MEASURED HEIGHT AND HEIGHT ESTIMATED FROM BODY SEGMENTS IN HOSPITALISED ADULTS IN BLOEMFONTEIN, SOUTH AFRICA

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DECLARATION

I, Hanna Williamson, declare that the dissertation or interrelated, publishable manuscripts/published articles hereby submitted by me for the Magister degree at the University of the Free State is my own independent work and has not previously been submitted by me to another university/faculty. I further cede copyright of this research report in favour of the University of the Free State.

30 June 2019

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SUMMARY

Background and motivation: Accurate height measurement is essential in the assessment of the hospitalised patient, amongst others, to screen for malnutrition or risk of malnutrition, which negatively affects morbidity and mortality. Height is also used to calculate nutrition requirements, adjust drug dosages and predict lung volumes, muscle strength and glomerular filtration rate. The gold standard is measuring standing height with a stadiometer using a standardised technique. In the hospital setting, however, patients often cannot stand up straight and unassisted for accurate height measurements according to the standardised technique. Globally, several equations predicting height have been standardised on various populations; none have been developed specifically for the general or hospitalised South African population.

Methods: This study investigated the agreement and association between directly measured (reference) height, and self-reported height, height recorded on admission in the medical files, recumbent length, and height estimated by indirect methods based on body segment measurements (, demi-span, ulna length, knee height, tibia length, fibula length, and foot length) in three public hospitals in Bloemfontein, South Africa. Bland–Altman analysis was used to assess the 95% limits of agreement between the height predicted from published estimate equations and reference height. Spearman correlations and multiple regression analysis were used to identify the body segment that best predicted height in this population.

Results: Less than 5% of 141 participants (61.7% male; median age 38.8 years [interquartile range: 10.1 years] could self-report their height, and, although stadiometers were available in all the wards, only 16% had height recorded in their medical files. Healthcare practitioners, thus, did not seem to consider the measuring and recording of height as a priority. Eleven published equations developed for adults <65 years (and standardised for gender), based on various upper and lower body segments, were tested. Only a set of equations standardised for males and females, and black and white ethnicities, by Chumlea et al. (1994) on 5415 healthy adults <60 years in the United States, yielded predicted heights that did not significantly differ from the reference height measured in this study (95% CI; -0.9; 0.2) (95%

limits of agreement indicating that, in 95% of cases, height was underestimated by 5.8 cm to overestimated by 7.2cm). Knee height also correlated the strongest with height in both genders (males: R^2:0.77; females R^2:0.86; $p<0.0001$) and was identified by multiple regression analysis as the best predictor of reference height. Foot length and ulna length showed the weakest correlation with reference height and performed weakest in the regression analysis. Recumbent height, measured strictly according to the standardised technique, differed significantly from reference height, but yielded 95% limits of agreement indicating that, in 95% of cases, the recumbent length only underestimated height by 4.0 cm to overestimated height by 1.3 cm.

Conclusions: Clinical studies commonly suggest that body segment-based equations for predicting height, need to be standardised for each population, and suggested ethnic differences as the reason. The findings of this study, however, support evidence from forensic science, anthropology and growth studies that environmental stresses, including disease load and dietary niche, influence the development and growth of the various long bones in ways that affect the body proportions. This developmental plasticity differs across different body segments, causing lower limb length to show a greater proportionality to height. Relative leg growth is accelerated during the early years of life; thus, stunting seems to have a more pronounced effect on the length of the lower leg long bones. Thus, the high prevalence of stunting among South Africans may explain why knee height, outperformed upper body measurements in this population of patients admitted to public hospitals in a South African city.

Recommendations: Health care practitioners should be educated on the importance of accurately measuring height, especially as an integral part of screening for malnutrition or those at risk of malnutrition. More extensive studies across different South African populations are needed to confirm the findings, better the current understanding of the effects of environmental stressors on body proportion, and to develop accurate height-prediction equations that may be used in South African populations. Stunting in South Africa should also be addressed.

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LIST OF ABBREVIATIONS

BMI – body mass index

CI – confidence intervals

cm – centimetre

DRM – disease-related malnutrition

ESPEN - European Society for Clinical Nutrition and Metabolism

€ - Euro

GDP – gross domestic product

GLIM - Global Leadership Initiative on Malnutrition

GnRH - Gonadotropin-releasing hormone

GWAS – genome-wide association studies

HSREC - Health Sciences Research Ethics Committee

IBI – ideal body weight

ICU – intensive care unit

IQR – inter quartile range

ISAK - International Society for the Advancement of Kinanthropometry

kg - kilogram

LOS – length of stay

m – meter

MGRS - Multicentre Growth Reference Study

mm – millimetre

MNA - Mini Nutritional Assessment

MSE – mean square error

MUST – Malnutrition Universal Screening Tool

NRS 2002 - Nutritional Risk Screening 2002

PPARγ - peroxisome proliferator-activated receptor gamma

PPIs – proton pump inhibitors

R^2 – correlation coefficient

SD – standard deviation

USA – United States of America

WHO – World Health Organisation

CHAPTER 1: BACKGROUND AND MOTIVATION FOR THE STUDY

1.1 Introduction

Height, defined as the distance from the vertex of the head to the bottom of the heels, is an essential anthropometric variable with many clinical applications in the health care setting. Health care workers often do not appreciate the clinical importance and complexity of measuring and recording height accurately in order to render optimal patient care (Bloomfield et al., 2006; Brown et al., 2002). Height is required for standardising physiological measures, including lung volumes, muscle strength and glomerular filtration rate, and for calculating drug dosages (Van Den Berg et al., 2016; Bjelica et al., 2012; Ter Goon et al., 2011). One of the essential applications of height in patient care is in assessing nutritional status and calculating individualised nutritional requirements (Whitney & Rolfes, 2019). This chapter briefly summarises the role of height in the assessment and treatment of adult hospitalised patients and explores the problems associated with obtaining accurate height measurements in the South African hospital setting, in order to formulate the problem statement and motivate the study. The ensuing aim and objectives of the study are stated, and the layout of the dissertation is outlined.

1.2 Height in assessing nutritional status

Assessment of nutritional status is important at all levels of patient/client care. Nutritional status is defined as a measurement of the degree to which an individual’s physiological needs for nutrients are met and primarily refers to the balance between an individual’s nutrient intake and the body’s requirements for nutrients (Hammond & Mahan, 2017). In more specific terms, it is the assessment of the state of nourishment of a person.

1.2.1 The burden of malnutrition amongst hospital patients

Illness or trauma negatively influences nutritional status through reduced or insufficient intake, altered digestion and absorption, and changes in the metabolism and excretion of nutrients (Rolfes et al., 2018; Winkler & Malone, 2017). Thus, in the acute care setting, without intervention, the nutritional status of a patient is expected to deteriorate throughout

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hospitalisation (Cederholm et al., 2017). According to the most recent consensus, this type of malnutrition is referred to as disease-related malnutrition (DRM) (Cederholm et al., 2017). Consequently, malnutrition remains highly prevalent amongst hospitalised patients (Cederholm et al., 2018), with reported global rates between 25% and 60% (Souza et al., 2015). In a recent South African study conducted in three public sector hospitals in the Eastern Cape, 72.3% of patients were found to be at risk of malnutrition according to the malnutrition universal screening tool (MUST) (Van Tonder et al., 2018). Previous South African studies, albeit less recent, reported malnutrition rates from 15% to 82% among hospitalised patients, depending on the geographical area (Grobler-Barnard et al., 1997; Symmonds, 1991; O'Keefe et al., 1986; O'Keefe et al., 1983; Van Tonder et al., 2018).

Malnutrition, or being at risk of malnutrition, is associated with an increase in morbidity and mortality (Cederholm et al., 2018). Poor nutritional status weakens the immune system, impairs the body's ability to fight off infections, and delays recovery time (Alwarawrah et al., 2018; Holmes, 2007). A weakened immune system, in turn, may interfere with treatment, lead to poor clinical outcomes, increase length of hospital stay (LOS), diminish quality of life, and increase mortality (Allard et al., 2015; Valente da Silva et al., 2012; Nygaard, 2008; Rolfes et al., 2018; Hammond & Mahan, 2017).

