Assessing the accuracy of soft-tissue correction factors for stature estimation in White South African males

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Declaration

I, Natasha Rosanne Loubser, declare that this dissertation is my own work. It is being submitted for the degree of Master of Science (Medicine) at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination, at this or any other University.

Natasha Rosanne Loubser

14th day of February 2022, in Parktown.

Abstract

It is widely accepted that living stature (LS) is most accurately estimated when using the anatomical method, however, recent research has questioned the accuracies of the soft-tissue correction factors associated with this method. Therefore, the aim of this study was to evaluate the accuracy of the soft-tissue correction factors associated with the anatomical method for the estimation of LS of White South African males.

White South African males volunteered to undergo a full-body MRI scan at the Wits-Donald Gordon Medical Centre. The bones directly contributing to stature were measured from these scans, used to determine total skeletal height (TSH), and estimate each participant's stature. The accuracies of these estimates were assessed using paired t-tests.

Fully's (1956) soft-tissue correction factors, as well as Raxter and colleagues' (2006), and Brits and colleagues' (2017) soft-tissue regression equations significantly underestimated the stature of White South African males by 6.14cm, 4.80cm, and 0.96cm, respectively, while, Bidmos and Manger's (2012) regression equation significantly overestimated stature by 9.65cm. Cloete's (2017) regression equation overestimated the stature of White South African males by 0.65cm, however, this was not significant. A Pearson's correlation indicated a strong, positive correlation between TSH and measured LS, and a soft-tissue regression equation was derived to improve the accuracy of the anatomical method for this group.

Results suggest population differences regarding soft-tissue correction factors, and therefore, it is suggested that either the newly derived regression equation from this study or that of Cloete (2017) be used to estimate the LS of White South African males.

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CHAPTER 1: Introduction

Considering the high incidences of crime in South Africa (Baliso *et al.*, 2019), and that a large number of human remains are recovered as skeletonised (Barrier & L'Abbé, 2008), it is imperative that forensic anthropologists can utilise South African specific standards to assist with the identification of unknown, skeletonised remains (Steyn & İşcan, 1997). Through skeletal analyses, a forensic anthropologist is able to estimate the biological profile of an unknown individual, of which the key characteristics include sex, population-affinity (ancestry), age-at-death, and living stature (LS) (İşcan, 1988; Dirkmaat *et al*., 2008; İşcan & Steyn, 2013; Ubelaker, 2018). Additional factors, such as trauma, pathology, and taphonomy can also be recorded which may assist with a possible identification (Dirkmaat *et al*., 2008; İşcan & Steyn, 2013; Ubelaker, 2018).

LS is the total height of an individual and is unique to each person, as such it is considered a factor of individualisation, which can assist the forensic anthropologist by narrowing down the pool of individuals of whom the remains could represent (Steyn & Smith, 2007). The estimation of stature is conducted using two methods, namely, the mathematical method based on the use of regression equations which was first introduced by Pearson (1899), and the anatomical method (Fully, 1956) first introduced by Dwight (1899, as cited in Lundy 1985). The mathematical method is based on how various skeletal lengths correlate with stature and are classified as either bone / stature ratios or regression equations (Sjøvold, 2000). The equations associated with the mathematical method do not require a complete skeleton, which is extremely advantageous as recovered skeletal remains are rarely found complete (Lundy, 1985; Sjøvold, 2000; Dayal *et al.,* 2008; Mays, 2016). These equations are, however, specific to the population and sex from which they are derived from, and applying the incorrect equation to estimate the stature of an unknown individual may incorrectly classify that individual (Albanese *et al.,* 2016).

The anatomical method utilises the summation of all of the skeletal lengths of the bones which directly contribute to stature, with an added soft-tissue correction factor, to estimate LS (Fully, 1956; King, 2004 Raxter *et al.*, 2006; Bidmos & Manger, 2012; Brits *et al.*, 2017). This method has been accredited as being the most accurate stature estimation method while being both population and sex non-specific (Raxter *et al.*, 2006; Maijanen, 2009). However, recent research has disputed this claim, and it has been concluded that there appears to be a population-specificity when using the anatomical method (King, 2004; Bidmos, 2005; Bidmos & Manger, 2012; Brits *et al.*, 2017; Cloete, 2017). Using full-body Magnetic Resonance Imaging (MRI) scans of White South African females, as well as Black South African males and females, it has been shown that stature estimates generated using the anatomical method are inaccurate when compared to the measured LS of these groups (Bidmos & Manger, 2012; Brits *et al.*, 2017; Cloete, 2017). The accuracy of this method in White South African males is, however, not known.

1.1. Study aims and objectives

The aim of this study was thus to assess the accuracy of the soft-tissue correction factors associated with the anatomical method for the estimation of stature in White South African males. The objectives of this study were to:

1. Calculate the total skeletal height (TSH) using skeletal measurements collected from full-body Magnetic Resonance Imaging (MRI) scans of White South African males.
2. Assess the accuracy of the soft-tissue correction factors proposed by Fully (1956), Raxter *et al*. (2006), Bidmos and Manger (2012), Brits *et al*. (2017), and Cloete (2017) for the stature estimation in White South African males.
3. Derive a new regression equation to convert TSH to living stature (LS) for White South African males, if necessary.

CHAPTER 2: Literature Review

2.1. Crime statistics in South Africa

South African anthropologists and pathologists are tasked with identifying high numbers of unknown human remains as a result of South Africa's high incidence of crime (Baliso *et al.*, 2019). The identification of these remains is vital from an ethical, legal, and civil perspective (Rupiah & Allison, 2020). While crime and the prevalence of unidentified human remains are issues that are faced on a global scale (Reza *et al.*, 2001; Centre for the Study of Violence and Reconciliation, 2009), the South African population is challenged with various factors which have resulted in these high incidences of crime. These factors include but are not limited to, a disproportionate percentage of the population who are faced with poverty, the legacy of apartheid, high levels of unemployment, and the high volume of migrant and immigrant workers within South Africa (Centre for the Study of Violence and Reconciliation, 2009).

Between 2019 and 2020, 21 325 murders and 18 635 attempted murders occurred in South Africa (South African Police Service, 2020), and the majority of the cases at Gauteng mortuaries were those of murdered individuals (Hlatshaneni, 2019). These remains are regularly presented to forensic pathologists as severely decomposed or skeletonised, and therefore, require the expertise of a forensic anthropologist to aid in the identification of these remains (Barrier & L'Abbé, 2008).

2.2. Forensic anthropology

The inception of forensic anthropology dates as early as the late nineteenth century, alongside that of physical anthropology (İşcan & Steyn, 2013). These disciplines were most notably defined as a unique forensic field with their inclusion into the American Academy of Forensic Sciences (AAFS) in 1972 (İşcan, 1988; İşcan & Steyn, 2013). Krogman, Stewart, and İşcan are accredited as three of the most influential early anthropologists due to their significant contributions to the development of the field (İşcan & Steyn, 2013). In 1988, İşcan published

an article outlining the history of the field and emphasizing the necessity for a global effort to develop, as well as standardise forensic anthropological methodologies and techniques to ensure that the future of the field would be based on sound scientific research. As described by İşcan (1988), the significant strides that had been achieved by the field were the development of techniques that lead to the estimation of age-at-death, living stature, sex, and population-affinity from unknown skeletal remains.

Dirkmaat and colleagues (2008) reviewed the advancements in forensic anthropology in the two decades since İşcan's (1988) influential article. In their review, Dirkmaat and colleagues (2008) outlined the effect of the Daubert criteria for the presentation of scientific evidence in the courtroom, as well as discussing the four major advancements of the field since 1988. The Daubert criteria set forth the precedent that admissible scientific evidence presented within a forensic context must be based on accurate, testable, reliable, and validated research (Dirkmaat *et al.*, 2008). These advancements included improved quantitative methodologies which were achieved through the establishment of comparative skeletal collections, the use of the context of recovery as an explanation for skeletal analyses, the use of taphonomic changes on the skeleton as evidence, and the use of forensic trauma analyses to identify changes in the skeleton (Dirkmaat *et al.*, 2008).

Ubelaker (2018) has subsequently reviewed what has been achieved in the field since 2008 and praised that current forensic anthropological methodologies are as a result of years of technological advancements, the establishment of well-documented skeletal collections and databases, as well as thoughtful research design. Ubelaker (2018) identified several fields of research that are aiding in the development of modern and innovative forensic anthropological techniques, namely the molecular analysis of skeletal evidence, the identification of undocumented migrants, the biomechanics of bone trauma, commingling analyses, bone

microscopy, isotope analyses, facial imaging, decomposition research, as well as the search, detection, and recovery of skeletal remains (Ubelaker, 2018).

Physical anthropology was first introduced within South Africa during the early 20th century and focused on the origins and typologies of southern African populations, as well as human evolution (Morris, 2012; Bernitz *et al.*, 2015). Towards the middle of the 20th century, the research being conducted shifted primarily to the modern descriptions of human variation observed within South Africa (L'Abbé & Steyn, 2012; Bernitz *et al.*, 2015). Currently, the research being conducted in biological anthropology, within South Africa, focuses on defining the variation observed between and among the various population groups, as well as developing anthropological standards specific to South African populations (Bernitz *et al.*, 2015). The need for South African specific standards was prompted by Steyn and İşcan's (1997) recommendation that applying international standards to South African populations will result in inaccuracies in identifying unknown human remains.

In conclusion, forensic anthropology is a scientific discipline, with the primary goal of identifying unknown, decomposed, or skeletal remains, within a medico-legal context, using ante-, peri-, and post-mortem indicators that persist on the skeleton, as well as analysing the taphonomic, pathological, traumatic, and contextual evidence associated with these remains (İşcan, 1988; Dirkmaat *et al*., 2008; İşcan & Steyn, 2013; Ubelaker, 2018). İşcan and Steyn (2013) attributes forensic anthropology as not only being useful in the identification of unidentified skeletal remains within a forensic and archaeological context but, as having proven to be an invaluable resource in the identification of remains in cases of mass disaster, such as tsunamis and earthquakes, where remains may be recovered as decomposing, mangled, and even scattered.

2.3. Skeletal collections

Skeletal collections have aided in the development of the techniques and standards that forensic anthropologists use to assist in the identification of unknown human remains (Dirkmaat *et al.*, 2008; Ubelaker, 2018). A number of South African specific human skeletal collections have been established for research, namely the Raymond A. Dart Collection of Modern Human Skeletons at the University of the Witwatersrand (Dayal *et al.*, 2009), the University of Cape Town Human Skeletal Repository (Gibbon & Morris, 2021), the University of Pretoria Bone Collection (L'Abbé *et al.*, 2005), and the Kirsten Skeletal Collection at Stellenbosch University (Alblas *et al.*, 2018). While these skeletal collections are advantageous for the development of population-specific research, there are numerous factors to consider when using these collections which may disadvantage researchers.

There are sampling biases which often affect these skeletal collections (Komar & Grivas, 2008), where there may be an over-representation of a particular population group (Hunt & Albanese, 2005; L'Abbé *et al.*, 2005; Komar & Grivas, 2008; Dayal *et al.*, 2009; Alblas *et al.*, 2018; Gibbon & Morris, 2021). This sampling bias is evident in the Pretoria Bone Collection, and the Raymond A. Dart Collection of Modern Human Skeletons, where a disproportionate percentage of these collections are represented by Black males, and individuals affected by lower socio-economic statuses (L'Abbé *et al.*, 2005; Dayal *et al.*, 2009). The skeletons of these skeletal collections are either from the unclaimed bodies at various hospitals or the voluntary bequeathal of cadavers into these collections (L'Abbé *et al.*, 2005; Dayal *et al.*, 2009). L'Abbé and colleagues (2005) attribute the high representation of Black individuals in these collections as being a result of a high incidence of unclaimed remains of Black African male migrant and immigrant workers (Brits *et al.*, 2020) being sent to these collections, rather than a voluntary donation of these remains for research, as individuals from these population groups tend to have cultural and religious aversions to donating their remains (De Gama, 2016).

In addition to sample bias, these collections often no longer represent the populations from which they have been derived as a result of effects that secular change has on living populations (Meadows & Jantz, 1995; Ousley & Jantz, 1997; Meadows-Jantz & Jantz, 1999; Dirkmaat *et al.,* 2008; Komar & Grivas, 2008). Secular change is characterised by changes in the environment that, over time, change the expression of particular biological traits (Moore & Ross, 2013). These environmental changes include, but are not limited to, changes in nutrition, medical care, health, and climate (Meadows & Jantz, 1995; Meadows-Jantz & Jantz, 1999; Bogin & Rios, 2003). Therefore, the data derived from skeletal collections, can misrepresent modern populations, and produce techniques and standards associated with low accuracies when derived from collections which have been affected by the secular change. As such, forensic anthropologists are moving towards the study of living individuals through the use of modern imaging modalities.

2.4. Virtual anthropology

Virtual anthropology, as coined by Weber and colleagues in 1998, affords a unique opportunity for researchers to combine anthropological techniques with radiographic imaging (Guglielmi *et al.,* 2015; Carew & Errickson, 2019). There are several benefits for the use of virtual anthropology to conduct research, including that this data may be manipulated and reconstructed continuously, it is permanently available and easily accessible, researchers are able to view the internal structures of a specimen in far more detail, and sharing this virtual data is easy, which allows for the increase of sample sizes and research collaboration (Weber, 2015). Additionally, the use of virtual anthropology negates the effects that secular change has on research. Researchers make use of these imaging modalities to assess the internal structures of living or post-mortem individuals without the need for dissection or maceration (Franklin *et al.,* 2016) to gather osteological data through non-invasive means, and to use these scans to

conduct research (Dedouit *et al.*, 2007; Hishmat *et al.*, 2015; Franklin *et al.*, 2016; Carew & Errickson, 2019).

The various types of imaging modalities are broadly categorised as either being reflective or transmissive (Errickson *et al.*, 2017; Carew & Errickson, 2019). Reflective imaging modalities, such as photogrammetry, make use of reflected light off of the exposed surface of the object being observed, however, they do require maceration and dissection (Errickson *et al.*, 2017). Whereas transmissive imaging modalities, such as magnetic resonance imaging (MRI) and computed tomography (CT), capture volumetric data passing through a sample (Mehta *et al.*, 1997; Carew & Errickson, 2019). MRI is a non-ionising imaging technique and is therefore potentially safer when imaging the internal structures of the living (Dempsey *et al.*, 2002; Semelka *et al.*, 2007; Kulaylat *et al.*, 2015; Carew & Errickson, 2019). MRI machines make use of radio waves, which causes the excitation of the protons in the body, producing electric signals, known as nuclear magnetic resonance (NMR), which is measured by the magnetic field of the machine and captured as images (Hinshaw *et al.*, 1977; Griffith & Genant, 2011; Carew & Errickson, 2019).

Although MRI scans are not the preferred imaging modality to visualise the skeletal system, as bone produces weaker signals than soft-tissue during the scan (Weber, 2001; Carew & Errickson, 2019), they do not expose an individual to harmful ionising radiation (Thorpe *et al.*, 2008), and produce accuracies of dry bone skeletal measurements (Doyle & Winsor, 2011) as compared to the dry bone measurements taken from CT scans (Rathnayaka *et al.*, 2012). Studies have also been conducted to estimate the various characteristics of the biological profile using MRI scans. These include the estimation of age-at-death (Hatipoglu *et al.*, 2008; Hillewig *et al.*, 2010; Hillewig *et al.*, 2013; Krämer *et al.*, 2014), sex (Hatipoglu *et al.*, 2008), as well as stature (Pelin *et al.*, 2005; Bidmos & Manger, 2012; Brits *et al.*, 2017; Cloete, 2017).

2.5. Stature

Identifying an individual from only their skeletonized remains can be a difficult task to undertake. Forensic anthropologists, therefore, examine the unidentified remains, using standardised methodologies, to estimate the biological profile of that individual (İşcan, 1988; Dirkmaat *et al*., 2008; İşcan & Steyn, 2013). The four key characteristics of the biological profile, as previously mentioned, are sex, age-at-death, population-affinity (ancestry), and stature (Stewart, 1979; İşcan, 1988; Dirkmaat *et al*., 2008; İşcan & Steyn, 2013).

There are three main types of stature that are recognised in the literature, cadaveric stature (CS), forensic stature (FS), and living stature (LS) (Ousley, 1995; Maijanen, 2009; Wilson *et al*., 2010; Cardoso *et al*., 2016). CS is the length of a cadaver measured prior to embalming, usually in the supine position (Bidmos, 2005; Cardoso *et al*., 2016), whereas, FS is the reported height of an individual, usually affiliated with official governmental documentation, such as driver's licences, and is often used as the reference height of an unknown individual (Maijanen, 2009). FS can either be self-reported, measured by a government official, or reported by the families of missing persons (Steyn & Smith, 2007; Giroux & Wescott, 2008; Cardoso *et al*., 2016). Lastly, LS is a multifactorial trait that is measured from the top of an individual's head to the soles of their feet, when standing in the anatomical position (Chibba & Bidmos, 2007).

