 113 M = 58 F = 55 Total = 113	29 – 75 y.o.a.	Metatarsal measurements
2009	Bidmos, M.A.	Raymond Dart Collection, WITS	Black or ISA (AD) White (ED)	M = 30 F = 30 Total = 60 M = 30 F = 30 Total = 60	Not specified	Femoral measurements
2014	Pininski, M. and Brits, D.	Raymond Dart Collection, WITS	Black (AD) White (ED)	M = 50 F = 58 Total = 108 M = 51 F = 51 Total = 102	Not specified	Sacral measurements
2017	Brits, D.M., Bidmos, M.A. and Manger, P.R.	Anthropometric data for sub-adults	Black South Africans (AD)	M = 29 F = 30 Total = 59	10 – 17 y.o.a.	Femur and tibia

Note:

1. Raymond Dart Collection is housed at the University of Witwatersrand, Johannesburg, Gauteng Province
2. Pretoria Bone Collection is housed at Pretoria University, Pretoria, Gauteng Province

Terminology:

ISA – Indigenous South Africans or ‘black’ population as described by Bidmos (2008) and Bidmos (2009)

AD – South Africans of African Descent (current study)

ED – South Africans of European Descent (current study)

2.6 Generic femur/stature ratio

The generic femur/stature ratio developed by Feldesman, Kleckner and Lundy in 1990 was based on the proportion of the maximum femur length to living stature. The authors calculated that based on the 55 samples from multiple published sources the percentage contribution of the maximum femur length was 26.74% of living stature. This would approximately translate to a ratio value of 3.74 (or more accurately 100/26.74). Physical anthropologists would thus be able to multiply this value with the maximum femur length of an individual to obtain an estimated living stature for said individual. The 1996 study done by Feldesman and Fountain reiterated this observation with a value of 26.75%. However the 1996 study recommended the use of the generic regression formula to the generic femur/stature ratio when they stated "... we would be remiss if we did not note our incidental finding that a generic regression of femur length on stature yields even more accurate results than the generic ratio" (Feldesman and Fountain, 1996: 222). They also recommended that the generic femur/stature ratio is best used in "... paleoanthropology where there is never any substantive basis for assigning "race" in order to choose a modern "race"- and gender-specific regression equation" (Feldesman and Fountain, 1996: 219). More importantly Feldesman *et al*. (1990) noted that the estimated living statures of "South African blacks (of known stature)" from their generic femur/stature ratio were less accurate than from the population-specific femur regression formula.

Formicola (1993) assessed various stature regression formulae to estimate stature of archaeological populations. It was found that Pearson (1899) and Trotter and Gleser's (1952) regression formulae produce better stature results than that from Feldesman *et al*.'s (1990) generic femur/stature ratio. The difference may be due to how the mathematical formulae were derived. The first two studies were based on actual skeletal or anthropometric measurements from which coefficients of correlation, means, standard deviations and standard error of estimates could be derived. The latter study was based on mean values from other published studies which would make it very difficult to derive a more accurate correlation between the maximum femur length and living stature. Formicola (1993) found that the femur/stature ratio tended to overestimate living stature for what they considered either very short or tall individuals.

First, consider Pearson's statement regarding the use of mean values to create regression formulae: "...to take the mean of these results for the true stature ... is not the best theoretical procedure (Pearson, 1899: 174)". Both Feldesman *et al*.'s (1990) generic femur/stature ratio and Feldesman and Fountain's (1996) generic regression formula were based on mean values from the published samples that they used to generate both.

Second, consider Pearson's (1899: 173 – 174) caution regarding the use of ratios: "This, of course, excludes all attempts to form type ratios of A/B or B/A as a method of prediction. We may, in fact, at once dismiss all reconstruction formulae, as insufficient which are not based on the theory of correlation. The theory as here applied, be it noted, depends on the linearity of the proposed formula and not on any special form of the distribution of variations."

Finally, in "*Méroires de la Société d'Anthropologie de Paris* Vol. 4: 347 – 402" Manouvrier (1892 *cited in* Pearson, 1899) developed a generalised ratio of "B/A" where 'A' represents long bone length and 'B' the living stature. He then set out the ratio values in a table for each of the six long bones. In addition he provided a second table of additional ratio values for 'A' when the long bone lengths in question are either below or above the value ranges of the first table. Pearson (1899: 171) noted of these ratio values that "... by determining the mean value of B/A for each value of A, we see that it is theoretically an erroneous principle to start from; no constancy of the ratio B/A ought, to be expected."

Therefore the overall idea from these considerations is that generic ratios in general and generic regression formulae based on mean values may not be statistically sensible to use.

Chapter 3: Materials and Methods

Materials

3.1 Skeletal collections

In South Africa, much of the skeletal remains used in studies of physical and biological anthropology are sourced from cadavers. These are initially used by medical and science students for their human anatomy dissection modules. The cadavers are from individuals who donate their remains for scientific research purposes or individuals who may have been unclaimed by family after death. Once the medical students have completed their dissection modules for the academic year, some of the cadavers are macerated at the various universities and accessioned into the bone collection of that particular university. The current study used the University of Cape Town's Bone Collection, the Kirsten Collection housed at the University of Stellenbosch and the Raymond A. Dart Collection housed at the School of Anatomical Sciences at the University of Witwatersrand, Johannesburg.

3.1.1 University of Cape Town (UCT) Human Skeletal Collection

The UCT Human Skeletal Collection is housed in the Division of Clinical Anatomy and Biological Anthropology, Faculty of Health Sciences, University of Cape Town. It was started in 1913 by Robert Black Thomson, as head of the Department of Anatomy at the time, though the first skeletal remains were officially accessioned in 1925 by Matthew Robertson Drennan (Gibbon *et al.*, unpublished manuscript). M.R. Drennan was head of the department from 1916 to 1955, and during his tenure as head of the department, the collection grew in number (Gibbon *et al.*, unpublished manuscript). The collection consists of archaeological-, forensic- and cadaveric-derived skeletal remains. The cadaveric-derived skeletal remains have been accessioned from sources as stated in the opening paragraph above. Every year a number of cadaver-derived skeletal remains are accessioned into the bone collection and therefore, the number of skeletal individuals grows annually. In comparison to the Kirsten Collection and the Raymond A. Dart Collection, the UCT Bone Collection is small and of a particular demographic group and hence the need to collect data from other sources. The majority of the skeletal remains either stem from South Africans of European Descent (donated/bequeathed) or Mixed Ancestry (usually unclaimed individuals from the mortuary or Groote Schuur Hospital). Most individuals who bequeath their remains to the university, for medical and scientific research, are mainly more mature individuals (+60 years of age) with most displaying osteophytic lipping on their vertebral bodies or corrective surgeries, especially hip - and knee-replacement surgeries.

Other skeletal remains only have partial remains with mainly long bones (femur, tibia, fibula, humerus, ulna and radius) available. These were factors which contributed to why only a very limited number of the current study's sample could be drawn from the UCT Bone Collection.

3.1.2 Kirsten Collection, Stellenbosch University (SUN)

The Kirsten Collection is housed at the Kirsten Anthropology Research Unit, Division of Anatomy and Histology, Faculty of Medicine and Health Sciences, Tygerberg Campus, Stellenbosch University (SUN) (Alblas & Greyling, Poster, ASSA, 2016). This collection has the largest number of cadaveric-derived skeletal remains of South Africans of Mixed Ancestry (MA). As in most of the human skeletal collections in South Africa, the Kirsten Collection have predominantly male individuals and to a lesser extent females. This collection has less than 15% of its total number comprise of all other population groups in South Africa other than those of Mixed Ancestry (Alblas & Greyling, Poster, ASSA, 2016). This may be attributed to the location of the research unit and the fact that it receives the majority of its cadavers from the adjacent Tygerberg Hospital and Tygerberg Mortuary. The surrounding areas are mainly inhabited by MA of poorer socio-economic circumstances and Tygerberg Hospital is government funded, hence the composition of the Kirsten Collection. Due to the large number of MA individuals and the intactness of the skeletal elements of each individual, the majority of the sample used for the current study was derived from this collection. One of the exclusion criteria at the Kirsten Collection was that a large number of individuals had no feet and thus could not be included in the sample to calculate total skeletal height. Other exclusion criteria were the absence of complete skulls, availability of only partial skulls and osteophytic lipping on vertebral bodies of some specimens. Some specimens had disintegrating thoracic vertebrae due to tuberculosis (TB) and therefore, these specimens had to be excluded from the sample for this study.

3.1.3 Raymond A. Dart Collection, University of Witwatersrand, Johannesburg (WITS)

The Raymond A. Dart Collection of Human Skeletons at the University of Witwatersrand (WITS), Johannesburg, was started in the early 1920's by the head of the Anatomy Department (as it was known then) Raymond Arthur Dart (Dayal *et al*., 2009). Today, this collection of human remains is commonly referred to as 'the Dart Collection'. It is one of the largest in the world and houses more than 4 000 skeletal remains of which more than 2 000 are derived from cadaveric specimens (Dayal *et al*., 2009). These cadavers are either bequeathed by donors for scientific research and teaching or are unclaimed individuals from the greater Gauteng surrounding area. It has been noted by past and current curators of the collection that a large number of the boxes involved during the flooding of 1958 have co-mingled content. Therefore, to prevent a possible statistical error during data analysis, it was decided to exclude all individuals accessioned prior to 1959. The article by Dayal *et al.* (2009) states females are not well represented in the collection especially with regard to female South Africans of Mixed Ancestry ('coloureds') and African Descent ('black').

3.2 Ethical clearance

The use of skeletal remains for research purposes falls under the provision of the National Health Act No. 61 of 2003. As the current study falls within the scope of scientific research at the University of Cape Town, it was not required to apply for specific ethical clearance from the UCT Ethics Board. Formal approval of the study was obtained by publication in the Dean's Circular, PG-Med in September 2016 by the Chair of the Dissertations/Doctoral and Masters Committee.

3.3 Summary of composition of skeletal remains used

The skeletal remains are grouped according to ancestral affinity and then further subdivided into female or male. The ancestral affinity groups are divided into South Africans of Mixed Ancestry (MA), South Africans of African Descent (AD) and South Africans of European Descent (ED). Table 3.1 below shows the composition of skeletal remains that make up the study sample.

Table 3.1: Composition of skeletal remains for the study sample

Bone collection	MA Females	MA Males	AD Females	AD Males	ED Females	ED Males	TOTAL
UCT	0	5	0	1	1	2	9
SUN	61	57	0	0	0	0	118
WITS	0	0	32	33	12	25	102
Total	61	62	32	34	13	27	229

3.4 Exclusion criteria

- Age cohort: Individuals born after 1930 were included in the study sample to create a relatively modern population, possibly excluding secular trends. Individuals with complete epiphyseal closure of the long bones (18 years or older) were included up to age 66 (subsection 4.2 and Table 4.2, page 32) due to the limited sample size available.
- Trauma: Skeletal elements to be measured featuring any type of trauma such as fractures or corrective surgery were excluded.

- Disease and age pathology: Skeletal remains featuring any type of pathology on skeletal elements to be measured, as part of the total skeletal height calculation, were excluded from the sample.
- Missing skeletal elements: Individuals who were missing any of the skeletal elements necessary to calculate the total skeletal height were also excluded.

Methods

3.5 Skeletal measurements

The skeletal elements used to calculate or sum up total skeletal height (TSH_{Calc}) for each individual was measured using two methods:

(1) The original Fully's anatomical method as used by Lundy and Feldesman (1987) for their study on South Africans of African Descent (AD).
(2) The revised Fully's anatomical method as described in Raxter *et al*. (2006) and used by Dayal *et al*. (2008) for their study on South Africans of European Descent (ED).

Each skeletal element was measured in millimeters and then converted to centimeters when entered into the Excel (Microsoft 2010) spreadsheet.

3.5.1 Measurements of skeletal elements used for TSH_{Calc}

Table 3.2 contain the description of each of the skeletal elements measured to calculate TSH_{Calc}. Under the column 'Description of measurement', the superscripted (1) or (2) indicate which measurement was used for a particular method.

TSH_{Calc} was summed for each individual as follows:

TSH_{Calc} (Lundy and Feldesman, 1987)

$$= BB + CV\ 2 + \text{combined lengths of } [CV\ 3 – CV\ 7]^{(1)} + \text{combined lengths of } [TV\ 1 – TV\ 12]^{(1)} + \text{combined lengths of } [LV\ 1 – LV\ 5]^{(1)} + SV\ 1 + Femur_{Phys} + Tibia_{Phys} + TC$$

TSH_{Calc} (Dayal *et al*., 2008)

$$= BB + CV\ 2 + \text{combined lengths of } [CV\ 3 – CV\ 7]^{(2)} + \text{combined lengths of } [TV\ 1 – TV\ 12]^{(2)} + \text{combined lengths of } [LV\ 1 – LV\ 5]^{(2)} + SV\ 1 + Femur_{Phys} + Tibia_{Malleolus} + TC$$

3.5.2 Table 3.3 contain the descriptions of additional long bones measurements to be used for substitution into univariate regression formulae.

Table 3.2: Description of skeletal measurements in mm used to calculate total skeletal height (TSH_{Calc})

Skeletal element [Abbreviation]	Description of measurement	Equipment
Basion-bregmatic height (cranial height) [BB]	Maximum length between bregma (at the confluence of the coronal and sagittal sutures) and the basion (at the anteroinferior margin of the foramen magnum, between the occipital condyles)	Sliding callipers
Second cervical vertebrae (axis) [CV 2]	The most superior point of the odontoid process (dens) to the most inferior point of the anteroinferior rim of the vertebral body	Digital vernier calliper
3rd to 7th cervical vertebrae [CV 3 – CV 7]	At the anterior midsagital line, from the superior margin to the inferior margin of the vertebral body (1)	Digital vernier calliper
	Measured from its anterior third, medial to the superiorly curving edges of the vertebral body (2)	
Thoracic vertebrae [TV 1 – TV 12]	At the anterior midsagital line, from the superior margin to the inferior margin of the vertebral body (1)	Digital vernier calliper
	At the anterior margin between the rib articular facets and pedicle's anterior third (2)	
Lumbar vertebrae [LV 1 – LV 5]	At the anterior midsagital line, from the superior margin to the inferior margin of the vertebral body (1)	Digital vernier calliper
	At the anterior margin to the pedicles, but not including any swelling of the vertebral body due to the pedicles (2)	
First sacral vertebra [SV 1]	From the anterior-superior margin of the sacrum (*i.e.* the sacral promontory margin) to the fusion/articulation point (line) between the first and second sacral vertebra bodies	Digital vernier calliper
Physiological femoral length [$\text{Femur}_{\text{Phys}}$]	The femoral distal end (condyles) was placed against the stationary end of an osteometric board, and flat against the horizontal plane of the osteometric board. The mobile end was placed against the most superior aspect of the femoral head (proximal end), parallel to the stationary end.	Osteometric board
Tibial length [$\text{Tibia}_{\text{Phys}}$]	The lateral condylar articulating surface of the tibia was placed against the stationary part of the osteometric board with the diaphysis (shaft of the bone) parallel to the osteometric board and the stationary part of the board was placed against the distal talo-articulating surface (1)	Osteometric board
Tibial length [$\text{Tibia}_{\text{Malleolus}}$]	The most superior aspect of the lateral condyle (proximal end) was placed against the stationary end of the osteometric board with the intercondylar eminence within the oval opening with the diaphysis parallel to the long axis of the osteometric board. The board 's mobile end was placed against the end of medial malleolus (distal end) of the tibia (2)	
Talus-calcaneus height [TC]	The talus and calcaneus were articulated and placed on the osteometric board with the talus at the stationary end and the calcaneus at the movable end. No adhesive material is used to maintain articulation. The talus and calcaneus were placed in a position so that the calcaneal inclination angle is in the normal range between 18° and 30°. This is the 'angle formed by the intersection of the plane of support and the calcaneal inclination axis' (Raxter *et al*., 2006)	Osteometric board

(1) Lundy and Feldesman (1987)

(2) Dayal *et al*. (2008)

Table 3.3: Descriptive measurements in mm for additional long bone measurements to be used in univariate regression formulae

Skeletal element	Description of measurement	Equipment
Humerus	The straight-line distance from the head of the humerus to the furthest point of the trochlea. The head of the humerus was placed against the stationary end of the osteometric board with the diaphysis (shaft) of the bone parallel to the board and the movable end was place against the inferior point of the trochlea. The movable end was parallel to the stationary end.	Osteometric board
Ulna	The straight-line distance from the superior aspect of the olecranon to the furthest point of the styloid process. The olecranon was placed against the stationary end of the osteometric board, and the movable end was placed against the most inferior point of the styloid process. The diaphysis (shaft) of the bone did not have to be parallel to the board, but the movable end of the osteometric board had to be parallel to the stationary end	Osteometric board
Radius	The most proximal margin of the radial head to the tip of the styloid process to determine the maximum length. The radial head was placed against the stationary end of the osteometric board and the movable end was placed against the most inferior point of the styloid process. Similar to the ulna measurement, the long axis of the bone did not have to be parallel to the board yet the movable end had to be parallel to the stationary end	Osteometric board
Fibula	The apex of the fibular head to the furthest point of the lateral malleolus to determine the maximum length of the bone. The head of the fibula (proximal end) was placed against the stationary end of the osteometric board, with the diaphysis (shaft) of the bone parallel to the board, and the movable end was placed against the lateral malleolus (distal end). The movable end of the osteometric board had to be parallel to the stationary end of the board.	Osteometric board

3.6 Stature regression formulae

3.6.1 Univariate stature regression formulae

The three South African population groups were tested using univariate stature regression formulae from two different sources based on the population group for which they were formulated.

3.6.1.1 Lundy and Feldesman (1987)

The univariate regression formulae, Table 3.4 below, were used to retest South Africans of African Descent (AD) and to test whether they were statistically appropriate to use for South Africans of Mixed Ancestry (MA).

3.6.1.2 Dayal *et al*. (2008)

The univariate regression formulae, Table 3.5, were used to retest the South Africans of European Descent (ED) population group and secondly to test the statistical appropriateness for the MA population group

Table 3.4: Lundy and Feldesman (1987) univariate regression formulae formulated for South Africans of African Descent (AD)

Long bone	Female	Male
Femur$_{\text{Phys}}$	y (cm) = [2,769 x bone length (cm)] + 27,424 ± 2,789	y (cm) = [2,403 x bone length (cm)] + 45,721 ± 2,777
Tibia$_{\text{Phys}}$	y (cm) = [2,485 x bone length (cm)] + 55,968 ± 3,056	y (cm) = [2,427 x bone length (cm)] + 60,789 ± 2,78
Fibula	y (cm) = [2,761 x bone length (cm)] + 47,575 ± 3,168	y (cm) = [2,515 x bone length (cm)] + 58,999 ± 2,98
Humerus	y (cm) = [3,291 x bone length (cm)] + 45,893 ± 3,715	y (cm) = [2,899 x bone length (cm)] + 60,212 ± 3,834
Ulna	y (cm) = [3,827 x bone length (cm)] + 47,574 ± 3,629	y (cm) = [2,961 x bone length (cm)] + 72,7 ± 3,727
Radius	y (cm) = [4,161 x bone length (cm)] + 47,12 ± 3,387	y (cm) = [3,196 x bone length (cm)] + 72,139 ± 3,643

Table 3.5: Dayal *et al*. (2008) univariate regression formulae formulated for South Africans of European Descent (ED)

Long bone	Female	Male
Femur$_{\text{Phys}}$	y (cm) = [2,64 x bone length (cm)] + 34.69 ± 2.40	y (cm) = [2,30 x bone length (cm)] + 51,17 ± 2,64
Tibia$_{\text{Malleolus}}$	y (cm) = [2,86 x bone length (cm)] + 47,52 ± 2.59	y (cm) = [2,49 x bone length (cm)] + 62,92 ± 3,16
Fibula	y (cm) = [3,06 x bone length (cm)] + 42,36 ± 2.75	y (cm) = [2,65 x bone length (cm)] + 58,00 ± 3,35
Humerus	y (cm) = [3,05 x bone length (cm)] + 55,58 ± 3.38	y (cm) = [3,10 x bone length (cm)] + 54,34 ± 3,76
Ulna	y (cm) = [3,67 x bone length (cm)] + 60,58 ± 3.54	y (cm) = [3,56 x bone length (cm)] + 63,85 ± 3,79
Radius	y (cm) = [3,77 x bone length (cm)] + 64,45 ± 3.38	y (cm) = [3,87 x bone length (cm)] + 62,25 ± 3,58

3.6.2 Multivariate stature regression formulae

When using multivariate stature regression formulae, the lengths and/or heights of two or more skeletal elements are used as a combined measurement in the regression formula.

The combinations of skeletal elements used were as follows:

(a) The combined heights of all the lumbar vertebrae in the spinal column which is stated as ‘Lumbar column’.

(b) The combination of the lumbar vertebrae heights, the physiological femoral height and the physiological or including malleolus height of the tibia. This is stated as ‘Lumbar column + Femur$_{\text{Phys}}$ + Tibia$_{\text{Phys}}$’ (Lundy and Feldesman, 1987) or ‘Lumbar column + Femur$_{\text{Phys}}$ + Tibia$_{\text{Malleolus}}$’ (Dayal *et al*., 2008).

(c) The combination of the physiological femoral height and the physiological or including malleolus height of the tibia which is written as either ‘Femur$_{\text{Phys}}$ + Tibia$_{\text{Phys}}$’ (Lundy and Feldesman, 1987) or ‘Femur$_{\text{Phys}}$ + Tibia$_{\text{Malleolus}}$’ (Dayal *et al*., 2008).

(d) The final combination is of the lumbar vertebrae heights and the physiological height of the femur, given as ‘Lumbar column + Femur$_{\text{Phys}}$’ for both sources.

These multivariate stature regression formulae have been set out in Tables 3.6 and 3.7 below.

Table 3.6: Lundy and Feldesman (1987) multivariate regression formulae formulated for South Africans of African Descent (AD)

Combined skeletal elements	Female	Male
(a) Lumbar column	y (cm) = [4,7 x combined bone lengths (cm)] + 84,047 ± 4,91	y (cm) = [3,987 x combined bone lengths (cm)] + 100,915 ± 5,28
(b) Lumbar column + Femur$_{\text{Phys}}$ + Tibia$_{\text{Phys}}$	y (cm) = [1,311 x combined bone lengths (cm)] + 25,664 ± 2,087	y (cm) = [1,239 x combined bone lengths (cm)] + 34,339 ± 1,839
(c) Femur$_{\text{Phys}}$ + Tibia$_{\text{Phys}}$	y (cm) = [1,41 x combined bone lengths (cm)] + 14,617 ± 2,497	y (cm) = [1,288 x combined bone lengths (cm)] + 46,543 ± 2,371
(d) Lumbar column + Femur$_{\text{Phys}}$	y (cm) = [2,317 x combined bone lengths (cm)] + 17,083 ± 2,346	y (cm) = [2,156 x combined bone lengths (cm)] + 28,448 ± 2,196

Table 3.7: Dayal *et al*. (2008) multivariate regression formulae formulated for South Africans of European Descent (ED)

Combined skeletal elements	Female	Male
(a) Lumbar column	y (cm) = [4,59 x combined bone lengths (cm)] + 84,18 ± 5.21	y (cm) = [3,47 x combined bone lengths (cm)] + 109,47 ± 5,54
(b) Lumbar column + Femur$_{\text{Phys}}$ + Tibia$_{\text{Malleolus}}$	y (cm) = [1,35 x combined bone lengths (cm)] + 23,75 ± 1.75	y (cm) = [1,19 x combined bone lengths (cm)] + 40,47 ± 1.92
(c) Femur$_{\text{Phys}}$ + Tibia$_{\text{Malleolus}}$	y (cm) = [1,44 x combined bone lengths (cm)] + 35,42 ± 2.13	y (cm) = [1,27 x combined bone lengths (cm)] + 50,67 ± 2.49
(d) Lumbar column + Femur$_{\text{Phys}}$	y (cm) = [2,25 x combined bone lengths (cm)] + 19,79 ± 2.13	y (cm) = [1,95 x combined bone lengths (cm)] + 39,92 ± 2.17

3.7 Generic femur/stature ratio (Feldesman *et al.*, 1990)

The generic femur/stature ratio formulated by Feldesman, Kleckner and Lundy (1990) estimates living stature (LSr). To statistically evaluate the estimated living stature results from the femur/stature ratio, the calculated total skeletal height (TSH_{Calc}) had to be converted to living stature by adding a soft tissue correction factor (Fully, 1956) and then subtracting an age correction factor (Trotter and Gleser, 1952) from the addition result.

3.7.1 Converting TSH_{Calc} to living stature with age correction (LSwA)

The current study employed the same methodology used by Lundy and Feldesman (1987) and Dayal *et al*. (2008). After calculating TSH (as described in subsection 3.5.1) for each individual a soft tissue correction factor was added as described by Fully (1956):

For total skeletal heights of:

≤153.5cm → add 10.0cm

153.6cm to 165.4cm → add 10.5cm

≥165.5cm →add 11.0cm

Next, the age correction factor described by Trotter and Gleser (1952) and employed by Lundy and Feldesman (1987) and Dayal *et al*. (2008) were used in the current study. The age correction factor is as follows:

$$\text{Loss of stature} = 0.06\text{cm} \times (\text{age of individual} - 30)$$

This indicates that after age 30 there is an annual 0.06cm loss of stature. Therefore, individuals aged 30 or less required no adjustment to their living stature.