In addition to negatively affecting patients' health and subsequent quality of life, poor nutritional status has significant financial implications. Hospital accounts of malnourished patients are 30% to 70% higher than those of patients who are not malnourished (Elia, 2015; Elia, 2009). Not only do patients with a poor nutritional status require prolonged hospitalisation, but they also consume more medication, require extra medical and nursing assistance, more extensive diagnostic workup, and additional interventions to deal with complications (Elia, 2015; Souza et al., 2015; Elia, 2009). Compared to patients with a satisfactory nutritional status, malnourished patients also more often require ongoing health care services after discharge (Souza et al., 2015). The financial burden incurred by malnutrition not only falls on the patient, but also impacts on medical aid and insurance companies, the hospital or clinic where the patient is treated, and the health care system as a whole. Indeed, the cost of hospitalisation can be up to four times higher for patients at risk of malnutrition (Van Tonder et al., 2018).

Currently, no data are available on the specific costs related to malnutrition in South Africa, but as malnutrition is a significant problem amongst hospitalised patients in the country (Van Tonder et al., 2018), the costs are expected to be substantial. Methods used to calculate the cost of malnutrition can differ vastly. In a 2015 review, Khalatbari-Soltani & Marques-Vidal (2015), calculated, based on nine European studies, that malnutrition resulted in an additional 1640 € to 5829 € per person in the hospital. The cost of malnutrition at a national level ranged from 32.8 million € and 1.2 billion €. In the same studies, malnutrition increased the length of hospital stay by between 2.4 and 7.2 days when compared to well-nourished patients. In a Canadian study, Curtis et al. (2017) reported an 18% and 34% increase in LOS for moderately malnourished patients and severely malnourished patients, respectively.

1.2.2 Screening to assess the risk of malnutrition amongst hospitalised patients

Deterioration of nutritional status among hospitalised patients can be prevented or improved by early detection of those who require expert nutritional care (Cederholm et al., 2018). Assessing a patient's nutritional status on admission and continuously monitoring it during hospital stay and follow-up, is therefore paramount.

All nutrition-related interventions should start with nutrition screening (Souza et al., 2015). Patients who are at risk of malnutrition should be identified using validated screening tools (Cederholm et al., 2018). Nutritional screening, defined as the collection of preliminary data related to nutritional status to identify patients who are malnourished or at risk of becoming malnourished, is highly cost-effective in reducing hospital malnutrition (Elia, 2015; Souza et al., 2015). If the nutrition screening indicates that a patient is at high risk for malnutrition, a full nutrition assessment by a trained dietitian should be conducted to determine appropriate treatment options (Whitney & Rolfes, 2019).

Nutrition screening involves obtaining information on, amongst others, dietary intake and anthropometry (Correia, 2018; Kondrup et al., 2003). Anthropometry is defined by Shah et al. (2012) as a series of systematised measuring techniques that express the dimensions of the human body quantitatively. Amongst anthropometric measurements, weight and height are fundamental to assess nutritional status (Report of a WHO Expert Committee, 1995; Whitney & Rolfes, 2019; Rolfes et al., 2018). Most validated screening tools, use body mass index (BMI)

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[weight (kg) ÷ height (m)²] as one of the variables to assess nutritional risk; this requires accurate recording of height (Report of a WHO Expert Committee, 1995).

Studies have proposed the use of numerous screening tools to assess nutritional status in the critically ill (Singer et al., 2019). The European Society for Clinical Nutrition and Metabolism (ESPEN), as well as the recently established Global Leadership Initiative on Malnutrition (GLIM), recommends the Malnutrition Universal Screening Tool (MUST), Mini Nutritional Assessment (MNA) and Nutritional Risk Screening 2002 (NRS 2002) as validated screening tools to assess the risk for malnutrition; all of these tools include the calculation of BMI as part of the diagnostic assessment criteria (Cederholm et al., 2018; Hammond & Mahan, 2017; Cederholm et al., 2017; Kondrup et al., 2003). Accurately recording the height of hospitalised patients is thus essential.

1.3 Obtaining accurate height in adult patients

Self-reported height is widely used in hospitals and other healthcare settings, as it is commonly considered as the most straightforward, least expensive and least time-consuming method of obtaining the data (Krul et al., 2010). Actual measurements are, however, considered superior to self-reported data (Mauldin & O'Leary-Kelley, 2015) as patients generally over-report their height, creating uncertainty of the accuracy and value of data collected in this manner (Haverkort et al., 2012; Stommel & Schoenborn, 2009; Shields et al., 2008; Gorber et al., 2007; Krul et al., 2010). Also, in South Africa, health care professionals experience that patients seldom know their height (from personal experience and communication with other dietitians).

When patients are not able to self-report their height, either because they do not know or are unable to communicate effectively, health care professionals often report 'observed height'. In other words, they estimate height based on their observation of the patient, usually while the patient is lying down (Maskin et al., 2010).

In the United Kingdom, a study by Coe et al. (1999) on orthopaedic and urology surgery patients, found that height estimated by health care workers were accurate to within 10% of the actual height. A similar finding was also reported in a more recent Argentinian study on patients in the intensive care unit (ICU) (Maskin et al., 2010). This margin of error was deemed acceptable. To the contrary, Coe et al. (1999) reported that observers had a propensity to overestimate height. Similarly, in an intensive care setting in the United Kingdom, Bloomfield et al. (2006), found that height estimated by health care professionals in this way was inaccurate by as much as 18%. In another study conducted in a trauma unit in the United States of America, Hendershot et al. (2006) found that only 41% of health care workers were able to estimate height with acceptable accuracy, while most rendered distinctly inaccurate estimates. Thus, observed height should be used with caution, and the skill of the observer and the application of the observed height should be considered.

The preferred method of obtaining a patient's height is by direct measurement. However, the standardised technique for directly and accurately measuring height requires the patient to be able to stand upright without assistance (Centre for Disease Control and Prevention, 2007). Thus, accurate direct measurement of height is nearly impossible in many hospital patients who are too ill and weak to stand unassisted, who are comatose or sedated or who have muscular dystrophy, paralysis, mobility problems, neuromuscular weakness, disability, debilitating pain or leg amputations. Also, measuring height by standardised technique is made near impossible in patients in ICUs when they are prostrate with several lines connected (Venkataraman et al., 2015). Direct measurement of height should also not be used in patients diagnosed with certain conditions that affect the curvature of the spine, such as scoliosis, kyphosis, or muscle contractures, as this could yield inaccurate measurements (Brown et al., 2002, Chhabra, 2008; Litchford, 2017).

For these situations where height cannot be directly measured, equations have been widely developed to predict height indirectly from the measurement of body segments, particularly the long bones (Bogin & Varela-Silva, 2010). These indirect measurements are applied in three different ways to predict height. Firstly, the measurement may be directly substituted for height (as with arm-span); secondly, a correction factor derived from general ratios between body segments may be used to predict height from the body segment; and thirdly, regression equations may be used to derive predicted height from the measurements of specific body segments (Chhabra, 2008). Regression-based equations for adults derived from direct measurements of ulna length, tibia length, fibula length, and foot length, as well as more inclusive body segments such as demi-span and knee height, have been published.

1.4 Problem statement

Height needs to be recorded accurately in hospitalised patients, as it is used for nutritional and pharmacological prescriptions, as well as for various diagnostic and therapeutic interventions (Dennis et al., 2015; Melo et al., 2014; Beghetto et al., 2006). A common practice amongst health care workers is to rely on the patient's self-reported height or to make an 'eyeball estimate' of the patient's height. Generally, estimations based on measurements of body segments, most commonly derived from regression equations, are considered more objective and more accurate to predict height. Almost all studies have shown a higher level of accuracy when these equations are population specific (Fogal et al., 2015; Bjelica et al., 2012; Madden et al., 2012). As these published equations were not derived from data collected on South African populations, the question arises regarding their accuracy in South African hospitalised populations.

To date, four studies have investigated the most accurate proxy for height. One by Marais et al. (2007) was aimed at older adults, while those by Lahner et al. (2016), van den Berg et al. (2016) and (2010) were unable to identify an accurate proxy for height measurement. There are thus, no data available to guide health care workers as to which method or equation, if any, can be used with acceptable accuracy to estimate height among hospitalised South African patients.

1.5 Aim and objectives

This study was designed with the following aim and objectives.

1.5.1 Aim

The study aimed to determine the agreement and association between directly measured height, and self-reported height, height recorded on admission in the participant's medical file, and height estimated by indirect methods, in patients admitted to Universitas Hospital, Pelonomi Hospital and National Hospital, in Bloemfontein, South Africa.