Each of these stature types is associated with various limitations. CS is generally larger than LS due to the loosening of the joints and the loss of muscle tone associated with death (Manouvrier, 1892; Trotter & Gleser, 1952; Bidmos, 2005; Cardoso *et al*., 2016), and is mostly available in skeletal collections (Hunt & Albanese, 2005; L'Abbé *et al*., 2005; Dayal *et al*., 2009). This becomes problematic when trying to estimate LS from equations derived using the CS affiliated with these collections (Bidmos, 2005). Among researchers, there is no consensus on a universal conversion factor which can accurately convert CS to LS, or whether this conversion is even necessary (Cardoso *et al*., 2016). Manouvrier (1892) suggested that 2 cm is

subtracted from CS to generate LS estimates, whereas Pearson (1899) recommended that 1.2 cm be subtracted from CS to generate LS for males and that 2 cm be added to the CS of females. Dupertuis and Hadden (1951) concluded that no conversion factor is necessary as they believe that CS is representative of LS, whereas, Trotter and Gleser (1952) suggested that 2.5 cm is subtracted from CS to obtain LS. Alternatively, Bidmos (2005) found that these conversion factors were both population- and sex-specific. They (2005) recommended that 4.1 and 8.5 cm would be subtracted from the CS for Black South African males and females, respectively, and 2.9 cm being subtracted for White South African females while adding 1.9 cm to the CS of White South African males.

Similarly, to CS, FS is generally larger than LS, due to the fact that FS is often incorrectly reported, where an individual's height may either be overestimated (Willey & Falsetti, 1991), or underestimated (Snow & Williams, 1971; Sjøvold, 2000). In addition to possibly being reported incorrectly, measured FS is rarely performed using standardised methodologies, whereby more than one individual measures FS, compounding the errors associated with these statures (Cardoso *et al.*, 2016).

2.6. Factors affecting stature

Approximately 80-90% of overall LS is determined by an individual's genetic make-up (Mascie-Taylor, 1991; Hirschhorn & Lettre, 2009), while the remaining 10-20% is further influenced by the quality of their environment (Hirschhorn & Lettre, 2009; Dauber *et al.*, 2014; Vercellotti *et al.*, 2014; Baron *et al.*, 2015; Mays, 2016).

2.6.1. Secular change

Environmental factors such as poor nutritional intake (Grasgruber *et al.*, 2014; Perkins *et al.*, 2016), chronic childhood infection and inflammation (Hwang *et al.*, 2013), as well as poor socioeconomic status (Cole, 2000; Cole, 2003; Zong *et al.*, 2015; Myburgh *et al.*, 2017) have a negative effect on the expression of stature in adults (Mascie-Taylor, 1991; Vercellotti *et al.*,

2014), and may even lead to the stunting of their growth and development (Steckel, 1995; Cole, 2000; Vercellotti *et al.*, 2014).

Changes in the environment will have a resultant effect on certain human traits over time, more commonly known as secular change (Cole, 2000; Stulp & Barret, 2016; Myburgh *et al.*, 2017). The directionality of these changes depends on the quality of the environment improving or worsening, and these can result in a positive, neutral, or negative change (Cole, 2000). A negative change is defined by periods of environmental stress, in which a population may experience a delay in growth, which could lead to stunting in adults and a decline in the mean stature for that population, as seen previously in Indian (Vogel, 1971, as cited in Tobias, 1985), Peruvian (Frisancho *et al.*, 1975) and South African (Tobias, 1985) populations. A positive change is conversely expressed during improvements in environmental conditions as noted in Finnish (Silventoinen *et al.*, 2000), Netherlander (Cole, 2003), and Chinese populations (Jiao & Ye, 2013). Finally, a neutral trend is expressed during periods of environmental stasis or when a population has reached its optimal growth potential as demonstrated in the rural Columbian (Himes & Mueller, 1977), Latin American (Keep & Bogin, 1999), Norwegian (Bolstad *et al.*, 2001), and Northern European populations (Larnkjær *et al.*, 2006). It can therefore be concluded that changes in a population's mean stature over time provides valuable insight into the quality of its environment (Ruff *et al.*, 2012; Shin *et al.*, 2012; Sládek *et al.*, 2015).

Differences in environments will, therefore, result in considerable variation in stature between different human populations (Gray & Wolfe, 1980; Eveleth & Tanner, 1990; Cole, 2003; Shin *et al.*, 2012). While this variation is generally attributed to differences in the environment, similarities in the stature of different populations are considered to be due to the genetic admixing between those populations (Gray & Wolfe, 1980; Gustafsson & Lindenfors, 2004; Wells, 2012). Differences in statures between populations have also been attributed to

the influence of Bergman's ecological rule and Allen's rule, where populations in colder geographic areas tend to be taller than those in warmer regions (Gray & Wolfe, 1980; Gustafsson & Lindenfors, 2004; Foster & Collard, 2013; Stulp & Barrett, 2016) and those in colder regions will tend to have shorter limbs than those in warmer regions (Gray & Wolfe, 1980; Tilkens *et al.,* 2007), respectively.

2.6.2. Sexual dimorphism & population-affinity

In addition to genetics and environmental factors, sexual dimorphism is also seen in the stature of males and females (Gray & Wolfe, 1980; Eveleth & Tanner, 1990; Gustafsson & Lindenfors, 2004), where males tend to be taller and heavier than females (Hauser *et al.,* 2005; Steyn & Smith, 2007; Wells, 2012). These differences between mean statures have been attributed to the differential growth rates and skeletal maturation between males and females (Cole *et al.*, 2015; Stulp & Barrett, 2016). Cole *et al.* (2015) conducted a longitudinal study to observe the effect of sex and population-affinity on the skeletal maturation of children in South Africa and concluded that females reached skeletal maturity 1.9 years earlier than males, and that there are differential growth rates between the different populations and sexes of South African children. Additionally, it was concluded that males were more sensitive to the unfavourable changes in the environment, such as nutritional intake and socioeconomic status (Cole *et al.*, 2015; Stulp & Barrett, 2016). Gray and Wolfe (1980) concluded that modern populations display differences in male and female sizes and that these differences vary between populations, and therefore not all human populations have the same relationship with stature. Gustafsson and Lindenfors (2004) found that the mean statures of males were consistently larger than females, and that the degree of dimorphism varied between different populations due to differences in their environments, and that the similarities that were observed between certain populations were as a result of genetic admixture between

populations in close proximity. Therefore, it can be concluded that sex and population-affinity have an effect on stature, and, consequently, stature estimation.

2.6.3. Diurnal variation

Another factor which has shown to affect LS is diurnal variation (Kobayashi & Togo, 1993; Botsford *et al.*, 1994; Voss & Bailey, 1997; Tillmann & Clayton, 2001; Krishan & Vij, 2007). An individual's stature is highest first thing in the morning (Ousley, 1995; Sjøvold, 2000), where diurnal variation occurs as stature decreases throughout the day, and recovers during periods of sleep (Kobayashi & Togo, 1993; Krishan & Vij, 2007). This loss in stature has largely been attributed to changes of the spine, namely the fluctuations in the volume, and size of the intervertebral discs, as well as the decrease in muscle tone due to the effects that standing has on soft-tissue (Botsford *et al.*, 1994; İşcan & Steyn, 2013).

Research has shown that stature decreases from the moment an individual wakes up, where the most significant decrease occurs between the first 30 minutes and two hours of waking up (Kobayashi & Togo, 1993; Voss & Bailey, 1997; Tillmann & Clayton, 2001; Krishan & Vij, 2007). Diurnal variation on LS appears to vary between age groups, however, there is no consensus on the extent of variation of this decrease. Kobayashi and Togo (1993) reported a mean reduction in stature for older children, younger children, and adults as 1.79 cm, 1.61 cm, and 1.43 cm, respectively. Krishan and Vij (2007) concluded a mean reduction of 2.81 cm in adults from their sample, while Siklar and colleagues (2005) found a mean difference of 0.47 ± 0.05 cm in children's stature measured throughout the day. While diurnal variation differs between different age groups, it does not seem to differ between males and females of the same age groups (Siklar *et al.*, 2005).

2.6.4. Age

In addition to the aforementioned factors, age also has a significant influence on stature (Trotter & Gleser, 1951; Raxter *et al.*, 2006; İşcan & Steyn, 2013). An individual's stature

increases during sub-adult growth periods and will only cease when the epiphyseal growth plates have completely fused (Cunningham *et al.*, 2016), where LS is consistent throughout adulthood and will begin to decline as an individual ages (Trotter & Gleser, 1951; Galloway, 1988; Cline *et al.*, 1989; Sjøvold, 2000; Raxter *et al.*, 2006; İşcan & Steyn, 2013). This decrease in LS has been attributed to the compression of the vertebrae, deterioration of the intervertebral discs, and pathologies, such as osteoporosis and kyphosis, as well as the decrease in muscle tone and the loss of elasticity of the soft-tissue (Trotter & Gleser, 1951; Galloway, 1988; Cline *et al.*, 1989; Sjøvold, 2000; Raxter *et al.*, 2006; İşcan & Steyn, 2013). It is important to note that it appears that the skeletal stature of an individual remains stable, regardless of age (Niskanen *et al*., 2013; Jeong & Jantz, 2016), and the reported decline in stature may be as a result of changes in the soft-tissue (Jeong & Jantz, 2016), except in cases of pathological changes, such as osteoporosis and osteophytic changes to the vertebral column.

Knowledge of an individual's age is imperative when estimating their stature, as both old and young age have been shown to affect stature (Trotter & Gleser, 1951; Galloway, 1988; Cline *et al*., 1989; İşcan & Steyn, 2013). Several age-correction factors have been suggested for the change in stature due to increasing age, however, there is no consensus as to the age of onset of this decline or the rate of change it has on LS (Trotter & Gleser, 1951; Galloway, 1988; Cline *et al.*, 1989; Raxter *et al.*, 2006). The age at which stature begins to decrease has been suggested to be 30 years (Trotter & Gleser, 1951; Raxter *et al.*, 2006), 40 years (Cline *et al.*, 1989), as well as 45 years (Galloway, 1988) of age. With regards to the rate of change of LS, Trotter and Gleser (1951) recommends subtracting 0.06 cm per year above the age of 30 years from the estimate of stature to compensate for the decline with age, while Galloway (1988) suggests subtracting 0.16 cm from the stature estimate. Cline and colleagues (1989) recommends that this decline in stature is insignificant until the age of 60 years and that no changes be made to the LS of individuals below 60 years to compensate for age.

2.7. Stature estimation methods

The estimation of stature is vital when trying to identify unknown remains, as it is not only one of the key characteristics of the biological profile (İşcan & Steyn, 2013), it additionally assists forensic anthropologists by narrowing down the number of individuals to whom the remains may belong to (Steyn & Smith, 2007; Krishan *et al.*, 2012). All stature estimation techniques are largely based on the relationship between specific skeletal elements and stature (Sjøvold, 2000). The estimation of stature is typically conducted using one of two approaches (Lundy, 1985): the mathematical method (Pearson, 1899), or the anatomical method (Fully, 1956).

2.7.1. Mathematical method

The mathematical method utilises the correlations that various skeletal lengths have with stature. From these correlations, regression formulae and bone / stature ratios can be developed to estimate stature from individual (univariate) or multiple (multivariate) measurements of skeletal elements (Lundy, 1985; Sjøvold, 2000; Moore and Ross, 2013). The mathematical method is the most frequently used method for LS estimation as it can be applied when a skeleton is not complete, which is advantageous as complete skeletons are rarely found in the forensic context (Lundy, 1985; Dayal *et al.*, 2009; Mays, 2016).

Bone / stature ratios

Utilised mainly during the nineteenth century, bone / stature ratios are based on the consistent correlation between specific bone lengths and stature (Humphry, 1858; Stewart, 1979; Feldesman, 1992; Zeman *et al.*, 2014). From this correlation, constant multiplication factors are generated, which are then applied to the lengths of specific long bones in order to obtain estimates of stature (Stewart, 1979; Feldesman, 1992; Sjøvold, 2000; Moore & Ross, 2013). Bone / stature ratios have been calculated for various long bones lengths, including the radius, humerus, and tibia which contribute approximately 14.3%, 20.0%, and 22.1%,

respectively to overall LS (Stewart, 1979). The femur has the strongest and most consistent correlation with stature, contributing 26.7% to the overall LS of an individual (Feldesman, 1992; Sjøvold, 2000; Chibba & Bidmos, 2007).

These ratios are independent of sex (Feldesman *et al.*, 1990) and were previously thought to be independent of the population-affinity of the individual (Feldesman *et al.*, 1990; Feldesman, 1992), however, it has been shown that population-specific ratios marginally outperform generalised femur / stature ratios (Feldesman & Fountain, 1996; Sjøvold, 2000). Feldesman and Fountain (1996), however, recommended that a generalised femur / stature ratio be used when estimating the stature of an individual whose demographics are unknown, which is often the situation in forensic cases. Additionally, applying the femur / stature ratio of a population group to an individual of a different population generates greater errors than the errors associated with a generalised ratio (Feldesman & Fountain, 1996). Finally, femur / stature ratios vary significantly between different age groups (Feldesman, 1992), and juvenile femur / stature ratios between the ages of 12 and 18, also vary considerably between males and females (Feldesman, 1992).

The accuracies associated with femur / stature ratios have been found to be comparable to the accuracies associated with regression equations, however, these ratios are most reliable when estimating the stature of individuals of average height, as they tend to overestimate the LS of taller individuals, and underestimate the LS of shorter individuals (Meadows & Jantz, 1995; Feldesman & Fountain, 1996; Sjøvold, 2000). The accuracies associated with the bone / stature ratios, in the form of the standard error of estimates (SEE) (Sjøvold, 2000), are rarely available when using this particular method (İşcan & Steyn, 2013). When SEE values are associated with these ratios, they are larger than the SEEs of regression equations, and are therefore less accurate (Krishan *et al*., 2012). While bone / stature ratios were widely used in

the past, they are no longer applicable to modern populations, and regression equations are more frequently used for stature estimation (Moore & Ross, 2013).

Regression Equations

Regression equations are based on a statistical model which demonstrates the linear relationship between an independent variable, such as various skeletal dimensions, and a dependent variable, such as stature. These regression equations allow for the estimation of LS from the lengths of one (univariate) or more (multivariate) skeletal elements (Pearson, 1899; Trotter & Gleser, 1952; Stewart, 1979; Lundy, 1985; Sjøvold, 2000; İşcan & Steyn, 2013). In addition to not requiring a complete skeleton, these equations are not as time-consuming as the anatomical method (Lundy, 1985; Dayal *et al.*, 2008; Cardoso *et al.*, 2016).

The skeletal measurements of an unknown individual are entered into an appropriate regression equation to estimate their total skeletal height (TSH), which is then input into an additional regression equation to estimate the LS of that individual (Lundy, 1985; Dayal *et al*., 2008). These equations are associated with SEE values, which can be inferred as an indicator of accuracy (Sjøvold, 2000), and therefore, the smaller the SEE, the more accurate the equation (Sjøvold, 2000). It has been found that the regression equations derived from long bones are associated with higher accuracies, with the femur and tibia yielding the most accurate results (Dayal *et al.*, 2008; Albanese *et al.*, 2016), as these bones directly contribute to stature (Lundy and Feldesman, 1987; Dayal *et al*., 2008; Khanal *et al*., 2017).

Due to the effect of varying environmental factors on different populations, and the differential effects on the sexes in those populations, regression equations are significantly dependent on the population, and sex from which they are derived (Trotter & Gleser, 1958; Sjøvold, 2000; Raxter *et al.*, 2006; Dayal *et al.*, 2008). Applying the incorrect regression equations to a group may result in the underestimation or overestimation of LS in that group

(Trotter & Gleser, 1952; Trotter & Gleser, 1958; Bidmos, 2006; Gocha *et al.*, 2013). As such, numerous regression equations have been generated for various populations around the world, such as North America (Trotter & Gleser, 1952; Trotter & Gleser, 1958; Giroux & Wescott, 2008), Italy (Giurazza *et al*., 2012), Spain (Muñoz *et al.*, 2001), Turkey (Özaslan *et al*., 2003), India (Kanchan *et al*., 2008), Korea (Jeong & Jantz, 2016), Japan (Torimitsu *et al*., 2017), Nigeria (Didia *et al*., 2009) and South Africa (Lundy & Feldesman, 1987; Bidmos & Asala, 2005; Dayal *et al.*, 2008; Bidmos & Brits 2020).

Although there is a general consensus in the literature that regression equations be applied only to individuals from the population and sex that they are obtained from, Albanese and colleagues (2016) have argued that there is a necessity for a generic equation to estimate the LS of individuals whose sex and population-affinity cannot be estimated. Albanese *et al.* (2016) noted that these general equations, while not as accurate as sex-specific equations, perform just as well as population-specific equations, and are more accurate than a regression equation which is applied to an individual not of the population or sex from which the equation was derived.