The final equation used to calculate living stature (LS) with both soft tissue and age correction factors were as follows:

$$\text{LS with age (LSwA)} = TSH_{Calc}\ (\text{cm}) + \text{soft tissue (cm)} - [0.06\text{cm} \times (\text{age}-30)]$$

3.7.2 Estimating living stature from generic femur/stature ratio (LSr)

The generic femur/stature ratio (Feldesman *et al*., 1990) requires the use of the maximum length of the femur ($Femur_{Max}$). This measurement was taken as follows:

$Femur_{Max}$: The most inferior part of the femoral medial condyle (distal end) was placed against the stationary end of an osteometric board. The mobile end was placed against the most superior part of the femoral head (proximal end) with the diaphysis (shaft) (Bidmos, 2009).

The measurement was taken in millimeters (mm) and converted to centimeters (cm) for use in the femur/stature ratio calculation.

$\text{Femur}_{\text{Max}}$ was multiplied by the factor 3.74 (Feldesman *et al*., 1990; Feldesman and Fountain, 1996) based on the percentage contribution (26.75%) of the maximum femur length to living stature, *i.e*. 100/26.75 (Feldesman *et al*., 1990). The estimated living stature from the generic ratio (LSr) was then compared to LSwA.

3.7.3 Calculating living stature from the Lundy and Feldesman (1987) femur regression formula's TSH_{Est} results (LSf)

The same methodology as described in 3.7.1 was used to convert the estimated TSH (TSH_{Est}) from the Lundy and Feldesman (1987) femur regression formula into living stature (LSf). This was done to compare the living stature results from the regression formula (LSf) and the generic femur/stature ratio (LSr) to the calculated living stature (LSwA) and analyse which of these two performed better.

3.8 Data captured

Initially all raw data were captured in a Microsoft Excel (Windows 10) spreadsheet where the total skeletal height (TSH_{Calc}) of each individual and the TSH from stature regression formulae could be calculated. Thereafter, the TSH_{Calc} results and the regression formulae-derived stature were imported into a Statistical Package for Social Sciences (SPSS; version 24) datasheet.

3.8.1 Inter- and intra-observer error

Re-measurement of the basion-bregmatic height, all long bone measurements and specific vertebral heights were done by the author and an independent observer, Dr. Petra Maass (a final-year PhD student at the time of measurement). The mean difference, upper and lower limit of the mean difference was calculated and plotted using the interrater reliability test of Bland Altman (Excel, Windows 10).

3.8.2 Age

Descriptive statistics, which included the mean, standard deviation, standard error of mean, minimum and maximum values, was performed for each sex per population group.

3.8.3 Total skeletal height (TSH): Calculated (summed) based on the methods described in the publications as indicated by the (brackets): TSH_{Calc} $^{\text{(publication indicated)}}$

Descriptive statistics, based on the calculated or summed total skeletal height (as indicated by the methods described in the publications placed in brackets), was performed for each sex per population group. This included the mean ($\bar{x}$), standard deviation (Std. Dev.), standard error of means (S.E.M.), maximum and minimum values. The study sample as a whole was tested for normality of distribution with the use of a normality of distribution curve, and then each population group was plotted on a histogram with a normality of distribution curve. The significance of differences between each population group was calculated by means of an analysis of variance (ANOVA) test. Independent *t*-tests were used to calculate the significance of difference between the sex groups (female versus males). Furthermore, box plots were used to graphically represent the distribution of each sex group within a population and compared to each population group. The means of each population group was plotted on the same axes for ease of interpretation.

3.8.4 Long bone measurements

Descriptive statistics were also performed for certain single long bone measurements such as the physiological femoral ($\text{Femur}_{\text{Phys}}$), tibial, fibular, humeral, ulnar and radial lengths per population group and sex-population group. The significance of differences between the sexes of each population group and between the sexes these groups were calculated by means of an ANOVA. Scatter plot diagrams representing the relationship between each of the long bone measurements and TSH_{Calc} was generated for each population group and for both sexes.

3.8.5 TSH_{Calc} versus stature results derived from univariate regression formulae

Paired *t*-tests were used to determine the significance of difference between the summed (calculated) total skeletal height of each individual and the result obtained from the different univariate stature regression formulae. This was done for both sexes from each population group. No comparison was executed between the sexes as different regression formulae were used for the separate sexes. The mean ($\bar{x}$), standard deviation (Std. Dev.), standard error of mean (S.E.M.) of, and the samples correlation, mean difference and significant difference between the two parameters have been displayed in a table in the next chapter.

3.8.6 TSH_{Calc} versus stature results derived from multivariate regression formulae

Paired *t*-tests were used once again to determine the samples correlation and if a significant difference occurred between the two parameters.

3.8.7 Calculated living stature (LSwA) versus estimated living stature from regression formula (LSf) and generic femur/stature ratio (LSr)

The conversion of TSH_{Calc} to living stature (LSwA) for each individual was done in a separate spreadsheet in Microsoft Excel (Windows 10). In addition the living stature calculations from the generic femur/stature ratio (LSr) and the Lundy and Feldesman (1987) femur regression formula (LSf) were entered into this spreadsheet. The completed spreadsheet was then imported into an SPSS (Version 24) datasheet. Paired *t*-tests were used to compare (1) LSr and (2) LSf to LSwA.

Chapter 4: Results

Descriptive and analytical statistics for age and calculated total skeletal height (TSH_{Calc}) including sample size, mean and standard deviation (Std. Dev.) are found in Tables 4.1 – 4.4, subdivided into sex and population groups.

Descriptive statistics of each long bone measurement per sex and per population group is set out in Appendix C (page 98) with the analytical statistics displayed in Tables 4.5 – 4.6. Different sample sizes were obtained for each sex and population group due to pathology, traumatic injury and/ or missing skeletal elements. Figure 4.7 show possible patterns between skeletal elements of the upper (*i.e*. humerus, ulna, radius) and the lower (*i.e.* femur, tibia, fibula) limbs.

Correlation statistics between TSH_{Calc} and the estimated (derived) TSH from univariate regression formulae, followed by the statistical comparison with the TSH results from multivariate regression formulae, are set out in Tables 4.7 – 4.10 and Tables 4.11 – 4.14, respectively.

Finally, correlation statistics comparing the calculated living stature (LSwA) with first the living stature from the generic femur/stature ratio (LSr) and secondly from the converted TSH_{Est} from the Lundy and Feldesman (1987) femur stature regression formula (LSf) are set out in Table 4.15.

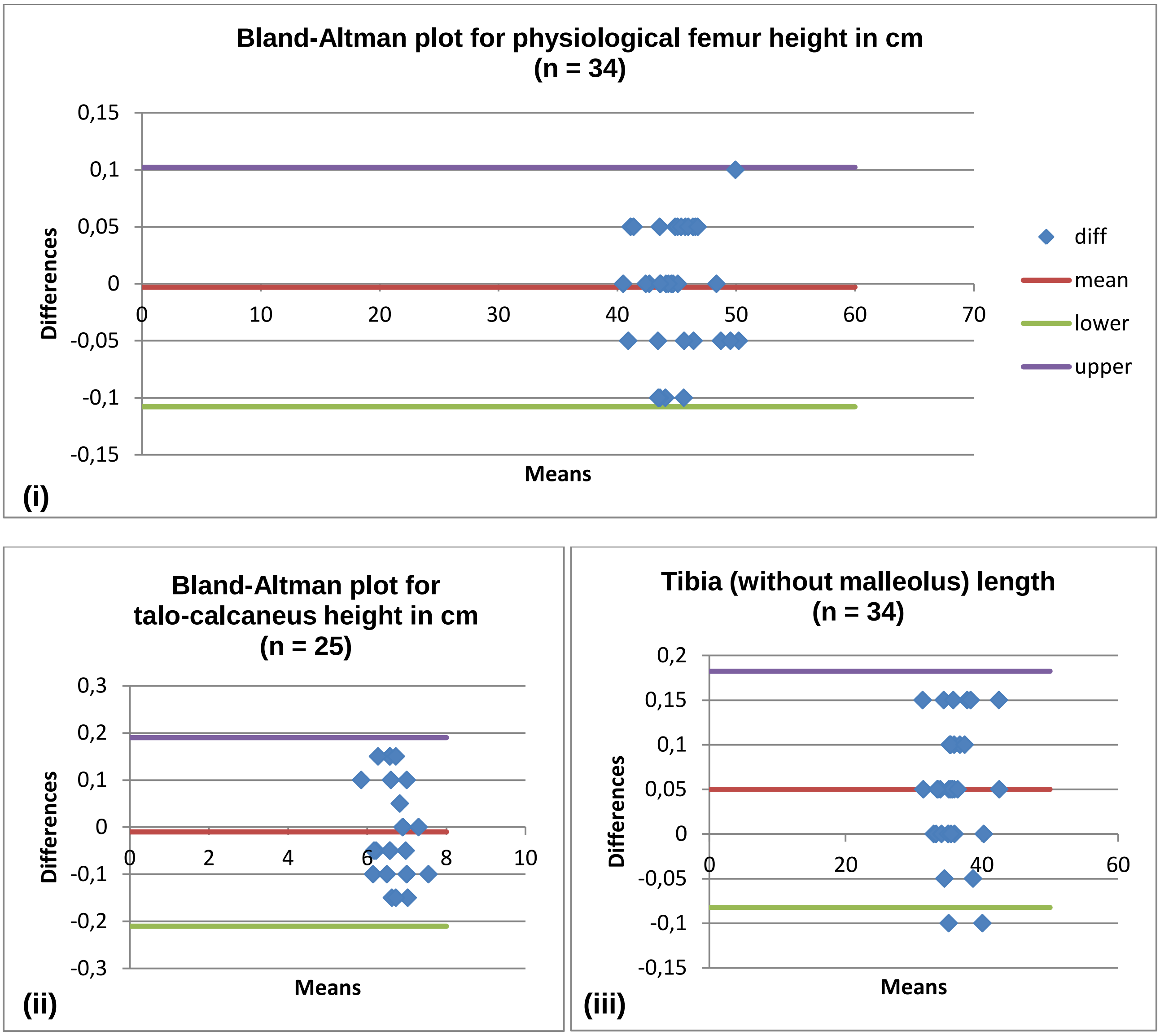
Outliers

Prior to statistical analyses, the data were explored for outliers as they may influence univariate and multivariate analyses such as the mean and variance of a sample, and therefore is an essential step in research.

Outliers may possibly reflect the outer edges of a population group or may be due to human error. Figure 4.6 a – f shows all long bone outliers and most of these outliers stem from a few individuals as is discussed later on.

4.1 Measurement reliability

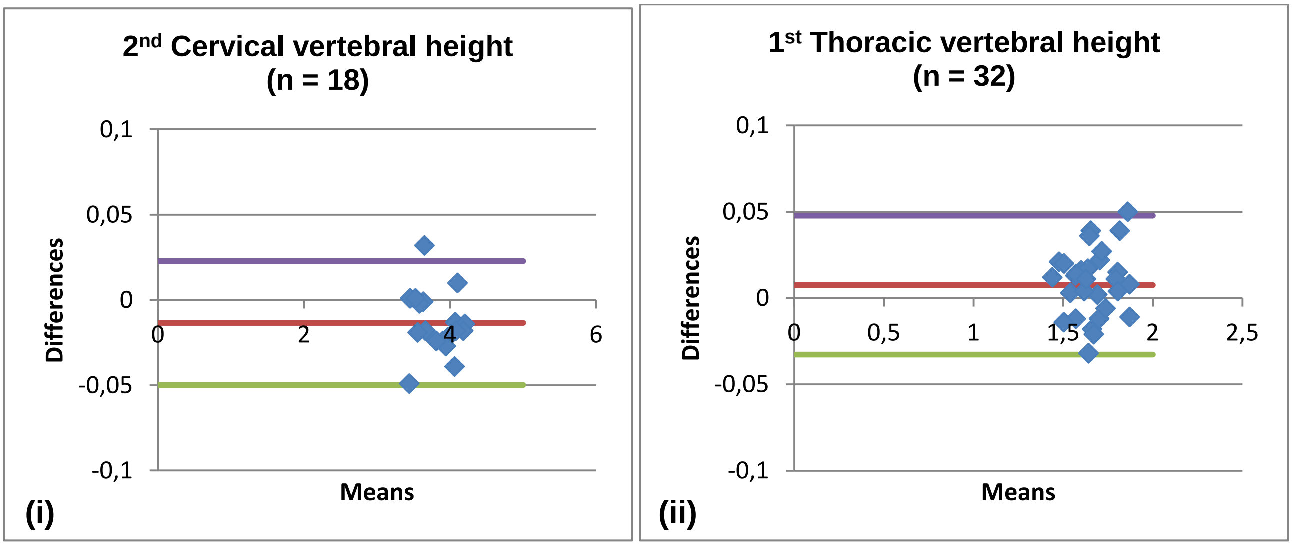
Technical error of measurement (TEM) was conducted for each measurement to evaluate intra- and inter-observer error. For the original dataset, 18 individuals (both left and right side of the same individual) were measured and re-measured by an independent observer and the author, respectively.


Bland-Altman plot for physiological femur height in cm (n = 34)

Bland-Altman plot for talo-calcaneus height in cm (n = 25)

Tibia (without malleolus) length (n = 34)

Figure 4.1 (a): **Bland Altman plots for inter-observer error of various skeletal measurements**


2nd Cervical vertebral height (n = 18)

1st Thoracic vertebral height (n = 32)

Figure 4.1 (b): **Bland Altman plots for intra-observer error of various skeletal measurements**

The intra-observer error is lower than the inter-observer error for all measurements. The mean intra-observer TEM is small at 0.4mm (0.3 – 0.5mm) whereas the mean inter-observer TEM is 1.5mm (1.0 – 2.0mm) (Figures 4.1 a & b).

Based on the Bland Altman (B-A) plots for measurement reliability (Figures 4.1 a & b), neither inter- nor intra-observer error show systematic bias. Most intra-observer measurement differences are within 0.5mm of the upper and lower agreement (Figures 7.1 a – c, Appendix) with the inter-observer error falling within the 2mm upper and lower limit range (Figures 7.2 a – c, Appendix).

4.2 Age

The study sample's age range is 20 – 66 years of age at death. For female South Africans of Mixed Ancestry (MA) age ranges from 22 – 65 years of age at death whereas the males range from approximately 20 – 66 years of age. For South Africans of African Descent (AD) age ranges from 20 – 47 years of age at death for females, and 20 – 57 years of age at death for males. Finally, for South Africans of European Descent (ED) the age ranges are 28 – 63 years of age for females, and 28 – 65 years of age at death for males. The age statistics are set out in Table 4.1 below.

Table 4.1: Descriptive statistics for Age of each of the sex groups per population

Population group	Sex	N	Mean age statistics		Std. Deviation
			Mean	Std. Error	
MA	F	61	40.00	1.51	11.78
	M	62	42.18	1.40	11.05
AD	F	32	31.56	1.20	6.76
	M	34	35.74	1.43	8.31
ED	F	13	49.62	3.18	11.45
	M	27	48.74	1.71	8.89

Note: F = Female
M = Male

MA = South Africans of Mixed Ancestry
AD = South Africans of African Descent
ED = South Africans of European Descent

4.3 Calculated total skeletal height (TSH_{Calc})

For ease of interpretation, the calculated total skeletal height (TSH_{Calc}) based on the method used by Lundy and Feldesman (1987) was used to construct the graphs in Figures 4.2 – 4.4. The mean difference between the two methods used to calculate total skeletal height is mainly based on the inclusion of the tibial malleolus by Dayal *et al*. (2008) whereas Lundy and Feldesman (1987) did not include the tibial malleolus when calculating the total skeletal height of an individual. This will be discussed at a later stage in this subsection.

The normality of TSH_{Calc} distribution for the entire study sample is shown in Figure 4.2 below.

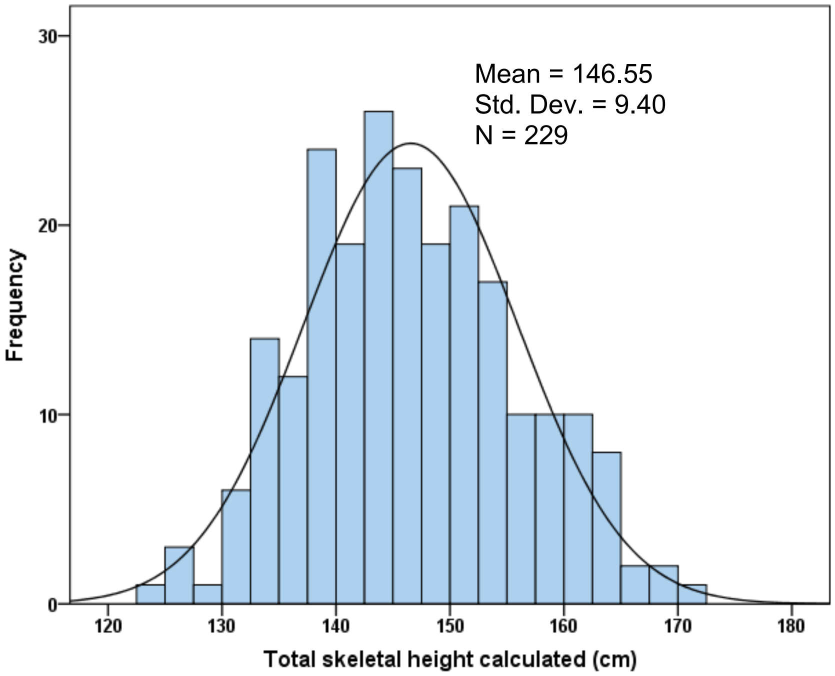
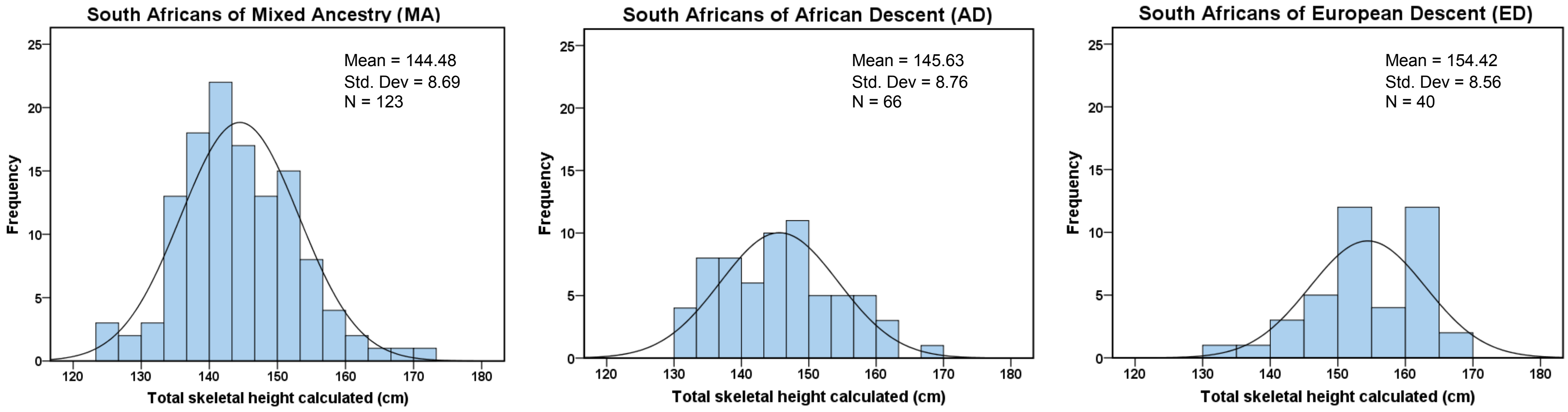


Figure 4.2: A histogram with a normal distribution curve of the frequencies for the calculated total skeletal height (in cm) for the study sample as a whole

Separating the study sample into the three population groups, the MA follows a similar distribution (Figure 4.3 a) to the overall study sample whereas ED have two distinct high frequency bars (Figure 4.3 c). The bar widths of the histograms are different due to different sample sizes for each population group and their TSH intervals.



(a) **(b)** **(c)**

Figure 4.3 a – c: **Histograms with a normal distribution curve of the frequencies for the calculated total skeletal height for (a) South Africans of Mixed Ancestry, (b) South Africans of African Descent and (c) South Africans of European Descent**

A stem-and-leaf plot (Appendix B, page 97) of the ED population group clearly indicates the bimodal grouping for the ED population seen in Figure 4.3 c. This occurrence is due to the combined total skeletal height (TSH) of male and female ED. The difference between TSH_{Calc} of females and males in the different population groups is evident in Figure 4.4 below.

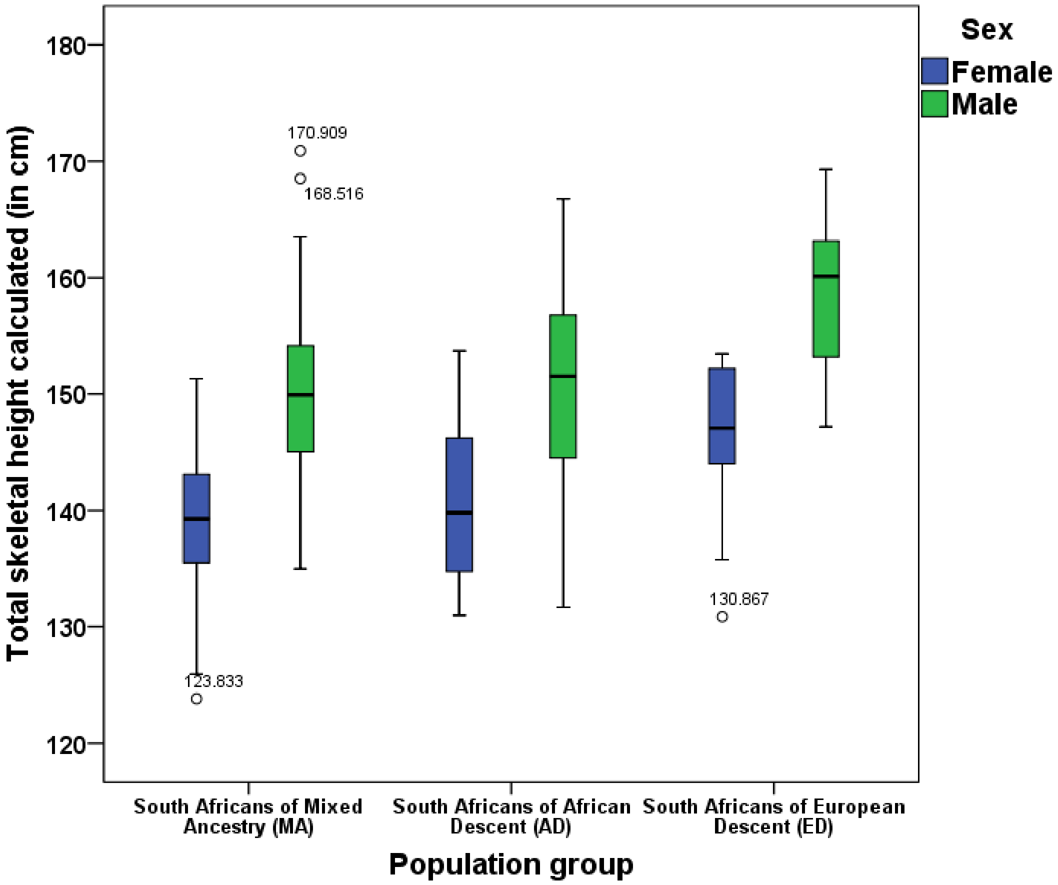


Figure 4.4: A box-&-whisker plot representing the calculated total skeletal height for the different sexes of each population group

The independent *t*-test statistics (Table 4.2) corroborate the significant difference ($p<0.000$) between females and males of each population group that is seen in Figure 4.4. Females have a mean TSH_{Calc} of 140.26cm – 141.36cm (depending on the method used) with a standard deviation (Std. Dev.) of approximately 6.5cm, and males have a mean TSH_{Calc} of 151.97cm – 153.62cm with a Std. Dev. of approximately 8cm. The independent *t*-test produced a mean difference of approximately 11-12cm between females and males. Both methods have an F = 4.8 and $p<0.000$, whether or not equal variance is assumed, indicating a very significant difference between the TSH_{Calc} of females and males. Appendix C (page 98) displays the general descriptive statistics for TSH_{Calc} of each sex-population group.

Table 4.2: Independent *t*-test statistics comparing the calculated total skeletal height (TSH$_{\text{Calc}}$) for females and males based on the two methods described in the publications as indicated in brackets

Calculated total skeletal height: TSH$_{\text{Calc}}$ (*)		Male			Female			Mean Difference	Std. Error Difference	Equality of variance	Equality of means
		Mean	Std. Dev.	S.E.M.	Mean	Std. Dev.	S.E.M.			*F*-value	*p*-value
TSH$_{\text{Calc}}$ (1)	A	151.97	8.05	0.73	140.26	6.47	0.63	11.71*	0.98	4.821	0.000
	B								0.96		0.000
TSH$_{\text{Calc}}$ (2)	A	153.62	8.22	0.74	141.36	6.54	0.64	12.26*	0.99	4.832	0.000
	B								0.98		0.000

*. The mean difference is significant at the ≤0.05 level.