1.5.2 Objectives

To achieve the aim of the study, the objectives were:

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i. **To determine the following on all participants:**

- Socio-demographics (gender, age and ethnicity);
- Height measured directly by standardised anthropometrical technique;
- Self-reported height;
- Height recorded in the participant's medical file on hospital admission;
- Height estimated by equations (standardised per gender), based on measurements of body segments, namely arm-span, demi-span and ulna length, knee height, tibia length, fibula length, and foot length, as well as recumbent length.

ii. **To determine the agreement between the following:**

- Height measured directly by standardised anthropometric technique, and
- Height estimated by the patient;
- Height recorded in the participant's medical file on admission; and
- Height estimated by published predictive equations (standardised per gender), based on measurements of body segments, including arm-span, demi-span, ulna length, knee height, tibia length, fibula length and foot length, as well as recumbent length.

iii. **To determine which of the body segments, namely arm-span, demi-span and ulna length, knee height, tibia length, fibula length or foot length, best correlate with and predict actual (reference) height.**

1.6 The layout of this dissertation

This dissertation is divided into six chapters covering the following:

Chapter 1:

Background, problem statement and motivation for the study, as well as the aim and objectives of the study;

Chapter 2:

Literature review regarding height measurement, factors that affect height, and direct and indirect methods of determining height;

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Chapter 3:

The methodology used to conduct the study and analyse the results;

Chapter 4:

Manuscript 1: Agreement between measured height and height predicted from published estimate equations, amongst adults in a South African hospitalised population;

Chapter 5:

Manuscript 2: Correlation between body segments and height amongst adults in a South African hospital population; and

Chapter 6:

Conclusions and recommendations for clinical practice and further research.

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CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Height is an essential measurement to assess the nutritional status of hospitalised patients, as most nutritional assessment tools rely on BMI, which, in turn, requires weight and height measurement (Power et al., 2018; Geurden et al., 2011; Kondrup et al., 2003). Besides nutritional status, height is also required for a variety of other therapeutically essential calculations in the clinical setting, including creatinine-height index, body surface area, tidal volume setting, drug-dosing, basal energy expenditure, ideal body weight, and ventilator settings (Venkataraman et al., 2015; Bloomfield et al., 2006; McWhirter & Pennington, 1994). The accurate measurement of height is, however, not always a straightforward task and often requires estimation. To date, numerous estimation equations have been developed, mostly based on long bone measurements. These equations vary according to the factors that affect the length of the long bones, including gender, ethnicity, and factors that affect the growth of the bones, as well as factors that affect the compression of the spine, such as time of day when the measurement is taken, and advancing age. Considering the vast number of factors that can influence height and long bone length, it is not known how appropriate indirect methods used to estimate height, are for South African populations as very little work has been published in this regard.

In this chapter, the need for, and importance of accurate height estimation in the clinical setting are discussed firstly. Secondly, the need for reliable estimation techniques is explained. Thirdly, the variety of available estimation equations that have been developed, based on long bone lengths, is explored, and, lastly, the factors that may affect long bone lengths, and overall height, are unpacked.

2.2 The importance of accurate height measurement or estimation in the clinical setting

Height, as a variable, has numerous clinical applications in the hospital setting such as assessing body composition, to calculate energy expenditure, lung volume, creatinine-height index, and drug dosages (Venkataraman et al., 2015; Bloomfield et al., 2006; McWhirter &

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Pennington, 1994). Height is also needed to calculate BMI and ideal body weight, which are fundamental components of screening for nutritional risk and calculating the nutritional requirements of patients.

Evidence-based guidelines recommend that all patients' should be screened for nutritional risk on admission (Correia, 2018; Geurden et al., 2011). In patients, poor nutritional status is associated with apathy, depression, fatigue, and loss of the will to recover. Weight loss, especially loss of muscle mass, can affect respiration, which, in turn, negatively affects cardiac function and respiratory infection rate. A decline in nutritional status also adversely affects immune functions. Poor nutritional status thus influences patient outcomes, including morbidity, mortality, and LOS (Gray & Gray, 1980; Allard et al., 2015; Valente da Silva et al., 2012). Poor nutritional status also increases readmissions and result in reduced quality of life (Cederholm et al., 2018).

In the clinical setting, BMI was recently reaffirmed by the GLIM diagnostic scheme as essential for screening, assessment, diagnosis, and grading of malnutrition (Cederholm et al., 2018). The GLIM criteria suggest that in order to make a diagnosis of malnutrition in adult patients, at least one phenotypic criterion (non-volitional weight loss, low BMI, or reduced muscle mass) and one etiologic criterion (reduced intake or assimilation of food, inflammation or disease burden) should be present. The severity of malnutrition is then graded based on the phenotypic criterion (Cederholm et al., 2018).

2.3 Reporting height in the clinical setting

Ideally, the height of each patient should be measured upon admission and recorded in the patient's medical file.

2.3.1 Direct measurement of height

The standardised technique for height measurement, endorsed by the International Society for the Advancement of Kinanthropometry (ISAK) (Stewart et al., 2011) and The Centre for Disease Control and Prevention (Centre for Disease Control and Prevention, 2007), is described in Chapter 3 of this dissertation. Accordingly, measuring height is a relatively simple task using a stadiometer, but may become challenging in the hospital setting when patients are unable to stand due to illness, disability or advanced age, or where patients are connected to several lines, prostrate in a hospital bed that may be elevated at various angles. Other challenges in measuring the height of hospitalised patients include a lack of appropriate equipment, skill, or time of the nursing staff who admit the patient. Due to these constraints, height is often guessed or recorded as reported by the patient or a relative (Leary et al., 2000). A Belgium national survey including 12 332 patients, showed that in one out of 10 cases, the nursing staff did not measure the patient, but just estimated height (Geurden et al., 2011). In a South African study 88.9% (n=24) of wards did not measure patients' height on admission (van Tonder et al., 2019).

2.3.2 Self-reported height

Self-reported height is widely used as a substitute for measured height. Some studies have shown statistically significant, albeit not always clinically significant differences between self-reported and measured height (Maskin et al., 2010; Bloomfield et al., 2006; Hendershot et al., 2006; Coe et al., 1999). Haverkort et al. (2012) found that among 488 adult preoperative outpatients in the Netherlands, self-reported height provided highly sensitive information to diagnose malnutrition. Similarly, a USA study by Froehlich-Grobe (2012) of 125 adults using wheelchairs, also found that self-reported height provided a reasonable substitute for height measurement.

Conversely, a 2007 systematic review of studies concluded that patients tend to overestimate their height (Gorber et al., 2007). Men are more likely to over-report their height, whereas females sometimes under-report their height. Also, a higher proportion of older men tend to overestimate their height in comparison with younger ones (Lucca & Moura, 2010; Shields et al., 2008). Patients have also been found to self-report different values for height and weight to different health care professionals. Geurden et al. (2011), therefore, warn that self-reported measurements should be used with caution when assessing the nutritional status of patients. In a study conducted on 1686 North American college students comparing their self-reported height to their measured height, Quick et al. (2015) found significant associations and supported the use of self-reported height.

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Significant differences between self-reported and measured height can result in misclassification of BMI and have other clinical implications (Gorber et al., 2007). Over-reporting height can result in the underestimation of BMI values (Babiarczyk & Sternal, 2015). Krul et al. (2010) reported that BMI values based on self-reported weight and height wrongly classified 11.2% of females and 12.0% of males into lower BMI categories ('underweight' to 'obesity') than actual measured values. Stommel & Schoenborn (2009) found that self-reported BMI values tend to overestimate measured BMI values at the lower end of the BMI scale (under 22 kg/m^2) and underestimate BMI values at the high end (especially over 28 kg/m^2). In addition to overestimating height (and underestimating weight) resulting in an underestimation of BMI, considerable differences in reporting were observed depending on the country of the study and the gender and age of the participants (Krul et al., 2010; Gorber et al., 2007).

2.3.3 Guessing or eyeballing height

Guessing a patient's height is a common practice and involves a healthcare professional estimating height by 'eyeballing' or looking at the patient. This method is simple, but the accuracy is questionable as the skill of healthcare professionals vary. Hendershot et al. (2006), for example, found that only 41% of healthcare professionals were able to estimate patients' height to within 2.5 cm of measured values in a critical care setting. Also, guessing the height may be complicated when the patient is seated or lying down. According to Kerker et al. (2014), the accuracy of guessing will also depend on the context and environment, such as the viewing distance and the attributes of the observer.