It has been shown that regression equations that are generated from the skeletal lengths of complete long bones present with the lowest SEE values and are considered to produce the most accurate estimates of stature (Prasad *et al.*, 1996; Sjøvold, 2000; Raxter *et al.*, 2006; Dayal *et al.*, 2008; Giurazza *et al*., 2012), and therefore, several researchers have generated regression equation for most long bones for their respective populations (Trotter & Gleser, 1952; Trotter & Gleser, 1958; Lundy & Feldesman, 1987; Muñoz *et al.*, 2001; Duyar & Pelin, 2003; Dayal *et al*., 2008; Giroux & Wescott, 2008; Didia *et al.*, 2009; Giurazza *et al.*, 2012; Jeong & Jantz, 2016). However, during the recovery of skeletal remains, the long bones can often present as fragmentary (Holland, 1992; Prasad *et al.*, 1996; Barrier & L'Abbé, 2008), which can be attributed to the taphonomic effects on the skeleton due to weathering (Urbanová *et al.*, 2017),

faunal scavenging (Pokines & Tersigni-Tarrant, 2017), violent crimes or the burning of remains (Waterhouse, 2013). Therefore, regression equations have been produced to estimate the LS of these skeletal remains from consistent landmarks on these fragmentary remains (Steele & McKern, 1969; Steele, 1970; Holland, 1992; Chibba & Bidmos, 2007; Bidmos, 2008a; Bidmos, 2008b; Spies *et al.,* 2019). These equations, however, are associated with greater errors than those affiliated with complete long bones (Byers *et al.,* 1989).

In addition to the regression equations obtained from complete and fragmentary long bones, equations have been derived from various other skeletal elements, with acceptable accuracies, such as the calcaneus (Bidmos & Asala, 2005; Bidmos, 2006; Zhang *et al.,* 2017), clavicle (Torimitsu *et al.,* 2017), metatarsals (Byers *et al.,* 1989; Cordeiro *et al*., 2009), sacrum (Pelin *et al.,* 2005; Pininski & Brits, 2014), scapula (Giurazza *et al.,* 2012; Zhang *et al.,* 2016), skull (Ryan & Bidmos, 2007; Giurazza *et al*. 2012), sternum (Yonguc *et al*., 2014; Tumram *et al.,* 2016), and vertebrae (Zhang *et al.,* 2015; Milani *et al.,* 2017). While these skeletal elements all present a statistical relationship with stature, it is imperative to note that not all these bones are biologically relevant to utilise for the estimation of LS from unknown skeletal remains (Fedak *et al.,* 2015). Therefore, the skeletal elements which directly contribute to stature should be favoured when making estimates of LS (Khanal *et al*., 2017).

2.7.2. Anatomical method

The anatomical method is often revered as the most accurate stature estimation method (Lundy, 1985; Ousley, 1995; Sjøvold, 2000; Raxter *et al.,* 2006; Maijanen, 2009) as it takes individual body proportions into consideration, and includes the skeletal lengths of the bones that directly contribute to stature (Raxter *et al.,* 2006; Dayal *et al.,* 2008; Maijanen, 2009). However, the major limitations of this method are that it requires the aforementioned skeletal elements and that these elements should not be damaged, which is often the case in a forensic

context (Lundy, 1985; Raxter *et al*., 2006; Dayal *et al*., 2008; Bidmos & Manger, 2012; İşcan & Steyn, 2013; Zeman *et al*., 2014; Mays, 2016; Brits *et al*., 2017).

The anatomical method for the estimation of stature involves adding together the skeletal measurements of the bones that directly contribute to an LS to estimate the total skeletal height (TSH) of an individual (Fully, 1956; Raxter *et al*., 2006; Maijanen, 2009). These measurements include cranial height, vertebral body heights, the length of the femur, the length of the tibia, as well as talo-calcaneal height (Raxter *et al.*, 2006). A subsequent soft-tissue correction factor is added to TSH, which compensates for the lack of soft-tissue associated with the joints, intervertebral discs, scalp, and the soles of the feet, to convert TSH to LS (Lundy, 1985; Raxter *et al*., 2006; Dayal *et al*., 2008; Bidmos & Manger, 2012; İşcan & Steyn, 2013). There are various soft-tissue correction factors which are presented within the literature.

Dwight (1899, as cited in Lundy 1985) is often accredited with being the first person to estimate LS using the anatomical method. He achieved this by rearticulating skeletal elements, in the anatomical position, and compensating for the lack of soft-tissue using clay, and measuring the articulated skeleton to estimate stature (Lundy, 1985). Based on the techniques of Dwight (1899, as cited in Lundy 1985), Fully (1956) measured the various skeletal elements contributing to stature, rather than rearticulating the skeleton, to estimate TSH, and finally adding generalised soft-tissue correction factors of either 10 cm, 10.5 cm, and 11 cm for individuals considered to be short (TSH $\leq$ 153.5 cm), average (TSH: 153.6 cm – 165.4 cm) and tall (TSH $\geq$ 165.5 cm), respectively. While Fully (1956) used the lengths of the aforementioned skeletal elements, he failed to clearly define how these measurements were taken. In addition, the aforementioned correction factors have subsequently been found to underestimate stature when applied to modern populations (King, 2004; Bidmos, 2005; Raxter *et al.*, 2006; Maijanen, 2009).

Raxter and colleagues (2006) evaluated Fully's (1956) method and agreed with the findings of King (2004) and Bidmos (2005) in that this method underestimates the LS of modern populations, due to the application of inaccurate soft-tissue correction factors, as well as the poorly defined skeletal measurements (Raxter *et al.*, 2006). These skeletal measurements were subsequently redefined as the basio-bregmatic height of the cranium, the anterior vertebral body heights of C2-S1, the physiological length of the femur, the condylar-malleolar length of the tibia, and the talo-calcaneal height of the tarsals. By clearly defining these measurements, a standardised methodology was presented, thereby reducing the errors associated with mismeasurement (Raxter *et al.*, 2006). In addition to redefining these measurements, Raxter and colleagues (2006) calculated their own soft-tissue correction factors, in the form of regression equations, which were considered to be appropriately applied to all individuals, regardless of their sex or population-affinity. They (2006) generated two soft-tissue regression equations, one which corrects for age and one which does not. The equation which corrects for age is considered more accurate, however, age-at-death is not usually known in a forensic case, and the equation which does not correct for age is, therefore, recommended in forensic anthropological case analyses (Raxter *et al.*, 2006; Raxter *et al.*, 2007).

As the anatomical method was thought to be independent of sex and population-affinity, South African researchers widely used this method to formulate regression equations for the estimation of LS of various South African population groups (Lundy & Feldesman, 1987; Bidmos, 2006; Bidmos & Asala, 2006; Chibba & Bidmos, 2007; Ryan & Bidmos, 2007; Bidmos, 2008a; Bidmos, 2008b; Dayal *et al.*, 2008). However, recent research has concluded that the soft-tissue correction factors of Fully (1956), and the soft-tissue regression equations of Raxter *et al.* (2006) may present with sex-, and population-specificity (King, 2004; Bidmos, 2005; Bidmos & Manger, 2012; Brits *et al.*, 2017; Cloete, 2017).

A vast amount of research regarding stature estimation has been conducted on the various skeletal collections within South Africa (Lundy & Feldesman, 1987; Bidmos, 2005; Bidmos & Asala, 2005; Chibba & Bidmos, 2007; Bidmos, 2008a; Bidmos, 2008b; Dayal *et al*., 2008; Pininski & Brits, 2014; Arendse, 2018; Spies *et al*., 2019), however, these collections are often not representative of the modern populations due to the effects of secular change, and sampling bias (Meadows & Jantz, 1997; Meadows-Jantz & Jantz, 1999; Komar & Grivas, 2008). Similarly, part of the stature estimation data and subsequent analysis from these collections included on the unreliable documented cadaveric statures (Lundy, 1983; Bidmos, 2005) associated with the collection, or the estimates of LS that are made using problematic methods, such as Fully's (1956) soft-tissue correction factors (Bidmos & Asala, 2005; Chibba & Bidmos, 2007; Bidmos, 2008a; Bidmos, 2008b; Dayal *et al*., 2008) and Raxter and colleagues' (2006) soft-tissue regression equations (Spies *et al*., 2019). Therefore, the use of radiographic techniques such as CT and MRI scans can negate the limitations associated with skeletal collections (Franklin *et al*., 2016), and various skeletal measurements can be directly regressed against measured LS, which is favourable for the derivation of stature estimation equations (Sjøvold, 2000).

To assess the applicability of the anatomical method in a modern South African context, Bidmos and Manger (2012) analysed the relationship between measured LS and LS estimates obtained from the soft-tissue correction factors of Fully (1956) and the soft-tissue regression equations of Raxter and colleagues (2006), using MRI scans of Black South African males. They (2012) found that the soft-tissue correction factors of Fully (1956) and Raxter *et al*.'s (2006) anatomical methods significantly underestimated the stature of this group, by 15.8 cm and 14.8 cm, respectively. From these results, Bidmos and Manger (2012) derived regression equations specific for the LS estimation in Black South African males.

With the recommendation for the further evaluation of this method within South Africa, Brits and colleagues (2017) analysed MRI scans of Black South African females to evaluate the applicability of the soft-tissue correction factors associated with the anatomical method in this group. Similar to the results of Bidmos and Manger (2012), Brits and colleagues (2017) concluded that the stature estimations obtained when using Fully (1956) and Raxter *et al.*'s (2006) anatomical methods, were significantly underestimated for their sample, by 7.9 and 6.8 cm, respectively. However, when applying the soft-tissue regression equation of Bidmos and Manger (2012), Brits and colleagues (2017) concluded that these stature estimates significantly overestimated the LS of Black South African females, by 7.8 cm. This under- and overestimation of stature was attributed to the application of inaccurate soft-tissue correction factors to this group, and as such Brits and colleagues (2017) generated sex-specific soft-tissue correction factors which should be applied, specifically, to Black South African females.

In conjunction with the aforementioned findings, Cloete (2017) conducted a similar study to assess the applicability of the anatomical method on White South African females. The findings indicated that the anatomical methods of Fully (1956) and Raxter and colleagues (2006) significantly underestimated the stature of this group, by 7.1 and 6.1 cm, respectively, whereas Bidmos and Manger's (2012) factors significantly overestimated stature, by 8.89 cm. Conversely to these results, Cloete (2017) concluded that the equation generated from Brits and colleagues (2017) for Black South African females only slightly overestimated the stature of their sample, by 0.04 cm but this overestimation was not found to be statistically significant. The accuracy of the anatomical method for the LS estimation of White South African males is however unknown, and therefore this study was aimed at assessing the accuracies of the soft-tissue correction factors associated with the anatomical method for the estimation of LS in White South African males.

CHAPTER 3: Materials and Methods

3.1. Participants

Ethical clearance was obtained from the Human Research Ethics Committee – Medical, University of the Witwatersrand (Clearance Certificate No: M200411 – Appendix A) to invite:

- Living White South Africans
- Male
- Between the ages of 20 and 60 years old to participate in this study.

There are four distinct population groups recognised by the South African government, namely the Black, Coloured, Indian / Asian, and White South African groups (Statistics South Africa, 2020) Black South Africans (80.8%) constitute the largest demographic within South Africa, followed by Coloured (8.8%), White (7.8%) and Indian / Asian (2.6%) South Africans (Statistics South Africa, 2020). Of interest to this study is the White South African population group who are descendants of individuals from various European countries, such as the Netherlands, Britain, France, and Germany (Henneberg & van der Berg, 1990; Steyn & İşcan, 1997), who settled in southern Africa during the 18th century (Guelke, 1976). The stature estimation standards of White South Africans were previously derived from data on White American (Trotter & Gleser, 1952; Raxter *et al*., 2006) and European (Olivier *et al*., 1978) populations. However, due to the effects of genetic admixture, geographic distance, and the Founder effect (whereby a small, isolated sample of a larger population establishes a new population), the White South African population is now widely accepted as being osteologically distinct from European and White North American populations (Steyn & İşcan, 1997; Steyn & İşcan, 1999; Steyn & Smith, 2007), and therefore require population-specific stature estimation standards.

Only White males between the ages of 20 and 60 years were approached to participate in this study. The lower age limit allows for enough time to guarantee that growth had ceased (Cunningham *et al.,* 2016), which typically occurs at 18 years of age in males and is indicated by the epiphyseal fusion of the long bones, however variation in epiphyseal fusion does occur (Murray & Clayton, 2013; Cunningham *et al*., 2016). The upper age limit ensures that the degenerative effects of aging on the skeleton has not significantly affected the height of the participants (Cline *et al*., 1989). These degenerative effects include the flattening of the intervertebral discs, loss of elasticity in the joints, loss of muscle mass and flattening of the vertebral bodies (Trotter & Gleser, 1951; Raxter *et al*., 2006; İşcan & Steyn, 2013; Jeong & Jantz, 2016). While there is no general consensus as to when stature begins to decrease due to the effects of age (Trotter & Gleser, 1951; Galloway, 1988; Cline *et al*., 1989; Raxter *et al*., 2006), Cline and colleagues (1989) argue that this decline is only measurable after the age of 60. Furthermore, the stipulated age limits are consistent with similar studies conducted by Bidmos and Manger (2012), Brits *et al*. (2017), and Cloete (2017).

To obtain measures of LS and associated TSH, individuals were verbally invited to partake in this study and were fully informed of the nature, benefits, and risks involved. Interested participants were given a study information document (Appendix B), as well as an informed consent sheet (Appendix C), which was signed to indicate their voluntary willingness to partake in this study. Due to the fact that participants had undergone a full-body MRI scan, standard MRI exclusion and the exclusion criteria set forth by the Department of Radiology, Wits-Donald Gordon Medical Centre were explained to each participant and adhered to. This exclusion criteria included:

- Individuals who presented with any metal surgical implants or foreign metal fragments or shrapnel (Shellock & Spinazzi, 2008) were excluded from this study. These individuals were excluded due to the fact that the magnetic properties associated with MRI scans have

a potential translational or rotational effect on ferromagnetic materials that are present around or in the body, which can be hazardous to the participant (Dempsey *et al*., 2002; Carew & Errickson, 2019).

- Individuals were excluded on the basis of presenting with any growth-related or nutritional diseases, abnormalities of the skeletal system, or having had broken a bone in the past year.
- Potential participants who were claustrophobic were also discouraged from participating in this study due to the narrow size of the helm of the MRI machine.

Numerous individuals were approached to participate in this study, with a total of 35 volunteers consenting to participate. Regrettably, 5 MRI scans had to be excluded from the overall sample of the study. One participant was too tall for the MRI scanner, and as such their heel height could not be measured. Two participants presented with sacralisation, and one participant presented with lumbarisation. One participant's MRI scan had presented with technical difficulties, and as such the data could not be retrieved from the disc. Therefore, there were a total of 30 participants in this study.

3.2. Method

3.2.1. Data Collection

Individuals were asked to ensure that they wore clothing which did not contain any metal parts, to negate any interference with the MRI machine. Any individuals who were unable to do so were asked to change into an MRI compliant satin gown to ensure their safety. Adhering to safety precautions to prevent the spread of COVID-19, the principal investigator and all participants sanitised their hands prior to any interaction, kept our respective masks on, and all equipment were sanitised before and after use. Each individual's height and weight were measured three times prior to their scan at the Wits-Donald Gordon Medical Centre, where they were also asked to complete the study participant data sheet (Appendix D). Their height

and weight measurements were measured, as it is well-documented that individuals tend to misreport these measurements (Snow & Williams, 1971; Willey & Falsetti, 1991; Sjøvold, 2000).

Measured height allows for the direct comparison of an individual's LS and their skeletal measurements, which negates the limitations of using the CS that is often affiliated with skeletal collections (Lundy, 1983; Bidmos, 2005). The height of each participant was measured, in the morning, prior to the MRI scan, to negate the effects of diurnal variation on LS (Kobayashi & Togo, 1993; Botsford *et al.*, 1994; Voss & Bailey, 1997; Tillmann & Clayton, 2001; Krishan & Vij, 2007), using a portable stadiometer with a movable head, following the guidelines set forth by Vallois (1965). Adhering to these guidelines, individuals stood upright, with their heels touching, palms facing inward, and arms to their side. Additionally, their heads were in the Frankfurt horizontal position, where the upper margin of the ear canal and the lower margin of the orbit are positioned in the same horizontal plane (Vallois, 1965). Each height measurement was recorded to the nearest 1mm. Weight, measured in kg, was recorded using a portable electronic scale. The average height and weight measurements were used for the subsequent data analyses.

Full-body MRI scans were taken, in the supine position, at the Department of Radiology at the Wits-Donald Gordon Medical Centre in Parktown, using a 1.5 Tesla Phillips Entera MR Scanner, with software version 12.1. Firstly, T2-weighted survey scans were completed using 6 mm slice thickness for the coronal sequence from the pelvis to the feet, and the T2-weighted survey was completed using 4 mm slice thickness for the sagittal sequence of the head to the pelvis. Each scan took approximately 8 minutes, and once completed, the multistack sequences were fused on a working station, where the images were saved as a Digital Imaging and Communication in Medicine (DICOM) file to a disc. These images were then analysed on an

Apple MAC desktop computer in the School of Anatomical Sciences, University of the Witwatersrand, where several skeletal measurements were taken.

3.2.2. Measurements

The MRI scans were imported into HOROS, version 3.3.6, an open-source DICOM reader which can be used to collect data from these radiographic scans (Cornell Institute of Biotechnology, 2020). The skeletal elements that directly contributes to an individual's LS were collected from the MRI scans according to the definitions by Raxter *et al.* (2006) with modifications for MRI scans described by Brits *et al.* (2017). As per convention, the femoral, tibial, and ankle measurements were taken from the bones of the left side of the body.