Note: A = Equal variances assumed
B = Equal variances not assumed

(1) Lundy and Feldesman (1987)
(2) Dayal *et al*. (2008)

Table 4.3 displays the post hoc multi-comparison ANOVA test results. Equal variance (δ) is not assumed between population groups due to different sample sizes. There is no significance difference ($p > 0.05$) between the AD and MA population groups with a mean difference of 1.16cm. Both the MA and AD population groups are significantly different ($p < 0.000$) when compared to the ED population group. There is a mean difference of 9.94cm between the MA and ED population groups. The mean difference is slightly less between the AD and the ED population groups at 8.78cm.

Table 4.3: ANOVA post hoc tests showing multiple comparisons between the three population groups including the mean difference and the significant difference between the groups

Post Hoc tests: Multiple Comparisons between population groups						
TSH_{Calc} (*)	**Variance method applied**	**Population groups compared**		**Mean Difference**	**Std. Error**	***p*-value**
TSH_{Calc} (1)	Tamhane Equal variances not assumed	AD	MA	1,16	1.33	0.770
		ED	MA	9.94*	1.56	0.000
		ED	AD	8.78*	1.73	0.000
TSH_{Calc} (2)	Tamhane Equal variances not assumed	AD	MA	1,37	1.37	0.681
		ED	MA	10.59*	1.61	0.000
		ED	AD	9.22*	1.79	0.000

*. The mean difference is significant at the ≤0.05 level.

Note: MA = South Africans of Mixed Ancestry
AD = South Africans of African Descent
ED = South Africans of European Descent

(1) Lundy and Feldesman (1987)
(2) Dayal *et al*. (2008)

Table 4.4 contains the mean, Std. Dev. and standard error of the mean (S.E.M.) for each population group, and the total of the study sample (all three population groups combined). The ANOVA produced an *F*-value of 20.272 or 21.905 (method-dependent), indicating a significant difference ($p < 0.000$) irrespective of the method used, between the different population groups.

Table 4.4: ANOVA comparing total skeletal height (TSH_{Calc}) of the three population groups to each other

TSH_{Calc}	MA			AD			ED			Total			ANOVA	
	Mean	Std. Deviation	Std. Error	Mean	Std. Deviation	Std. Error	Mean	Std. Deviation	Std. Error	Mean	Std. Deviation	Std. Error	*F* - value	*p* - value
TSH_{Calc} (1)	144.48	8.69	0.78	145.63	8.76	1.08	154.42	8.56	1.35	146.55	9.39	0.62	20.272	0.000
TSH_{Calc} (2)	145.70	8.80	0.79	147.07	9.04	1.11	156.29	8.89	1.41	147.94	9.66	0.64	21.906	0.000

Note: MA = South Africans of Mixed Ancestry
AD = South Africans of African Descent
ED = South Africans of European Descent

(1) Lundy and Feldesman (1987)
(2) Dayal *et al*. (2008)

Figure 4.5 illustrates the overall differences of the mean TSH_{Calc} between the three population groups. Taking the ANOVA results into account, the graphic representation clearly shows the significant difference between the first two groups, MA and AD, and the ED group.

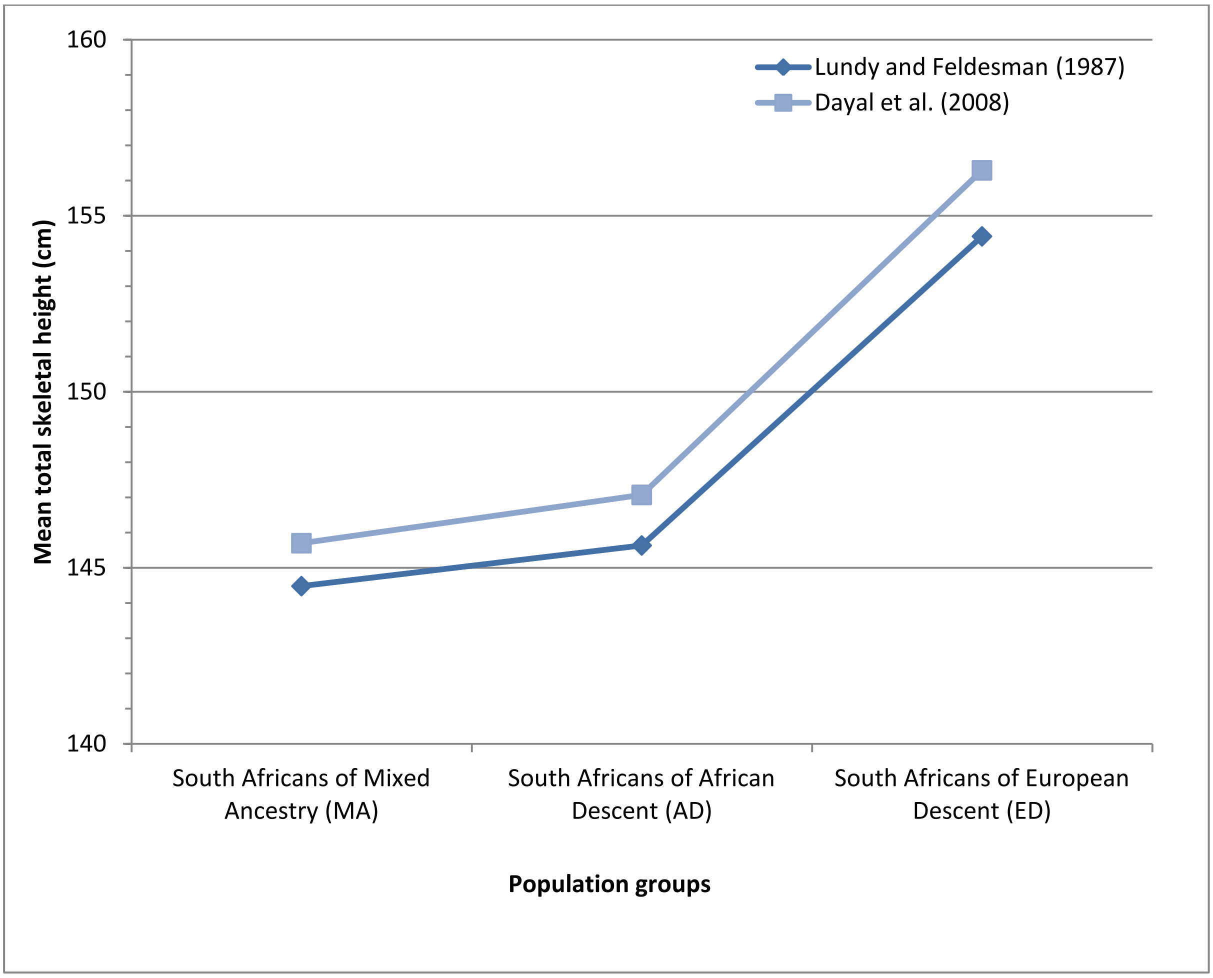


Figure 4.5: The mean TSH_{Calc} for each population group have been plotted based on the methods followed by Lundy and Feldesman (1987) and Dayal *et al*. (2008)

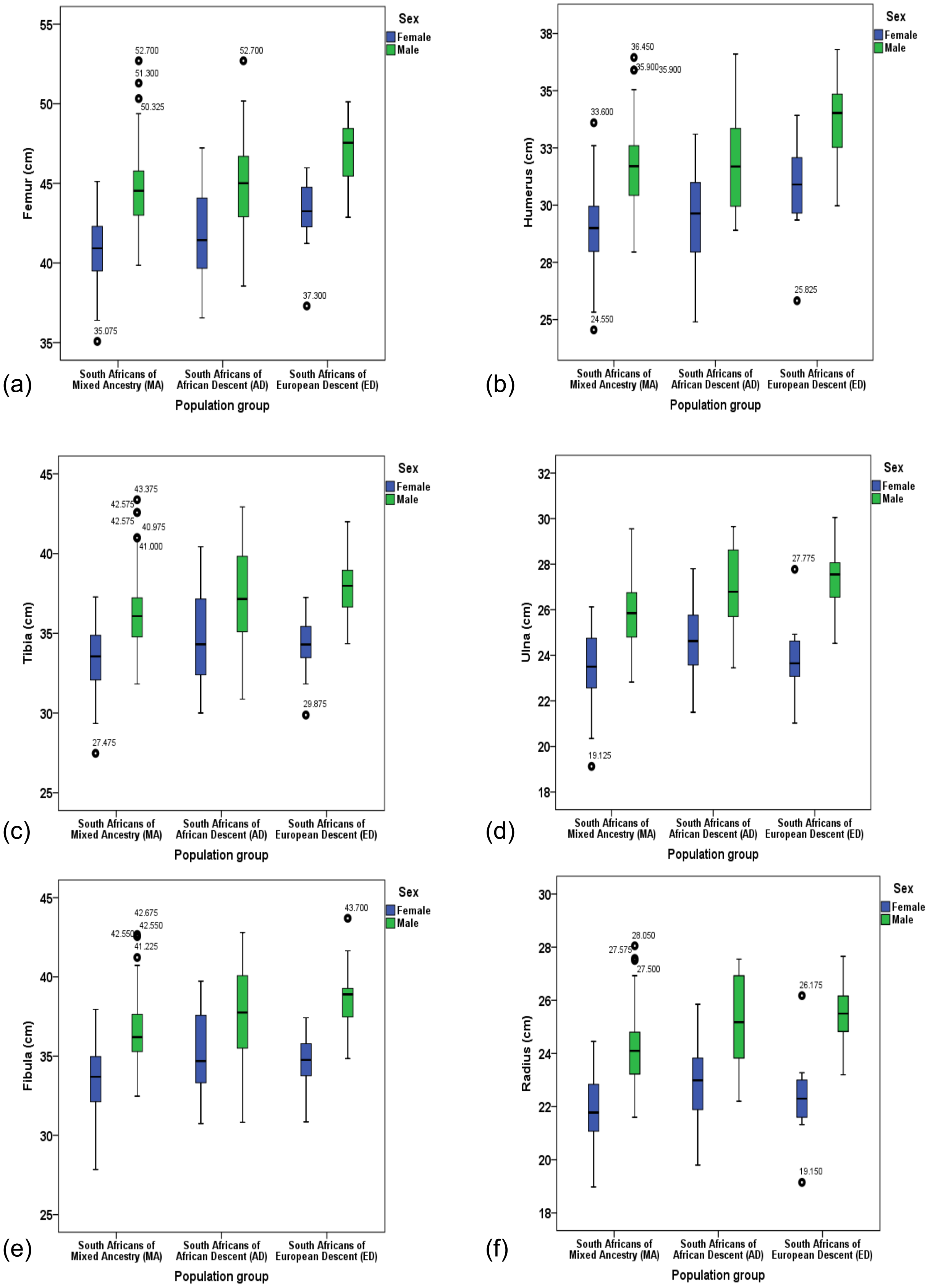
The mean difference between TSH_{Calc} of the two methods (described in subsection 3.5.1, Chapter 3) range from 1.22cm - 1.44cm (Table 4.4) and the mean difference between the $Tibia_{Phys}$ and $Tibia_{Malleolus}$ range from 0.98cm - 1.08cm (Table 4.5) depending on the population group. The remaining mean difference (±0.4cm) between the two methods is attributed to the difference in vertebral body measurement (Table 3.2, Chapter 3).

4.4 Long bone measurement statistics

The femur (35.08cm), humerus (24.55cm), tibia (27.48cm) and ulna (19.13cm) box-&-whisker plot outliers (Figures 4.6 a – d) represented a single small MA female (SUN, 347). The same individual has the lowest value for the fibula and the radius, but here the values form part of the box-&-whisker plot. A small ED female (WITS, 3579) is similarly represented by four outliers: femur (37.30cm), humerus (25.83cm), tibia (29.88cm) and radius (19.15cm). This ED female represents the lowest value for the box-&-whisker plots of the ulna and the fibula. The tallest ED female ulna and radius outliers are also represented by the same individual (WITS, 4297) with their femoral, tibial and fibular lengths forming the max value of those specific box-&-whisker plots.

The only AD male outlier is for femoral length (52.70cm) and this tall individual's (WITS, 4339) tibial, fibular, humeral and ulna lengths form the maximum value of these specific box-&-whisker plots. The ED male fibula (43.70cm) top outlier and the maximum value for the tibia box-&-whisker plot are from the same tall individual (WITS, 4029). Although none of the other long bone lengths of this tall ED male individual represent the maximum value of any other box-&-whisker plot, these lengths fall within the 95th percentile of the ED male data. The majority of the outliers per graph are within the MA male group at the upper end of the box-&-whisker plot. These outliers represent five individuals in total (all from SUN). The three femur (52.70cm, 51.30cm, 50.33cm) outliers correspond with the tibia (42.58cm, 43.38cm, 42.58cm), fibula (42.55cm, 42.68cm, 42.55cm), humerus (36.45cm) and radius (28.05cm, 27.5cm) outliers, respectively. The remaining tibia (41.00cm, 40.98cm) outliers correspond with the fibula (41.23cm), humerus (35.90cm, 35.90cm) and radius (27.58cm) outliers, respectively.

The median difference between females and males for all long bones is clearly visible. The median value for the femur and humerus follow a similar distribution between the subgroups whereas the median for the tibia and fibula, and the ulna and radius, follow a similar distribution. The latter distribution may relate to the adjacent anatomical positioning of these specific long bones. Although the humerus follows a similar distribution as the femur, there is a marked difference between the tibia-fibula and ulna-radius median distributions of the AD population group. This distribution difference is more visible in Figures 4.7 a & b. Figures 4.7 a & b represent the mean of the (a) lower limb (*i.e.* femur, tibia, fibula) and (b) upper limb (*i.e.* humerus, ulna, radius) for each population group.



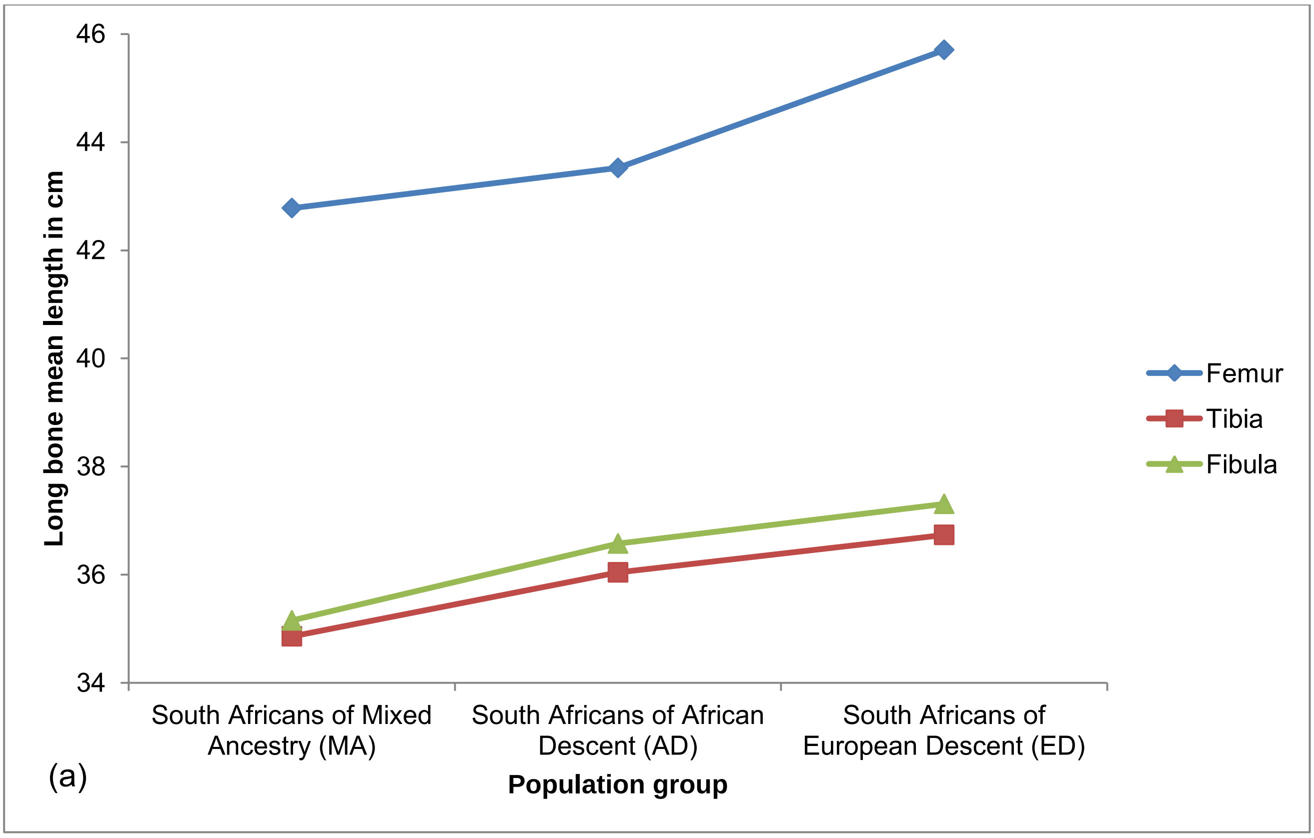
Figures 4.6 a – f: **Box plots of long bone measurements for females and males for each population group**

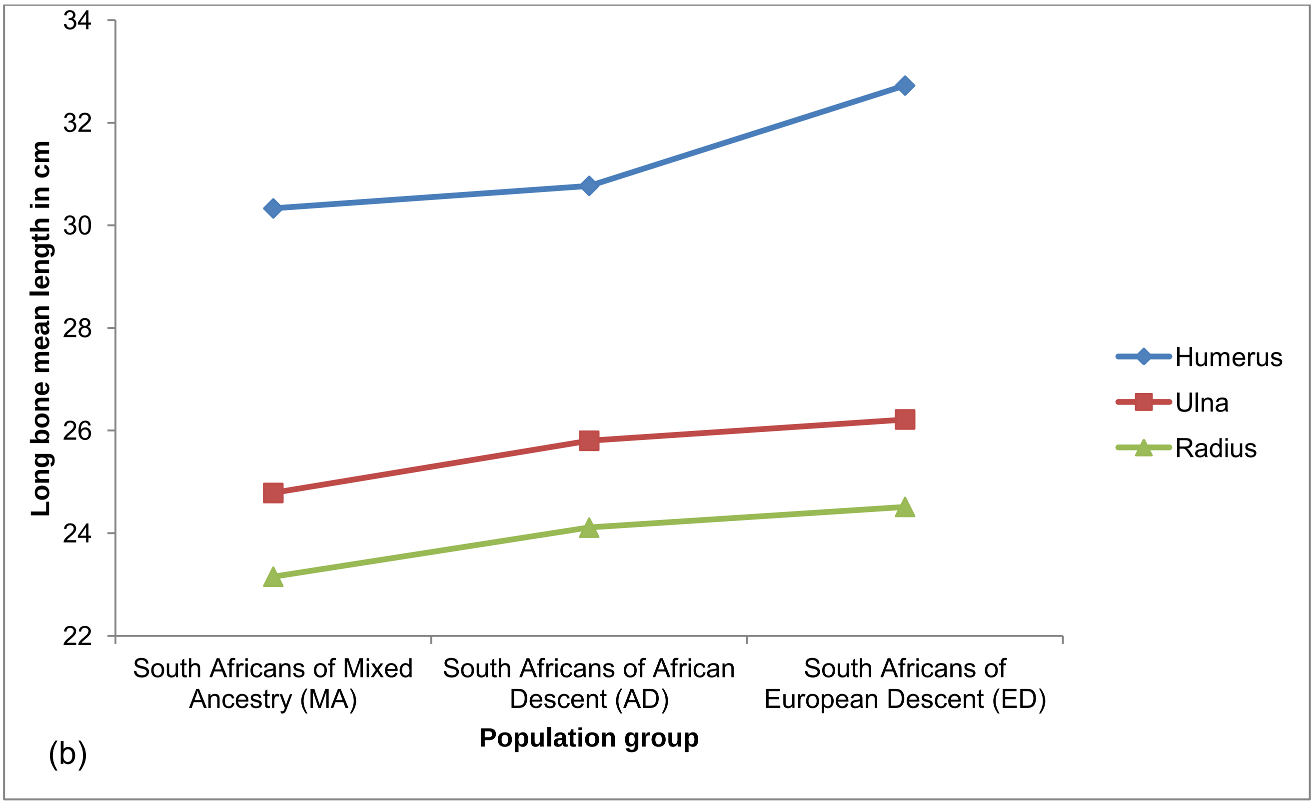
In Figures 7.4 a – f (Appendix) the individual long bone mean lengths for each population group have been plotted. Here the similarity in mean distribution between the femur and humerus between the population groups can be seen. Furthermore, the similarity in mean length distribution between the tibia and fibula, and the ulna and radius, is evident.

The combined femur and tibia lengths contribute a large proportion to anatomical stature. Figure 4.7 seem to indicate a difference of proportionality for the femur and tibia in relation to stature for the AD population group. The AD difference in femur : tibia proportion will consequently affect the derived total skeletal height (TSH) from regression formulae as these equations are based on long bone proportion to TSH. Furthermore, the difference in mean distribution of the tibia and fibula to the ulna and radius for the AD group may also indicate a difference of proportion from the other two population groups.

The long bone mean lengths are significantly different ($p<0.000$) between the MA and ED population groups (Table 4.5). The multiple comparisons of the ANOVA corroborate the differences that are seen in Figure 4.7.

In Table 4.5 the femur length shows no significant difference ($p>0.05$) between MA and AD, whereas the femur length between MA and ED is significantly different ($p<0.000$). It is also significantly different ($p<0.01$) between AD and ED. The ANOVA shows a similar trend for humerus length with no significant difference ($p>0.05$) between MA and AD, whereas there is a significant difference ($p<0.000$) for MA versus ED. For the tibia, with or without the malleolus included in the measurement, there is a significant difference ($p<0.01$) for MA versus either AD or ED, whereas no significant difference ($p>0.05$) was calculated between AD and ED. The fibula, ulna and radius show a significant difference ($p<0.01$) for MA versus either AD or ED whereas no significant difference ($p>0.05$) for AD versus ED.





Figures 4.7 a & b: Mean length plots of long bones in the (a) lower and (b) upper limbs

Table 4.5: ANOVA multiple comparisons of long bone measurements between the different population groups

Long bone analysed	Mean per population group		Population groups compared		Mean Difference	Std. Error	*p*-value
Femur	MA	42.78	AD	MA	0.85	0.49	0.237
	AD	43.63	ED	MA	2.95*	0.54	0.000
	ED	45.73	ED	AD	2.10*	0.61	0.003
Tibia (1)	MA	34.85	AD	MA	1.31*	0.44	0.011
	AD	36.16	ED	MA	1.90*	0.50	0.001
	ED	36.75	ED	AD	0.59	0.57	0.660
Tibia (2)	MA	35.83	AD	MA	1.41*	0.45	0.007
	AD	37.24	ED	MA	1.97*	0.50	0.001
	ED	37.80	ED	AD	0.55	0.58	0.713
Fibula	MA	35.16	AD	MA	1.41*	0.44	0.005
	AD	36.58	ED	MA	2.15*	0.50	0.000
	ED	37.31	ED	AD	0.73	0.57	0.497
Humerus	MA	30.38	AD	MA	0.49	0.36	0.441
	AD	30.87	ED	MA	2.39*	0.44	0.000
	ED	32.77	ED	AD	1.90*	0.48	0.000
Ulna	MA	24.79	AD	MA	1.11*	0.30	0.001
	AD	25.90	ED	MA	1.48*	0.39	0.001
	ED	26.27	ED	AD	0.37	0.43	0.783
Radius	MA	23.13	AD	MA	1.07*	0.31	0.002
	AD	24.20	ED	MA	1.42*	0.37	0.001
	ED	24.55	ED	AD	0.35	0.41	0.779

*. The mean difference is significant at the 0.05 level.

Note: MA = South Africans of Mixed Ancestry
AD = South Africans of African Descent
ED = South Africans of European Descent

(1) Lundy and Feldesman (1987)
(2) Dayal *et al*. (2008)

The independent *t*-test statistics for females versus males are displayed in Table 4.6. The equality of means shows a significant difference (p<0.000) between the sexes for each long bone length. This is statistical corroboration for the trend seen in the box-&-whisker plots of Figures 4.6 a – f. It is this statistical difference that underlies the sex-specific stature regression formulae. In Appendix D (page 99) each of the long bone measurements shows a significant difference (p<0.000) between the sexes and the three population groups.