The accuracy with which height is observed differs between healthcare professionals (Maskin et al., 2010; Coe et al., 1999). In a small (n=42) prospective study among the critically ill in Argentina, Maskin et al. (2010) found that the mean error in height estimation by eyeballing was 2.5%. A study in the United Kingdom on patients in the ICU reported errors in guessing height that ranged from a 16 cm underestimate to a 27 cm overestimate (Bloomfield et al., 2006). Leary et al. (2000) also found this method to be unreliable and reported a degree of inaccuracy that was clinically significant in English ICUs.

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2.3.4 Measuring the recumbent length

In some cases, health care professionals measure recumbent length as a proxy for standing height. To measure recumbent length accurately and reproducibly, requires a standardised technique, which requires the patient to be lying flat on the bed without blankets or pillows; this is often time-consuming and may require moving the patient into uncomfortable or painful positions (Frid et al., 2013; Dennis et al., 2015; Venkataraman et al., 2015). Freitag et al. (2010) also reported that recumbent length is not commonly measured as most healthcare professionals do not have measuring tapes at hand (Freitag et al., 2010).

Nevertheless, in Brazilian adults, Ferreira-Melo et al. (2017) found a high level of agreement between actual height and recumbent length. Among the elderly, recumbent length showed the best agreement with actual height when compared to other methods of height estimations (height derived from knee height, arm length and demi-span (Ferreira-Melo et al., 2017). A study by Froehlich-Grobe (2011) comparing self-reported height, recumbent length, height derived from knee height and height derived from arm-span among wheelchair users, found significant differences between the results obtained with these methods. Recumbent length gave the shortest, but most accurate estimate of height, with a variance of 92%.

Recumbent length, however, still overestimated actual height by a mean of 3 cm in males and 4 cm in females (Ferreira-Melo et al., 2017). Rodrigues et al. (2011) reported a similar result in a study among adult patients in Brazil, while Lahner & Kassier (2016) reported on a USA study that recumbent length over-estimated actual height by 3.68 cm.

2.3.5 Height estimation equations based on body components

Other empirical methods of estimating the height when a patient's standing height cannot be measured, is by means of equations derived from regression analysis, based on measurements of mostly long bones (Bojmehrani et al., 2014; Hickson & Frost, 2003; Ferreira Melo et al., 2014), but also specific body segments (Chibba & Bidmos, 2007). Consensus is lacking with regard to which long bones should be used, as some recommend those of the lower limbs (e.g., knee height) (Ozaslan et al., 2003; Frid et al., 2013; Marais et al., 2007; Hickson & Frost, 2003), whereas others recommend using those of the upper limbs (e.g., arm-

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span) (Hirani & Mindell, 2008; Mohanty et al., 2001; Ter Goon et al., 2011). The most accurate method of measuring height in critically ill patients should, however, be identified to be able to render the best medical treatment (Venkataraman et al., 2015).

The different factors that influence height and the length of long bones may explain the lack of agreement on which method and long bone measurements to use when standing height cannot be measured. Gender, for example, undisputedly influences height as well as the length of long bones. Thus, men are generally taller than their female counterparts (Anibor et al., 2014). Age is another determining factor as long bones reach maturity by 18 and 20 years of age in males and females, respectively. From 50 years of age onwards, significant bone loss occurs, which may also influence measurements (Chapman-Novakofski, 2017; Mondal et al., 2012).

2.4 Factors that affect long bone lengths and overall height

Adult height is determined by factors that affect long bone lengths, including genetic determination, growth and development, gender, age of pubertal onset, ethnicity, geographic location, and environmental factors, most notably nutrition and illness or infections, as well as medication and medical conditions that impact on the growth of the bones. Also, adult height is affected by factors that lead to compression of the intervertebral cartilage cushions, such as time of day when the measurement is taken, as well as advancing age.

2.4.1 Genetic determination

Studies in the late 19th and early 20th-century gave rise to quantitative genetics that involves the study of continuous phenotypes that vary widely, such as height (Jelenkovic et al., 2016; Allen et al., 2010). Height, being a genetic trait, displays continuous variation. If height did not display continuous variation, a person would either be as tall as their mother or their father (Cummings, 2016), which is not the case. Height is also a sexually dimorphic trait; on average men are taller than their female counterparts (Dubois et al., 2012).

Based on twin studies in high-income countries, the heritability of height was initially approximated at 0.8, which means that 80% of the differences in height between people can be accounted for by genes (Perkins et al., 2016; McEvoy & Visscher, 2009; Jelenkovic et al., 2016). These estimates are lower for women than for men, indicating that genetics are a better predictor of height in men than in women (Perkins et al., 2016).

More recently, genome-wide association studies (GWAS) have made it possible to estimate the contribution of common genetic variants (single-nucleotide polymorphisms) to the proportion of variation in height (Perkins et al., 2016). One such GWAS identified 180 loci, many not previously recognised, that are linked to height and skeletal growth (Chan et al., 2015). Subsequent research identified loci that could consistently be associated with height in various lineages (Jelenkovic et al., 2016; Allen et al., 2010).

Height is, therefore, a polygenic trait, which means that many genes, each contributing a small effect, determine attained height. Some genes may have a minor effect on height, whereas other genes are more significant determinants of height (McEvoy & Visscher, 2009). Approximately 50 separate regions of the human genome have been associated with height; these regions differ significantly in the number of genes they contain. These genes encode for several proteins that are responsible for bone and cartilage development, as well as proteins involved in gene expression that influences growth and attained height. The relationship between height and some of the regions that have been identified, have yet to be investigated (McEvoy & Visscher, 2009).

Overall, height is composed of head, trunk, and leg length. Even though the genes responsible for height have been well researched, not much is known about the genetic relationship between height and body segments (Chan et al., 2015). Height and body segment length is not only determined by genes, but also by the interactions between genes and the environment (Gupta et al., 2018).

2.4.2 Growth and development

During early development, an embryo’s skeleton is made up of fibrous membranes and hyaline cartilage. By six or seven weeks, osteogenesis begins. Bone can either be directly formed from fibrous connective tissue (intramembranous ossification) or hyaline cartilage (endochondral ossification). Long bones are formed by endochondral ossification (Biga et al., 2019).

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A long bone consists of the diaphysis between the epiphyses at both ends. Ossification of immature bones occurs in a layer of hyaline cartilage, known as the epiphyseal plate between the diaphysis and the epiphysis. On the diaphyseal side of the epiphyseal plate, the diaphysis grows in length as the cartilage is ossified. Bones stop growing in length when chondrocytes no longer participate in proliferation, and bone replaces cartilage in the epiphyseal plate (Biga et al., 2019).

Growth is most vulnerable to adverse conditions from conception until the age of two. A host of environmental factors influence height during the growth period, including maternal health and nutrition, breastfeeding and introduction of solid foods, socio-economic factors, as well as infectious diseases (Black et al., 2013; Eveleth & Tanner, 1990). Chronic undernutrition during early life mostly affects the long bones, thus, leading to stunting (Lahner & Kassier, 2016; Black et al., 2013). Stunting results from the long-standing cumulative effects of nutritional deficits and/ or recurrent infections and is defined as a height-for-age less than -2 standard deviations from the reference median of the WHO Child Growth Standards (de Onis et al., 2012).

2.4.2.1 In utero

In addition to genetics, the length of a new-born is also affected by the intra-uterine environment. The intra-uterine environment, in turn, is affected by the mother’s health, size, nutrition, and lifestyle.

2.4.2.2 During infancy and early childhood

Soon after birth, an infant’s genes become a more critical determinant of growth. During the first 18 months of life, the growth rate adapts to genetic potential. A child might, for example, move up the growth chart if they were born relatively short and have tall parents. Between 18 and 24 months of age, most healthy children have reached their genetically-determined percentiles. After this, growth usually follows the same percentile until the onset of puberty (Nwosu & Lee, 2008).

The growth that occurs during infancy is likely the most susceptible to environmental factors (Jelenkovic et al., 2016; Eveleth & Tanner, 1990). Two growth periods are essential for determining adult height: growth occurring from conception to two years of age, and growth occurring before the onset of puberty. Adult height is primarily established during the first growth period in early childhood when nutritional requirements are higher than at any subsequent time, and when infections, particularly diseases involving diarrhoea, occur most frequently. The second growth period presents an opportunity for “catch-up growth,” defined as body growth that is more rapid than normal for age and that follows a period of growth inhibition (Perkins et al., 2016).

The primary environmental determinant of height is nutrition, mainly sufficient protein. Illness, such as infections, can negatively affect growth, which could partly explain the differences in height between higher and lower socio-economic groups (Steckel, 2009; Jelenkovic et al., 2016).