Cranial height: On dry bone, this measurement is taken from the basion of the cranium to the bregma (Raxter *et al.*, 2006). However, due to the fact that MRI scans were collected in the sagittal plane, these landmarks are difficult to visualise and therefore this measurement was taken from the basion (the most anterior aspect of the foramen magnum) to the ectocranium directly opposite to the basion (Brits *et al.*, 2017) (Figure 3.1).

Height of C2: The height of C2 was measured from the superior aspect of the odontoid process to the inferior margin of its anterior body (Raxter *et al.*, 2006) (Figure 3.1).

Height of C3 to L5: The heights of C3-L5 were taken as the maximum length between the superior-most and inferior-most margins of the anterolateral aspect of the anterior vertebral bodies, excluding any swellings of the centrum caused by the pedicles or costal facets located more posteriorly (Raxter *et al.*, 2006) (Figure 3.1).

Height of the 1st sacral element: The height of S1 was measured from the sacral promontory to the junction between the first and second sacral vertebrae, anteriorly (Raxter *et al.*, 2006) (Figure 3.1).

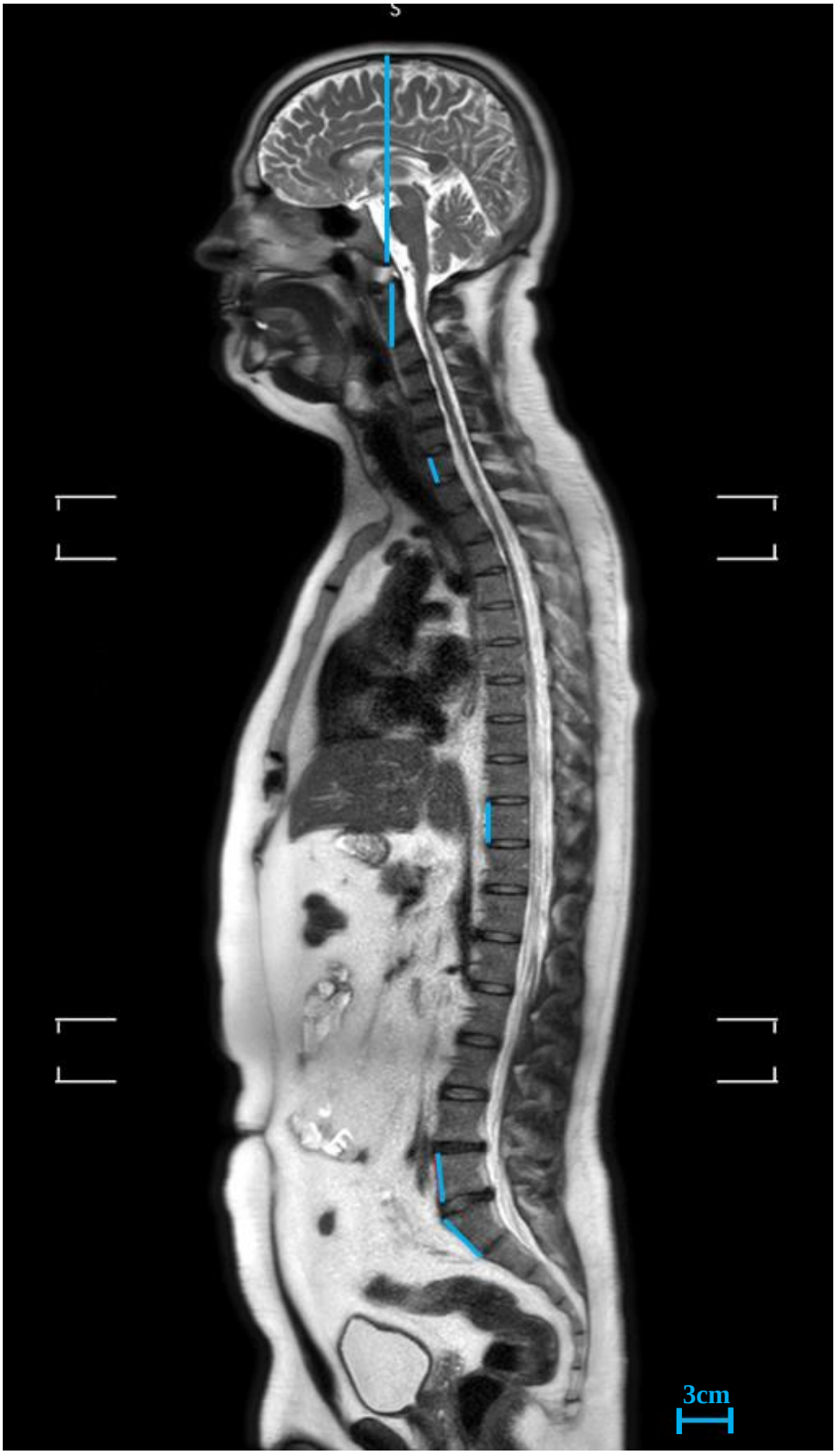

Figure 3.1: A sagittal MRI scan indicating a typical example of the skeletal measurements taken in this study of the cranium, C2 (axis), and the anterior body heights of C7, T10, L5, and S1 (Scale = 3 cm).

Physiological femoral length: By convention, the physiological length of the femur is measured, using an osteometric board, with both femoral condyles against the fixed end of the board and the femoral head placed against the mobile end (Raxter *et al.*, 2006). To represent this measurement from the MRI scans, it was recorded by drawing a line between the two distal-most ends of the femoral condyles and measuring the distance from the midpoint of this line to the superior most aspect of the femoral head (Brits *et al.*, 2017) (Figure 3.2).

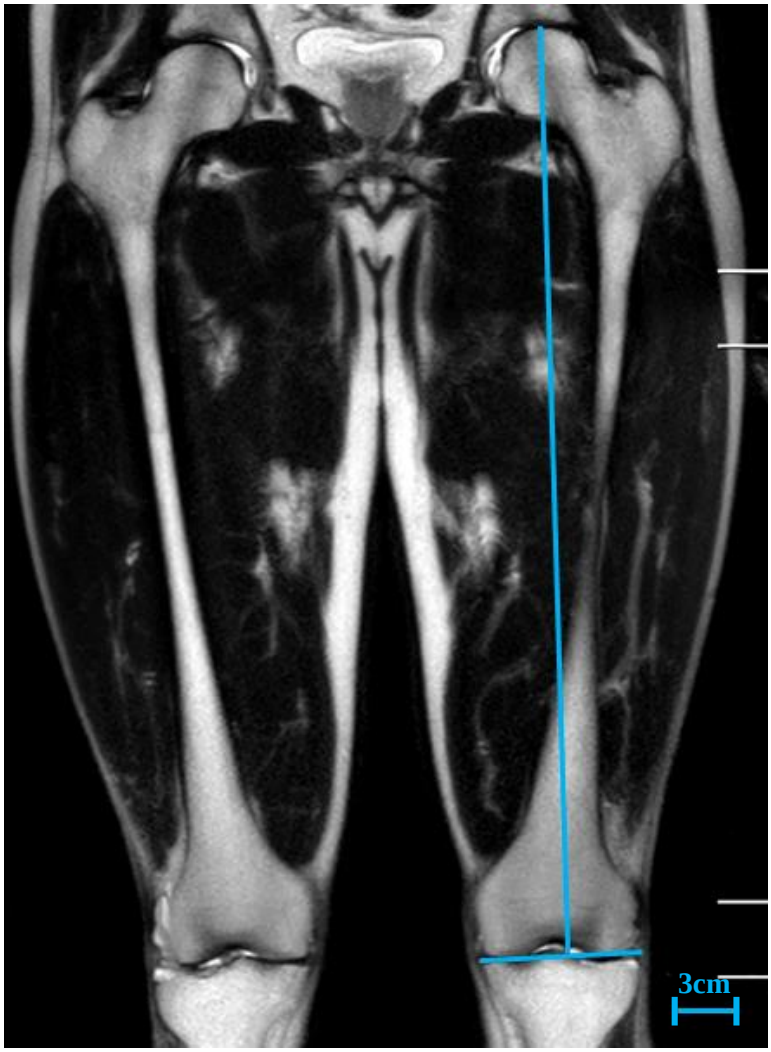

Figure 3.2: A coronal MRI scan indicating a typical example of the skeletal measurement taken in this study of the physiological length of the femur (Scale = 3cm).

Tibial length: Similarly, to the physiological length of the femur, an osteometric board is typically used to record the length of the tibia, measured from the lateral condylar surface to the medial malleolus (Raxter *et al.*, 2006). To collect this measurement on the MRI scans, a line parallel to the articular surface of the lateral condyle was drawn. The length of the tibia is measured from the tip of the medial malleolus to a point, perpendicular to the parallel line (Brits *et al.*, 2017) (Figure 3.3).

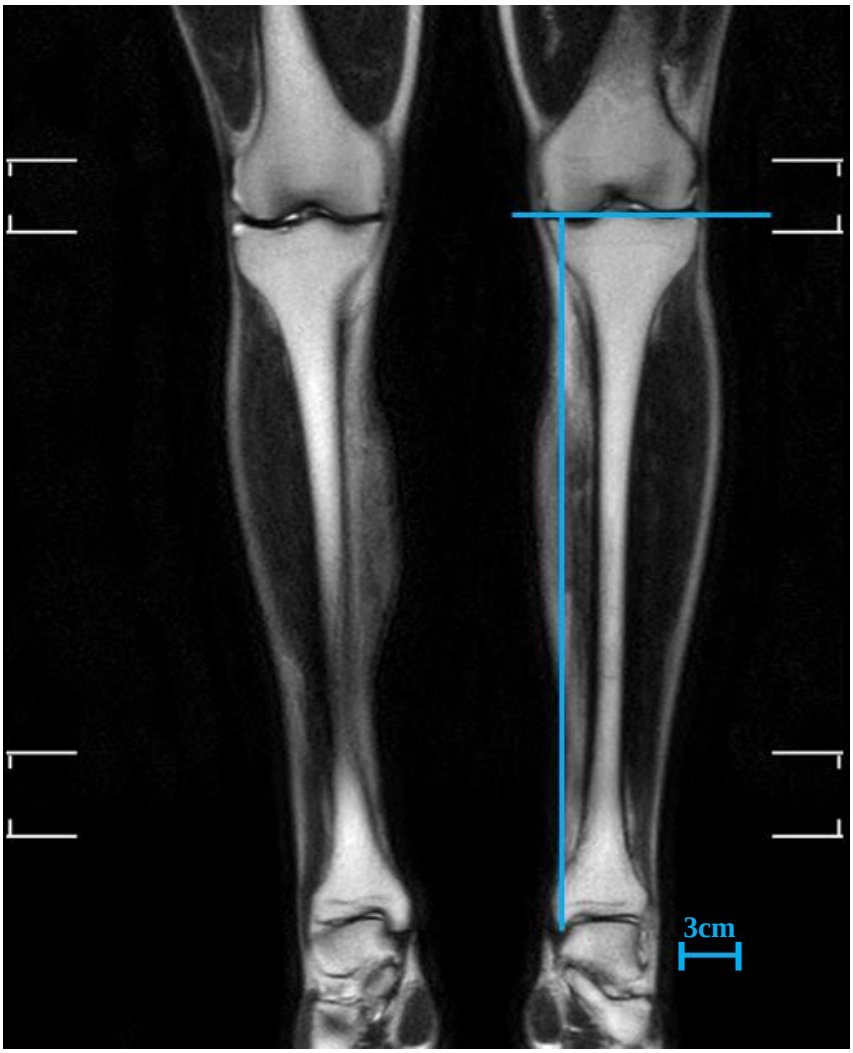

Figure 3.3: A coronal MRI scan indicating a typical example of the skeletal measurement taken in this study of the tibial length (Scale = 3 cm).

Heel height: On dry bone, this measurement is recorded, using an osteometric board, as the distance between the trochlea of the talus, to the inferior margin of the calcaneal tuber while the two tarsals are articulated (Raxter *et al.*, 2006). However, from the MRI scans this measurement was taken, from the survey scan, as the perpendicular length from the superior aspect of the trochlea to a line (also known as the plane of support, Dayal *et al.*, 2008) drawn from the inferior portion of calcaneal tuberosity to the head of the 5th metatarsal (Brits *et al.*, 2017). In the case where the head of the 5th metatarsal was not visible in the survey scan, this measurement was taken from multiple slices of the full-body coronal scan, where the plane of support was drawn from the calcaneal tuberosity to the head of the 5th metatarsal, and a perpendicular length was drawn from this plane of support to the superior aspect of the talus (Figure 3.4).

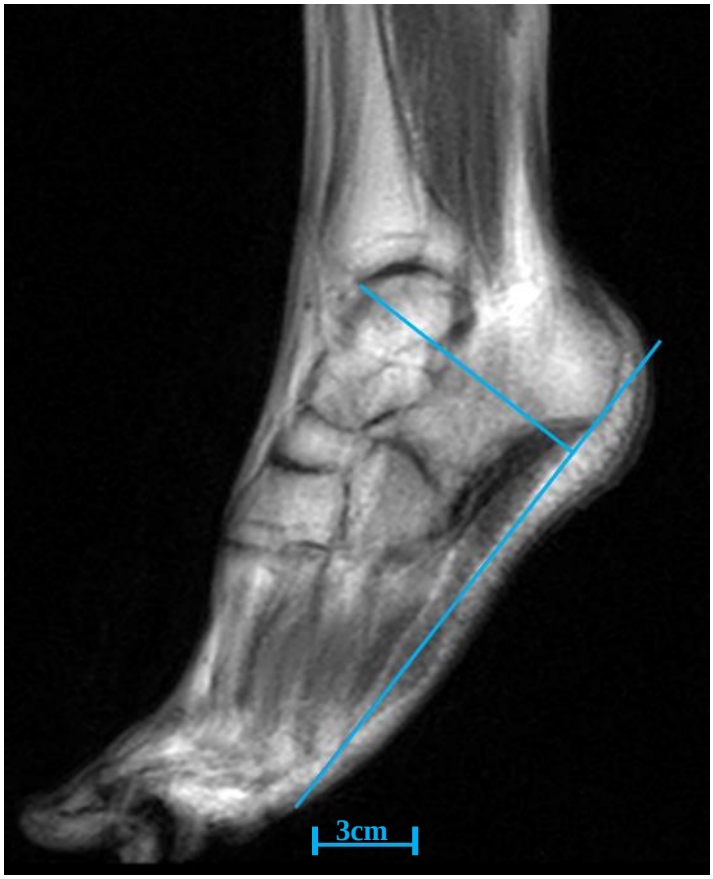

Figure 3.4: A sagittal MRI scan indicating a typical example of the skeletal measurement taken in this study of the talus-calcaneus height from the trochlea of the talus to a line that represents the plane of support (Scale = 3 cm).

Total skeletal height (TSH): In accordance with Fully (1956), and Raxter *et al*. (2006) the aforementioned measurements were added to calculate the TSH of each individual. These TSH values were then used to estimate the LS of each individual.

Estimated living stature (ELS): Several estimates of LS were calculated from the TSH values. Firstly, the appropriate soft-tissue correction factors proposed by Fully (1956) were applied to the TSH to estimate LS_{Fully}. Next, these TSH values were incorporated into the regression equations of Raxter and colleagues (2006), Bidmos and Manger (2012), Brits and colleagues (2017), and Cloete (2017) to estimate LS_{Raxter}, LS_{Bidmos}, LS_{Brits}, and LS_{Cloete} respectively.

3.3. Data analysis

Intra- and inter-observer repeatability was assessed for the skeletal measurements collected in this study. The cranial height, the anterior vertebral body heights of C2, C7, T10, L5 and S1, the physiological length of the femur, the length of the tibia, and the heel height of 10 participants were re-measured by the principal investigator and an independent observer to demonstrate the intra- and inter-observer repeatability, respectively. Only the heights of C2, C7, T10, L5, and S1 were re-measured in accordance with Bidmos and Manger (2012), Brits *et al.* (2017), and Cloete (2017). These repeatabilities were assessed using the technical error of measurement (TEM), the relative technical error of measurement (%TEM), and the coefficient of reliability (R).

Subsequent data analysis was run using the IBM Statistical Package for Social Sciences (SPSS: Version 26). The various skeletal measurements in this study were summed together to determine the TSH of each individual. The TSH were then used to make various estimates of LS which were compared to the measured stature of each participant. Therefore, these data were assessed for outliers using the Outlier labelling rule (Hoaglin *et al.,* 1986; Hoaglin & Iglewicz, 1987), and for normality using the Shapiro-Wilk normality test (Shapiro & Wilk,

1965). The normality of the data were additionally assessed using histograms associated with the data presented as a bell curve.

Descriptive statistics were calculated for the physiological length of the femur, the length of the tibia, measured LS, TSH, and the estimates of LS based on the soft-tissue correction factors of Fully (1956), and the soft-tissue regression equations of Raxter *et al.* (2006), Bidmos and Manger (2012), Brits *et al.* (2017), and Cloete (2017), this included the minimum, maximum, mean and standard deviations of the data.

As all the variables were found to be normally distributed, Pearson's correlation coefficients were run to analyse the correlations between measured LS and TSH, as well as the physiological length of the femur and the length of the tibia used in this study. The various correlations between measured LS, TSH, the physiological length of the femur, and the length of the tibia were visualised using scatterplots to better understand the relationships between these variables.