Table 4.6: Independent *t*-test statistics of long bone measurements comparing females and males

Long bone analysed		Male			Female			Mean Difference	Std. Error Difference	Equality of variance	Equality of means
		Mean	Std. Dev	S.E.M.	Mean	Std. Dev.	S.E.M.			***F*** **-value**	***p*** **-value**
Femur	A	45.24	2.75	0.25	41.49	2.44	0.24	3.76*	0.35	1.216	0.000
	B								0.34		
Tibia [(1)]	A	36.97	2.53	0.23	33.86	2.28	0.22	3.10*	0.32	1.133	0.000
	B								0.32		
Tibia [(2)]	A	38.02	2.59	0.23	34.77	2.30	0.22	3.24*	0.33	1.389	0.000
	B								0.32		
Fibula	A	37.38	2.54	0.23	34.22	2.24	0.22	3.16*	0.33	1.930	0.000
	B								0.32		
Humerus	A	32.21	2.04	0.18	29.35	1.92	0.19	2.86*	0.26	1.401	0.000
	B								0.26		
Ulna	A	26.52	1.63	0.15	23.92	1.57	0.16	2.60*	0.21	0.729	0.000
	B								0.21		
Radius	A	24.85	1.56	0.14	22.28	1.44	0.14	2.57*	0.20	2.026	0.000
	B								0.20		

*. The mean difference is significant at the ≤0.05 level.

Note: A = Equal variances assumed
B = Equal variances not assumed

(1) Lundy and Feldesman (1987)
(2) Dayal *et al.* (2008)

4.5 Univariate regression formulae results versus TSH_{Calc}

In this subsection of the results, the females and males were analysed separately due to the stature regression formulae being sex-specific. For the females, and then the males, the calculated total skeletal height (TSH_{Calc}) summed according to the method used by the indicated publication will be compared to the estimated TSH (TSH_{Est}) from sex-specific univariate regression formulae from that particular publication.

4.5.1 Females

The results from the paired *t*-test for females from the three population groups are given in Table 4.7. Lundy and Feldesman (1987) developed their regression formulae for South Africans of African Descent (AD).

Comparing the TSH_{Calc}, based on the method they used, of AD individuals to TSH_{Est} from their sex-specific regression formulae, only the results of the ulna regression formula shows no significant difference ($p>0.05$) between the two variables. There is a significant difference ($p<0.05$) for TSH_{Calc} versus TSH_{Est} from the radius regression formulae. Both TSH_{Est} from the tibia and humerus regression formulae are significantly different ($p<0.01$) compared to TSH_{Calc}. TSH_{Est} from the femur and fibula regression formulae yielded a very significant difference ($p<0.000$) when compared to TSH_{Calc}. Therefore, excluding the ulna regression formula results, all other long bone regression results are significantly different to TSH_{Calc}.

The paired *t*-test results for South Africans of European Descent (ED) based on the Lundy and Feldesman (1987) regression formulae were different from what was expected. These regression formulae were not designed from or for ED and thus should have yielded a significant difference ($p<0.000$) between TSH_{Calc} and TSH_{Est} for all long bone regression formulae. This was the case for the tibia, fibula, ulna and radius regression formulae results which showed a significant difference ($p<0.01$) when compared to TSH_{Calc}. For these four regression formulae the mean difference between TSH_{Calc} and TSH_{Est} from the formulae was positive indicating an underestimation of TSH by the regression formulae. Yet, there was no significant difference ($p>0.05$) between TSH_{Calc} and TSH_{Est} from the femur and humerus regression formulae.

Table 4.7: Paired *t*-test statistics for females of each population group comparing calculated total skeletal height to estimated total skeletal height from published univariate regression formulae

TSH_{Calc} compared to estimated TSH from univariate regression formulae	MA			AD			ED		
	% correlation	Paired Differences		% correlation	Paired Differences		% correlation	Paired Differences	
		Mean Difference	*p*-value		Mean Difference	*p*-value		Mean Difference	*p*-value
TSH_{Calc} vs Femur (1)	84.4	-1.93*	0.000	92.4	-2.75*	0.000	95.7	-0.83	0.168
TSH_{Calc} vs Femur (2)	81.3	-2.87*	0.000	95.7	-3.53*	0.000	95.5	-1.17	0.065
TSH_{Calc} vs Tibia (1)	85.5	0.02	0.965	88.9	-1.70*	0.003	92.0	5.25*	0.000
TSH_{Calc} vs Tibia (2)	80.8	-5.44*	0.000	93.5	-8.08*	0.000	90.9	-0.36	0.677
TSH_{Calc} vs Fibula (1)	87.8	-1.68*	0.000	93.6	-4.24*	0.000	95.8	2.48*	0.008
TSH_{Calc} vs Fibula (2)	81.0	-5.39*	0.000	93.5	-8.09*	0.000	96.2	-1.21	0.091
TSH_{Calc} vs Humerus (1)	82.0	-2.31*	0.000	81.9	-2.65*	0.001	86.5	-0.76	0.457
TSH_{Calc} vs Humerus (2)	78.4	-3.97*	0.000	88.6	-4.12*	0.000	88.9	-1.69	0.077
TSH_{Calc} vs Ulna (1)	81.1	1.09*	0.026	85.0	-1.17	0.060	75.2	7.17*	0.000
TSH_{Calc} vs Ulna (2)	77.8	-7.36*	0.000	90.8	-9.22*	0.000	75.9	-0.73	0.573
TSH_{Calc} vs Radius (1)	80.7	0.58	0.198	84.5	-1.59*	0.017	76.8	5.96*	0.001
TSH_{Calc} vs Radius (2)	71.5	-7.11*	0.000	90.2	-8.90*	0.000	78.4	-1.28	0.307

*. The mean difference is significant at the ≤0.05 level.

Note: MA = South Africans of Mixed Ancestry
AD = South Africans of African Descent
ED = South Africans of European Descent

(1) Lundy and Feldesman (1987)
(2) Dayal *et al*. (2008)

For South Africans of Mixed Ancestry (MA), the Lundy and Feldesman (1987) femur, fibula and humerus regression formulae TSH_{Est} results were significantly different ($p<0.000$) compared to TSH_{Calc}. MA's TSH_{Est} results from the ulna regression formulae were significantly different ($p<0.05$) yet not significantly different ($p>0.05$) for the radius regression formulae results when compared to TSH_{Calc}.

The best correlation, for any population group, between TSH_{Calc} and TSH_{Est} from a long bone regression formula was that of the MA's tibia which produced a mean difference of only 0.02cm and $p = 0.965$. The mean difference is calculated by subtracting the estimated TSH (TSH_{Est}), from the regression formula, from TSH_{Calc}. A negative mean difference would therefore indicate that TSH_{Est} is greater than TSH_{Calc}, and vice versa.

Dayal *et al*. (2008) developed their regression formulae for ED within the last decade. None of the ED long bone regression formulae results were significantly different ($p>0.05$) compared to $TSH_{Calc.}$ For AD and MA, TSH_{Est} from the Dayal *et al.* (2008) long bone regression formulae were significantly different ($p<0.000$) from TSH_{Calc}.

For the Lundy and Feldesman (1987) long bone regression formulae, when the standard error of estimate (SEE) value is added/subtracted to/from MA and AD's TSH_{Est} results from the regression formulae, all but one of the mean differences fall within the SEE range (Table 4.8). The only exception is AD's TSH_{Est} results from the fibula regression formula which has a mean difference of -4.24cm whereas the SEE value for this regression formula is ± 3.168cm. For AD, all TSH_{Est} from regression formulae are slightly overestimated. For ED, the mean difference is mostly positive and hence shows a general trend to underestimate TSH for this population group. The addition/subtraction of the SEE value to/from TSH_{Est} from the regression formulae only incorporates three (femur, fibula and humerus formulae results) of the mean differences with the remaining three (tibia, ulna and radius formulae results) mean differences still significantly different ($p<0.05$) when the SEE value is added to TSH_{Est} from the regression formulae.

For the Dayal *et al*. (2008) long bone regression formulae, all MA and AD's TSH_{Est} results from the long bone regression formulae are overestimated, hence the negative values of the mean differences. Adding the SEE value to TSH_{Est}, the mean differences remain significant ($p<0.05$) for all long bone regression formulae results of MA and AD. Whereas for ED, when the SEE value is added to TSH_{Est} from the regression formulae, the mean differences lie within the SEE range. Although low, the negative mean differences do indicate a trend of overestimating TSH when the regression formulae are used to calculate total skeletal height.

Table 4.8: **Standard error of estimate (SEE) and mean difference between calculated total skeletal height (TSH_{Calc}) and estimated TSH from univariate regression formulae for females from the three population groups**

Publication of Regression Formulae	Ancestry	Mean difference between TSH_{Calc} and the estimated TSH from univariate regression formulae: FEMALES					
	Standard error of estimate (SEE)	Calculated total skeletal height (TSH_{Calc}) – estimated TSH from					
		Femur Regression	Tibia Regression	Fibula Regression	Humerus Regression	Ulna Regression	Radius Regression
Lundy & Feldesman (1987)	MA	-1.93	0.02	-1.68	-2.31	1.09	0.58
	AD	-2.75	-1.70	-4.24	-2.65	-1.17	-1.59
	ED	-0.83	5.25	2.48	-0.76	7.17	5.96
	SEE	**± 2.789**	**± 3.056**	**± 3.168**	**± 3.629**	**± 3.387**	**± 3.715**
Dayal *et al.* (2008)	MA	-2.87	-5.44	-5.39	-3.97	-7.36	-7.11
	AD	-3.53	-8.08	-8.09	-4.12	-9.22	-8.90
	ED	-1.17	-0.36	-1.21	-1.69	-0.73	-1.28
	SEE	**± 2.4**	**± 2.59**	**± 2.75**	**± 3.54**	**± 3.38**	**± 3.38**

Note: MA = South Africans of Mixed Ancestry
AD = South Africans of African Descent
ED = South Africans of European Descent

4.5.2 Males

The results from the paired *t*-test for males from the three population groups are given in Table 4.9.

For AD, all but one of the Lundy and Feldesman (1987) long bone regression formulae produced TSH_{Est} that were significantly different ($p<0.01$) compared to the calculated total skeletal height (TSH_{Calc}). TSH_{Est} from the tibia regression formula showed no significant difference ($p>0.05$) compared to TSH_{Calc}.

ED's TSH_{Est} from the Lundy and Feldesman (1987) tibia, fibula, ulna and radius regression formulae were all significantly different ($p<0.000$) compared to TSH_{Calc}. The femur and humerus regression formulae results showed no significant difference ($p>0.05$) compared to TSH_{Calc}.

For South Africans of Mixed Ancestry (MA), there was no significant difference ($p>0.05$) between TSH_{Calc} and TSH_{Est} from the Lundy and Feldesman (1987) ulna and radius regression formulae. MA's TSH_{Est} from the Lundy and Feldesman (1987) tibia and fibula regression formulae were significantly different ($p<0.05$) compared to their TSH_{Calc}, and TSH_{Est} from the femur and humerus regression formulae were very significantly different ($p<0.000$).

For the Dayal *et al*. (2008) long bone regression formulae, there was no significant difference ($p>0.05$) between ED's TSH_{Calc} and TSH_{Est} from the tibia, fibula, ulna or radius regression formulae, but TSH_{Est} from the femur and humerus regression formulae were significantly different ($p<0.05$) to TSH_{Calc}. AD's TSH_{Calc} was significantly different ($p<0.000$) compared to TSH_{Est} from the Dayal *et al*. (2008) long bone regression formulae except for the humerus regression formulae results which was not significantly different ($p>0.05$). And finally, all MA's TSH_{Est} from the Dayal *et al*. (2008) long bone regression were significantly different compared to their TSH_{Calc}. TSH_{Est} from the femur, tibia, fibula, ulna and radius regression formulae were significantly different at $p<0.000$ whereas the humerus regression results were significantly different at $p<0.05$.

Table 4.9: Paired *t*-test results for males of each population group comparing calculated total skeletal height to estimated total skeletal height from published univariate regression formulae

TSH$_{\text{Calc}}$ compared to estimated TSH from univariate regression formulae	**MA**			**AD**			**ED**		
	% correlation	**Paired Differences**		**% correlation**	**Paired Differences**		**% correlation**	**Paired Differences**	
		Mean Difference	***p*-value**		**Mean Difference**	***p*-value**		**Mean Difference**	***p*-value**
TSH$_{\text{Calc}}$ vs Femur (1)	91.6	-2.87*	0.000	95.4	-3.66*	0.000	89.7	-0.07	0.890
TSH$_{\text{Calc}}$ vs Femur (2)	91.6	-2.34*	0.000	96.2	-2.71*	0.000	89.5	1.44*	0.017
TSH$_{\text{Calc}}$ vs Tibia (1)	91.5	1.00*	0.014	94.6	-0.87	0.074	83.9	5.46*	0.000
TSH$_{\text{Calc}}$ vs Tibia (2)	91.3	-4.53*	0.000	94.2	-6.39*	0.000	82.3	0.40	0.563
TSH$_{\text{Calc}}$ vs Fibula (1)	91.6	-1.01*	0.017	94.3	-3.55*	0.000	86.0	2.50*	0.000
TSH$_{\text{Calc}}$ vs Fibula (2)	91.3	-3.54*	0.000	94.7	-5.90*	0.000	86.7	0.52	0.399
TSH$_{\text{Calc}}$ vs Humerus (1)	80.1	-2.35*	0.000	85.1	-2.27*	0.005	86.7	0.49	0.404
TSH$_{\text{Calc}}$ vs Humerus (2)	79.7	-1.48*	0.012	86.0	-1.06	0.154	85.6	1.70*	0.010
TSH$_{\text{Calc}}$ vs Ulna (1)	85.4	0.42	0.455	88.7	-2.02*	0.008	62.1	4.75*	0.000
TSH$_{\text{Calc}}$ vs Ulna (2)	85.7	-4.85*	0.000	88.6	-7.56*	0.000	63.8	-0.66	0.479
TSH$_{\text{Calc}}$ vs Radius (1)	85.9	0.22	0.680	84.3	-2.60*	0.002	63.7	4.62*	0.000
TSH$_{\text{Calc}}$ vs Radius (2)	85.4	-4.87*	0.000	84.0	-8.02*	0.000	64.2	-0.60	0.516

*. The mean difference is significant at the ≤0.05 level.

Note: MA = South Africans of Mixed Ancestry
AD = South Africans of African Descent
ED = South Africans of European Descent

(1) Lundy and Feldesman (1987)
(2) Dayal *et al*. (2008)

Incorporating the specific standard error of estimate (SEE) value of each long bone regression formulae from Lundy and Feldesman (1987) into the TSH_{Est} results, all but one of the mean differences of the MA population group falls within the SEE range (Table 4.10). TSH_{Est} from the femur regression formulae, with the addition of the SEE value, falls just outside the SEE range.

For the AD population group, for whom these regression formulae were developed, four of the six regression formulae have a mean difference that fall within the SEE range for that specific regression formula. AD's TSH_{Est}, with the addition of the SEE value, from the femur and fibula regression formulae remains significantly different ($p<0.05$) from TSH_{Calc}. Whereas ED's TSH_{Est}, with or without incorporating the SEE value, from the femur regression formula correlates with TSH_{Calc}. Except for the femur regression formula, all other long bone formulae tend to underestimate TSH of ED; *i.e*. positive mean differences. ED's TSH_{Est}, including the SEE value, from the tibia, ulna and radius regression formulae remains significantly different ($p<0.05$) from their TSH_{Calc}.

In comparison, the mean differences between ED's TSH_{Calc} and resulting TSH_{Est} from the various Dayal *et al*. (2008) long bone regression formulae fall within the SEE range. The Dayal *et al*. (2008) long bone regression formulae mean difference results for MA and AD males are not as straightforward as the results for the MA and AD females. For MA males, the mean difference between TSH_{Calc} and TSH_{Est} (including the SEE value) from the femur or the humerus regression formula lies within the SEE range and will therefore not be significantly different. The other four (tibia, fibula, ulna, radius) long bone regression formulae TSH_{Est} results, including the SEE, remain significantly different to TSH_{Calc} as the mean difference is greater than the SEE.

For AD males, all but one mean difference is greater than the SEE for a specific regression formula result and therefore remains significantly different when compared to TSH_{Calc}. TSH_{Est}, including the SEE, from the humerus regression formula lies within the SEE range. The general trend of the Dayal *et al*. (2008) long bone regression formulae is to overestimate TSH of MA and AD males, hence the negative mean differences.

Table 4.10: Standard error of estimate (SEE) and mean difference between calculated total skeletal height (TSH_{Calc}) and estimated TSH from univariate regression formulae for males from the three population groups

Publication of Regression Formulae	Ancestry	Mean difference between TSH_{Calc} and the estimated TSH from univariate regression formulae: MALES					
	Standard error of estimate (SEE)	Calculated total skeletal height (TSH_{Calc}) – estimated TSH from					
		Femur Regression	Tibia Regression	Fibula Regression	Humerus Regression	Ulna Regression	Radius Regression
Lundy & Feldesman (1987)	MA	-2.87	1.00	-1.01	-2.35	0.42	0.22
	AD	-3.66	-0.87	-3.55	-2.27	-2.02	-2.60
	ED	-0.07	5.46	2.50	0.49	4.75	4.62
	SEE	**± 2.777**	**± 2.78**	**± 2.98**	**± 3.834**	**± 3.727**	**± 3.643**
Dayal *et al.* (2008)	MA	-2.34	-4.53	-3.54	-1.48	-4.85	-4.87
	AD	-2.71	-6.39	-5.90	-1.06	-7.60	-8.02
	ED	1.44	0.40	0.52	1.70	-0.66	-0.60
	SEE	**± 2.64**	**± 3.16**	**± 3.35**	**± 3.76**	**± 3.79**	**± 3.58**

Note: MA = South Africans of Mixed Ancestry
AD = South Africans of African Descent
ED = South Africans of European Descent

4.6 Multivariate regression formulae results versus TSH_{Calc}

The estimated total skeletal height (TSH_{Est}) from the various multivariate stature regression formulae will be dealt with the same as the univariate subsection. Female, and then male, calculated total skeletal height (TSH_{Calc}) will be compared to TSH_{Est} from sex specific multivariate regression formulae based on the method and formulae from the two publications, *i.e*. Lundy and Feldesman (1987) or Dayal *et al*. (2008).

The combinations of skeletal elements used were as follows:

(e) The combined heights of all the lumbar vertebrae in the spinal column which is stated as 'Lumbar column': $[LV]^{(1)}$ (Lundy and Feldesman, 1987) or $[LV]^{(2)}$ (Dayal *et al.*, 2008)

(f) The combination of the lumbar vertebrae heights, the physiological femoral height and the physiological or including the malleolus height of the tibia. This is stated as 'Lumbar column + $Femur_{Phys}$ + $Tibia_{Phys}$' (Lundy and Feldesman, 1987) or 'Lumbar column + $Femur_{Phys}$ + $Tibia_{Malleolus}$' (Dayal *et al*., 2008): $[LV + F + T]^{(1)}$ or $[LV + F + T]^{(2)}$

(g) The combination of the physiological femoral height and the physiological or including malleolus height of the tibia which is written as either '$Femur_{Phys}$ + $Tibia_{Phys}$' (Lundy and Feldesman, 1987) or '$Femur_{Phys}$ + $Tibia_{Malleolus}$' (Dayal *et al*., 2008): $[F + T]^{(1)}$ or $[F + T]^{(2)}$

(h) The final combination is of the lumbar vertebrae heights and the physiological height of the femur, given as 'Lumbar column + $Femur_{Phys}$' for both sources: $[LV + F]^{(1)}$ or $[LV + F]^{(2)}$

4.6.1 Females

The results from the paired *t*-test for females from the three population groups are given in Table 4.11.

For both South Africans of African Descent (AD) and European Descent (ED) there is no significant difference ($p>0.05$) between TSH_{Calc} and TSH_{Est} results from the Lundy and Feldesman (1987) combined lumbar column height regression formula whereas South Africans of Mixed Ancestry (MA) shows a significant difference ($p<0.000$) between the two variables. For all other Lundy and Feldesman (1987) combined height regression formulae, there is a significant difference ($p<0.000$) between the two variables.

Table 4.11: Paired *t*-test results for females of each population group comparing calculated total skeletal height to estimated total skeletal height from published multivariate regression formulae

TSH_{Calc} compared to estimated TSH from multivariate regression formulae	**MA**			**AD**			**ED**		
	% correlation	**Paired Differences**		**% correlation**	**Paired Differences**		**% correlation**	**Paired Differences**	
		Mean Difference	***p*-value**		**Mean Difference**	***p*-value**		**Mean Difference**	***p*-value**
TSH_{Calc} vs [LV] CHf $^{(1)}$	33.5	-4.65*	0.000	31.1	-1.53	0.155	73.2	-2.03	0.149
TSH_{Calc} vs [LV] CHf $^{(2)}$	42.5	-0.85	0.246	35.5	1.56	0.150	70.4	1.58	0.268
TSH_{Calc} vs [LV +F+T] CHf $^{(1)}$	89.6	-0.80*	0.022	92.2	-1.66*	0.002	98.2	1.21*	0.008
TSH_{Calc} vs [LV +F+T] CHf $^{(2)}$	87.8	-1.95*	0.000	97.1	-3.27*	0.000	98.0	-0.03	0.941
TSH_{Calc} vs [F + T] CHf $^{(1)}$	88.2	19.49*	0.000	92.0	17.98*	0.000	95.1	22.47*	0.000
TSH_{Calc} vs [F + T] CHf $^{(2)}$	84.4	-3.73*	0.000	96.2	-5.50*	0.000	94.8	-0.61	0.353
TSH_{Calc} vs [LV + F] CHf $^{(1)}$	83.9	-2.42*	0.000	91.6	-2.08*	0.000	98.2	-2.56*	0.000
TSH_{Calc} vs [LV + F] CHf $^{(2)}$	85.5	0.25	0.535	96.5	0.31	0.301	98.3	0.34	0.358

*. The mean difference is significant at the ≤0.05 level.

Note: LV = Lumbar column
F = Physiological femoral height ($\text{Femur}_{\text{Phys}}$)
T = Tibial height: $\text{Tibia}_{\text{Phys}}$ $^{(1)}$ or $\text{Tibia}_{\text{Malleolus}}$ $^{(2)}$
CHf = Combined Height formula

(1) Lundy and Feldesman (1987)
(2) Dayal *et al*. (2008)

Most of the Dayal *et al*. (2008) combined height regression formulae TSH results shows no significant difference ($p>0.05$) between TSH$_{\text{Calc}}$ and the regression formulae results for females from all three population groups except for the combined height formulae of [LV + F + T] and [F + T] which shows a significant difference ($p<0.000$) for MA and AD females. It remains significant with the addition of the standard error of estimate (SEE) to TSH$_{\text{Est}}$ results from these regression formulae.

When adding the [LV] and [LV + F + T] SEE values to the respective TSH$_{\text{Est}}$ results obtained from the Lundy and Feldesman (1897) regression formulae for the three population groups, the mean differences between TSH$_{\text{Calc}}$ and TSH$_{\text{Est}}$ fall within the respective SEE ranges (Table 4.12). The mean difference between TSH$_{\text{Calc}}$ and TSH$_{\text{Est}}$ from the [F + T] regression formulae are exceptionally high (in comparison to all other mean difference results), and thus the formula was verified repeatedly with the publication's. No formula error could be found. Finally, only the [LV + F] mean difference of AD individuals lies within the SEE range.

Table 4.12: Standard error of estimate (SEE) and mean difference between TSH$_{\text{Calc}}$ and estimated TSH from multivariate regression formulae for females from the three population groups

Publication of Regression Formulae	**Ancestry**	**Mean difference between TSH$_{\text{Calc}}$ and the estimated TSH from multivariate regression formulae: FEMALES**			
	Standard error of estimate (SEE)	**Calculated total skeletal height (TSH$_{\text{Calc}}$) – estimated TSH from**			
		[LV] height regression formula	**[LV + F +T] height regression formula**	**[F + T] height regression formula**	**[LV + F] height regression formula**
Lundy & Feldesman (1987)	MA	-4.65	-0.80	19.50	-2.42
	AD	-1.53	-1.66	17.98	-2.08
	ED	-2.03	1.21	22.47	-2.56
	SEE	**± 4.910**	**± 2.087**	**± 2.497**	**± 2.346**
Dayal *et al.* (2008)	MA	-0.85	-1.95	-3.73	0.25
	AD	1.56	-3.27	-5.50	0.31
	ED	1.58	-0.03	-0.61	0.34
	SEE	**± 5.21**	**± 1.75**	**± 2.13**	**± 2.13**

4.6.2 Males

Most of the TSH$_{Est}$ results for males from the Lundy and Feldesman (1987) multivariate regression formulae are significantly different ($p \leq 0.02$) compared to the calculated total skeletal height (TSH$_{Calc}$). There is one exception. AD and ED's TSH$_{Est}$ results from the [LV] regression formula is not significantly different ($p > 0.05$) from TSH$_{Calc}$ (Table 4.14).

For the Dayal *et al*. (2008) multivariate regression formulae, AD's TSH$_{Est}$ results from the [LV] and [LV + F] formulae are not significantly different ($p > 0.05$) to TSH$_{Calc}$, and neither are ED's TSH$_{Est}$ results from the [F + T] formula (Table 4.15) in comparison to their TSH$_{Calc}$. All other TSH$_{Est}$ results for males from the various multivariate regression formulae are significantly different ($p < 0.05$) to TSH$_{Calc}$.