The rate of growth is also influenced by season. Growth is more rapid during spring and summer, possibly due to changes in how the body responds to hormones (Land et al., 2005; Gupta et al., 2018).

2.4.2.3 After the onset of puberty

Pubertal timing can affect adult height. Reaching puberty at an earlier or later stage can influence adult height and segmental proportions of the body. During the prepubertal years, the long bones grow faster than the trunk. During the growth spurt that accompanies puberty, trunk growth becomes more rapid than long bone growth. Precocious puberty has been identified as a contributing factor of shorter leg length without affecting sitting height (Lorentzon et al., 2011; McIntyre, 2011).

Delaying puberty or slowing its progression might result in greater attained adult height by allowing additional time for growth to occur. Timing of puberty may be influenced by ethnicity, as well as socioeconomic and nutritional status (Stinson, 1985; McCance & Widdowson, 1974). Age at menarche is positively associated with attained height and inversely associated with a risk of overweight and obesity in young adulthood (Stein et al., 2010).

Childhood BMI will affect pubertal timing and thus, body segment proportions. Prepubertal BMI is inversely correlated with leg length and adult height (Lorentzon et al., 2011; Sandhu et al., 2006). Lorentzon et al. (2011) reported a positive correlation between childhood BMI and sitting height. Conversely, in female subjects, low BMI has been linked to a decline in growth of the trunk. Pubertal timing and childhood BMI will thus influence growth, bone acquisition, and adult height (Lorentzon et al., 2011).

2.4.3 Ethnicity

Height has been reported to vary between ethnicities around the world. Differences in body proportions between ethnic groups have also been reported (Anibor et al., 2014; Mondal et al., 2012). Consequently, height was traditionally believed to be a result of race and ethnicity, and, although now controversial, some of the differences between ethnic groups in height and length of bones, have been ascribed to genetic variations (Bogin & Varela-Silva, 2010). Therefore, formulas that have been standardised on specific populations are often used for height estimation in clinical settings.

However, there is more variance in height within countries than between countries, and the average height in a country makes group differences indistinguishable within countries, especially regarding socioeconomic and ethnic groups (Perkins et al., 2016). Thus, although genetics explain some of the variation in height between individuals, it is unlikely to explain the differences in height across populations and changes in height within populations over time (Yeboah, 2017; Perkins et al., 2016). Over the past 150 years, there has been a noticeable increase in mean height globally. Due to the relatively short time frame in which height has increased, it is unlikely to be as a result in genetic changes (Grasgruber et al., 2014; Perkins et al., 2016). The most probable explanation is an environment more conducive to growth.

2.4.4 The role of the environment

The impact of environmental factors was illustrated by the Multicentre Growth Reference Study (MGRS) that monitored and compared the growth of six cohorts of children from six diverse countries, from birth onward. The MGRS found considerably more differences in growth between similar ethnic groups than between populations from different countries (de Onis, 2007). The similar trend in the growth pattern of children around the world is in agreement with findings from GWAS describing a high degree of similarity between populations (Jorde & Wooding, 2004; Rosenberg et al., 2002; King & Motulsky, 2002). The

MGRS cohorts, which differed significantly ethnically, culturally, and genetically (de Onis, 2007), were purposefully born and raised to similar environments that were supportive of healthy development (all exclusively breastfed for six months, given healthy complementary weaning foods, mothers did not smoke and infections/ illness treated adequately). The fact that all six cohorts followed almost identical growth patterns suggests that all children, regardless of race or ethnicity, given the same supportive environment, have the same potential for growth, at least during the first five years of life (Garza & de Onis, 2004).

Height is therefore also a multifactorial trait, which means that, although height is a genetic characteristic dependent on more than one gene, it is significantly dependent on changes in the environment (Perkins et al., 2016). Thus, environmental and socioeconomic factors seem to have a more significant effect on height than ethnicity (Gupta et al., 2018). Studies have aimed to identify the main contributor to an environment that is conducive to optimal growth. Most have identified various contributing factors that affect the availability of, access to, and use of resources, as well as exposure to health risks within a given context. Improved environments are thus associated with increased gross domestic product (GDP) per capita, advancements in health care, improved education, social equality, urbanisation and better nutrition (Grasgruber et al., 2014; McEvoy & Visscher, 2009).

Adequate nutrition during critical developmental stages is one of the most vital factors that determine growth and affect height. Thus, height may be seen as "a measure of cumulative net nutrition" (Perkins et al., 2016). The level of exposure to factors that negatively affect net nutritional status remains high in many low- and middle-income countries, factors such as less than optimal nutrition, poor sanitation, and poor quality water. These exposures can lead to undernutrition and stunting among children, and ultimately cause failure to reach one's genetic adult height potential (Perkins et al., 2016).

Other environmental factors that impact on height include climate, physical activity, medication and disease (Popovic et al., 2013; Dunsky et al., 2012; Banik, 2011; Bogin & Varela-Silva, 2010). Importantly, these factors do not operate in isolation or sequential order; conditions may be relevant at multiple time points, operate across multiple levels, and exhibit substantial effect modification (Perkins et al., 2016). Notably, social and environmental differences, both within and between countries, dominate any genetic variation between groups in determining average adult height (Perkins et al., 2016).

Some classic research suggests that an adverse environment has a more significant effect on the growth of boys than of girls (Stinson, 1985; McCance & Widdowson, 1974). The most significant differences in height between genders occur in the countries with the overall tallest populations (the correlation between average height and the gender gap is 0.7), which would suggest pronounced sexual dimorphism when environmental conditions like undernutrition and childhood disease are diminished (Perkins et al., 2016).

Interestingly, the environment also affects segmental body proportions differently. For example, studies show that exposure to poor nutrition and harmful substances *in utero* results specifically in reduced leg length (Barbosa et al., 2012; Bogin & Varela-Silva, 2010).

Similarly, research conducted among healthy populations, have shown that during infancy, childhood and adolescence, the quality of the environment not only affects attained height but specifically influences relative leg length (Nwosu & Lee, 2008). Human beings follow a cephalo-caudal gradient of growth, which is the pattern of growth common to all mammals. Thus, during the period from birth to puberty, the legs grow faster relative to other post-cranial body segments. Short height due to relatively short legs in childhood and adolescence may, therefore, be an indicator of an adverse environment (Nwosu & Lee, 2008; Bogin & Varela-Silva, 2010).

2.4.4.1 Socio-economic status

Heritability of height may be lower in middle and low-income countries where the environment becomes a more significant determinant (Perkins et al., 2016). In a study by Gigante et al. (2009) examining the effect of socioeconomic, gestational and early life exposures on height, leg and trunk length, maternal height and birth weight were the only factors associated with all three variables of growth. Gigante et al. (2009) also found that socioeconomic factors were more critical than biological factors in the determination of height during early growth. Gunnell et al. (1998) found that childhood diet and socio-economic status were the interdependent components that were most strongly associated

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with height, while the district of residence and family food expenditure were also found to influence height significantly.

Mean height in adult males has been widely studied in persons from different geographical areas. Differences in height have been correlated with average GDP per capita. Similarly, data from the World Health Surveys indicate that between 1934 and 1978, the smallest increases in adult height occurred in Africa, while the most significant increases occurred in Europe (Perkins et al., 2016). There are, however, cases where differences in height between various regions cannot be explained by economic differences. For example, Montenegro and Albania have comparable GDPs, but a difference of 9 cm in the average height of the population (Grasgruber et al., 2014).

Socioeconomic circumstances and maternal education influence attained height due to the association with access to resources, risk factor exposure, and lifestyle of the mother. Socio-economic factors that may negatively influence health include overcrowding, limited access to healthcare, poor infant feeding practices, inadequate dietary intake, and consumption of unclean food or beverages (Perkins et al., 2016).

The early environment seems to have a more significant influence on leg length than on trunk length. Using data from the 1958 British birth cohort on height in childhood and at 45 years, Li et al. (2007) found that large family size, overcrowding, and social housing were more strongly associated with leg length, than with trunk length. They also found that prenatal smoking showed a more significant association with leg length, whereas birth order showed a more significant impact on trunk length (Li et al., 2007).

2.4.4.2 Nutritional influences

Nutrition conceivably has the most significant influence on height, since most socioeconomic factors impact growth through effects on nutritional status (Eckhardt et al., 2005). Diseases can also negatively affect growth through its effect on nutritional status, by reducing nutrient intake, absorption and usage, and increasing nutrient requirements and nutrient losses (Perkins et al., 2016). Stunted growth due to a poor nutritional status often results from inadequate delivery of nutrients at the cellular level as life-sustaining functions are prioritised by diverting nutrients from usage for growth (Perkins et al., 2016). A study by Krishna et al.