Paired samples t-tests were used to assess the accuracy of the stature estimates made using the soft-tissue correction factors of Fully (1956), and the soft-tissue regression equations of Raxter *et al.* (2006), Bidmos and Manger (2012), Brits *et al.* (2017), and Cloete (2017), compared to the measured LS of the participants in this study. Descriptive statistics were additionally calculated for the under- and overestimations of each of the LS estimates when compared to measured LS.

Lastly, a linear regression equation specific for stature estimation of White South African males was generated, following the recommendation of Raxter and colleagues (2006), where LS was the dependent variable and TSH the independent variable. The accuracy of this equation was determined by estimating the LS of each participant using their TSH in conjunction with the new soft-tissue regression equation and then comparing these estimates

to the measured LS. An associated SEE value was obtained for this regression equation and is considered an indicator of the degree of accuracy of the equation (Sjøvold, 2000).

CHAPTER 4: Results

4.1. Repeatability

The technical error of measurement (TEM), relative technical error of measurement (%TEM), and the coefficient of reliability (R) were calculated to demonstrate the intra- and inter-observer replicability of the measurements used in this study (Table 4.1). Intra-observer TEM ranged from 0.0 cm to 0.1 cm, whereas %TEM ranged from 0.1% to 3.2%. The inter-observer TEM and %TEM values, which were slightly higher than those of intra-observer repeatability, ranged from 0.1 cm to 0.3 cm, and from 0.2% to 6.3%, respectively. R values ranged between 0.8 – 1.0 for intra-observer and 0.7 – 0.9 for the inter-observer repeatability, respectively.

Overall, the physiological length of the femur and the length of the tibia produced the highest degree of reproducibility for both intra- and inter-observer repeatability. Conversely, the anterior vertebral body heights produced the lowest degree of repeatability for both the intra- and inter-observer repeatability. The measurements that displayed low degrees of repeatability are highlighted as bold text in Table 4.1. These include the heights of C2 and C7 for intra-observer repeatability, as well as the heights of C2, C7, T10, L5, and the heel height for inter-observer repeatability.

Table 4.1: Intra- and inter-observer repeatability results.

	Intra-observer repeatability			Inter-observer repeatability		
	TEM (cm)	%TEM	R	TEM (cm)	%TEM	R
Cranial height	0.1	0.4	1.0	0.2	1.7	0.9
Height of C2	0.0	0.8	1.0	0.2	**6.3**	**0.7**
Height of C7	0.1	**3.2**	0.8	0.1	**3.8**	**0.7**
Height of T10	0.1	**2.1**	0.9	0.1	**3.6**	0.9
Height of L5	0.1	1.5	0.9	0.1	**2.2**	0.9
Height of S1	0.0	0.8	1.0	0.1	1.7	0.9
Physiological femoral length	0.1	0.1	1.0	0.1	0.2	1.0
Tibial length	0.1	0.2	1.0	0.2	0.6	1.0
Heel height	0.1	1.0	1.0	**0.3**	**3.4**	0.8

Key: values highlighted in bold text indicate low degrees of repeatability

4.2. Outliers & normality

The data which were used for the subsequent data analyses were assessed for outliers and normality. This data included measured LS, TSH, and estimates of LS of each individual, as well as their physiological lengths of the femur, and their lengths of the tibia. No outliers were detected using the outlier labelling rule (Hoaglin *et al*., 1986; Hoaglin & Iglewicz, 1987), which uses the median, quartile, and interquartile ranges for the data. The data were, additionally tested for normality using the Shapiro-Wilk test (Shapiro & Wilk, 1965), and these variables were found to be normally distributed ($p > 0.05$), as shown in Table 4.2.

Table 4.2: The Shapiro-Wilk test results for normality for the measured living stature (LS), total skeletal (TSH), estimates of LS, femoral and tibial length measurements.

	W	df	p-value
Measured LS	0.99	30	0.96
TSH	0.99	30	0.97
LS_{Fully}	0.99	30	0.94
LS_{Raxter}	0.98	30	0.91
LS_{Bidmos}	0.99	30	0.97
LS_{Brits}	0.99	30	0.97
LS_{Cloete}	0.99	30	0.97
Physiological femoral length	0.94	30	0.09
Tibial length	0.98	30	0.68

4.3. Descriptive statistics

The participant sample consisted of White South African males between the ages of 22 and 59 years old (34.73 ± 9.79 years), with 87% of the current sample being between 21 and 42 years of age. This is graphically depicted in Figure 4.1.

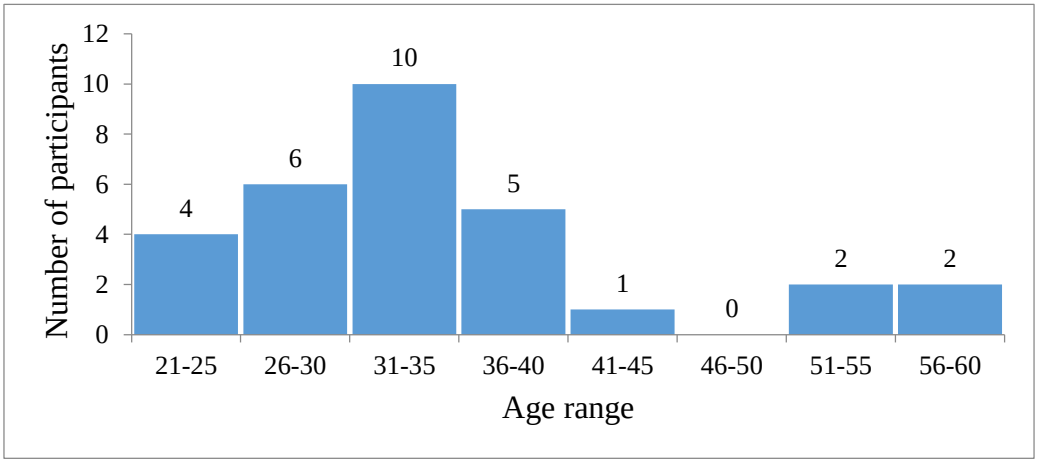

Figure 4.1: A histogram showing the number of participants of particular age ranges in the sample for this study.

The descriptive statistics, including the minimum, maximum, mean, and standard deviation of the measured LS, TSH, estimates of LS, and the measurements of the long bones are presented in Table 4.3. The measured LS of the participants in this study fell between 164.77 cm and 190.10 cm (178.05 ± 6.29 cm), and the total skeletal height (TSH) ranged between 148.80 cm and 173.60 (161.18 ± 6.15 cm). The estimates of LS ranged between 158.82 cm and 185.13 cm (171.92 ± 6.56 cm) based on the soft-tissue correction factors of Fully (1956), and 160.98 cm and 185.88 cm (173.25 ± 6.36 cm) based on the soft-tissue regression equations of Raxter and colleagues (2006). The LS estimates fell between 174.88 cm and 200.61 cm (187.71 ± 6.38 cm) when using the soft-tissue regression equation specific for Black South African males (Bidmos & Manger, 2012), 166.02 cm and 188.25 cm (177.10 ± 5.51 cm) when using the soft-tissue regression equation derived specifically for Black South African females, and 165.48 cm ± 192.02 cm (178.70 ± 6.58 cm) when using the soft-tissue regression equation specific for White South African females. The physiological length of the femur of the participants in this study fell between 43.60 cm and 51.20 cm (47.84 ± 2.16 cm), and the length of the tibia ranged between 33.50 cm and 43.70 cm (39.21 ± 2.44 cm).

The estimates of stature of $LS_{Fully,}$ LS_{Raxter}, and LS_{Brits} were, on average, below the measured LS of the participants in this study, whereas the estimates of LS_{Bidmos} were, on average, larger than the measured LS. On the other hand, the mean values of LS_{Cloete} were the most similar to the means of measured LS.

Table 4.3: Descriptive statistics for measured living stature (LS), total skeletal height (TSH), estimates of LS, femoral, and tibial length measurements.

	n	Minimum (cm)	Maximum (cm)	Mean (cm)	SD (cm)
Measured LS	30	164.77	190.10	178.05	6.29
TSH	30	148.80	173.60	161.18	6.15
LS_{Fully}	30	158.82	185.13	171.92	6.56
LS_{Raxter}	30	160.98	185.88	173.25	6.36
$LS_{B\&M}$	30	174.88	200.61	187.71	6.38
LS_{Brits}	30	166.02	188.25	177.10	5.51
LS_{Cloete}	30	165.48	192.02	178.70	6.58
Physiological length of the femur	30	43.60	51.20	47.84	2.16
Length of the tibia	30	33.50	43.70	39.21	2.44

4.4. Correlations

The correlations between measured LS, and the long bone measurements, as well as TSH, are shown in Table 4.4, whereas the correlations between TSH and these measurements are presented in Table 4.5. The TSH, as well as the physiological length of the femur, and the length of the tibia were significantly ($p < 0.05$) correlated to measured LS. Additionally, these long bone measurements were also significantly ($p < 0.05$) correlated to TSH. The strong, positive correlations between measured LS and TSH, as well as the long bone measurements, were graphically represented with scatterplots (Figure 4.2 - Figure 4.4). From these scatterplots, it can be concluded that the correlations between the long bones measurements, TSH, and measured LS were positive and linear, and the associated high R^2 values represent the adjacent scattering of the respective variables around the line of best fit.

Table 4.4: Pearson's correlation coefficient results between measured living stature (LS), femoral and tibial length measurements, and total skeletal height (TSH).

	n	r	R^2	p
Physiological length of the femur	30	0.849	0.720	$p < 0.01$
Length of the tibia	30	0.874	0.763	$p < 0.01$
TSH	30	0.948	0.899	$p < 0.01$

Table 4.5: Pearson's correlation coefficient results between total skeletal height (TSH), and femoral and tibial measurements.

	n	r	R^2	p
Physiological length of the femur	30	0.913	0.832	$p < 0.01$
Length of the tibia	30	0.914	0.835	$p < 0.01$

Overall the correlations between the skeletal measurements and TSH (r: 0.913 – 0.914) were slightly greater than for measured LS (r: 0.849 – 0.874), as well as these variables being more closely distributed to the line of best fit for TSH (R^2: 0.832 – 0.835) than measured LS (R^2: 0.720 – 0.763). It is evident that the strongest relationship was demonstrated between measured LS and TSH (Figure 4.2: $p < 0.01$; $r = 0.948$), followed by the relationship between TSH and the length of the tibia (Figure 4.3. A: $p < 0.01$; $r = 0.914$), TSH and the physiological length of the femur (Figure 4.3. B: $p < 0.01$; $r = 0.913$), measured LS and the length of the tibia (Figure 4.4. A: $p < 0.01$; $r = 0.874$), and finally the measured LS and physiological length of the femur (Figure 4.4. B: $p < 0.01$; $r = 0.849$).

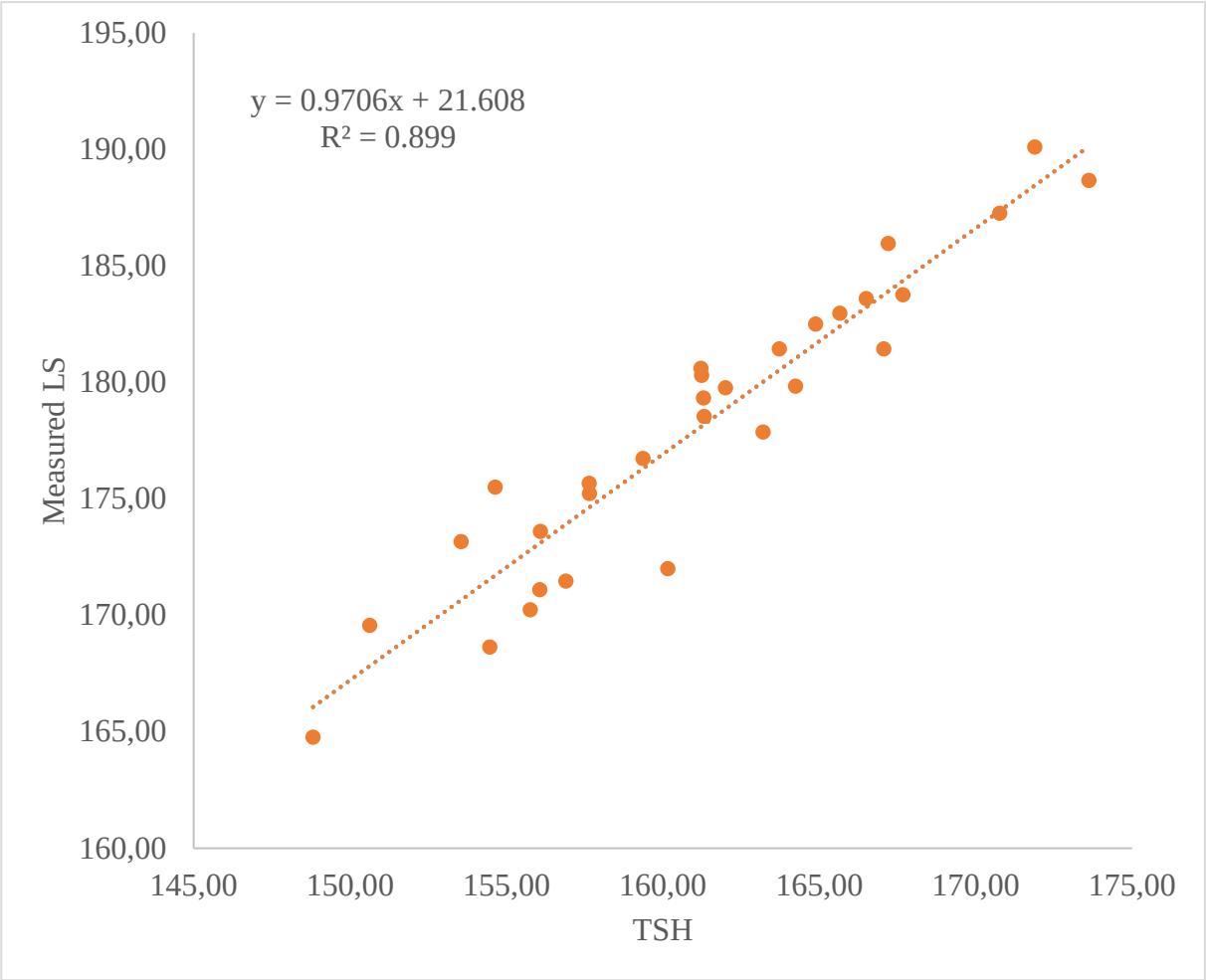

Figure 4.2: Scatter plot indicating the correlation between measured LS and total skeletal height (TSH) ($p < 0.01$; $r = 0.948$).

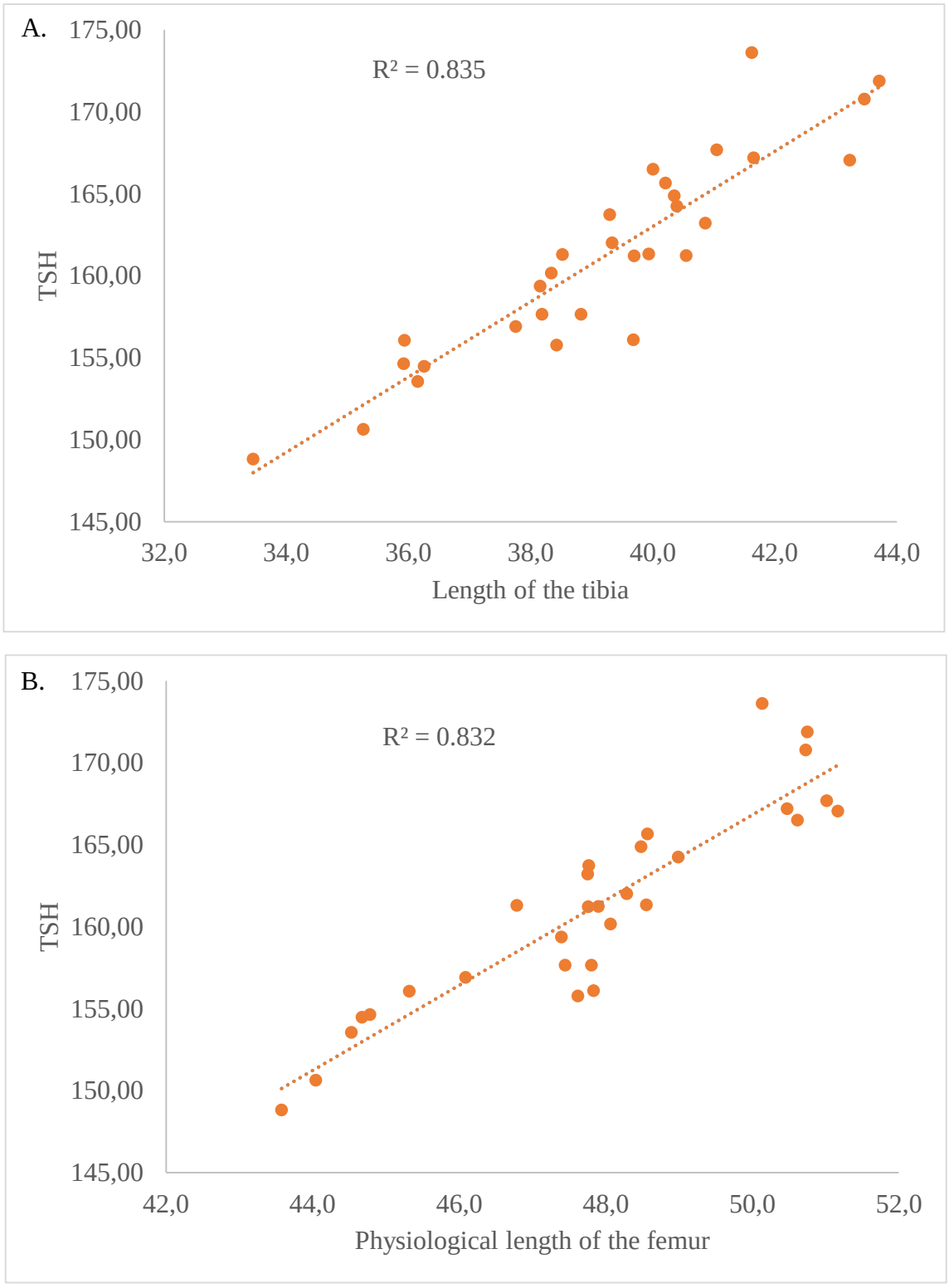

Figure 4.3: Scatter plot indicating the correlation between A: total skeletal height (TSH) and the length of the tibia ($p < 0.01$; $r = 0.914$), B: total skeletal height (TSH) and the physiological length of the femur ($p < 0.01$; $r = 0.913$).