Most of the mean differences fall within the SEE ranges of various regression formulae except for Lundy and Feldesman's (1987) [F + T] formula for ED individuals, and [LV + F] for MA and AD individuals (Table 4.13). Finally, the mean differences between TSH$_{Calc}$ and TSH$_{Est}$ from the Dayal *et al*. (2008) regression formulae lie within the specific SEE range of the respective regression formula except for MA and AD males with regard to the [LV + F + T] and [F + T] TSH$_{Est}$ results.

Table 4.13: Standard error of estimate (SEE) and mean difference between TSH$_{Calc}$ and estimated TSH from multivariate regression formulae for males from the three population groups

Publication of Regression Formulae	**Ancestry**	**Mean difference between TSH$_{Calc}$ and the estimated TSH from multivariate regression formulae: MALES**			
	Standard error of estimate (SEE)	**Calculated total skeletal height (TSH$_{Calc}$) – estimated TSH from**			
		[LV] height regression formula	**[LV + F +T] height regression formula**	**[F + T] height regression formula**	**[LV + F] height regression formula**
Lundy & Feldesman (1987)	MA	-3.62	-0.98	-0.78	-3.06
	AD	-1.31	-1.80	-2.24	-2.76
	ED	0.83	1.26	2.52	-1.87
	SEE	**± 5.28**	**± 1.839**	**± 2.371**	**± 2.196**
Dayal *et al*. (2008)	MA	-3.55	-2.17	-3.34	-1.02
	AD	-1.56	-2.87	-4.55	-0.58
	ED	2.30	1.03	0.68	1.69
	SEE	**± 5.54**	**± 1.92**	**± 2.49**	**± 2.17**

Table 4.14: Paired *t*-test results for males of each population group comparing calculated total skeletal height to estimated total skeletal height from published multivariate regression formulae

TSH$_{Calc}$ compared to estimated TSH from multivariate regression formulae	**MA**			**AD**			**ED**		
	% correlation	**Paired Differences**		**% correlation**	**Paired Differences**		**% correlation**	**Paired Differences**	
		Mean Difference	***p*-value**		**Mean Difference**	***p*-value**		**Mean Difference**	***p*-value**
TSH$_{Calc}$ vs [LV] CHf (1)	63.2	-3.62*	0.000	60.2	-1.32	0.250	84.9	0.83	0.247
TSH$_{Calc}$ vs [LV] CHf (2)	64.5	-3.55*	0.000	58.9	-1.56	0.191	88.2	2.30*	0.008
TSH$_{Calc}$ vs [LV +F+T] CHf (1)	96.1	-0.98*	0.000	97.4	-1.80*	0.000	93.7	1.26*	0.004
TSH$_{Calc}$ vs [LV +F+T] CHf (2)	96.5	-2.17*	0.000	97.8	-2.87*	0.000	92.8	1.03*	0.035
TSH$_{Calc}$ vs [F + T] CHf (1)	94.0	-0.78*	0.020	95.9	-2.24*	0.000	90.2	2.52*	0.000
TSH$_{Calc}$ vs [F + T] CHf (2)	93.9	-3.34*	0.000	96.2	-4.55*	0.000	89.2	0.68	0.233
TSH$_{Calc}$ vs [LV + F] CHf (1)	93.6	-3.06*	0.000	97.4	-2.76*	0.000	94.4	-1.87*	0.000
TSH$_{Calc}$ vs [LV + F] CHf (2)	94.1	-1.02*	0.003	98.0	-0.58	0.123	94.7	1.69*	0.000

*. The mean difference is significant at the ≤0.05 level.

Note: LV = Lumbar column
F = Physiological femoral height (Femur$_{Phys}$)
T = Tibial height: Tibia$_{Phys}$ (1) or Tibia$_{Malleolus}$ (2)
CHf = Combined Height formula

(1) Lundy and Feldesman (1987)
(2) Dayal *et al*. (2008)

4.7 Estimated living statures (LSr and LSf) versus calculated living stature (LSwA)

The estimated living stature from the generic femur/stature ratio (LSr) and the converted TSH_{Est} from Lundy and Feldesman's (1987) femur regression formula (LSf) were compared to the calculated living stature (LSwA) (Table 4.15). Paired *t*-test results will be reported on for females and then males.

4.7.1 Females

All of the paired *t*-tests showed a very significant difference ($p<0.000$) between LSwA and LSr. For MA nearly one in ten (9.84%) individuals was overestimated by more than 10.0cm. For AD one in five individuals were overestimated by more than 10.0cm. Only one (in thirteen) ED was overestimated by 10.0cm. Individual scrutiny shows that four in ten MA, nearly six in ten AD and nearly seven in ten ED with a maximum femur length greater than 40.0cm were overestimated by the femur/stature ratio. Only one Mixed Ancestry individual had a maximum femur length greater than 40.0cm where the estimated living stature (LSr) from the generic ratio was less than LSwA. On the other hand two in ten MA, one in ten AD and two in ten ED with a maximum femur length greater than 40.0cm had an estimated LSr within 5.0cm of LSwA.

All, except one, of the paired *t*-tests showed a very significant difference ($p<0.000$) between LSwA and LSf. Only ED's LSf showed no significant difference ($p>0.05$) compared to LSwA which is in line with the results from the Lundy and Feldesman's (1987) univariate femur regression results.

4.7.2 Males

All of the paired *t*-tests showed a very significant difference ($p<0.000$) between LSwA and LSr. Three in ten MA males were overestimated by 10.0cm compared to their LSwA. The same was found for AD whereas two in ten ED were overestimated by 10.0cm. It was found that one in five AD had LSr greater than 8.18cm whereas the statistics are relatively similar for MA and ED (four in ten). Further individual scrutiny showed that nearly seven in ten MA and eight in ten for both AD and ED with a maximum femur length greater than 40.0cm had an estimated living stature that was overestimated by the generic femur/stature ratio. Only one MA had a maximum femur length greater than 40.0cm where LSr was less than LSwA. In contrast two in ten MA and ED, but only one in ten for AD, who had a maximum femur length greater than 40.0cm had LSr within 5.0cm of LSwA.

All, except one, of the paired *t*-tests showed very significant differences ($p<0.000$) between LSwA and LSf. Only ED's LSf showed no significant difference ($p>0.05$) compared to LSwA.

Table 4.15: Paired *t*-test comparing the calculated living stature (LSwA) to the living statures from the femur/stature ratio (LSr) and the Lundy and Feldesman (1987) femur regression formula (LSf)

Population group	Sex	Variables compared	Paired Differences		S.E.M	*p*-value
			Mean	Std. Dev.		
MA	F	LSwA - LSr	-6.32*	4.44	0.57	0.000
		LSwA - LSf	-1.93*	3.29	0.42	0.000
	M	LSwA - LSr	-8.48*	4.58	0.58	0.000
		LSwA - LSf	-2.87*	3.01	0.38	0.000
AD	F	LSwA - LSr	-7.64*	5.13	0.91	0.000
		LSwA - LSf	-2.74*	2.96	0.52	0.000
	M	LSwA - LSr	-9.61*	4.02	0.69	0.000
		LSwA - LSf	-3.68*	2.50	0.43	0.000
ED	F	LSwA - LSr	--7.84*	3.29	0.91	0.000
		LSwA - LSf	-0.83	2.04	0.57	0.168
	M	LSwA - LSr	-8.91*	3.51	0.68	0.000
		LSwA - LSf	-0.09	2.73	0.52	0.862

*. The mean difference is significant at the ≤0.05 level.

Note: MA = South Africans of Mixed Ancestry
AD = South Africans of African Descent
ED = South Africans of European Descent

F = Female
M = Male

LSwA = Living stature with age correction factor added (LS = TSH_{Calc} + soft tissue correction factor – age correction factor)
LSr = Living stature from femur/stature ratio (Feldesman *et al*., 1990)

LSf = Living stature from femur regression formula's TSH_{Est} (Lundy and Feldesman, 1987) with soft tissue (Fully, 1956) and age (Trotter and Gleser, 1952) correction factors added and subtracted, respectively (LS = TSH_{Est} + soft tissue correction factor – age correction factor)

Chapter 5: Discussion

The use of stature regression formulae aid forensic anthropologists to compose a biological profile for recovered unidentifiable human remains (Pearson, 1899). The use of the full anatomical method, as described in Chapter 2, is only possible when all stature contributing skeletal elements are available (Fully, 1956). It is also a very laborious and time consuming method. Indirect methods such as regression formulae can be used when incomplete, fragmentary or burned human remains are recovered (Pearson, 1899). It is also less time consuming and statistically comparable with the full anatomical method (Pearson, 1899; Bidmos, 2008).

Numerous researchers have advocated the use of sex- and/or population-specific regression formulae when both these attributes can be ascertained with certainty (Pearson, 1899; Trotter and Gleser, 1952; Lundy and Feldesman, 1987; Feldesman *et al*., 1990; Dayal *et al*., 2008). Others have cautioned the use of sex- and/or population-specific regression formulae when neither of these attributes can be ascertained with certainty (Albanese *et al*., 2016). Furthermore it has been said that regression formulae should be updated to account for temporal changes within a population group (Dayal *et al*., 2008).

Numerous anthropometric and osteological stature researches have been conducted on South Africans of African Descent (AD), South Africans of European Descent (ED) and South Africans of Mixed Ancestry (MA) (Lundy and Feldesman, 1987; Bidmos and Asala, 2005, Bidmos, 2006; Chibba and Bidmos, 2007; Ryan and Bidmos; 2007; Bidmos, 2008; Dayal *et al*., 2008; Bidmos, 2008; Bidmos, 2009; Pininski and Brits, 2014; Brits *et al*., 2017). The current study re-evaluated existing regression formulae for AD and ED, and tested the applicability of using these formulae to estimate stature of MA. Additionally, the reliability of the generic femur/stature ratio (Feldesman *et al*., 1990) to estimate living stature (LS) for all three population groups was investigated.

Measurements were taken from a total of 229 individuals (MA, AD and ED) at three South African skeletal collections. Statistical analyses determined if there was a significant difference ($p<0.05$) between (1) estimated total skeletal height (TSH_{Est}) from regression formulae and that from the full anatomical method (TSH_{Calc}), and (2) the estimated living stature from the femur/stature ratio (LSr) and a calculated living stature (LSwA) for the three population groups.

AD and MA showed no significant difference ($p>0.05$) for TSH_{Calc}, but both were significantly different ($p<0.000$) to ED. Results indicated that Lundy and Feldesman's (1987) regression formulae should be re-assessed for contemporary AD whereas Dayal *et al*.'s (2008) regression formulae are still relevant for contemporary ED. Furthermore the results indicate the importance of developing population-specific regression formulae for MA.

The femur/stature ratio's living stature were significantly different ($p<0.000$) from the calculated living stature, and generally overestimated it for maximum femur lengths greater than 50cm.

5.1 Sample size, outliers and individual variation

Based on the available cadaveric sample cohort at university bone collections, it proved difficult to assemble a large sample size for any particular population group considering the exclusion criteria regarding pathology, trauma and disease. The source of the sample cohort also restricted the acquisition of a wide spread of stature ranges within population groups.

Bidmos (2008) stated that the standard error of estimate (SEE) depends on the variation between individuals within a specific population group and that the SEE value for population-specific stature regressions should be low. In 1972 Lewontin (*cited in* Ousley *et al*., 2009) found that approximately 85% of human variation existed within population groups and only around 6% variation could be found between population groups. To test the influence of greater variation with a larger sample size, it was found that there was no significant difference ($p>0.05$) of the six mean long bone lengths for MA or AD. ED showed a lower mean for all six long bone lengths, but not significantly different ($p>0.05$) between the two sample sizes. The influence of individual long bone variation on population-specific regression formulae will be discussed in subsection 5.4.

The mean and variance of a sample cohort are sample-size dependent and highly influenced by data outliers. Irrespective of the definition used to classify an outlier (Barnett and Lewis, 1994; Jackson and Chen, 2004; Ben-Gal, 2005; Hair *et al*., 2010) it is important to identify and investigate outliers and their potential influence on variation parameters. By increasing the sample size, as was done for the long bones in this study, these were kept in mind when doing statistical analyses.

A larger sample size may thus affect what is construed an outlier as it would incorporate greater variation within a living population group, but this is problematic considering the cadaveric-derived sample source. Furthermore, Hodge and Austin (2004) noted that the *p*-value is predisposed to the number of data points in a data set. The larger the sample size the "... more statistically representative the sample is likely to be" (Hodge and Austin, 2004).

Due to the limited sample size and thus limited stature ranges for all three population groups the interpretation of data statistics was mindful of parameters such as sample size.

5.2 Stature and socio-economic factors

Stature differences between population groups may be attributed to ancestral genetic influences, but it is also affected by the nutrient input (food) versus metabolic output (physical activity) ratio of an individual (Rühli *et al*., 2008; Martorell and Zongrone, 2012; Balogun *et al*., 2015).

In the latter half of the 20th century, the South African government legally suppressed (Prohibition of Mixed Marriages Act of 1949; Immorality Act of 1950) admixture between ED and AD preventing legal genetic admixture between the two population groups (Jacobson *et al*., 2004; Petersen *et al*., 2013). Socio-economic conditions such as psycho-social stress, poor living conditions and physically strenuous labour were the norm for AD whereas ED benefitted from higher income, better housing and medical benefits (Petrus and Isaacs-Martin, 2012; Inwood and Masakure, 2013; Van Niekerk *et al*., 2014). The continued exposure of AD to adverse socio-economic and environmental stressors may have caused an intergenerational reduction in stature (Bogin, 2012; Stulp and Barrett, 2016). Steyn and Smith's (2007) anthropometric study which was based on military personnel between 2000 and 2005 and the current study's TSH show a very significant difference between AD and ED. Although the sample size of the 2007 study was far greater than the current study, the results showed a similar trend between the ED and AD population groups for living stature and the current study's TSH. The data from the current study show a significant mean TSH difference (p<0.000) of 7.65cm between male ED and AD (0.49cm less than the 2007 study), and a significant mean TSH difference (p<0.000) of 5.56cm between female ED and AD (0.01cm less that the 2007 study).

As with AD, ED and MA were similarly separated. The enforcement of SA segregation laws was not as strict to prevent AD and MA to admix yet socio-ethnic association within the MA population group did. The implementation, and subsequent failure, of the Population Registration Act of 1950 lead to social and economic microcosmic levels within the mixed ancestry population group (Petrus and Isaacs-Martin, 2012).

The 2007 MA anthropometric data was based on military personnel information collected from 2000 to 2005 (Steyn and Smith, 2007). It is more likely that individuals from low income families would enlist in the military (no tertiary education needed and a steady income) than individuals from a higher socio-economic bracket. The current study's skeletal (MA and AD) data was based on cadavers from individuals who donate their remains for scientific research purposes or individuals who may have been unclaimed after death. The latter source of data, and the major contributor of AD and MA data for the current study, may thus exclude the higher income bracket of mixed ancestry families or at best have a very limited number of these individuals. In addition, both AD and MA groups may have an ancestral Khoesan genetic contribution (discussed in Chapter 2) that could possibly account for their shorter stature. The average LS of Khoesan males are 165.5cm and 149.5cm for females (*cited in* Eideh *et al*, 2012).

The genetic contributing factors and the additional environmental stressors, as mentioned above, may or may not have contributed to the significantly lower stature distribution for AD and MA in comparison to ED in the current study. Both AD and MA are significantly shorter (p<0.000; Table 4.3) than ED according to the current study's statistics. The data from the current study show that MA males and females are slightly shorter (p = 0.985 and 0.569, respectively) than their AD counterparts. This difference from the 2007 study may possibly be due to the different sources from which the conclusions were drawn. The 2007 anthropometric data is based on data collected from living individuals who were military personnel whereas the current study's findings were based on cadaveric-derived skeletal remains, *i.e*. deceased individuals. Although a number of young MA individuals were used in the current study, the lack of severe trauma (death was not by severe trauma/accident) may be indicative of extreme poverty (such as nutritional conditions) or communicable diseases (Global Burden of Diseases, Stats SA, 2017) with very limited nutrient input affecting growth. Therefore, the sample source and sample size may skew the data for either study.

What is evident is the significant stature (LS or TSH) difference between ED and MA's males (p<0.000) and females (p≤0.01). Based on the current study's osteological data both MA males and females have much lower minimum TSH_{Calc} values than their ED counterparts. This could merely be indicative of the sample source and size, but it has also been noted by Liebenberg *et al.* (2015) when they did a postcranial analysis of MA, AD and ED population groups. Therefore, stature regression formulae developed from ED cannot be used to estimate stature of MA as the coefficients, the constant and the SEE value of the regression formulae would not reflect the variation and stature ranges of this population group.

5.3 Sex-specific stature regression formulae

The global (Mall *et al.*, 2001; Duyar *et al*., 2006; Mahakkanukrauh *et al*., 2011; Ross and Manneschi, 2011; Béguelin, 2011; Cardosa, 2016; Mahakizadeh *et al*., 2016) and local (Lundy and Feldesman, 1987; Feldesman, 1990; Dayal *et al.*, 2008; Bidmos and Asala, 2005; Bidmos, 2006; Chibba and Bidmos; 2007; Ryan and Bidmos; 2007; Bidmos; 2008; Bidmos; 2009; Vance *et al*., 2010) trend in stature literature is to assign sex-specific regression formulae. These publications all show a significant difference between male and female stature ranges for specific population groups.

A number of researchers have shown that the significant sexual dimorphism difference in long bone lengths can be attributed to the different onset age of puberty between girls (±11 years of age) and boys (±13.5 years of age) (Humphrey, 1998; Scheuer, 2002; Wehkalampi *et al*., 2008; Rissech *et al*., 2008). As expected boys would thus have an extra two year growth period prior to the fusion of the epihyseal plates in the long bones. Not only does the different growth rate and duration thereof affect adult stature (Humphrey, 1998), but nutritional and physical expenditure influences contribute to the complex interaction of factors creating the sexual dimorphism phenomenon (Akachi and Canning, 2007; Albertyn, 2009; Balogun *et al*., 2015).

The current study showed a mean difference of 11.71cm – 12.26cm between the sexes (method dependent; Table 4.2). According to the current study's MA data (Appendix C, page 98) the male maximum TSH_{Calc} (derived from the Lundy and Feldesman (1987) regression formulae) value of 170.91cm is more than three times the female standard deviation of 5.87cm (*i.e*. statistical outlier) when compared to the female maximum TSH_{Calc} value of 151.33cm. This may be due to sample size and source, but it does indicate a very significant difference ($p<0.000$) between the sexes. Therefore the mean, standard deviation and coefficients of correlation which are based on the scale of stature ranges from a particular sex-group will be different for males and females. As a result, male regression formulae would reflect higher stature ranges than would be warranted for females, and female regression formulae would reflect much lower stature ranges than those warranted for males.

In addition Trotter and Gleser (1952) stated that the constant term reflects the mean length of the long bone. Thus, the constant term of a male long bone regression formula will be significantly ($p<0.000$) higher than that of the female regression formula which is clearly evident in Tables 3.4 and 3.5. Considering the effect of sex-specific stature ranges and the significant difference ($p<0.000$) between long bone lengths when formulating regression formulae, the use of a male regression formula may estimate a female's TSH much higher whereas use of a female regression formula may significantly underestimate TSH of a male. Albanese *et al.*'s (2016) results showed a "...slight to moderate tendency..." for male regression formulae to overestimate stature for females and female regression formulae to underestimate male stature.

Based on the current study's data for TSH_{Calc} and the individual long bone lengths for the three population groups, it may indicate the need to develop sex-specific regression formulae for each population group. This would decrease possible error when estimating stature of unknown skeletal remains in a forensic case, correctly narrowing the pool of possible victims/missing persons and assigning the correct biological profile to skeletal remains (Brues, 1958; Vance *et al*., 2010).

It should be noted though that without certain ascertainment of population affinity and/or sex it would be erroneous to use sex-specific or population-specific regression formulae (Albanese *et al*., 2012; Albanese *et al*., 2016a; Albanese *et al*., 2016b). In forensic cases where the skull and hip bones (os coxae) are missing it would be difficult to assign the skeletal remains of an individual to the correct sex-population group. It would therefore seem statistically and medico-legally prudent to use a generic regression formula (Feldesman and Fountain, 1996).

5.4 Long bone lengths and proportionality

5.4.1 Long bone lengths

Pearson (1899) stated that regression coefficients depend on the variability of the long bones and their correlation to stature. Furthermore, he said that every random, natural or artificial selection from a specific population group would change the variation, and therefore the correlation, of the variables. To counter this effect, he suggested obtaining a larger sample to incorporate as much individual variation in a population group and hence reduce changes to the formulae. In 1952 Trotter and Gleser echoed this sentiment when they stated "...formulae are most accurate when derived from an extensive number of subjects and are applied most suitably to the population from which they were derived."

Increasing the sample size of the six long bones changed the means and standard deviations of most of the AD and ED population groups with the exception of the AD humerus standard deviation. The MA population group had three (physiological tibia excluding the medial malleolus, humerus, radius) standard deviations (blue) unchanged although the minimum and/or maximum values changed for those particular long bones. The change in mean for these long bones where less than 1mm or none at all.

5.4.2 Proportionality of long bones to stature

Numerous skeletal elements contribute to total skeletal height, but the femur and tibia, either separate or combined, contribute a significant proportion to TSH. Feldesman and Fountain (1996) found that the femur contribute approximately 26.74% (mean for all groups combined) to stature. They found that "Blacks" (as they defined this group) had the highest femur to stature ratio percentage (27.13%) of all the groups and "Asians" the lowest (26.47%). Not many publications included data for the physiological tibial length and mean stature to enable a rough percentage contribution calculation. Lundy and Feldesman (1987) and Chibba and Bidmos (2007) focused on the linear relationship, *i.e*. regression coefficients and SEE values, between the tibia and stature whereas Steyn and Işcan (1997) focused on sexual dimorphism between various measurements of the femur and tibia.

As with Feldesman and Fountain (1996), the current study shows AD has a higher percentage contribution of the physiological femoral length to TSH than MA or ED. The physiological femoral length contributed approximately 29.96% to TSH for AD and 29.61% for both MA and ED. When TSH was estimated for male and female MA using an AD-derived sex-specific femoral length regression formula there was a significant difference ($p<0.000$) when either sexes' TSH_{Est} was compared to their TSH_{Calc}.

Furthermore, the current study indicates that physiological tibial length contributed 24.12% (MA), 24.83% (AD) and 23.80% (ED) to TSH. This may imply that an AD-derived tibia length regression formula may tend to underestimate TSH for ED, and MA, whereas an ED-derived tibia length regression formula may tend to overestimate TSH for AD and MA. It would appear to be erroneous to use a population-specific regression formula based on one population group to estimate TSH of a second population group when the percentage contribution of the specific bone length to TSH is different between the two population groups. The proportion differences would affect the coefficients of correlation (Pearson, 1899) and thus the slope of the linear regression.

In total the physiological femoral + tibial lengths contribute 53.73% for MA, 54.79% for AD and 53.41% for ED towards TSH in the current study. Based on the proportion contribution difference of the physiological femoral + tibial lengths to TSH between MA and AD it would indicate that such a particular AD-derived multivariate regression formula will incorrectly estimate TSH for MA. Although the proportion contributions are similar for ED and MA, the higher mean long bone lengths of ED will consequently render a higher constant value in the ED-derived regression formula which would not represent long bone length ranges for MA. All in all this highlights what Pearson (1899) and many others after him cautioned against: The use of regression formulae derived from one population group to estimate TSH or LS for a second population group.

5.5 Univariate regression formulae

Considering the TSH_{Calc} and mean long bone length differences between the different population groups it stands to reason why there would be significant inter-population differences when comparing TSH_{Calc} to TSH_{Est} for both AD- (Lundy and Feldesman, 1987) and ED-derived (Dayal *et al.*, 2008) univariate regression formulae. The mean long bone length data for each sex per population group were split and graphically represented, *i.e*. Appendices F.2 (page 102) and Appendix G.2 (page 103), to further elucidate the paired *t*-test statistics for the univariate regression formulae.

5.5.1 Females

Although AD's TSH_{Est} from the Lundy and Feldesman (1987) AD-derived regression formulae showed significant differences ($p<0.01$) compared to TSH_{Calc}, most of the mean differences fell within the SEE ranges except for the fibula regression formula. TSH_{Est} was overestimated from the fibular regression formula even after the inclusion of the SEE value. In terms of the Dayal *et al*. (2008) ED-derived regression formulae, AD TSH_{Est} showed significant differences from TSH_{Calc} with the inclusion of the SEE values. Although AD's distal long bone lengths show no significant difference from ED's (Table 4.5, page 44), AD's mean stature is significantly different ($p<0.000$) from ED's (Table 4.3, page 37). Therefore, the linear relationship (*i.e*. correlation coefficients) between the long bone mean length and the mean stature will be different for AD and ED. This may provide a viable explanation for AD's overestimated TSH (negative mean differences) results from the ED-derived distal long bone regression formulae.