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(2015) showed that malnutrition had lasting influences on growth even beyond the critical growth period during the first 1000 days, between conception and two years of age. Intrauterine growth failure and growth failure in the first year of life is strongly associated with adult height (Victora et al., 2008; Stein et al., 2010)

Wadsworth et al. (2002) found that parental height, birth weight, and weight at four years were each positively associated with both adult leg and trunk length. Leg length at four years was associated positively with breastfeeding and energy intake. Attained leg length seems to be particularly sensitive to environmental factors and diet in early childhood because that is the period during which most rapid leg growth occurs. Trunk length was negatively associated with severe illness in childhood and possibly also parental divorce, but not with the dietary data (Wadsworth et al., 2002).

Mean height differences between populations from various geographical areas may also be attributed to nutrition. These height variations are most likely due to interactions between genetics and nutrition, as optimal nutrition might result in better growth and development, but the metabolism and use of nutrients may be genetically determined (Bogin & Rios, 2003). The average height has been increasing in certain European countries since the 19^{th} century and may be attributed to advances in nutrition, as well as in healthcare. The same reasoning may explain why, for example, children of Guatemalans who immigrated to the United States are, on average, 12 cm taller than those who stayed in Guatemala (Bogin & Rios, 2003).

A study including men from 45 European countries showed that nutrition is mainly responsible for the variation in adult height. The study showed that the consumption of high-quality proteins found in milk, pork, fish, and wheat was positively associated with height. A small Guatemalan trial, however, indicated no effect of maternal and childhood protein supplementation on adult height. Results from a Gambian study in which mothers were supplemented with protein during pregnancy and lactation showed no increase in height in late adolescence (Perkins et al., 2016).

Adult height could thus be viewed as the long-term balance between nutrient intake and losses, including losses due to physical activity, psychological stress, and disease from conception to maturity. Adult height may thus act as an indicator of overall nutrition (net nutrition) and health (Perkins et al., 2016; Eveleth & Tanner, 1990).

2.4.4.2.1 Energy, macronutrients, and growth

Height during post-infancy is positively associated with energy intake (Eckhardt et al., 2005). Adequate consumption of protein, as well as the quality of protein, has been deemed essential to attain maximum height. Protein is part of the organic matrix of bone for collagen structure and is essential to maintain the production of hormones and growth factors that modulate bone synthesis (Palacios, 2006). Using FAOSTAT (Food and Agriculture Organization of the United Nations, Statistics Division) data, male height was found to be positively correlated with the intake of animal protein (Grasgruber et al., 2014).

2.4.4.2.2 Micronutrients and growth

Micronutrients perform essential functions in the growth and development of bone. Optimal intake of vitamins and minerals will support growth, whereas deficiencies may impair growth.

Calcium is a principal constituent of bone. Increasing calcium intake increases bone acquisition during growth and slows down bone loss in later life. Adequate calcium is essential in obtaining peak bone mass density and reducing fracture incidence (Ahmadieh & Arabi, 2011; Bacciottini & Brandi, 2004; Palacios, 2006). Also, nutrients that affect calcium absorption may impact on bone health and growth. Animal studies show a reduction in calcium absorption with an increase in fat intake (Lorincz et al., 2009), whereas Lorincz et al. (2009) reports that consumption of refined carbohydrates increases urinary excretion of calcium. Conversely, consuming the right types of fat and carbohydrates in the necessary quantities may inhibit osteoclast activity, and improve osteoblast activity to augment skeletal growth (Lorincz et al., 2009).

Phosphorous has a vital role in bone formation through mineralisation of bone, and thus in growth. A magnesium deficiency could negatively affect bone growth through its function as a cofactor for various enzymes and metabolism of adenosine triphosphate. Fluoride strengthens bone by replacing the hydroxyl groups in hydroxyapatite and forming fluorapatite which is less soluble in acidic environments (Ahmadieh & Arabi, 2011; Palacios, 2006).

In stunted children, zinc supplementation can improve growth as well as bone and collagen synthesis (Ilich & Kerstetter, 2000; Palacios, 2006). Copper plays a role in bone formation and mineralisation and is also involved in strengthening connective tissue. Boron may influence bone health by reducing urinary losses and improving absorption of calcium (Miggiano & Gagliardi, 2005). Manganese is involved in bone matrix formation and acts as a cofactor for enzymes in bone tissue. Iron, as a cofactor in enzymes, affects both collagen bone matrix synthesis and calcium absorption (Palacios, 2006).

Adequate vitamin D promotes bone health by increasing the efficiency of calcium absorption (Ahmadieh & Arabi, 2011; Palacios, 2006). Vitamin K improves bone integrity as a cofactor of γ-carboxylase, an enzyme necessary in bone formation (Price et al., 2012; Bacciottini & Brandi, 2004) Vitamin C is a cofactor required in the cross-linking of collagen fibrils in bone (Miggiano & Gagliardi, 2005). Vitamin A is essential for bone remodelling, and inadequate intakes are linked to reduced bone mass density (Palacios, 2006).

Thus, an overall balanced and adequate intake of protein, carbohydrate, and fat, as well as minerals and vitamins are required for optimal growth.

2.4.4.3 Medication

Medication is another type of environmental influence that can significantly affect bone growth and health. Anticoagulants, antacids, corticosteroids, and antineoplastic agents are examples of medication with adverse effects on bone (Table 2.1). The mechanism by which the medication affects the skeletal system varies but includes increased calcium excretion, reduced bone formation, and decreased calcium absorption amongst others (Davidge Pitts & Kearns, 2011).

Selective serotonin reuptake inhibitors, which are commonly used anti-depressants, seem to negatively affect bone by reducing bone mineral density and increasing fracture risk. Serotonin receptors are present on osteocytes, osteoclasts, and osteoblasts, indicating a regulatory role in bone remodelling (Sansone & Sansone, 2012; Davidge Pitts & Kearns, 2011).

Glucocorticoids reduce bone acquisition by directly affecting osteoblast activity and increasing osteocyte apoptosis. Also, glucocorticoids indirectly adversely affect bone health

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by decreasing calcium absorption in the intestine and increasing calcium excretion via the kidneys (Davidge Pitts & Kearns, 2011).

Table 2.1 Summary of medication adversely affecting bone health (Davidge Pitts & Kearns, 2011)

Drug class	**Mechanism**
Glucocorticoids	Reduced bone formation
Unfractionated heparin	Reduced bone formation, increased resorption
Aromatase inhibitors	Reduced estrogen production
Gonadotropin-releasing hormone	Hypogonadism
Medroxyprogesterone acetate	Reduced estrogen levels
Excessive thyroid hormone replacement	Increased bone resorption
Thiazolidinediones	Possible decreased bone formation
Proton pump inhibitors	Possible decreased calcium absorption
Serotonin selective reuptake inhibitors	Inhibition of serotonin transporter
Antiepileptics	Uncertain
Calcineurin inhibitors	Uncertain
Antiretrovirals	Uncertain

Aromatase inhibitors are used in the treatment of breast cancer. Aromatase inhibitors bind the aromatase enzyme, which converts androgens to oestrogens, thus reducing oestrogen levels. This interaction negatively impacts bone health as oestrogen suppresses bone resorption and promotes bone formation (O'Sullivan & Grey, 2015; Davidge Pitts & Kearns, 2011).

Medroxyprogesterone acetate is an injectable contraceptive agent administered once every three months, which decreases oestrogen levels, resulting in bone loss. Bone is lost the fastest over the first few years of usage, after which the loss declines. Bone mass may be recovered after cessation or ameliorated with oestrogen therapy (O'Sullivan & Grey, 2015; Davidge Pitts & Kearns, 2011).

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Chemotherapeutic agents such as methotrexate, doxorubicin, and cisplatin, adversely affect bone by depleting osteoblast precursors. In children, these agents may reduce bone growth and attained height (O'Sullivan & Grey, 2015). Antiretrovirals are also suggested to inhibit osteoblast function and accelerate bone loss. Cyclosporine A and tacrolimus are immunosuppressive drugs used in the treatment of autoimmune disorders and to prevent graft rejection post-organ transplant, which affects bone health negatively by suppressing osteoblast activity (O'Sullivan & Grey, 2015).