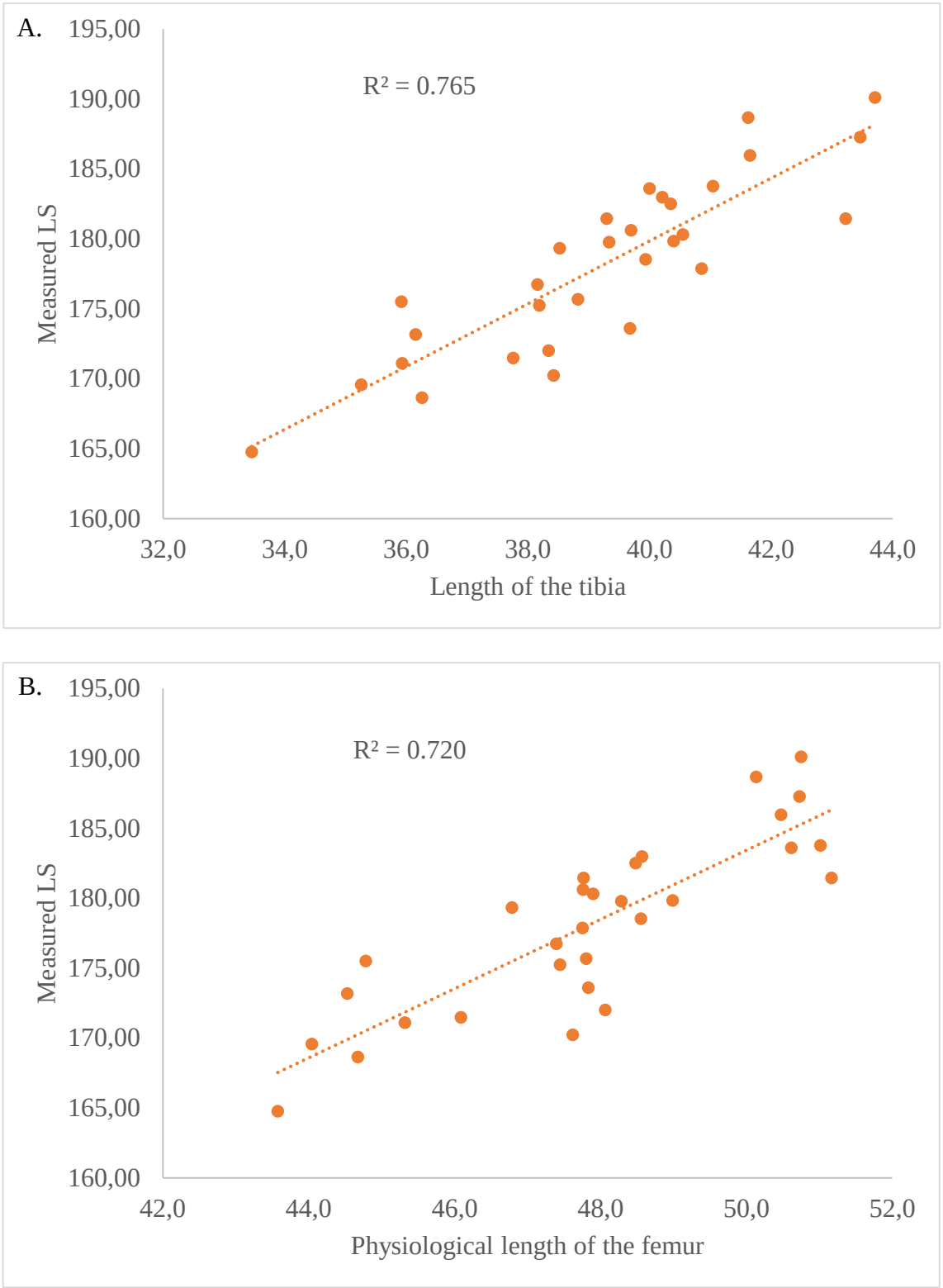

Figure 4.4: Scatter plot indicating the correlation between A: measured living stature (LS) and the length of the tibia ($p < 0.01$; $r = 0.874$), B: measured living stature (LS) and the physiological length of the femur ($p < 0.01$; $r = 0.849$).

4.5. Paired t-test

Several estimates of LS were obtained by adding previously derived soft-tissue correction factors that are associated with the anatomical method. These soft-tissue correction factors were added to the TSH of each participant to estimate the LS of that individual. The paired t-test results and average under- and overestimation of the LS estimates when compared to the measured LS are presented in Table 4.6. All estimates of stature, apart from those derived using the soft-tissue regression equation derived by Cloete (2017), differ significantly from the measured LS. The soft-tissue correction factors proposed by Fully (1956) significantly underestimated the LS of the participants by an average of 6.14 ± 2.05 cm (1.34 cm – 10.35 cm). The soft-tissue regression equations stipulated by Raxter *et al.* (2006), and Brits *et al.* (2017) both significantly underestimated the stature of the participants by 4.80 ± 1.83 cm (0.81 cm – 8.77 cm), and by 0.96 ± 2.00 cm (4.26 cm – 4.18 cm), respectively. The soft-tissue regression equations stipulated by Bidmos and Manger (2012) significantly overestimated the measured LS of the participants by an average of 9.65 ± 2.00 cm (5.43 cm – 14.65 cm). Whereas the soft-tissue regression equations stipulated by Cloete (2017) only slightly overestimated the stature of the participants by an average of 0.65 ± 2.04 cm ((-3.79 cm) – 5.62 cm), however, this was not significant ($p = 0.10$).

Figure 4.5 graphically represents the data in Table 4.6. The lines representing LS_{Fully}, and LS_{Raxter} clearly show the significant underestimation of LS when compared to the black line of measured LS, whereas LS_{Bidmos} significantly overestimates the stature of the participants when compared to the measured LS. The lines of LS_{Brits} and LS_{Cloete} are closely related to the measured LS line, demonstrating the slight, although significant, underestimation of $LS_{Brits,}$ and the slight, but not significant, overestimation of LS_{Cloete}.

Table 4.6: The paired t-test results of the comparison between measured LS and the estimates of LS, as well as the maximum, minimum, mean, and standard deviation (SD), of the over- and underestimations of the estimates of LS when compared to the measured LS.

	p-value	Maximum (cm)	Minimum (cm)	Mean (cm)	SD (cm)
LS_{Fully}	$p < 0.0001$	-1.34	-10.35	-6.14	2.05
LS_{Raxter}	$p < 0.0001$	-0.81	-8.77	-4.80	1.83
LS_{Bidmos}	$p < 0.0001$	14.65	5.43	9.65	1.99
LS_{Brits}	$p = 0.02$	4.18	-4.26	-0.96	2.00
LS_{Cloete}	$p = 0.10$	5.62	-3.79	0.65	2.04

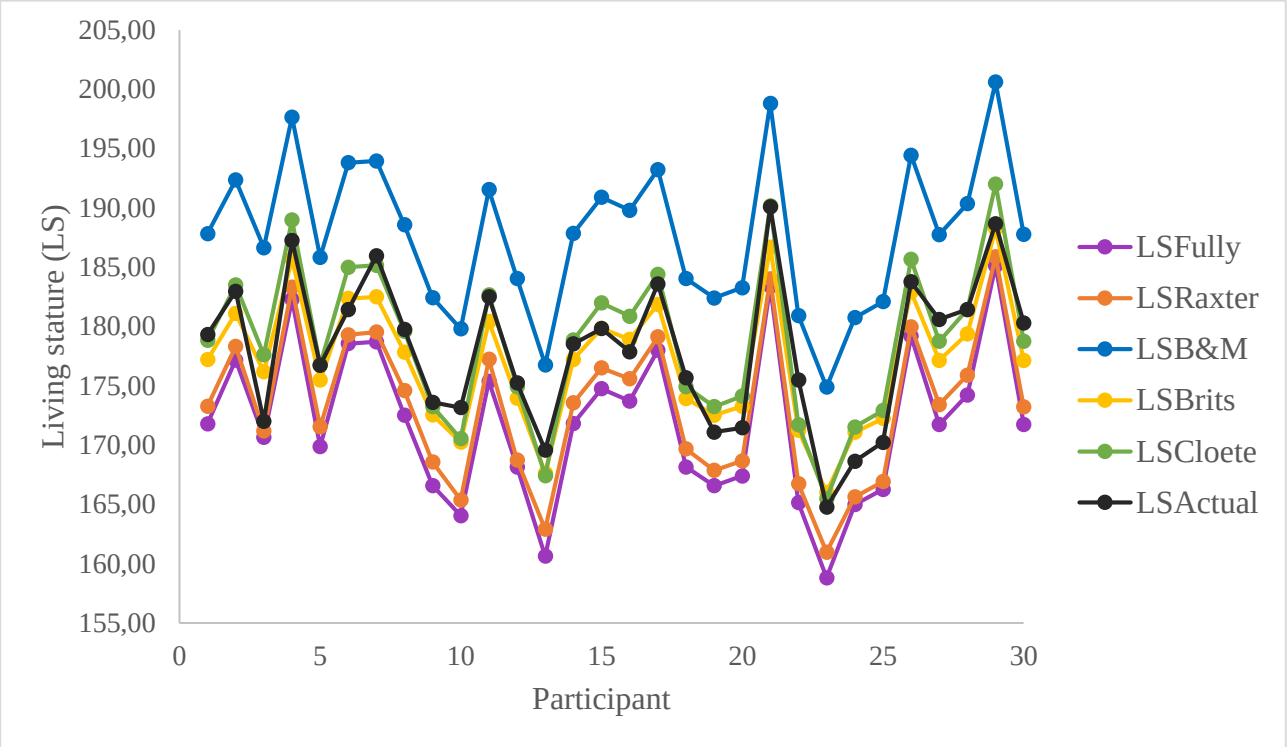

Figure 4.5: Line graph illustrating the underestimation and overestimation of measured LS according to the soft-tissue correction factors proposed by Fully (1956), Raxter *et al.* (2006), Bidmos and Manger (2012), Brits *et al.* (2017), and Cloete (2017).

4.6. New regression equation

The significant under- and overestimation of LS using current versions of the anatomical method suggest the necessity for a soft-tissue regression equation specific for the stature estimation of White South African males. Although Cloete's (2017) soft-tissue regression equation developed specifically for White South African females, did not significantly overestimate the LS of the participants, a newly derived soft-tissue regression equation specific for the stature estimation for White South African males was generated to improve the overall accuracy of stature estimates.

Living stature = 0.948*TSH + 21.77 (SEE = 2.03 cm)

This regression equation was derived using the relationship between measured LS and TSH and represents a significant ($p < 0.01$), and strong, positive correlation ($r = 0.948$). Larger correlation values indicate a stronger relationship between two variables, where a correlation of 1 indicates a perfect relationship. Additionally, the R^2 value associated with this equation is 0.899, meaning that 89.9% of the variation in measured LS is as a result of TSH variance (Table 4.4). This equation is also characterised by a small standard error of estimate (SEE), indicating a high degree of accuracy. The accuracy of this regression equation was tested by comparing the measured LS to the estimated LS calculated using the above newly calculated soft-tissue regression equation, by adding and subtracting one SEE-value, and two SEE-values, respectively. From these results, 63% of the estimates of LS fell within one SEE (SEE = 2.03 cm), and 97% fell within two SEE values (SEE = 4.06 cm), when compared to the measured LS. Interestingly, 87% of the LS_{Cloete} estimates fell within one SEE (SEE = 3.18 cm), and 100% fell within two SEE values (SEE = 6.36 cm) of Cloete's (2017) regression equation, when compared to the measured LS of the current sample.

CHAPTER 5: Discussion

This study was aimed at assessing the accuracy of the soft-tissue correction factors associated with the anatomical method for stature estimation in a sample of White South African males. The accuracy of these soft-tissue correction factors have been called into question as previous research has shown that these correction factors may be specific to the population, and sex from which they were derived (King, 2004; Bidmos, 2005). The soft-tissue correction factors associated with the anatomical method for LS estimation were previously derived from the research of Fully (1956) and Raxter and colleagues (2006). Recent research has, however, shown that these soft-tissue correction factors were not appropriate when applied within a South African context (Bidmos & Manger, 2012; Brits *et al.*, 2017; Cloete, 2017). It is imperative that the accuracy of the soft-tissue correction factors associated with the anatomical method be assessed, as this method is largely considered to be the most accurate when estimating the LS of unknown skeletal remains (Bidmos, 2005; Maijanen, 2009), and, therefore, should be evaluated to ensure that the integrity of the method is maintained when applied to the South African and other population groups.

5.1. Virtual anthropology and MRI scans

Due to the effects of secular change, skeletal collections may no longer represent individuals of modern populations (Meadows & Jantz, 1995; Meadows-Jantz & Jantz, 1999; Dirkmaat *et al*., 2008; Wilson *et al.*, 2010). Additionally, these skeletal collections have an associated CS (Hunt & Albanese, 2005; L'Abbé *et al.*, 2005; Dayal *et al.*, 2009; Maijanen & Jeong, 2018) which oftentimes is either missing or incorrect (Lundy, 1983; Bidmos, 2005). CS is the height of a cadaver and is associated with several errors due to various different types of measurement techniques that are used to collect this data (Christensen *et al.*, 2014). For example, researchers have collected CS while the individual is in the supine position, whereas others measured the upright CS of the individual on an upright pivot table (Maijanen, 2009; Cardoso *et al.*, 2016).

Therefore, using the measured LS of an individual removes these errors, and also negates the sampling biases associated with these skeletal collections (Komar & Grivas, 2008).

Anthropologists have sought out alternative methods to conduct research on modern populations, to circumvent the problems associated with skeletal collections. Virtual anthropology (Weber *et al.*, 1998) affords researchers the unique opportunity to study the osteology of modern populations through non-invasive means and does not require the maceration and dissection of these individuals (Dedouit *et al.*, 2007; Hishmat *et al.*, 2015; Franklin *et al.*, 2016; Carew & Errickson, 2019). MRI is a non-ionising imaging technique and is, therefore, safer when imaging the internal structures of the living individuals (Dempsey *et al.*, 2002; Semelka *et al.*, 2007; Kulaylat *et al.*, 2015; Carew & Errickson, 2019), and as such was used in this study.

5.2. Repeatability

The skeletal measurements obtained from the MRI scans used in this study were those of the bones that directly contribute to the LS of an individual as per the recommendations of Fully (1956). Fully (1956), however, was vague in his descriptions on how to take these measurements, and therefore, Raxter and colleagues (2006) clearly defined the techniques used to collect these measurements. Although the definitions set forth by Raxter and colleagues (2006) were adhered to, where possible, modifications made by Brits and colleagues (2017) had to be used to allow for these skeletal measurements to be collected from the MRI scans. These modifications had to be followed as certain landmarks suggested by Raxter *et al.* (2006) were not visible in the coronal or sagittal orientations of the MRI scans. These modifications are stipulated in the "Materials and Methods" chapter, section 3.1 (pages 28-32).

The intra- and inter-observer repeatability regarding the measurements used were assessed using the technical error of measurements (TEM), the relative technical error of measurement (%TEM), and the coefficient of reliability (R). TEM is the most commonly used method to

estimate the precision of repeated measurements (Ward & Jamison, 1991; Ulijaszek & Kerr, 1999). TEM values are positively associated with the means of the measurement being assessed, where smaller TEM values indicate a smaller error, and therefore a more precise measurement (Ulijaszek & Kerr, 1999; Weinberg *et al.*, 2005; Arroyo *et al.*, 2010). Although there is no universally agreed upon cut-off for TEM (Liebenberg & Krüger, 2020), a maximum value of 3 mm has been recommended by Sierp and Henneberg (2016) for skeletal measurements, while forensic anthropologists suggest a maximum acceptable level of 2mm (Stull *et al.*, 2013).