To test the effect different coefficients may have when estimating stature from regression formulae first the mean tibial length of the AD population group was used to demonstrate the effect of different (AD- and ED-derived) coefficients and secondly an individual was randomly selected from the AD sample group to demonstrate the overall effect on TSH_{Est} for the same individual. The individual was selected from the original AD study sample and would therefore have adhered to the inclusion criteria of the study. First the manual multiplication of AD's mean tibial length of 36.16cm with the AD-derived coefficient of 2.485

resulted in 89.86cm whereas when multiplied with the ED-derived coefficient of 2.86 the result was 103.06cm. That's a difference of 13.2cm which is not compensated for by the difference between the two constants [55.968 (AD) – 47.52 (ED) = 8.448cm]. Secondly, the overall effect on one randomly selected African Descent individual from the study sample would therefore be:

- Tibia$_{Phys}$ length: 34.23cm (Lundy and Feldesman, 1987)

  TSH_{Est} = [**2.485** x 34.23cm] + $\underline{55.968}$ ± 3.056cm = 141.03cm ± 3.056cm
  TSH_{Calc} = 140.64cm
  Difference = $TSH_{Calc} – TSH_{Est}$ = -0.39cm ± 3.056cm

- Tibia$_{Malleolus}$ length: 35.5cm (Dayal *et al.*, 2008)

  TSH_{Est} = [**2.86** x 35.50cm] + $\underline{47.52}$ ± 2.59cm = 149.05cm ± 2.59cm
  TSH_{Calc} = 141.46cm
  Difference = $TSH_{Calc} – TSH_{Est}$ = -7.59cm ± 2.59cm (*i.e*. overestimated TSH)

If the same test is done for a female of European Descent (from the study sample) of nearly similar tibia lengths (Tibia$_{Phys}$ length = 34.30cm and Tibia$_{Malleolus}$ length = 35.45cm), the estimated AD-derived TSH is 141.204cm ± 3.056cm (TSH_{Calc} = 148.22cm; difference = 7.02cm ± 3.056cm; *i.e*. underestimated TSH for AD-derived tibia regression formula) and 148.91cm ± 2.59cm for the ED-derived TSH (TSH_{Calc} = 149.97cm; difference = 1.06cm ± 2.59cm), respectively. This shows the importance of the relationship between all the variables in a regression formula. Neither a higher coefficient (ED's 2.86 compared to AD's 2.485) nor a high constant (AD's 55.968cm compared to ED's 47.52cm) can compensate for another variable in the regression formula.

Similarly, the ED-derived female ulnar regression formula constant was tested against the much lower AD-derived female constant for the same regression formula. For the ulna regression formula the difference between the constants were 13.006cm [60.58 (ED) – 47.574 (AD)]. Again random selection of a female from the study sample's ED population group was used to test the effect different constant values would have on TSH_{Est}. The ED female's ulna length of 24.70cm was substituted into the AD-derived (Lundy and Feldesman, 1987) and then the ED-derived (Dayal *et al*., 2008) ulna regression formulae:

- ED ulna length: 24.70cm (Lundy and Feldesman, 1987)

  TSH_{Est} = [$\underline{3.827}$ x 24.70cm] + **47.574** ± 3.629cm = 142.10cm ± 3.629cm
  TSH_{Calc} = 152.20cm
  Difference = $TSH_{Calc} – TSH_{Est}$ = 10.1cm ± 3.629cm

- ED ulna length: 24.70cm (Dayal *et al*., 2008)

  TSH_{Est} = [$\underline{3.67}$ x 24.70cm] + **60.58** ± 3.54cm = 151.23cm ± 3.54cm
  TSH_{Calc} = 152.05cm
  Difference = $TSH_{Calc} – TSH_{Est}$ = 0.82cm ± 3.54cm

Note that the higher AD-derived formula coefficient of 3.827 (ED-derived coefficient is 3.67) does not compensate for the high constant of the ED-derived formula.

From the examples above it is evident that higher coefficients or constant terms from one population group can cause an overestimation (negative difference) or underestimation (positive difference) of TSH for another population group. Therefore recognizing the methodological consequences of differing proportions, mean lengths and the range of individual variation between population groups indicates the inappropriateness of using univariate regression formulae developed for a specific sex and/or population group on a different sex and/or population group.

Before discussing the female ED group in greater detail than the example used above, it must be stated that the sample size was very small (n = 13) due to exclusion criteria, time constraint and the unavailability (renovations) of the Pretoria Bone Collection at the University of Pretoria. The current study was therefore cognisant of the effect the small sample size would have on either the ANOVAs' or paired *t*-tests' *p*-values (as discussed in subsection 5.1).

ED's TSH_{Est} from the Dayal *et al*. (2008) ED-derived regression formulae performed exceptionally well compared to TSH_{Calc} as these regression formulae were developed within the last two decades (initial formulae were developed in 2003 during Dayal's Masters Degree research project). Without the inclusion of the SEE values, all TSH_{Est} showed no significant difference from TSH_{Calc}. Therefore it can be presupposed that the formulae continue to represent modern females of European Descent in South Africa.

Yet again the AD-derived formulae were used to test the effect of population-specific regression formulae on a different population group, *i.e*. ED, to clarify the importance of using population-specific regression formulae only for individuals that stem from the specific population group (Pearson, 1899) or a possible indication of temporal osteological change of one population group towards a second more established population group in similar ecogeographic locations (Cowgill *et al.*, 2012; Jantz and Meadows Jantz, 2017; Myburgh *et al.*, 2017).

In terms of the Lundy and Feldesman (1987) AD-derived regression formulae, ED's TSH_{Est} showed significant differences from their TSH_{Calc} with the inclusion of the SEE values for the tibial, ulnar and radial regression formulae. The high positive (+) mean differences indicate an underestimation of TSH. What is interesting is ED's TSH_{Est} result from the AD-derived humerus regression formula, and to a lesser extend TSH_{Est} from the femur regression formula. Both regression formulae produced no significant difference (p>0.05) for ED's TSH_{Est} (without taking the SEE values into account) compared to their TSH_{Calc}.

ED's female TSH_{Est} results from the AD-derived femur and humerus regression formulae were better than those produced for the AD female sample which were significant (p<0.000) without the inclusion of the SEE values. This may be due to the very small sample size for ED and thus limited range of individual variation. Or it may be due to changes in proportion for female ED. It would appear that the overall ED TSH_{Est} results from the AD-derived femur regression formula (p = 0.168, mean difference = -0.831) were better than those from the ED-derived formula (p = 0.065, mean difference = -1.171). Similarly the overall ED TSH_{Est} results from the AD-derived humerus regression formula (p = 0.475; mean difference = -0.1.757) displayed better comparative results to TSH_{Calc} than the ED-derived formula (p = 0.077, mean difference = -1.693).

The relatively close TSH_{Calc} association between MA and AD may be the reason most of the MA TSH_{Est} results from the AD-derived regression formulae, when compared to TSH_{Calc}, produced mean differences which fell within the SEE range. The best performing regression formula for estimating TSH for MA was the AD-derived tibial formula. In contrast to this AD's TSH_{Est} from the AD-derived tibia regression formula showed a significant difference (p<0.01) when compared to their TSH_{Calc}. In addition the tibial mean lengths of MA and AD show a significant difference (p<0.05). This may indicate that the MA population group's proportion contribution of the tibia length to TSH is more aligned with the AD sample used by Lundy and Feldesman (1987) whereas the current study's AD sample is not. With such contrasting results, it was decided to individually scrutinise the data. According to the paired *t*-test statistic the MA mean difference was 0.02 yet analysed individually almost a quarter (24.59%) of the individuals had a TSH_{Est} difference outside the SEE range (some as high as 6.19cm or -6.40cm). The same is true for the radial regression TSH_{Est} mean difference of 0.58. Nearly one in three (32.79%) individuals had a TSH_{Est} difference outside the SEE range (some as high as 7.6cm or -7.92cm) It was anticipated that the Dayal *et al*. (2008) regression formulae would show a significant difference (p<0.000) for MA TSH_{Est} considering the overall mean difference in TSH and long bone lengths between MA and ED. Each of the univariate mean differences fall outside the SEE range and these formulae generally overestimate (negative values) TSH for MA. Overall this would indicate that ED-derived regression formulae should not be used to estimate TSH for MA, and that the AD-derived regression formulae should be used with extreme caution. It is best to develop specific regression formulae for female MA as both

MA stature ranges, individual variation within the population and long bone length proportion to TSH is significantly different from female AD and ED.

5.5.2 Males

Most of the Lundy and Feldesman (1987) AD-derived regression formulae produced AD TSH_{Est} results within the specific SEE ranges, *i.e*. tibia, humerus, ulna and radius regression formulae. An in-depth analysis of AD's TSH_{Est} from the tibia regression formulae reveal nearly four in ten (38.24%) individuals had a TSH_{Est} difference from TSH_{Calc} as high as -5.15cm or 4.71cm. The individual (WITS, 4309) with a TSH_{Est} difference of 4.71cm had a 13th thoracic vertebrate (2.4cm; SEE is ±2.78) yet the same individual's TSH_{Est} from the fibula regression formula only differed by 0.78cm from TSH_{Calc}. Two other individuals (WITS, 4053 and 3891) with a 13th thoracic vertebrate (2.4cm and 2.3cm, respectively) had TSH_{Est} differences (0.73cm and 0.54cm, respectively) within the SEE range. In a separate case, an individual (WITS, 4280) with a 6th lumbar vertebrate (2.7cm) had a TSH_{Est} difference of -0.26cm from TSH_{Calc}. Based on the results of the current study it could indicate that a 13th thoracic or 6th lumbar vertebrate may not affect TSH_{Est} significantly. The femur and fibula regression formulae produced TSH_{Est} results outside the SEE ranges resulting in significant differences compared to TSH_{Calc}. Overall the AD-derived regression formulae overestimated (negative values) TSH and may be indicative of a shorter stature for male AD in a modern SA population. AD's TSH_{Est} from ED-derived regression formulae were significantly different and overestimated (negative mean differences) compared to TSH_{Calc}. This was anticipated based on mean stature and long bone length proportion differences between these two population groups. Although the humerus regression formula produced TSH_{Est} results with a mean difference of -1.507cm from TSH_{Calc} (p = 0.154) and thus not significant, three in ten (32.35%) individuals had a TSH_{Est} difference outside the SEE range (±3.76) with one as high as -10.56cm. One (WITS, 4309) of the eleven individuals who had a TSH_{Est} difference outside the SEE range had a 13th thoracic vertebrate (2.4cm), but the addition of this length to TSH_{Calc} did not compensate for the TSH_{Est} difference of 7.70cm. None of the other individuals with a 13th thoracic or 6th lumbar vertebrate had a TSH_{Est} difference outside the SEE range.

As anticipated, most ED-derived TSH_{Est} for male ED compared reasonably well with TSH_{Calc}. However, TSH_{Est} from the ED-derived femur and humerus regression formulae show a significant difference ($p<0.02$) compared to TSH_{Calc}. As with the females of ED population group, the males' TSH_{Est} from the AD-derived femur and humerus regression formulae show no significant difference ($p>0.05$) when compared to their TSH_{Calc}. For both population groups' femur regression formula this may be due to a similar percentage contribution of mean femur length to mean TSH between AD (29.98%) and ED (29.62%). Although the AD-derived femur regression formula generally overestimates AD's TSH, it estimates ED's TSH with reasonable accuracy whereas the ED-derived femur regression formula tends to underestimate ED's TSH. Similarly ED's TSH_{Est} from AD-derived humerus regression formula show no significant difference (p>0.05) compared to TSH_{Calc}, but on closer inspection one in three individuals has a TSH difference beyond the SEE range. For TSH_{Est} from the ED-derived humerus regression formula one in three ED are underestimated (positive values) by as much as 7.37cm. The initial thought was that the range of ED TSH_{Est} results may strongly be associated with the current study's relatively small sample size (n = 27) but comparing mean and standard deviation for each bone length with the 2003 study by Dayal (n = 98) revealed the highest difference between the two studies' mean lengths were 0.81cm with all the current study's standard deviation below 2.00. It is thus suggested that the femur and humerus regression formulae for South African males of European Descent be re-assessed.

As discussed for the females, male MA's TSH_{Est} from AD-derived regression formulae were anticipated to closely correlate with TSH_{Calc}. This proved not to be the case with most regression formulae. TSH_{Est} from the femur, tibia, fibula and humerus showed significant differences (p<0.05) when compared to TSH_{Calc}. In addition, TSH_{Est} from the ulna and radius regression formulae may show no significant difference (p>0.05) from TSH_{Calc} but on closer inspection one in three individuals had a TSH_{Est} difference greater than the SEE range. Some were as high as -8.46cm and 10.71cm for the ulna formula. For the radius formula differences were recorded as high as -9.34cm and 10.32cm. As noted for female MA, TSH of male MA should not be estimated using ED-derived regression formulae. Forensic anthropologists more often than not use the long bone lengths of the lower limb for stature estimation purposes. Based on the general results and the in-depth analysis of MA TSH_{Est} from the AD- and ED-derived regression formulae, it is herewith proposed that development of population-specific regression formulae for South African males of Mixed Ancestry is paramount.

In conclusion, regression formulae for South African males and females of African Descent should be amended to represent a possible temporal osteological change within the modern AD population group. Moreover, it is apparent that neither AD- nor ED-derived regression formulae should be used to estimate TSH for South African males and females of Mixed Ancestry.

5.6 Multivariate regression formulae

The proportion difference of skeletal elements' contribution to TSH between different population groups is compounded when using the combined heights of these specific elements in a multivariate regression formula (Jackson and Chen, 2004; Ben-Gal, 2005). As stated in subsection 5.1 the *p*-value is depended on sample size. When interpreting the *p*-value results from the paired *t*-test the current study was cognisant of the effect a small sample size may have on *p*-values. It was shown in the previous subsection that certain *p*-values which showed either no significant difference ($p>0.05$) or a significant difference ($p<0.05$) between two variables may be erroneous.

5.6.1 Females

Most of AD's TSH_{Est} from both AD- and ED-derived multivariate regression formulae performed poorly compared to TSH_{Calc}. Furthermore although AD's TSH_{Est} results from the AD-derived combined lumbar vertebrae (LV) height formula showed no significant difference ($p>0.05$) for the paired *t*-test individual scrutiny indicated that one in two individuals' TSH_{Est} was significantly different ($p<0.000$) from their TSH_{Calc}. Some differences were as high as 13.26cm and -10.27cm compared to TSH_{Calc}. AD's TSH_{Est} results from the ED-derived LV formula also showed no significant difference ($p>0.05$) with three in ten individuals' TSH_{Est} significantly different ($p<0.000$) from their TSH_{Calc}. Some differences were as high as 16.99cm overestimated.

A marginal difference of ≤1.29cm for the mean length of the lumbar column was observed between the three population groups (Appendix H a, page 104). But as a result of multivariate combinations with femur and/or tibia lengths (Appendix I a, page 105), differing percentage TSH contribution among the population groups resulted in significant differences ($p<0.000$) between TSH_{Calc} and TSH_{Est}. This is evident when the MA and AD *p*-values from the ED-derived univariate femur, multivariate combined lumbar column and multivariate femur-lumbar column formulae are compared to each other. Or if the mean distribution differences of femur length (Appendix F.2 a, page 102), tibia (Appendix F.2 c, page 102) and lumbar column (Appendix H a, page 104) are compared, the overall effect (Appendix I a, page 105) is very different. This overall effect translates into TSH_{Est} that compare well with TSH_{Calc} with no significant difference ($p>0.05$) recorded.

For ED's females the best performing ($p = 0.941$) multivariate regression formula was that of the combined [LV + F + T] height formula. All other TSH_{Est} results from the other ED-derived multivariate formulae also showed no significant difference ($p>0.05$) when compared to their TSH_{Calc}. These regression formulae were developed a decade ago and appear to still be applicable to this specific sex-population group. It could be said that the sample used by Dayal *et al*. (2008) contained most of the specimens used in the current study, but three of the individuals in the current study's sample were accessioned into the Raymond Dart Collection after 2007. This would be after Dayal's initial collection of data from 2002 to 2003. Another individual from the ED female sample was part of the UCT Bone Collection which Dayal did not sample as part of her research. All four individuals' TSH_{Est} from the [LV + F + T] formula showed no significant difference ($p>0.05$) compared to their TSH_{Calc} with differences less than 1.5cm.

5.6.2 Males

The *p*-values for AD males show no significant difference ($p>0.05$) between TSH_{Calc} and TSH_{Est} for the AD- and ED-derived combined lumbar vertebrae (LV) height regression formulae. This may be misleading. Individual scrutiny of the AD population group shows that for both AD- and ED-derived formulae four in ten individuals have a TSH_{Est} outside the respective SEE range. Some of AD's TSH_{Est} differences are as high as 13.16cm or -16.94cm for the AD-derived and 14.01cm or -15.4cm for the ED-derived formulae. What should also be noted are the high SEE values of ±5.28 (AD-derived) and ±5.54 (ED-derived). SEE ranges indicate the maximum difference allowed between an individual's actual stature and the estimated stature from population-specific regression formulae. An individual analysis of AD's TSH_{Est} differences for the ED-derived combined [LV + Femur (F)] height formula show that less than three in ten individuals have an estimated TSH outside the SEE range with the highest differences being 4.15cm or -4.21cm. The [LV + F] formula's TSH_{Est} differences are very small when compared to the [LV] formula's TSH_{Est} differences. This is evident when the overall mean differences between the formulae (Table 4.16) are considered. The remaining AD-derived formulae all show a significant difference ($p<0.000$) for AD's TSH_{Est} compared to TSH_{Calc}. This is testament to the caution many researchers have noted regarding small sample sizes (Hodge and Austin, 2004), and the need for continuous re-evaluation of regression formulae for a specific population group (Cole, 2003; Mahakkanukrauh *et al*., 2011). Hence this indicates a re-assessment of Lundy and Feldesman's (1987) AD-derived multivariate formulae.

For ED the results were a mixed bag. The AD-derived LV formulae produced no significant difference ($p>0.05$) for ED yet individual analysis showed that 18 (out of 27) individuals had positive TSH_{Est} differences (underestimation). The ED-derived [LV + F] formula clearly indicates the combined effect that the femur length and lumbar column height would have when used in a multivariate formula. Individually these formulae showed significant differences (*p*<0.017 and *p*<0.008, respectively) from TSH_{Calc} and consequently combined even more so (*p*<0.000). This is evidence that the combined effect of individual variables, *i.e*. multivariate regression formulae, can present a more realistic observation.

The multivariate TSH_{Est} results for Mixed Ancestry males provide an unambiguous observation of inappropriate use of regression formulae for a population group for which they were not developed from or for. As stated previously, proportion differences and stature ranges decidedly affect the coefficient, constant term and SEE values of regression formulae. The perceptible differences between the three population groups for all these factors are unmistakable when the means of either individual long bone lengths or the combined lengths of different skeletal elements are compared. The current study's analyses show the apparent importance of population-specific regression formulae for the modern South African population groups that were evaluated.

5.7 The effect of a 13th thoracic and/or 6th lumbar vertebrate on TSH_{Est}

The inclusion of individuals with a 13th thoracic and/or 6th lumbar vertebrate was allowed as these individuals form part of the variation within a population group. Overall the data showed that TSH_{Est} results from these individuals performed comparatively similar as those without the extra vertebrae.

None of the females in the current study's sample cohort had a 13th thoracic vertebrate and only two females of Mixed Ancestry had a 6th lumbar vertebrate. None of the ED males had either a 13th thoracic or 6th lumbar vertebrate. Five MA males had a 6th lumbar vertebrate, but none had a 13th thoracic vertebrate. Although none of the AD females had any extra vertebrae, three males had a 13th thoracic vertebrate and a separate male had a 6th lumbar vertebrate.

For the MA females, TSH_{Est} from the long bone regression formulae produced similar results as those without the extra vertebrate for both AD- and ED-derived formulae. The TSH_{Est} results from both AD- and ED-derived LV regression formula were highly overestimated. Differences were as high as -12.39cm for the ED-derived and -17.87cm for the AD-derived LV formula. The mean difference when those individuals are excluded is 0.07cm and neither represents the maximum value. The standard deviation changed from 1.079 (included) to 1.012 (excluded). Therefore the inclusion of these individuals produced no significant difference (*p*>0.05) in the overall statistical results.

The five MA males with a 6th lumbar vertebrate represented the maximum values for the population group. The maximum value was reduced from 17.38cm to 14.50cm yet the mean difference was 0.22cm and the standard deviation difference was 0.32cm. Yet again this shows no significant difference (*p*>0.05) when these individuals were included. What is noticeable is the generally higher overestimation (-14.68cm for AD-derived or -11.8cm for ED-derived) of TSH_{Est} from both LV formulae. This is very significantly different (*p*<0.000) to any of the long bone regression formulae. These differences stem from higher stature ranges for both AD and ED and the effect this has on regression formulae. The increase in lumbar column height 'signifies' a taller individual to the regression formula and thus produces a taller TSH_{Est}. Excluding the single AD male there is a mean difference of 0.07cm and a standard deviation of 0.09. Again this shows no significant difference (*p*>0.05) with the inclusion of this individual.

Excluding the three AD males with a 13th thoracic vertebrate changed the mean by 0.86cm and 0.24 for the standard deviation. Generally these individuals' TSH_{Est} is underestimated, but mostly these differences from TSH_{Calc} fall with the SEE range. Those differences that are outside the SEE range are positive, *i.e*. underestimated TSH, and all of them are less than individuals without a 13th thoracic vertebrate.

Therefore the inclusion of individuals with a 13th thoracic or 6th lumbar vertebrate does not significantly alter the statistical results. If the number of individuals with the extra vertebrae were significantly more, it may have. But then again it would be a significant feature of the population group if many more individuals had extra vertebrae and should be incorporated into the regression formulae.

5.8 Estimated living stature from the generic femur/stature ratio

The estimated living stature (LS) from the generic femur/stature ratio (LSr) were very significantly different (*p*<0.000) from the calculated living stature (LSwA) and generally overestimated LS, *i.e*. negative mean differences, for all population groups.

For both males and females with a maximum femur length that was greater than 40.0cm the generic ratio overestimated living stature. For maximum femur lengths less than 35.0cm LSr was more often than not underestimated by 5.0cm or more. For maximum femur lengths that were greater than 49.0cm LSr was highly overestimated. In the current study these individuals were male. The overestimated LSr for these males were as high as 15.58cm to 21.06cm. It would therefore appear that living statures from maximum femur lengths either smaller than 35.0cm or greater than 40.0cm would be estimated erroneously.

In the current study only one MA and one AD male had a maximum femur length less than 40.0cm. If this is the general trend for males as a whole, it would indicate that the generic femur/stature ratio will overestimate the living stature of these individuals.

Females tend to have shorter maximum femur lengths than males and in the current study most females tended to have maximum femur lengths between 35.0cm and 40.0cm with a few greater than 40cm. In the current study less than 30% of AD, 20% of MA and 10% of ED females' living stature were overestimated by more than 10.0cm. This may due to the sample sizes for these population groups, but it does appear that more often than not the generic femur/stature ratio estimates females' living stature within 10.0cm or less from their calculated living stature.

According to the current study's data individuals (all male) with a maximum femur length exceeding 50cm vary between what Steyn and Smith (2007) would consider medium to tall height (living stature). Formicola (1993) found that the femur/stature ratio tended to overestimate living stature for what they considered either very short or tall individuals. The current study show similar results (as indicated above) to their conclusion.

It would therefore be advisable to use sex- and/or population-specific regression formulae for individuals for whom either of these attributes can be ascertained with certainty. If not, it would be more prudent to use Feldesman and Fountain's (1996) generic regression formula.

5.9 Factors that may influence the formulation and use of stature regression formulae

Various factors may influence the variables used in formulating stature regression formulae. Differing methodology and temporal changes in limb proportion may amount to differences in the mean, standard deviations and coefficients of correlation used to derive the regression formulae.

One of the methodology differences in Lundy and Feldesman (1987) is the use of the physiological tibial length for total skeletal height (TSH) calculation. The authors specify that they used the full anatomical method as described by Fully (1956), but instead of using the maximum tibial length which includes the medial malleolus and excludes the intercondylar tubercles (or intercondylar eminence) they used the physiological tibial length which excludes both these features. The lateral surface of the medial malleolus articulates with the talar body. If the medial malleolus does not directly contribute to stature, which it does not, it should not be included in the calculation of TSH. This may possibly have been the rationale of Lundy and Feldesman (1987) for using the physiological tibial length and not the maximum tibial length.