Specific anti-epileptic medication such as phenobarbital, phenytoin, carbamazepine, primidone, and valproate affect bone mineral density and bone metabolism (O'Sullivan & Grey, 2015). Gonadotropin-releasing hormone (GnRH) agonists used in the treatment of endometriosis, certain breast cancers and prostate cancer, suppress gonadal function, thus reducing bone mass and accelerating bone loss (O'Sullivan & Grey, 2015).

Thiazolidinediones improve insulin sensitivity by acting on peroxisome proliferator-activated receptor gamma (PPARγ) expressed in bone marrow stromal cells, osteoblasts, and osteoclasts. Thiazolidinediones, therefore, regulate bone cell differentiation and may decrease bone formation and increase bone resorption (O'Sullivan & Grey, 2015; Davidge Pitts & Kearns, 2011).

Loop diuretics have been reported in several studies to affect bone health adversely. It is proposed that loop diuretics increase bone turnover by increasing urinary calcium excretion, which subsequently increases parathyroid hormone levels and bone resorption (O'Sullivan & Grey, 2015).

Proton pump inhibitors (PPIs) are commonly used to reduce gastric acid over long periods. The reduction in gastric acid brought on by PPIs will reduce calcium absorption and have been found to reduce serum calcium and urinary calcium excretion (Davidge Pitts & Kearns, 2011).

2.4.5 Factors that affect height via spinal compression

Factors, such as advancing age and time of day at which height is measured, may also influence height by compressing intervertebral discs.

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2.4.5.1 Ageing

Ageing affects the skeletal system, causing a decrease in height over time. Protein synthesis and collagen production decline with age, which leads to bones becoming increasingly brittle. Other changes that accompany ageing include an increase in body fat and loss of lean body mass. These changes, along with arthritis, inflammation of the spinal joints, and herniated disks, can result in vertebral deformity or kyphosis, contributing to the loss of height. In the Baltimore longitudinal study of aging, men had lost 5cm in height and women 8cm by the time they reached 80 years of age (Sorkin et al., 1999). Loss of height that occurs with ageing can also be worsened by flattening of the vertebrae, vertebral fractures, decrease in intervertebral disc thickness, scoliosis, dorsal kyphosis, flattening of the plantar arch of the foot, and bowing of the legs due to osteomalacia, osteoporosis and postmenopausal hormone imbalances (Xu et al., 2011).

Loss of height may be worse in lower socioeconomic groups due to poorer health (Chmielewski et al., 2015; Huang et al., 2013; Lahner & Kassier, 2016). As height decreases with age, estimation equations may be more suitable than direct height measurement to determine attained height in the elderly. These equations would need to be specific for the elderly (Huang et al., 2013).

Lahner et al. (2016) found a curvilinear relationship between height and ageing, best described by a quadratic equation, which indicates that height is lost at increasing rates with increasing age. In South Africa, the shortest population is females in the age group 65 years and older (Shisana et al., 2013). The loss of height was also found to be faster in females than in males. Lahner et al. (2016) thus argues that BMI should be carefully interpreted as no consideration is given to age when calculating BMI, which might be problematic as a small decrease in height can increase BMI. Most studies have found no significant loss of height before the age of 45. After the age of 75, height decreases 40% faster in males and 60% faster in females than before 75. The rate at which height is lost in the elderly is related to nutritional status and physical activity (Chmielewski et al., 2015).

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2.4.5.2 Time of day that measurement is taken

Research has shown that height is lost during the day as the intervertebral discs compress due to gravity. During lying down to sleep, the load on the intervertebral discs is reduced, as fluid absorption is increased. Height is usually at a maximum in the morning upon waking up. As the day progresses and the load on the spine increases, the fluid is expelled, leading to a decrease in height. Most of the compression occurs in the first few hours of the day but is dependent on the load on the spine. The average diurnal variation in human height is approximately 10 - 15 mm (Adams et al., 1990; Chmielewski et al., 2015). Individuals are thus slightly (about 1%) shorter in the evening than in the morning (Lahner et al., 2016; Stewart et al., 2011; Adams et al., 1990). Conversely, alternate periods of rest and activity is speculated to only have a minor effect (Chmielewski et al., 2015; Adams et al., 1990).

The diurnal variation in height can be minimised by making use of the stretch stature method (described in Chapter 3) when measuring individuals (Stewart et al., 2011). Thus, measurements should ideally not be taken within the first two hours after waking up, and when measuring height, the measurer should place their hands on the participants mastoid processes and gently lift upwards to improve the accuracy of the measurement (Krishan & Krishan, 2007; Stewart et al., 2011).

The above discussion shows that attained height as well as the length of body segments, are not only determined by genetics, but are dependent on many variables. This variability brings into question the accuracy of equations developed to estimate height in the clinical setting. These equations are commonly claimed to be ethnic-specific, while the evidence discussed seemed to indicate that environmental factors may cause more variability in height and length of body segments than genetics.

2.5 Height determination based on measurements of body segments

Artists and sculptors were once the only professionals concerned with the proportions of the human body. The use of exact measurements of body segments became important when prosthetic and orthotic devices had to be designed for physically disabled individuals. This data also became important for sports analysis and the construction of test dummies. The earliest studies of body segment measurements were conducted on white, male cadavers.

The first effort at a complete investigation of body segment measurements was by a physiologist in 1857 who conducted research related to anatomy in the arts (Dempster & Gaughran, 1967). Subsequently, many professionals, such as anatomists and pathologists, have shown interest in the mass and size of various human body parts. Today, this information is widely used in forensic and medical science, including the clinical setting, where various measurements of the upper and lower body are commonly used to estimate height.

2.5.1 Upper body measurements

Arm length, humerus length, forearm length, as well as proximal phalanx length, have been highly correlated with height (Jarzem & Gledhill, 1993). Mitchell & Lipschitz (1982) suggested that arm length should be used in assessing nutritional status in the elderly as these measurements are easy to obtain, and arm length is less affected by the shrinking effect of the ageing process. In the clinical setting, arm-span, demi-span, and ulna length are commonly used to estimate the actual height of patients whose height cannot be measured by the standardised stretch technique.

2.5.1.1 Arm-span

Arm-span is the distance between the tips of the middle fingers while both arms are outstretched at a 90-degree angle (see **Error! Reference source not found.**). The first known study investigating the relationship between arm-span and height was a small study (n=84) dating back to 1880 (Bonomi, 1880). Ensuing studies have shown strong associations between height and arm-span before the onset of puberty. For example, a multi-ethnic study conducted on 1479 healthy infants and children under six years across 8 study centres in the United States, found that arm-span accurately estimated height (Forman et al., 2014). After puberty, the correlation decreases and arm-span tends to overestimate height, although the association remains strong. In a recent study by Ferreira-Melo et al. (2017) among 241 adults and elders in Brazil, no statistically significant difference was found between measured height and height predicted by arm-span.

Due to loss of height in the elderly, arm-span is often used as a proxy for height and is a reliable estimate of height in this population (Kwok & Whitelaw, 1991). For example, an American study of 165 elderly inpatients found that total arm length was more strongly

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associated with standing height than knee-to-floor measurements, tibia length, upper arm length or forearm length (Haboubi et al., 1990). Conversely, Froehlich et al. (2011) found arm-span to result in the longest estimate, and to be poorly associated with height when compared to recumbent length, self-reported height and knee height in 141 wheelchair users in Kansas City, USA.

Interestingly, in a multi-ethnic study of 553 young adults, a clear association between arm-span measurements and height was found in all groups, but arm-span was found to be significantly different from height in two ethnic groups, namely Afro-Caribbeans of both sexes and Asian males (Reeves et al., 1996). Moreover, Lahner et al. (2016) described a more considerable variation between the two variables in females than in males, and this variation was reported to increase with age.

2.5.1.2 Demi-span

The demi-span is measured from the suprasternal notch to the base of the middle finger (Bassey, 1986) (see 3.4.2.6). In the European population, demi-span has been significantly correlated with height (Bassey, 1986). In a Brazilian study, however, demi-span was found to underestimate height in adult men, while overestimating height in older men (Ferreira-Melo et al., 2017). Demi-span has been extensively used in studies on the elderly, but due to loss of height with ageing, it may be inaccurate in BMI estimation (Weinbrenner et al., 2006; Bassey, 1986).