As expected, the results for intra-observer repeatability demonstrated a higher degree of reproducibility than the results of inter-observer repeatability (Perini *et al.*, 2005). The TEM values for both intra- and inter-observer repeatability fell within or below the 3 mm cut-off and are therefore considered to be repeatable. However, for inter-observer repeatability, heel height exceeds the 2 mm limit deemed acceptable in forensic anthropology (Stull *et al.*, 2013).

The subsequent conversion of TEM to %TEM allows for the comparison of imprecision between different measurements, despite the size of their means (Ulijaszek & Kerr, 1999). Perini and colleagues (2005) have recommended that the %TEM does not exceed 1.5% for intra-observer and 2.0% for inter-observer error, respectively. The only two measurements, for intra-observer repeatability, that do not comply with these error rates were the anterior vertebral heights of T10 and L5. Whereas, for inter-observer repeatability, the anterior vertebral body heights of C2, C7, T10, and L5, as well as heel height did not comply with these cut-off points. However, these repeatabilities comply with the cut-off point of <5% set forth by Uzun and colleagues (2019).

The coefficient of reliability (R) is used as an additional measure of precision (Ulijaszek & Kerr, 1999), and ranges between values of 0 and 1. Conversely to the TEM and %TEM values, the higher the R-values, the greater the measure of precision, where values greater than 0.75

are considered to be sufficiently precise (Ward & Jamison, 1991; Weinberg *et al.*, 2005). The only measurements that lies outside of the acceptable level of R > 0.75, were the anterior vertebral body heights of C2 and C7, for inter-observer repeatability.

A major limiting factor of this study was that some of the participants found it difficult to maintain their feet in the anatomical position while being scanned, which was similarly described by Bidmos and Manger (2012). Therefore, certain heel height measurements had to be taken over several slices of the MRI scan which made it difficult to maintain consistent landmarks when re-measuring the heel heights of some individuals. In addition, the vertebral measurements were often obscured by the presence of soft-tissue, making it difficult to clearly identify and maintain the landmarks used. Overall, it is likely that training in radiographic imaging analysis may improve the repeatability of these measurements, as the degree of imprecision is increased if measurements are taken by poorly-trained individuals (Ulijaszek & Kerr, 1999). Additionally, a consensus must be reached in clearly defining how osteological measurements are taken from radiographic images to ensure that these measurements are taken consistently across various research studies, which would also allow for the direct comparison with various studies of a similar nature.

5.3. The living stature of White South African males

The mean measured LS of White South African males from various studies is summarised in Table 5.1, along with the mean LS of Black South African males and females, White South African females, as well as males of various other populations. The measured LS of the individuals in this study ranged between 164.77 cm and 190.10 cm (178.05 ± 6.29 cm) and is comparable to the statures of White South African military males (178.45 ± 6.85 cm) reported by Steyn and Smith (2007). This sample is, therefore, considered a representation of modern living White South African males. However, the LS reported for White South African males by Henneberg and van der Berg (1990) was taller (179.30 cm) than the LS of the current

sample. This difference could be attributed to the fact that Henneberg and van der Berg (1990) used the measured heights of first-year medical students, while the current study made use of the measured LS of individuals of the general population. As such Henneberg and van der Berg's (1990) sample may be taller as they could present with a higher socioeconomic status, as well as being younger than the individuals of the current sample, and as such may still be affected by the variation observed in the skeletal maturation of young males (Murray & Clayton, 2013; Cunningham *et al*., 2016). The measured LS of the current study is also comparable to the recorded heights of White South African males reported by Myburgh and colleagues (2017), whose sample was similar to Steyn and Smith's (2007) sample.

The measured LS of males from the current study were similarly comparable to the reported heights of White North American males (Fryar *et al.*, 2021) while being taller than some populations, such as "Caucasian" Italian males (Giurazza *et al.*, 2012), Indian males (Geetha *et al.*, 2015), Swiss males (Myburgh *et al.*, 2017), and Black North American males (Fryar *et al.*, 2021), and shorter than others, such as Nigerian (Didia *et al.*, 2009), and Dutch (Myburgh *et al.*, 2017) males. Additionally, White South African males were concluded to be significantly ($p < 0.05$) taller than the LS of White South African females (Cloete, 2017: 166.43± 6.46 cm), Black South African males (Bidmos & Manger, 2012: 170.79 ± 5.29 cm), and Black South African females (Brits *et al.*, 2017: 159.0 ± 5.30 cm).

Table 5.1: Comparison of the means and standard deviations (SD) of the measured living statures (LS) between various populations.

Population	Reference	Mean (cm)	SD (cm)
White South African males	Present study	178.05	6.29
White South African males	Henneberg & van der Berg, 1990	179.30	-
White South African males	Steyn & Smith, 2007	178.45	6.85
White South African males	Myburgh *et al.*, 2017	178.60	6.55
White South African females*	Cloete, 2017	166.43	6.46
Black South African males*	Bidmos & Manger, 2012	170.79	5.29
Black South African females*	Brits *et al.*, 2017	159.00	5.30
White North American males	Fryar *et al.*, 2021	178.00	0.39
Black North American males	Fryar *et al.*, 2021	176.40	0.34
Nigerian males	Didia *et al.*, 2009	183.44	46.66
Indian males	Geetha *et al.*, 2015	157.95	6.42
Japanese males	Torimitsu *et al.*, 2016	168.10	6.00
"Caucasian" Italian males	Giurazza *et al.*, 2012	167.00	7.10
Swiss males	Myburgh *et al.*, 2017	176.50	0.60
Dutch males	Myburgh *et al.*, 2017	180.20	-

* indicates a significant difference when compared to the measured LS of White South African males at $p < 0.05$.

The mean TSH for White South African males was 161.18 cm, which is taller than the TSH calculated for White South African male skeletal samples from the Raymond A. Dart Collection reported by Chibba and Bidmos (2007: 159.20 cm), and Bidmos (2008b: 157.65 cm). The mean TSH for the current sample is also taller than the reported skeletal heights of "European" (156.20 cm) and "African" (155.80 cm) American males, made by Niskanen and colleagues (2013). Differences in the sample types between the osteological data of Chibba and Bidmos (2007), Bidmos (2008b), and Niskanen and colleagues (2013), and the radiographic data of the current sample could, in part, explain these differences. Similarly, the

differences observed between Niskanen *et al.*'s (2013) sample and the current sample could be attributed to the differing genetic make-up and environmental influences that act upon these two samples. Additionally, the average TSH of White South African males is taller than the TSH of Black South African males (Bidmos & Manger, 2012: 144.92 cm), and females (Brits *et al.*, 2017: 141.13 cm), as well as White South African females (Cloete, 2017: 149.22 cm), which supports the population differences that is observed between these samples.

These results support the consensus that there are sex differences between the statures of males and females (Gray & Wolfe, 1980; Eveleth & Tanner, 1990; Gustafsson & Lindenfors, 2004), whereby males are significantly taller than females (Lundy & Feldesman, 1987; Steyn & İşcan, 1997; Hauser *et al.*, 2005; Bidmos, 2006; Chibba & Bidmos, 2007; Steyn & Smith, 2007; Dayal *et al*., 2008; Wells, 2012). The populational differences observed between Black South African males and White South African males from this study is also supported by the differences between these groups as reported by Steyn and Smith (2007), as well as the differences observed between Black and White North American populations (Fryar *et al.*, 2021). These differences were additionally observed in the research conducted by Myburgh (2016) where the stature of White South African males, is significantly taller than White South African females, as well as Black South African males and females. These differences could be attributed to the differences in the genetic make-up, and socioeconomic statuses between these two groups (Steyn & Smith, 2007; Myburgh, 2016). And lastly, the differences observed between the measured LS, and the TSH of the White South African male sample of this study and the heights of other population groups may be due to the differential effects that genetics and environmental factors, such as health, nutrition, and socioeconomic status have on the different population groups (Eveleth & Tanner, 1990; Stulp & Barrett, 2016).

The mean physiological lengths of the femur (47.84 cm) and the mean lengths of the tibia (39.21 cm) of the current sample are larger than the reported means of White South African

females (Cloete, 2017: femur: 44.54 cm; tibia: 36.16 cm), Black South African females (Brits *et al.*, 2017: femur: 43.30 cm; tibia: 36.50 cm), and Black South African males (Bidmos & Manger, 2012: femur: 45.20 cm; tibia: 38.20 cm). Additionally, the mean physiological length of the femur and the length of the tibia of this study are slightly higher than those of the mean femoral lengths (46.47 cm) and tibial lengths (38.25 cm) reported by Dayal and colleagues (2008), and the mean length of the tibia (37.67 cm) reported by Steyn and İşcan (1997). The measurements from this sample are also larger than the physiological length of the femur (42.43 cm), and the length of the tibia (34.33 cm) of a Korean sample reported by Jeong and Jantz (2016). These differences could be attributed to the fact that this study utilised MRI scans, and the comparative studies made use of osteological data from various skeletal collections (Steyn & İşcan, 1997; Dayal *et al*., 2008; Jeong & Jantz, 2016). Additionally, the differences in the averages between the lengths of the femur and tibia between different population groups could also be attributed to the differences between the environmental influences of these different populations, as well as the genetic and sex differences between the population groups within South Africa.

5.4. Accuracy of the soft-tissue correction factors of the anatomical method

King (2004) tested Fully's (1956) method on a sample of 36 Black and White North American individuals from the William M. Bass Donated Skeletal Collection and concluded that the estimates of stature using Fully's (1956) soft-tissue correction factors, on average, underestimated the stature of these groups by 2.4 cm. Larger underestimations were concluded by Bidmos (2005), when he assessed Fully's (1956) method on a South African sample of 156 Black and White skeletons from the Raymond A. Dart Collection of Modern Human Skeletons and found that Fully's (1956) method, on average, underestimated the stature of these groups by 4.3 cm. However, the higher magnitude of Bidmos' (2005) results may be due to the fact that the cadaveric statures affiliated with the Dart collection has been found to be an

overestimation of LS, and therefore the differences between the estimates of LS and CS would be considered larger (Bidmos, 2005; Raxter *et al.*, 2006). Additionally, the differences between the two studies could be attributed to the variations in the genetics and environmental conditions of the two samples.

Raxter and colleagues (2006) concluded the same magnitude of underestimation (2.4 cm) as King (2004) when they applied the Fully's (1956) method to a sample of 119 Black and White North American skeletons from the Terry Collection at the National Museum of Natural History. The similarities between the findings of King (2004), and Raxter *et al.* (2006) could be explained by the genetic and environmental similarities of their samples (Béguelin, 2011; Sládek *et al.*, 2015). Both King (2004), and Bidmos (2005) suggested that there is a sex- and population-specificity associated with the soft-tissue correction factors affiliated with the anatomical method, which would have to be applied only to the populations from which they are derived, whereas Raxter and colleagues (2006) disagreed.

Similar to the reported results of King (2004), Bidmos (2005), and Raxter and colleagues (2006), the current study found that the soft-tissue correction factors of Fully (1956) significantly underestimated the stature of White South African males, by a magnitude of 6.1 cm. This underestimation is comparably smaller than those stipulated by the findings of Bidmos and Manger (2012), Brits and colleagues (2017), as well as Cloete (2017), for the underestimation of stature of Black South African males (15.8 cm), and females (7.9 cm), and White South African females (7.1 cm), respectively. Similarly, there was a significant underestimation of stature when using the soft-tissue regression equations stipulated by Raxter and colleagues (2006) by a magnitude of 4.8 cm, which is smaller than the underestimations of 14.8 cm for Black South African males (Bidmos & Manger, 2012), of 6.8 cm for Black South African females (Brits *et al.*, 2017), and 6.1 cm for White South African females (Cloete, 2017). These underestimations agree with the findings of King (2004), and Bidmos (2005), in

that there may be sex-, and population-specificity associated with the soft-tissue correction factors of the anatomical method, at least within South African populations.

The soft-tissue regression equations derived specifically for the LS estimation of Black South African males (Bidmos & Manger, 2012), significantly overestimated the LS of Black South African females by 7.8 cm (Brits *et al.*, 2017), White South African females by 8.9 cm (Cloete, 2017), as well as the White South African male sample of the current study by a magnitude of 9.7 cm. The soft-tissue regression equations for Black South African females (Brits *et al.*, 2017), only slightly underestimated the stature of White South African females by 0.04 cm (Cloete, 2017), however, this underestimation was found to not be significant. Conversely, the current study found that the soft-tissue regression equation formulated for the stature estimation of Black South African females only slightly, but significantly, underestimated the stature of White South African males by 1.0 cm, while the soft-tissue regression equation specifically formulated for the stature estimation of White South African females (Cloete, 2017) only slightly, but not significantly, overestimated the stature of White South African males by 0.7 cm.

From these results, we can infer that there appears to be sex differences in the soft-tissue between Black South African males and females, as the stature estimations made for Black South African females were significantly overestimated when using the soft-tissue regression equations formulated for Black South African males. However, the same cannot be inferred for White South African males and females, as there was only a slight but not significant overestimation of the stature of White South African males when using the soft-tissue regression equations specific for White South African females. These differences between Black South African males and females support the idea that there are sex differences between male and female individuals of the same population (Gray & Wolfe, 1980; Eveleth & Tanner, 1990; Gustafsson & Lindenfors, 2004). Another factor that may better describe this relationship

is that males are thought to be more sensitive to unfavourable changes in the environment (Cole *et al.*, 2015; Stulp & Barrett, 2016), and as such, during the period of Apartheid in South Africa, where Black South Africans were extremely disadvantaged and oppressed, male statures could have been more severely affected than female stature. Therefore, the measured LS of Black South African males may be undergoing a more rapid increase in mean stature as these environmental conditions improve. This is supported whereby Black South Africans previously presented with a negative secular trend in LS (Tobias, 1985), but in more recent years, this trend was found to be leaning towards a slight positive secular change in the mean stature of Black South African males as described by Steyn and Smith (2007). Similarly, Myburgh (2016) concluded that Black South African males were the only population group that presented with a positive secular trend in recent years, while White South African males and females, and Black South African females had not had a significant increase in stature in the past 60 years.

This is similarly observed in the lack of a significant difference between the measured LS of White South African males and females, whereby White South Africans had similar environmental conditions as they do now, and as such the relationship between White South Africans and stature are similar, despite the sex differences between these two groups. This is supported by this current study as the equation derived from a White South African female sample is considered accurate when estimating the stature of White South African males, and it can therefore be inferred that White South Africans have been subjected to similar environmental factors.

The significant differences between the measured LS of White South African males compared to Black South Africans appears to be affected by population differences in soft-tissue, however the same cannot be inferred for the lack of significant differences between Black and White South African females. These differences may be attributed to the differential effects that genetics and environmental factors have on the different population groups (Eveleth

& Tanner, 1990; Stulp & Barrett, 2016), as well as the differences of the effect of secular change has on different population groups within a South African context (Myburgh, 2016). The similarities between the measured LS of Black and White South African females were explained by Cloete (2017) as the possibility that the variations in height of females are not as diverse as the variation observed in males, similarly noted by Bidmos (2005), and Bidmos and Manger (2012). The possibility of sex and population differences is similarly demonstrated in the research by Lan (1995), Aulsebrook and colleagues (1996), and Cavanagh and Steyn (2011) for the use of soft-tissue correction factors in facial reconstruction.

It is, however, important to note that Ruff and colleagues (2012) proposed the possibility of an underestimation of TSH based on the measurements used by Bidmos and Manger (2012). For example, Ruff and colleagues (2012) suggested that Bidmos and Manger (2012) underestimated the height of the vertebral column and overestimated the height of the intervertebral discs, by approximately 9 cm, as well as underestimating the talocalcaneal height by 2 cm. Additionally, the average soft-tissue correction factors of Bidmos and Manger (2012) were 25.9 cm, which was larger than those proposed within the literature (Fully, 1956: 10.5 and 11.5 cm; Raxter *et al.*, 2006: 12.4 cm; Brits *et al.*, 2017: 17.9 cm; Cloete, 2017: 17.2 cm; and 16.9 cm of the current study). Therefore, the TSH for Bidmos and Manger's (2012) sample may be slightly smaller than the TSH of Brits *et al.* (2017), Cloete (2017), as well as the TSH of the current study, which could contribute to the differences observed between the estimations of stature.

5.5. New soft-tissue regression equation

It has been ascertained from the current study that previous soft-tissue correction factors and regression equations have yielded inaccurate results when estimating the stature of White South African males. Although the Cloete (2017) regression equation did not show any significant difference between the measured LS and estimated LS, a new soft-tissue regression

equation was generated in an attempt to improve the accuracy of the estimation of stature of White South African males.

The correlations, R^2, and SEE-values of the regression analyses used in the present study and various other studies are summarised in Table 5.2. The newly derived regression equation specific for the stature estimation of White South African males demonstrates a strong, positive linear correlation between measured LS and TSH. This correlation, as well as the SEE value and the R^2 value associated with this equation, were larger than the correlations, SEE and R^2 values between the measured LS, the physiological length of the femur, and the length of the tibia for White South African males. This was to be expected due to the fact that TSH constitutes all the skeletal lengths that directly contribute to an individual's LS, and would have the strongest association with the measured LS (Raxter *et al.*, 2006; Maijanen, 2009).