Due to this difference it was decided to run statistical analysis on all paired variations for tibia lengths to find out if it would make a difference on the results obtain for the current study. This included the calculated total skeletal height (TSH_{Calc}) which (1) excluded the medial malleolus and (2) included the medial malleolus. Both would exclude the intercondylar tubercles. Next TSH_{Est} from Lundy and Feldesman's (1987) tibia regression formula were calculated using (i) the physiological tibial length and (ii) the maximum tibial length as described above. As the regression formula was derived from South Africans of African Descent (AD), these were the results that were deemed more informative than the results for the other two population groups. For AD's females the mean difference for the 1-i pair was -1.70cm ($p<0.01$) and for the 2-ii pair it was -3.14cm ($p<0.000$). For AD's males the mean difference for the 1-i pair was -0.87cm ($p>0.05$) and for the 2-ii pair it was -1.83cm ($p<0.01$). The results from the 2-i pair were rather surprising. Comparing the TSH_{Calc} which included the medial malleolus (which would be greater than without it) and the TSH_{Est} result when the physiological tibial length (which is shorter than the maximum length) was used, no significant difference ($p>0.05$) was found between the two variables for both sexes. The mean difference for the 2-i pair (-0.60cm) is approximately 1.1cm less than for the 1-i pair (-1.70cm) which is very similar to the mean difference between AD's $Tibia_{Phys}$ and $Tibia_{Malleolus}$ of 1.08cm (Table 4.5). This may indicate that a greater TSH_{Calc} performed better with a shorter tibia length. This may therefore translate to a possible change in the tibia length's percentage contribution to TSH for AD.

Methodology and measurement descriptions must therefore always be clearly defined in publications which in turn will aid new and future researchers to reproduce results or compare current results to previous results from stature regression formulae (Smith and Boaks, 2014). It is thus important to standardise procedures and methodology used by different researchers and in turn aid correct interpretation of their results.

Limb proportion to stature has been shown to vary between population groups (Feldesman and Fountain, 1996; Raxter *et al*., 2008). Most forensic anthropologists use the femur, when available, to estimate stature. This isn't always possible with incomplete, fragmentary or burned human remains. Pearson (1899) noted from his results that a regression formula based on the humerus performed better than a regression formula based on the tibia. This is interesting considering that the humerus does not contribute to stature whereas the tibia does. A possible reason for this may be since the tibia's growth and development is more susceptible to nutritional and environmental stressors than that of the humerus' it is more likely to display short-term temporal changes, *i.e*. secular changes, compared to the humerus (Mahakkanukrauh *et al*., 2011; Bogin, 2012).

Interestingly Albanese *et al*. (2016) found that the sex-specific tibia regression formula performed better than the humerus regression formula whereas is was the opposite for the generic formula. The authors found that for the multivariate approach a combination of the femur, humerus and tibia performed best for both sex-specific and generic regression formulae. Therefore the general idea would be to use a multivariate approach when possible as these regression formulae will incorporate a multitude of diverse variation within a population group (Liebenberg *et al.*, 2015). In addition the multivariate regression formulae should not merely combine various long bone heights, but rather incorporate each bone's coefficients of correlation to stature (Pearson, 1899: 182; Bidmos, 2008: 131.e3 – e4, Tables 3 - 5; Bidmos, 2009: 507, Table 3).

However it should be noted that researchers using a multivariate approach caution that a multitude of measurements do not necessary render a better performing regression formula. It is best to use two to four measurements (from the same bone or various bones) that show the best correlation to stature and, importantly, to each other. This would reduce the standard error of estimate (SEE) used for such a multivariate approach.

Standard error of estimates represent the difference between what the actual (or calculated) value of a variable, such as stature, is and what it is predicted to be by the regression formula. Therefore the lower the SEE value of a regression formula is, the better the prediction by the regression formula should be and thus the greater the accuracy of said formula (Bidmos, 2008). Hence, when the mean difference between the calculated and estimated TSH of a sex and/or population group falls within the SEE range the regression formula can be considered a good estimator of stature for that specific group.

Note the mean difference between TSH_{Calc} and TSH_{Est} from one (females, Table 4.9) or both (males, Table 4.11) sex-specific humerus regression formulae fall within the SEE range for all three South African population groups. This would strongly suggest that a South African generic sex-specific humerus regression formula can be developed and then used when forensic anthropologists are able to assign sex, but cannot ascertain population affinity with certainty for unidentified human remains. Based on the findings by Steyn and İşcan (1999) the humerus could be used to determine sex with a 95% accuracy for AD ('black') and a 96% accuracy for ED ('white'). The current study therefore strongly advocate the development of a South African generic yet sex-specific humerus stature regression formula when (1) the population affinity of unidentified human remains cannot be ascertained and (2) the femur and/or tibia is not available.

Although the SEE values of the Lundy and Feldesman (1987) female femur (2.789) and humerus (3.629) are relatively high, the mean differences for all three population groups fall within the SEE range. Hence, a possible generic multivariate regression formula incorporating the femur and humerus lengths could be developed for South African females. How this would compare to a univariate generic female humerus regression formula, as suggested above, could be the focus of future stature regression development research.

As stated previously a multivariate approach with a few well correlated variables may provide a regression formula that estimates stature more accurate than a single length measurement of a specific bone. Note that MA and AD's mean difference results for the Dayal *et al*. (2008) female univariate femur [F] regression formula lies outside the SEE range, but their mean difference results from the combined lumbar column [LV] regression formula fall well within the high SEE (±5.21cm) range. Combined, the [LV + F] mean difference results for these two population groups are even better. Hence, when compared with the ED group, another possible generic multivariate regression formula seems possible with even greater accuracy if the humerus is included in the combination. The same generic multivariate combination of femur, humerus and lumbar column also appears to be a strong possibility for South African males.

When developing regression formulae, whether a univariate or multivariate approach is followed, the actual stature is required. Most researchers either obtain this data from records or must manually calculate it. When dealing with a living population, or cadavers, measuring the actual stature of the individual is relatively straightforward. The use of skeletal material does however present a problem.

First, the source of the human remains limit the range of statures found within a specific population group as it may only represent certain factions of the population group. For example most of the data for MA in the current study represent a lower socio-economic faction of this population group (as discussed in subsection 3.1, page 17). The data for ED mainly represent individuals of middle age to the senior phase. Therefore the range of statures that would be incorporated in the regression formulae may not necessarily represent those individuals in a higher socio-economic bracket or those that may have support structures for burial. Yet considering the purpose of regression formulae, it may be that for MA and AD this is the portion of the population most likely to require forensic identification.

Second, the condition of the skeletal material may reduce the available sample material for research. Skeletal remains had to be excluded from the current study due to pathology based on disease and/or age-related factors, traumatic injuries that were not subjected to adequate medical care or missing skeletal elements required for the calculation of total skeletal height. Pearson (1899) noted that 50 – 100 individuals were sufficient to develop regression formulae from, but it was best to have a few hundred individuals. Feldesman *et al.* (1990) stated that their findings were based on 13 149 'contemporary humans' from 55 population sample groups. Steyn and Smith (2007) noted that their findings were based on 3 415 military personnel. The research findings of either of these authors are different to the current study's findings. This may be due to a few discrepancies between the current study's and the mentioned researchers' sourced data. One, the current study's findings are based on skeletal material whereas Steyn and Smith's (2007) is based on a living population in the military. The question here would be whether the sample faction represented by each population group in the findings are the same. Two, the current study measured each individual's skeletal elements and manually calculated total skeletal height for each individual whereas Feldesman *et al*. (1990) used the mean values from 55 various publications. The question here would be whether each of the 55 publications' authors followed the same measurement procedure and therefore the data could be combined. The data used by Feldesman *et al*. (1990) included South Africans, but as the authors themselves conclude in their abstract "South African blacks ...()... predictions from the femur/stature ratio are less accurate than from the appropriate regression equation...". Based on these observations it is cautiously suggested that the different findings of the current study may therefore stem from the points highlighted.

Chapter 6: Conclusion

The statistical results indicate that the population-specific regression formulae of Lundy and Feldesman (1987) which were derived from South Africans of African Descent should be re-assessed for a more contemporary population group. The results from the Dayal *et al*. (2008) regression formulae indicate that the formulae are still relevant for South Africans of European Descent. In general, the use of either of these population-specific regression formulae on a different population group show a significant difference of the estimated total skeletal height compared to the calculated height.

The current study's data showed no significant difference of total skeletal heights between Mixed Ancestry and African Descent individuals yet most of the regression formulae's results indicated that African Descent-derived regression formulae may not incorporate the range of stature variation or percentage proportion contribution found within the Mixed Ancestry population group. It is therefore recommended that regression formulae are developed for this population group in South Africa. At present a team of researchers at the University of Pretoria (UP) in collaboration with other South African universities have been and are collecting data for South Africans of African Descent, Mixed Ancestry and European Descent which have been and are being incorporated into the South African database (SADB) in FORDISC 3.0. (FD3). This data is designed to be used for ancestry estimation, but may also be used for stature estimation in the future. Stature research collaboration between UCT, SUN and UP would be advantages as pooled resources and knowledge would expedite the process of developing regression formulae for South Africans of Mixed Ancestry and its availability to all parties that may have need of such formulae.

Furthermore the current study shows that use of Feldesman *et al*.'s (1990) generic femur/stature ratio provide incorrect estimations of living stature especially for individuals with maximum femur lengths greater than 50cm and for whom population affinity and sex can be ascertained with certainty. Although some physical/forensic anthropologists in the field prefer to use this generic ratio due to time constraints, medico-legal investigations require scientifically robust forensic methodology and procedures to allow scientific evidence in a court case according to Act 37 of 2013: Criminal Law (Forensic Procedures) Amendment Act, Republic of South Africa.

The current study highly recommends the development of a possible sex-specific humerus regression formula and a sex-specific multivariate formula that includes the femur, humerus and tibia for South Africans when population affinity cannot be ascertained with certainty for unidentified human remains.

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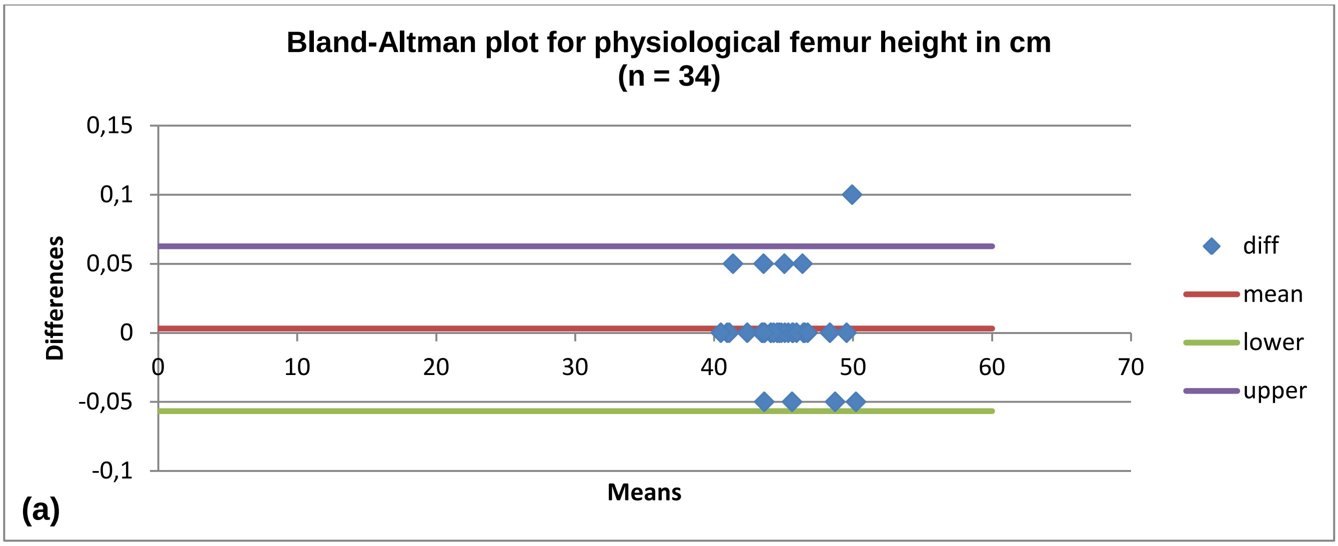
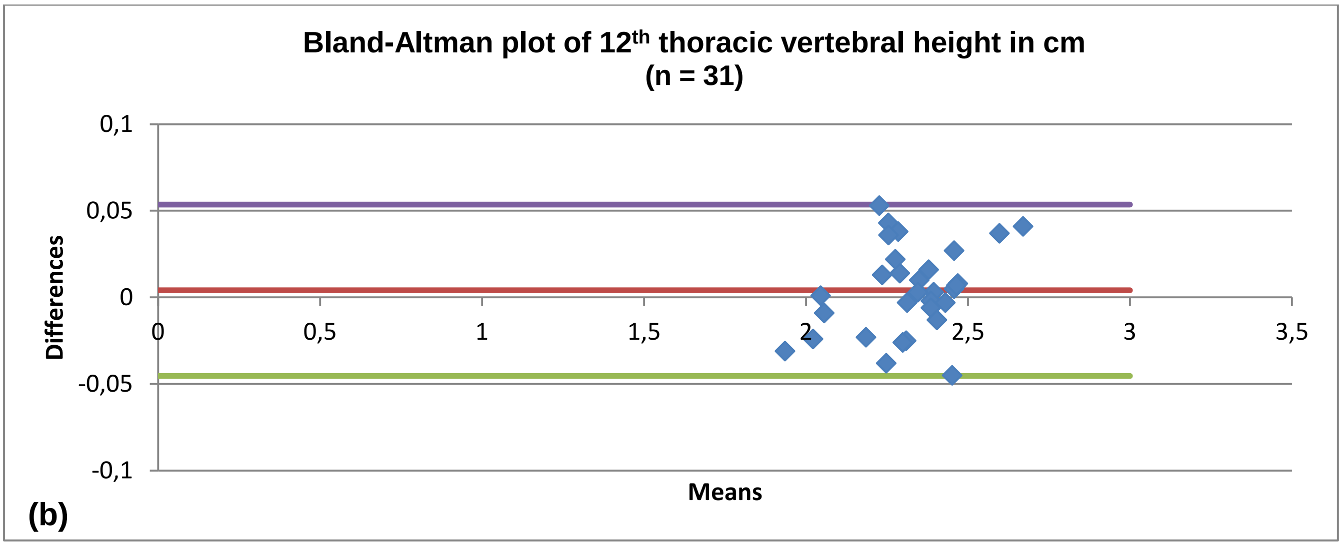
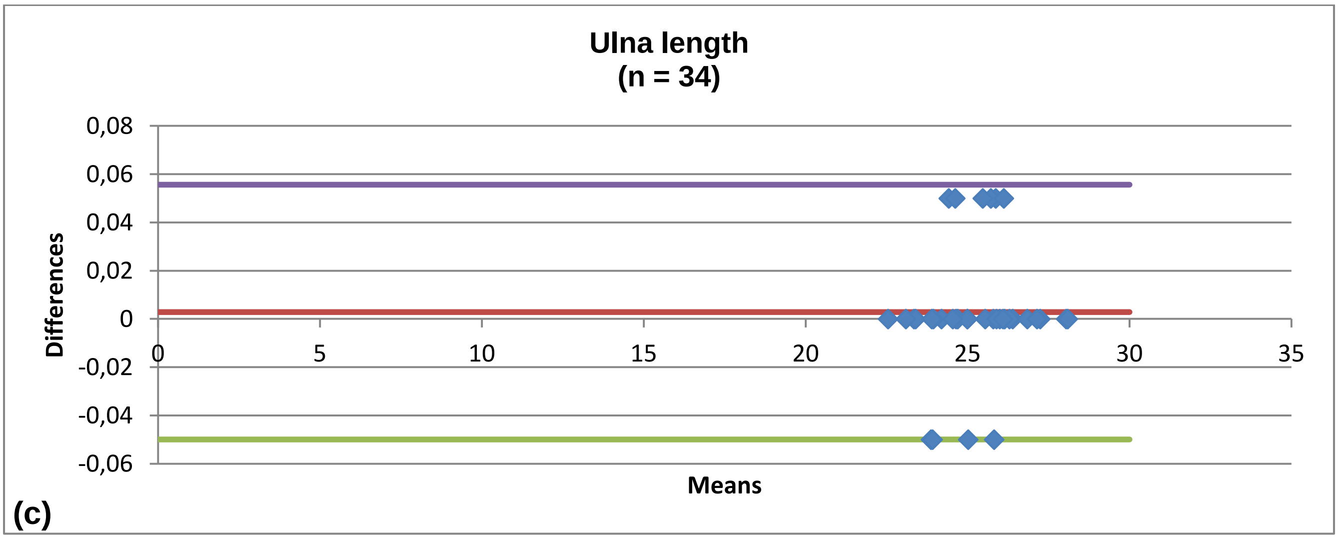
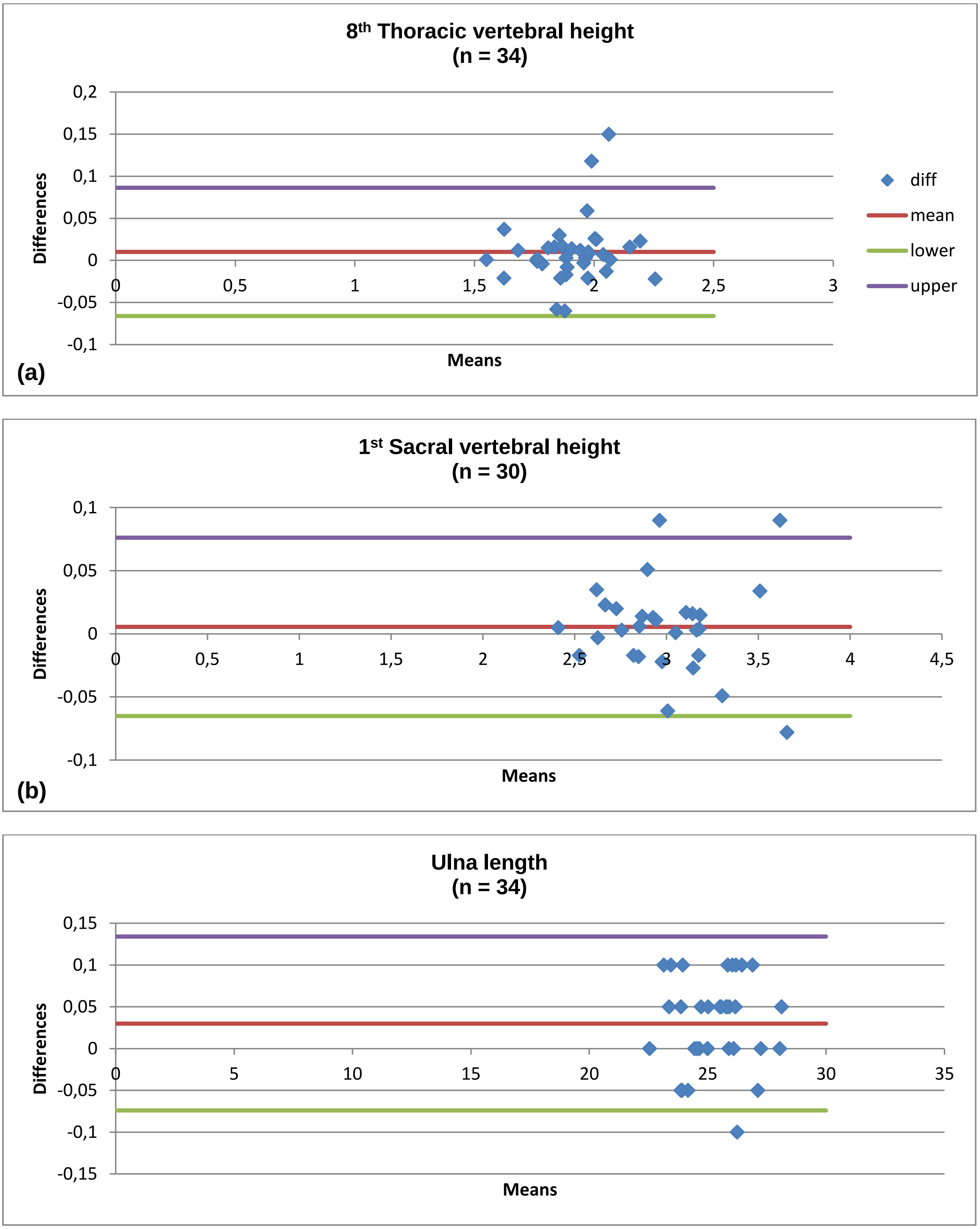
Appendices







Appendix A.1: **Bland Altman plots for intra-observer skeletal measurements**



Appendix A.2: **Bland Altman plots for inter-observer skeletal measurements**

```
Stem width:   10
Each leaf:    1 case(s)

ED: Females: Frequency    Stem &  Leaf

                 1,00     Extremes    (=<131)
                 1,00      13 .  5
                 3,00      14 .  034
                 3,00      14 .  578
                 5,00      15 .  12223

                                                    Combined AD:  Frequency     Stem &  Leaf
                                                                    1,00     Extremes    (=<131)
ED: Males:       2,00      14 .  79                                 1,00        13 .  5
                 7,00      15 .  0002234                             3,00       14 .  034
                 4,00      15 .  5789                                5,00       14 .  57789
                12,00      16 .  000222233334                       12,00       15 .  000122222334
                 2,00      16 .  79                                  4,00       15 .  5789
                                                                    12,00       16 .  000222233334
                                                                     2,00       16 .  79
```

Appendix B: Stem and leaf plots for the calculated total skeletal height of male and female South Africans of European Descent (ED)

Appendix C: Descriptive statistics of the calculated total skeletal height (TSH_{Calc}) for each sex per population group based on the methods described in the two publications

Population group	Sex	TSH_{Calc}	N	Min value	Max value	Mean statistics		Std. Dev.
						Mean	Std. Error	
MA	F	TSH_{Calc} (1)	61	123.83	151.33	138.91	0.75	5.87
		TSH_{Calc} (2)	61	124.77	150.55	139.96	0.75	5.85
	M	TSH_{Calc} (1)	62	135.00	170.91	149.96	0.95	7.45
		TSH_{Calc} (2)	62	136.98	173.15	151.35	0.95	7.47
AD	F	TSH_{Calc} (1)	32	130.99	153.72	140.48	1.10	6.22
		TSH_{Calc} (2)	32	132.59	155.74	141.57	1.13	6.38
	M	TSH_{Calc} (1)	34	131.70	166.76	150.49	1.38	8.04
		TSH_{Calc} (2)	34	133.49	168.98	152.25	1.39	8.10
ED	F	TSH_{Calc} (1)	13	130.87	153.45	146.04	1.93	6.97
		TSH_{Calc} (2)	13	131.93	155.62	147.41	1.91	6.89
	M	TSH_{Calc} (1)	27	147.18	169.29	158.45	1.15	5.97
		TSH_{Calc} (2)	27	149.49	172.96	160.57	1.19	6.17

Note: MA = South Africans of Mixed Ancestry
AD = South Africans of African Descent
ED = South Africans of European Descent

F = Female
M = Male

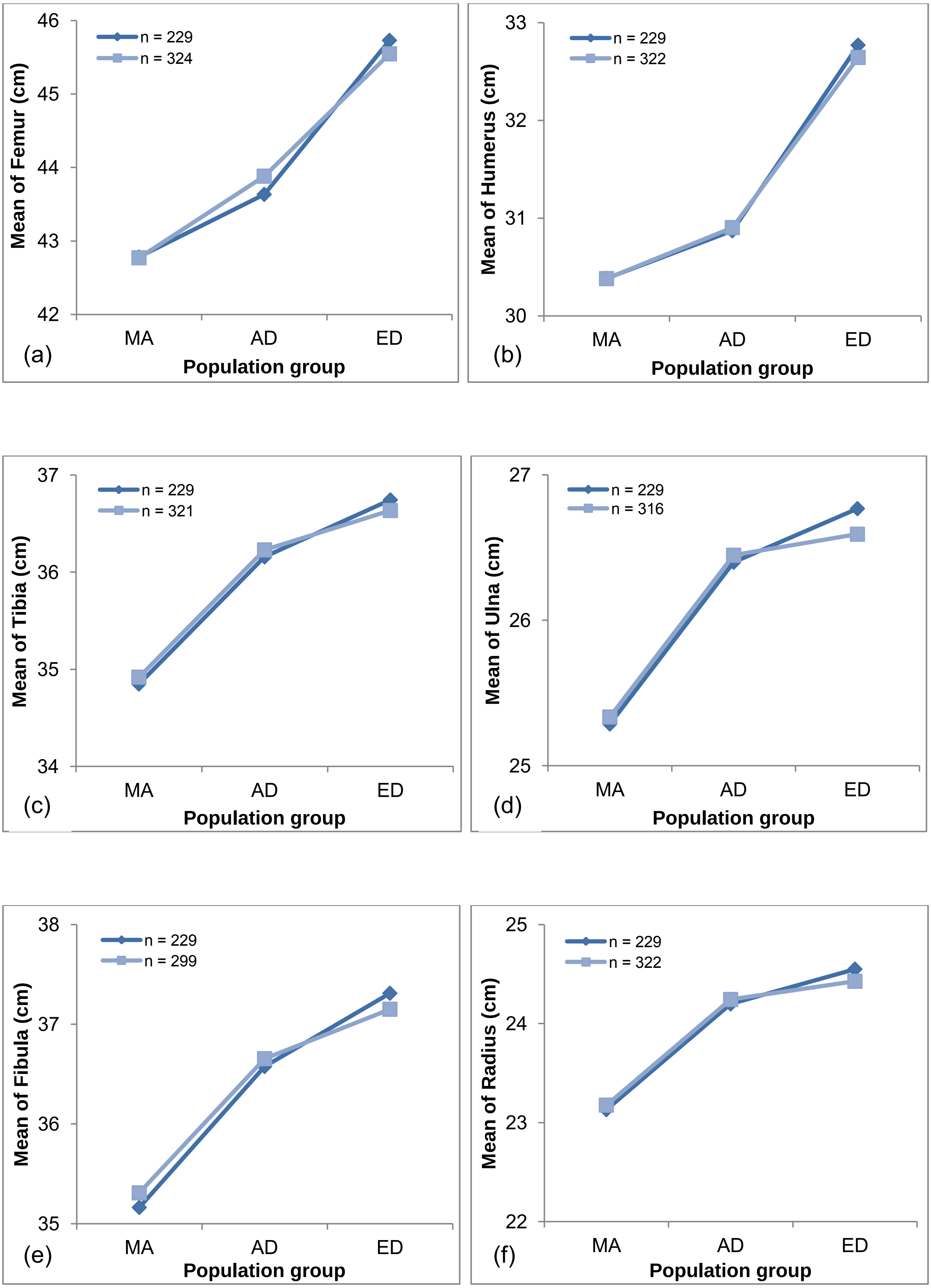
(1) Lundy and Feldesman (1987)
(2) Dayal *et al*. (2008)

Appendix D: Descriptive statistics of each long bone per sex and per population group

Long bone	**Sex**							**Population Group**										
	Female			**Male**			***p*-value**	**MA**			**AD**			**ED**			***p*-value**
	N	Mean	Std. Dev	N	Mean	Std. Dev		N	Mean	Std. Dev	N	Mean	Std. Dev	N	Mean	Std. Dev	
Femur	106	41.49	2.44	123	45.24	2.75	0.000	123	42.78	2.95	66	43.63	3.24	40	45.73	2.77	0.000
Tibia (1)	106	33.86	2.28	123	36.97	2.53	0.000	123	34.85	2.60	66	36.16	2.95	40	36.75	2.61	0.000
Tibia (2)	106	34.77	2.30	123	38.02	2.59	0.000	123	35.83	2.64	66	37.24	3.01	40	37.80	2.65	0.000
Fibula	100	34.22	2.24	119	37.38	2.54	0.000	118	35.16	2.51	64	36.58	2.96	37	37.31	2.67	0.000
Humerus	106	29.35	1.92	122	32.21	2.04	0.000	122	30.38	2.24	66	30.87	2.30	40	32.77	2.31	0.000
Ulna	102	23.92	1.57	122	26.52	1.63	0.000	118	24.79	1.79	66	25.90	2.01	40	26.27	2.15	0.000
Radius	104	22.28	1.44	123	24.85	1.56	0.000	121	23.13	1.80	66	24.20	2.02	40	24.55	1.97	0.000

Note: MA = South Africans of Mixed Ancestry
AD = South Africans of African Descent
ED = South Africans of European Descent

(1) Lundy and Feldesman (1987)
(2) Dayal *et al*. (2008)



Appendix E.1: **Mean plots of long bone measurements for each of the three population groups**

Appendix E.2: Descriptive statistics of long bone lengths for the TSH$_{Calc}$ sample cohort versus an increased sample size which includes the TSH$_{Calc}$ sample cohort

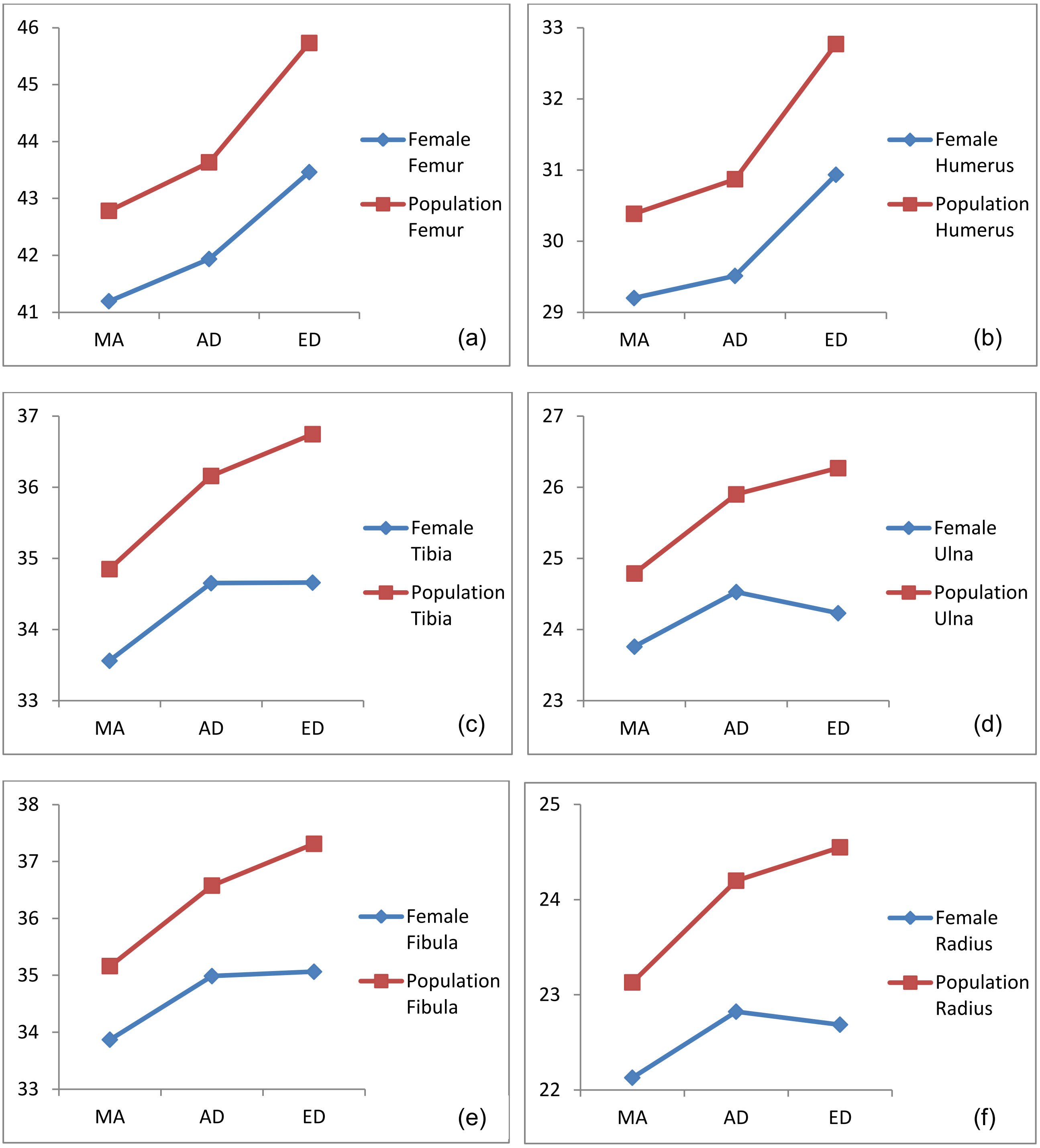
Long bone	Population group	TSH$_{Calc}$ sample cohort (n = 229)					Increased sample size incl. TSH$_{Calc}$ sample cohort				
		N	Mean	Std. Dev.	Min	Max	N	Mean	Std. Dev.	Min	Max
Femur	MA	123	42.78	2.95	36.40	52.70	189	42.77	2.84	35.08	52.70
	AD	66	43.63	3.24	36.55	52.70	87	43.88	3.18	36.55	52.70
	ED	40	45.73	2.77	37.30	50.13	48	45.55	2.66	37.30	50.13
Tibia (1)	MA	123	34.85	2.60	29.35	42.58	186	34.92	2.60	27.48	43.38
	AD	66	36.16	2.95	30.00	42.93	87	36.23	2.84	30.00	42.93
	ED	40	36.75	2.61	29.88	42.00	48	36.64	2.50	29.88	42.00
Tibia (2)	MA	123	35.83	2.64	30.23	43.93	185	35.88	2.67	28.55	44.63
	AD	66	37.24	3.01	31.13	44.23	87	37.34	2.92	31.13	44.23
	ED	40	37.80	2.65	30.68	43.33	47	37.61	2.57	30.68	43.33
Fibula	MA	118	35.16	2.51	29.08	42.55	173	35.31	2.57	27.85	42.68
	AD	64	36.58	2.96	30.75	42.80	81	36.65	2.97	28.35	42.80
	ED	37	37.31	2.67	30.85	43.70	45	37.15	2.52	30.85	43.70
Humerus	MA	122	30.38	2.24	25.33	36.45	187	30.38	2.24	24.55	36.45
	AD	66	30.87	2.30	24.90	36.60	87	30.90	2.30	24.10	36.60
	ED	40	32.77	2.31	25.83	36.80	48	32.64	2.21	25.83	36.80
Ulna	MA	118	24.79	1.79	20.35	29.55	181	24.84	1.83	19.13	30.15
	AD	66	25.90	2.01	21.50	29.65	87	25.95	1.97	21.50	29.65
	ED	40	26.27	2.15	21.03	30.05	48	26.09	2.03	21.03	30.05
Radius	MA	121	23.13	1.80	18.98	28.05	187	23.18	1.80	18.70	28.05
	AD	66	24.20	2.02	19.80	27.55	87	24.24	1.91	19.80	27.55
	ED	40	24.55	1.97	19.15	27.65	48	24.43	1.88	19.15	27.65

Note: MA = South Africans of Mixed Ancestry
AD = South Africans of African Descent
ED = South Africans of European Descent

(1) Lundy and Feldesman (1987)
(2) Dayal *et al.* (2008)

Appendix F.1: Mean long bone length of females per population group

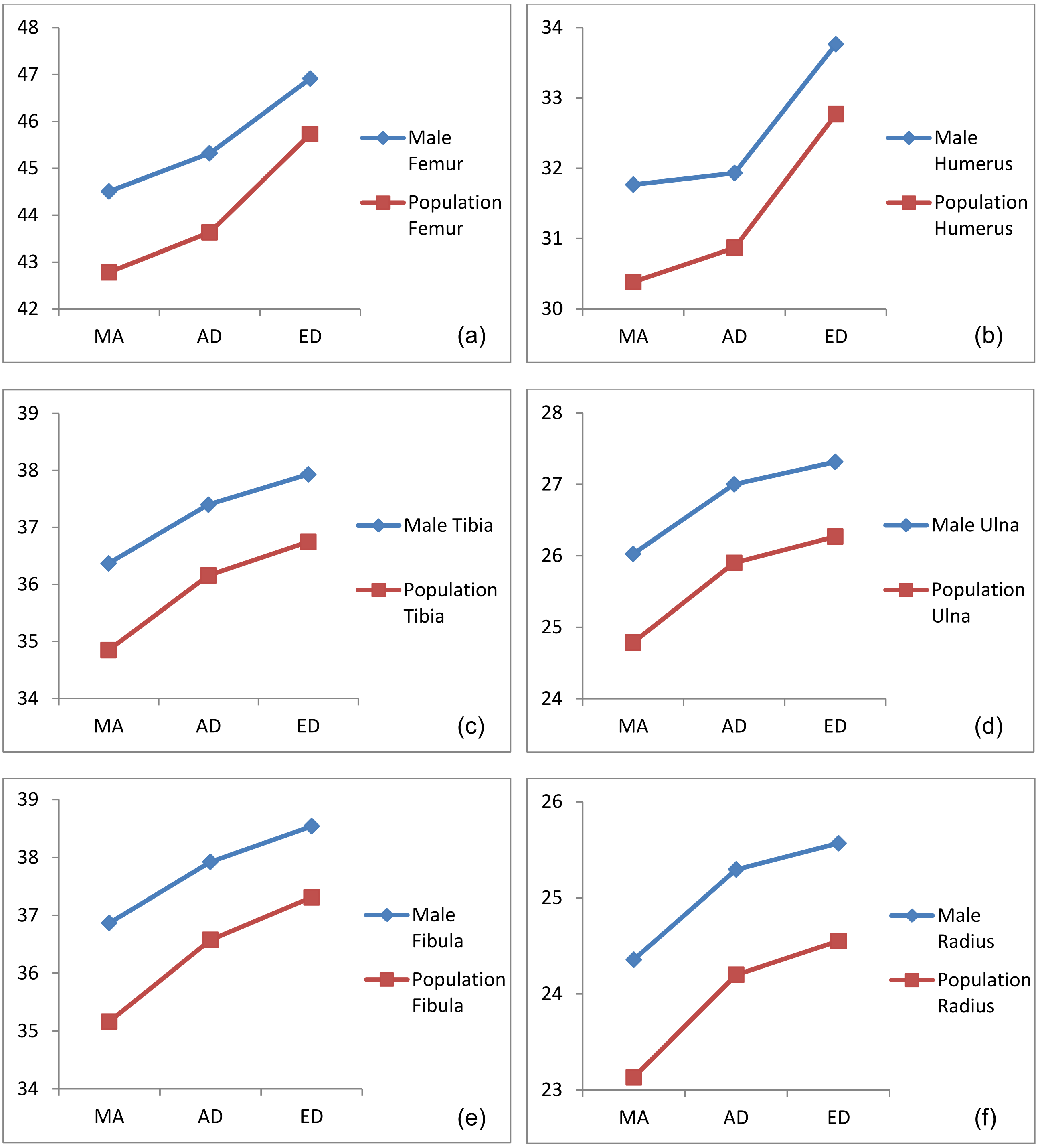
Sex-population	Statistic	Femur	Tibia	Fibula	Humerus	Ulna	Radius
MA Female	Mean	41.19	33.56	33.87	29.20	23.76	22.13
	N	99	96	90	101	95	99
AD Female	Mean	41.94	34.65	34.99	29.51	24.53	22.82
	N	37	37	35	37	37	37
ED Female	Mean	43.46	34.66	35.06	30.93	24.23	22.69
	N	19	19	18	19	19	19



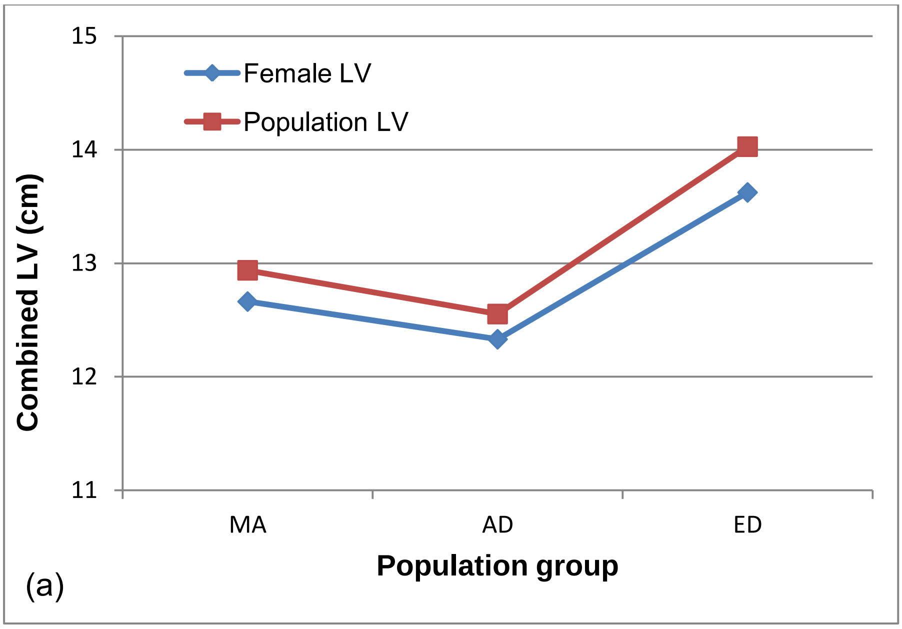
Appendix F.2: **Comparison of mean long bone lengths (cm) for females per population group versus total population group combined**

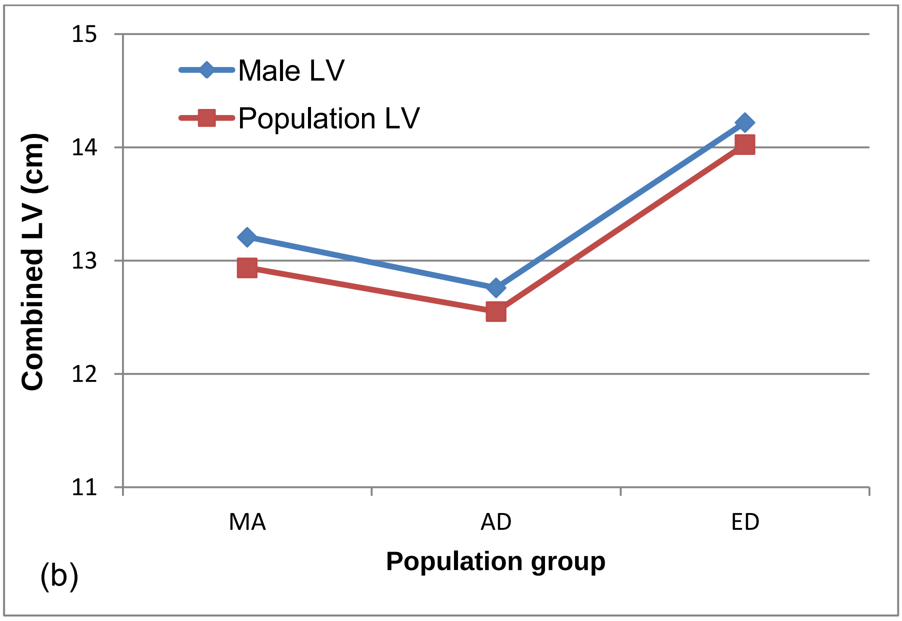
Appendix G.1: Mean long bone length of males per population group

Sex-population	Statistic	Femur	Tibia	Fibula	Humerus	Ulna	Radius
MA Male	Mean	44.51	36.37	36.87	31.77	26.03	24.35
	N	90	90	83	86	86	88
AD Male	Mean	45.32	37.40	37.92	31.93	27.00	25.29
	N	50	50	46	50	50	50
ED Male	Mean	46.91	37.93	38.54	33.76	27.31	25.57
	N	29	29	27	29	29	29

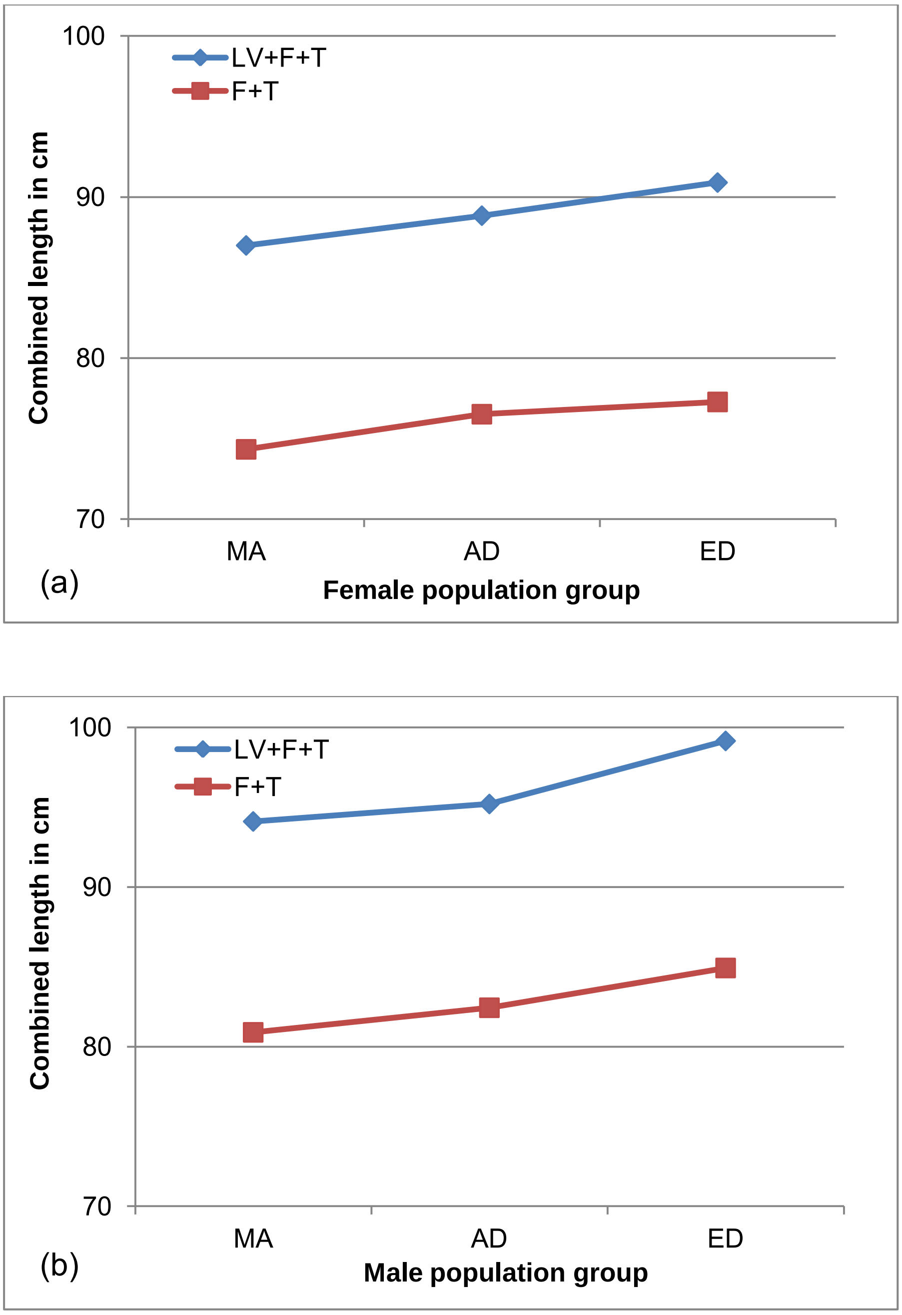


Appendix G.2: Comparison of mean long bone lengths (cm) for males per population group versus total population group combined





Appendix H: Comparison of the mean combined lumbar vertebrae (LV) height in cm for (a) females and (b) males per population group versus total population group combined



Appendix I: **Comparison of the mean multivariate combined lengths for (a) females and (b) males per population group**

Appendix J: Paired *t*-test comparing the calculated living stature (LSwA) with the generic femur/stature ratio (Feldesman *et al*., 1990), the generic femur regression formula (Feldesman and Fountain, 1996) and the South African AD-derived femur regression formula (Lundy and Feldesman, 1987).

Sex	Population group	Variables compared	N	Paired Samples Correlations		Paired Differences			
				% Correlation	Sig.	Mean	Std. Dev.	S.E.M.	*p*-value
Female	MA	LSwA & LSr	61	84.48	0.000	-6.32*	4.44	0.57	0.000
		LSwA & LSf (GenFF'96)	61	84.48	0.000	-7.80*	3.52	0.45	0.000
		LSwA & LSf (LF'87)	61	84.65	0.000	-1.93*	3.29	0.42	0.000
	AD	LSwA & LSr	32	92.15	0.000	-7.64*	5.13	0.91	0.000
		LSwA & LSf (GenFF'96)	32	92.15	0.000	-8.48*	3.51	0.62	0.000
		LSwA & LSf (LF'87)	32	92.62	0.000	-2.74*	2.96	0.52	0.000
	ED	LSwA & LSr	13	96.22	0.000	-7.84*	3.29	0.91	0.000
		LSwA & LSf (GenFF'96)	13	96.22	0.000	-7.75*	2.06	0.57	0.000
		LSwA & LSf (LF'87)	13	95.08	0.000	-0.83	2.04	0.57	0.168
Males	MA	LSwA & LSr (Max Fem)	62	89.93	0.000	-8.48*	4.58	0.58	0.000
		LSwA & LSf (GenFF'96)	62	89.93	0.000	-7.41*	3.55	0.45	0.000
		LSwA & LSf (LF'87)	62	92.18	0.000	-2.87*	3.01	0.38	0.000
	AD	LSwA & LSr (Max Fem)	34	95.17	0.000	-9.61*	4.02	0.69	0.000
		LSwA & LSf (GenFF'96)	34	95.17	0.000	-8.14*	2.72	0.47	0.000
		LSwA & LSf (LF'87)	34	95.50	0.000	-3.68*	2.50	0.43	0.000
	ED	LSwA & LSr (Max Fem)	27	88.18	0.000	-8.91*	3.51	0.68	0.000
		LSwA & LSf (GenFF'96)	27	88.18	0.000	-6.14*	2.98	0.57	0.000
		LSwA & LSf (LF'87)	27	90.69	0.000	-0.09	2.73	0.52	0.862

*. The mean difference is significant at the ≤0.05 level.

Note:

MA = South Africans of Mixed Ancestry
AD = South Africans of African Descent
ED = South Africans of European Descent

LSwA = Living stature with age correction factor added (LS = TSH_{Calc} + soft tissue correction factor – age correction factor)

LSr = Living stature from Feldesman *et al.*'s (1990) generic femur/stature ratio

LSf (GenFF'96)
= Living stature from Feldesman and Fountain's (1996) generic femur regression formula

LSf (LF'87)
= Living stature from Lundy and Feldesman's (1987) femur regression formula's TSH_{Est} with soft tissue (Fully, 1956) and age (Trotter and Gleser, 1952) correction factors added and subtracted, respectively