The correlation (0.948) of the newly derived equation is also comparable to the correlations between LS and TSH reported for North Americans (Raxter *et al.*, 2006: 0.956), Black South African males (Bidmos & Manger, 2012: 0.934), and females (Brits *et al.*, 2017: 0.942), and was greater than the correlation for White South African females (Cloete, 2017: 0.877). Additionally, this correlation was similar to the correlations described between LS and the multivariate relationships of the lumbar spine, the femur, and the tibia reported by Dayal *et al.* (2008) for the stature estimation of White South African males using these measurements. In addition to the strong correlations observed between TSH and measured LS, the strong correlations between the lower limb measurements and measured LS was expected, as the lower limb bones contribute the majority of the proportion of LS (Dayal *et al.*, 2008; Bidmos & Manger, 2012; Brits *et al.*, 2017).

Table 5.2: Comparison of the regression equations of various studies.

Population	Equation	Reference	Correlation	R^2	SEE (cm)
White South African males	Living stature estimation	Present study	0.948	0.899	2.03
White South African males	Physiological length of the femur	Present study	0.849	0.720	3.39
White South African males	Length of the tibia	Present study	0.874	0.763	3.11
White South African females	Living stature estimation	Cloete, 2017	0.877	0.768	3.18
Black South African females	Living stature estimation	Brits *et al.*, 2017c	0.942	0.888	1.80
Black South African males	Living stature estimation	Bidmos & Manger, 2012	0.934	0.872	1.93
North American males & females	Living stature estimation	Raxter *et al.*, 2006	0.956	-	2.22
White South African males	Lumbar spine + femur + tibia	Dayal *et al.*, 2008	0.960	0.920	1.92
White South African males	Lumbar spine + femur	Dayal *et al.*, 2008	0.950	0.900	2.17
White South African males	Femur + tibia	Dayal *et al.*, 2008	0.930	0.860	2.49

It is interesting to note, however, that the length of the tibia had a higher correlation with measured LS than the physiological length of the femur, which is not commonly reported within the literature. The correlation between LS and the physiological length of the femur is typically higher than the correlation between LS and the length of the tibia, as described by the vast majority of research (Trotter & Gleser, 1952; Feldesman & Fountain, 1996; Dobisíková *et al.*, 2001 as described in Dobisíková *et al.*, 2008; Dayal *et al.*, 2008; Bidmos & Manger, 2012; Hishmat *et al.*, 2015; Sládek *et al.*, 2015; Brits *et al.*, 2017; Cloete, 2017; Bidmos & Brits, 2020). However, the stronger correlation between tibial length and LS reported by the current study is supported by the findings of Petrovečki and colleagues (2007), as well as Jeong

and Jantz (2016). It is unsurprising that the results from the current study concur with the findings that stature estimation equations are most accurately derived from the lengths of the lower limb, long bones, with the length of the tibia presenting with the most accurate results of the individual skeletal elements, in the current study.

The R^2 of the newly derived soft-tissue regression equation (0.899) indicates that 89.9% of the variation observed for the measured LS is as a result of the variation in TSH which is comparable to R^2 values described by Dayal and colleagues (2008), Bidmos and Manger (2012), Brits and colleagues (2017), and is greater than the R^2 value described by Cloete (2017). Additionally, the differences between the correlations, R^2 and SEE-values observed between the equation described by the relationship between measured LS and the lower limb measurements of the present study, and those of Dayal *et al.* (2008) could be attributed to the fact that Dayal and colleagues (2008) derived their equations from the osteological data of skeletons in the Raymond A. Dart Collection of Modern Human Skeletons, while the present study made use of the osteological data derived from the MRI scans of living individuals.

If SEE is an indicator of the accuracy of a regression equation (Sjøvold, 2000), the accuracy of the newly derived soft-tissue regression equation is comparable to accuracies of the equations derived by Raxter *et al.* (2006), Dayal *et al.* (2008), Bidmos and Manger (2012), Brits *et al.* (2017), and was higher than the accuracy of Cloete's (2017) equation for the stature estimation of White South African females. Similarly, 97 % of the stature estimates made using the new regression equation fell within two SEEs of the measured LS. Although 100% of the LS_{Cloete} estimates fell within two SEEs of the measured LS, it is important to remember that Cloete's (2017) equation is associated with a higher SEE value than what is presented in the current study, and as such is considered less accurate, particularly for the estimation of stature of White South African males. The strong correlation, high R^2, and low SEE values attest to

the accuracy of the newly derived soft-tissue regression equation, and its applicability for the stature estimation of White South African males.

5.6. Limitations

The sample size of the current study is quite low but comparable to that by Bidmos and Manger (2012), Brits and colleagues (2017), and Cloete (2017), and this was due to difficulties in recruiting participants, particularly with the restrictions imposed by the COVID-19 and the associated lockdown levels which prevented travel and all nonessential hospital visits. The cost associated with MRI scans was also a limiting factor. Additionally, some participants withdrew from the study as they felt claustrophobic when undergoing the MRI scan, as well as some participants having to be excluded due to technical difficulties in scanning. Future research would be greatly improved by an increased sample size.

A lack of radiographic imaging analysis training, along with using MRI scans to collect osteological data proved to be limiting factors in this study. As more research is conducted through virtual anthropology, a consensus must be made on how to collect osteological measurements from radiographic material to ensure consistency when making comparisons with other studies, while adhering to the Daubert criteria (Dirkmaat *et al.*, 2008).

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CHAPTER 6: Conclusion

The aim of this study was to assess the accuracy of the soft-tissue correction factors associated with the anatomical method for the estimation of stature in a White South African male sample. These soft-tissue correction factors were long believed to be applicable regardless of the sex or population-affinity of the individual being assessed, however, the validity of these soft-tissue correction factors has been questioned. Previous research has demonstrated problems associated with these factors, particularly within a South African context. The current study made use of Magnetic Resonance Imaging (MRI) scans to assess the accuracies of the soft-tissue correction factors and soft-tissue regression equations associated with the anatomical method and found that, barring the soft-tissue regression equation derived by Cloete (2017) from a White South African female sample, previously established soft-tissue correction factors and regression equations were inappropriate when used to estimate the LS of White South African males.

Although Cloete's (2017) soft-tissue regression equation is considered sufficiently accurate for the estimation of stature for White South African males, a new regression equation was derived specifically for White South African males, in an attempt to increase the accuracy of the stature estimation for this group. This equation was characterised by a strong positive correlation between measured LS and TSH, as well as a small SEE value further attesting to its accuracy. Therefore, either the newly derived soft-tissue regression equation or Cloete's (2017) equation may be used to estimate the stature of White South African males, providing sufficiently accurate results.

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APPENDIX A: Human Research Ethics Committee (Medical)

Clearance Certificate No. M200411

UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

R14/49 Miles N Loubser and E Bussy

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
CLEARANCE CERTIFICATE NO. M200411

NAME: (Principal Investigator)	Miles N Loubser and E Bussy
DEPARTMENT:	School of Anatomical Sciences Medical School University
PROJECT TITLE:	Assessing the accuracy of soft-tissue correction factors for stature estimation in White South African males
DATE CONSIDERED:	2020/04/24
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Dr D Brits and Professor M Bidmos
APPROVED BY:	Dr CB Penny, Chairperson, HREC (Medical)
DATE OF APPROVAL:	2020/08/19

This clearance certificate is valid for 5 years from the date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and ONE COPY returned to the Research Office Secretary on the 3rd Floor, Phillip Tobias Building, Parktown, University of the Witwatersrand, Johannesburg.

I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to submit details to the Committee. I agree to submit a yearly progress report. When a funder requires annual re-certification, the application date will be one year after the date when the study was initially reviewed. In this case, the study was initially reviewed in April and will therefore reports and re-certification will be due early in the month of April each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature

20/08/2020
Date

APPENDIX B: Study information document

WITS UNIVERSITY

STUDY INFORMATION DOCUMENT

Study Title: Assessing the accuracy of soft-tissue correction factors for stature estimation in White South African males.

Good day! My name is Natasha Loubser and I am a Masters student in the School of Anatomical Sciences at the University of the Witwatersrand, in Johannesburg. My research is focused on estimating the height of an individual from their bones and developing South African specific techniques to do so. In order to achieve this I want to use Magnetic Resonance Imaging (MRI) scans of healthy individuals to develop more accurate methods of stature estimation.

Your involvement:

I would like to invite you to voluntarily participate by having a full body MRI scan taken at the Wits-Donald Gordon Medical Centre in Parktown. Before the scan, your height and weight will be measured. You will then be asked to lie as still as possible on the MRI scanning bed while the scan is being taken. This scan should take approximately 20 minutes. Once the MRI scan is complete, the images will be saved to a disc and reconstructed on a computer at the School of Anatomical Sciences where various bone measurements will be taken.

Please read the following statements, thoroughly, before considering to participate:

1. Prior to the scan, we will ask you to fill in the medical form attached. It is important to know and understand your medical and surgical history before you can qualify for this study.
2. Please be open with us regarding your health history to ensure no harm is done to you.
3. Information pertaining to your chromosomal sex, age, weight, and handedness (the dominant hand) will also be asked for. All your personal information will be kept confidential and you will remain anonymous in the study.
4. You will be asked to sign a consent form as confirmation of your understanding of the study. You will also receive a copy of this form.
5. You will not receive a copy of your MRI scan, nor will you be able to see it. As I am not a trained clinician, I will also not be able to discuss these scans with you.
6. Please only participate in this study if you are satisfied and comfortable with all the procedures involved.
7. Please do not hesitate to ask any further questions about this study to either myself, or my supervisors.

Will the MRI scan cause any discomfort or inconvenience?

Magnetic Resonance Imaging (MRI) is a non-invasive and painless medical imaging method with no known side-effects. Unlike X-rays and CT scans, MRI does not expose individuals to any radiation and is therefore considered to be the safest mode of rendering images of internal organs and structures. However, researchers have found that medical implants, such as pacemakers, cochlear implants and surgical implants may cause discomfort. Any foreign metal, such as shrapnel, may have the same effect. This discomfort is caused due to the fact that MRI machines create a magnetic field with strong static and radiofrequency energy to create the images. Therefore, individuals with any foreign metal

implants will not be allowed to participate in this study. Please note that all jewellery will be asked to be removed for the same reason. The MRI machine can also be noisy and for this reason earphones will be provided with some background music. The bore of the MRI machine is a small, confined space and individuals uncomfortable in small spaces (claustrophobic) should not participate. MRI scans may also cause heating as well as muscle twitching.
The qualified and experienced staff from the Department of Radiology at Wits-Donald Gordon Medical Centre will be performing all the scans. Please note that due to high patient loads at the Wits-Donald Gordon Medical Centre, the MRI scanning process may be delayed. For this reason, you may need to wait before you can be scanned. Alternatively, your appointment may be rescheduled.

Benefits and rights of this study:

- You will not directly benefit from this study, however, your participation will greatly contribute to the improvement of Forensic Sciences in South Africa.
- You may, at any point and without justification, withdraw from this study as your participation is completely voluntary.
- We do reserve the right to withdraw you from this study, at any point.
- Please note that a qualified radiologist will not be reviewing the MRI scans and therefore, no abnormalities will be recognised if they occur.

You may not participate if:

- You have suffered from any nutritional disease, including but not limited to, kwashiorkor.
- You have been afflicted by any bone-affecting diseases.
- You have broken a bone in the last year.
- You think you may or if you do suffer from claustrophobia.
- You have answered yes to any questions on the Wits-Donald Gordon Medical Centre MRI exclusion criteria list.

Financial arrangements:

- Due to the current COVID-19 pandemic afflicting the world, it is unsafe for potential participants to be transported to the Wits-Donald Gordon Medical Centre and therefore, all participants will be asked to travel there themselves.
- Each participant will be reimbursed for the fuel used from the Wits Health Sciences Campus to the Wits-Donald Gordon Medical Centre, at the standard Wits rate of R3.61/km. You will also be reimbursed for the parking cost incurred at the medical centre (± R10.00).

Ethical approval:

An application for ethical clearance has been approved by the Human Research Ethics Committee – Medical (Clearance certificate number: M200411) at the University of the Witwatersrand. If you want any information regarding your rights as a research participant, or have any complaints regarding this study, you may contact Prof. C Penny, the Chairperson of the University of the Witwatersrand, Human Research Ethics Committee (HREC), which is an independent committee established to help protect the rights of research participants at (011) 717 2301.

Confidentiality:

Participation is voluntary, and there is no requirement to provide a reason for withdrawing. All information collected during this study, including personal and research data, will remain confidential and the anonymity of each participant will be preserved. Participant information will kept anonymous. Each participant will receive a unique participation number associated with their MRI scan and therefore I will not have access to any identifiable information. All personal data will be kept with the research supervisor, Dr Brits. Data will be combined, ensuring that no individual can be identified.

Data that may be reported on in scientific journals or at scientific conferences will not include any information that may identify you as a participant. Your signature of confirmation additionally authorizes us to release your information to respective authorities, which include:

1. Personal information that may be disclosed if required by law.
2. The Human Research Ethics Committees of the University may require personal data to respond to a formal complaint or in the case of a compliance audit.

All full body MRI scans, associated with your unique participation number, will remain on a secured computer in the School of Anatomical Sciences at the Wits Health Sciences campus where they will be available for possible future research. Informed consent to use these scans for future research is given when you sign the participation consent form. Possible future researchers will, however, have to receive ethical clearance before they will be allowed to use these scans. Your information will also be kept anonymous in future research. Additionally, demographic information (i.e. age, height, weight etc.), scans and/or measurements can be shared with prospective researchers upon ethical approval. The MRI scans will be stored at the School of Anatomical Sciences at the University of the Witwatersrand. Furthermore, subject to the Human Research Ethics Committee (HREC, Medical), the MRI scans taken in this study may be used for future research.

Please contact me if you have any questions or require any additional information about this study:

- Natasha Loubser: 062 237 2127 or 1471341@students.wits.ac.za
- Alternatively, you can contact my supervisor, Dr Desiré Brits at 011 717 2304 or desire.brits@wits.ac.za

APPENDIX C: Participant consent sheet

WITS UNIVERSITY

PARTICIPANT CONSENT SHEET

Project Title: Assessing the accuracy of soft-tissue correction factors for stature estimation in White South African males

I hereby confirm that I, _____, have been informed by the investigator, Natasha Loubser, about the nature, conduct, benefits and risks of the study.

I have received, read and understood the Study Information Document of the study, which explains the possible risks and benefits of the study. I understand the exclusion criteria of participating in this study and I confirm that they do not apply to me.

I understand that all my information collected during this study, including my age, sex, weight, height, population affinity, handedness, and the MRI scan will be used anonymously in this study and possibly in future research.

I understand that I will not receive a copy of my MRI scan and that the researcher will not discuss my MRI scan with me.

If anything anomalous is picked up by the researcher I will be informed based on the selection made on the participant data sheet. I, however, note that these scans will not be reviewed by a medically trained person and are not for diagnostic purposes.

I understand that I may withdraw my participation from this study, without reason, at any point. I also understand that I may be withdrawn from the study at any point, without reason.

I have had sufficient time to ask questions as well as do further research on my own if needed.

I am completely willing to participate in the study through the use of MRI scans.

I understand that I will receive a copy of this consent form.

Contact details:

Natasha Loubser, Principal Investigator, telephone no. 062 237 2127, or by e-mail at 1471341@students.wits.ac.za,

Dr Desiré Brits, Supervisor, on telephone no. 011 717 2304, or by e-mail at desire.brits@wits.ac.za.

Professor CB Penny, Chairperson of the Human Research Ethics Committee (Medical) at the University of Witwatersrand, on telephone no. 011 717 2301, or by e-mail at Clement.Penny@wits.ac.za.

Ms. Z Ndlovu or Mr Rhulani Mkansi, Committee Secretariat, telephone nos.: 011 717 2700 or 1234, or by e-mail at: Zanele.Ndlovu@wits.ac.za or Rhulani.Mkansi@wits.ac.za.

Name of Participant: _____

Date: _____

Place: _____

Signature or mark _____

Witnessed by:

Name of Witness: _____

Signature: _____

Date: _____

APPENDIX D: Study participant data sheet

WITS UNIVERSITY

PARTICIPANT DATA SHEET

Age: _____ Sex (X): M F

Population affinity: _____ Handedness (X): Left Right

Height: _____ Weight: _____

There are a number of factors that can interfere with the reliability of this study. Please tick the appropriate box (X) and describe where applicable:

Have you ever suffered from any nutritional diseases? Y N

Describe: _____

Have you ever suffered from any growth related diseases? Y N

Describe: _____

Do you have any skeletal abnormalities? Y N

Describe: _____

Have you ever broken any bones? Y N

Which bones? _____

When: _____

Did you say yes to any of the questions on the form provided by Donald Gordon Medical Centre? Y N

Describe: _____

Do you participate in any sports? Y N

Describe: _____

Would you like to be informed of any <u>suspected</u> irregularities? Y N

Date: _____

APPENDIX E: Turn-it-in Digital Report

NLoubser - MSc Dissertation.docx

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