2.5.1.3 Ulna length

The ulna length can be measured from the olecranon process to the styloid process in the forearm (Vinayachandra et al., 2013) (see 3.4.2.7). In a multi-ethnic study of 1479 healthy infants and children aged under six years, in the United States, Forman et al. (2014) found that ulna length could serve as an accurate and reliable surrogate measure of height in healthy children. Similarly, among 2443 older adults, 65 to 98 years old, in Hong Kong, Auyeung et al. (2009) found that when using ulna length in a regression model together with fibula length to estimate actual height, the 95% limits of agreement were -6.65 to +7.70 cm for males and -6.59 to +7.49 cm for females. Ulna length is commonly used in the MUST equations to screen adult patients for malnutrition, mostly in the British population (Lahner et al., 2016; Madden et al., 2011). Madden et al. (2011) did, however, caution the use of the MUST equations in a multi-ethnic setting. In a South African study, van den Berg et al. (2016), found that, in adult inpatients 19 to 60 years old, height estimated by ulna length in the MUST equations ranged from underestimating height by 8.9 cm to overestimating height by 47.7 cm. This variance would be clinically significant, especially when using the calculated height to determine BMI.

2.5.2 Lower body measurements

The long bone lengths of the lower limbs are considered to provide an accurate estimate of height. The most accurate method is considered to be regression equations derived from regression analysis (Trivedi et al., 2014). Several studies have suggested that lower limb bone measurements are more accurate in estimating height when compared to measurements of the upper limbs (Gaur et al., 2016; Pelin & Duyar, 2003; Jitapunkul & Benchajareonwong, 1998), but findings vary across settings.

2.5.2.1 Knee height

Knee height is measured from the plantar surface of the foot to just above the patella (Teichtahl et al., 2012) (see 3.4.2.8). The race, gender, and age-specific Chumlea equations are perhaps the most well-known to estimate height from knee height.

Knee height has been widely studied among the elderly population because ageing shrinks the trunk length by its effect on the vertebra, leaving limb length relatively untouched (Chumlea et al., 1985). In a study using knee height to estimate maximum height in an elderly Chinese population living in Melbourne, Australia, age showed no association with knee height making it a suitable proxy for height in the elderly (Zhang et al., 1998). Similar results have been shown in elderly Turkish (Ozer et al., 2007), Mexican (García-Peña & Pérez-Zepeda, 2017) and French (Ritz, 2004) populations. In a South African study comparing different proxy measures in adults and the elderly (over 60 years of age), knee height was found to be the most accurate in estimating height in the elderly. In the same study, knee height overestimated measured height by approximately 6 cm in those between 18 to 59 years of age (Marais et al., 2007). This estimation affected the classification of participants' BMI and nutritional status and should thus be considered clinically significant (Lahner & Kassier, 2016). Conversely, height estimated from knee height based on the method of Chumlea has been

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found to significantly underestimate height in other population groups, deeming it unfit as a substitute for actual height in inpatients (Ferreira-Melo et al., 2017; Fogal et al., 2015).

2.5.2.2 Tibia length

Tibia length is measured from the top of the medial condylar surface to the lower point of the medial malleolus (Pelin & Duyar, 2003) (see 3.4.2.9). Tibia length is highly correlated with height (Yousafzai et al., 2003; Gaur et al., 2016). In a Californian prospective study of 49 inpatients, Stehman et al. (2011) found a correlation coefficient of 0.94 between tibia length and height. The correlation between the length of the tibia and height is stronger among females than among males (Gaur et al., 2016). The tibia has also been identified as a superior predictor of height in males when compared to the fibula (Gaur et al., 2016).

Trivedi et al. (2014) stated that tibia comprises 22% of total height and that no significant difference exists in the length of the left and the right tibia. Some researchers hold the opinion that tibia length and height have a constant proportionality and therefore, use multiplying factors instead of regression equations (Banerjee et al., 2015). However, Jantz & Jantz (1999) found that in order to best estimate height from tibia length, tibia length should be substituted into equations derived from regression analysis rather than making use of a multiplication factor. Trivedi (2014) has also found that individuals with the same height can have different tibia lengths.

Regression equations have been formulated taking factors such as gender and race into consideration (Banerjee et al., 2015). Tibia would act as a reliable proxy for height in the elderly as it resists erosion and maintains its shape even after burial (Trivedi et al., 2014).

A study by Pelin & Duyar (2003) proposed a new method of estimating height based on tibia length. In the study, participants were classified into a short, medium, or tall group based on percentiles. Formulas were then applied to the specific groups, which yielded more accurate estimations of height than when the same formulas are applied to all participants (Pelin & Duyar, 2003).

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2.5.2.3 Fibula length

Fibula length is measured from the proximal end of the fibula to the lowest point of the lateral malleolus (Hussein Al-wasfi & Puranik, 2015) (see 3.4.2.10). Pereira (2017) identified a definite correlation between fibula length and height. Fibula derived estimation equations provide a better estimate of height in females than those based on the tibia. Fibula length shows a stronger correlation with height in females than in males and can, therefore, more accurately predict height in females (Gaur et al., 2016).

A study on 2443 elderly participants (65-98 years) developed a multiple linear regression model based on fibula length. The results showed comparable accuracy to predicted measurements using knee height. Fibula length could thus be used in patients (including the elderly) who are unable to bend their knee at a 90-degree angle or if a knee height calliper is not available (Auyeung et al., 2009). Fibula length can also be used in individuals with deformities of the knee or ankle joint or those with joint effusion accompanying arthritis (Auyeung et al., 2009).

2.5.2.4 Foot length

Foot length is measured from the most posterior part of the heel to the most anterior part of the toes (Ahmad et al., 2014) (see 3.4.2.11). The use of foot length to calculate height has not been studied as widely as the long bones of the body (Pandey et al., 2014; Singh et al., 2013). Foot length is often used in forensic sciences to identify individuals and determine height (Swuro, 2018).

The variation between the length of the left and right foot have been deemed insignificant (Mohamed, 2013). Singh et al. (2013) observed a good correlation between foot length and height in 250 females, with a standard deviation of 5.38 cm. Foot length is highly correlated with height and, thus, considered to be a good predictor of adult height in males and females (Soltani et al., 2017; Malik et al., 2015).

2.6 Summary

Height is an essential measurement in hospitalised patients for assessing nutritional status and identifying malnourished patients, amongst other important clinical evaluations. Use of

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inaccurate height measurements can have clinical implications. Height is most commonly self-reported by patients or guessed by healthcare practitioners. Height may also be measured while a patient is in the supine position or calculated from body segment measurements.

Height and length of body segments are affected by various factors. Many genes are involved in height determination, each contributing a small effect, but environmental factors also play a role in whether an individual attains their genetically determined height. The most important environmental determinants of height include the intra-uterine and physical environments that a child is exposed to during growth and development, the onset of puberty, socio-economic status, and nutritional influences. Ageing and time of day at which height is measured can also influence height measurement.

Both upper body measurements, such as arm-span, demi-span, and ulna length, and lower body measurements, such as knee height, tibia length, fibula length, and foot length, can be used to determine height with variable degrees of accuracy. Work done in the clinical domains seem to find that the accuracy with which height can be determined from body segment measurements in adults depends on ethnicity, age, and gender. On the other hand, research in the fields of forensics as well as intra-uterine and childhood growth monitoring highlights that environmental factors do not affect the proportional growth of the various long bones of the body in the same way. Therefore, more research is needed to guide the use of equations to estimate height in different clinical settings.

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CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter describes the methods that were followed to achieve the aim and objectives of this study. The methodology is outlined with regard to the ethical approval and permissions for the study, the study design, study population and sample selection, variables, techniques, validity, reliability, and procedures that were followed. The pilot study, statistical analysis, ethical considerations and challenges experienced during the implementation of the study, are also described.

3.2 Ethical consideration

Ethics approval was obtained from the Health Sciences Research Ethics Committee (HSREC 125/2016) (Appendix A) at the University of the Free State and the Free State Department of Health Provincial Research Committee (Appendix B). The hospitals and included wards were informed in advance of the purpose of the study and the procedures that would be followed for recruiting participants, gaining informed consent and collecting the data.

3.3 Study design

A cross-sectional analytical study was conducted.

3.3.1 Study population

The study population consisted of patients admitted to the medical, surgical, pulmonary, orthopaedic, cardiovascular and general wards of Universitas Academic Hospital, Pelonomi Academic Hospital and National District Hospital in Bloemfontein (as patients in these wards are likely to be able to stand upright without assistance). These wards have a combined capacity of 305 beds with variable occupation. Taking length of hospital stay (average 2 to 3 days according to the Health Systems Trust), the average age of hospitalised patients, and the time that the researcher had available for data collection (estimated eight patients a day for five days a week, over a three month period); into consideration, the initial aim was to include 520 participants.

3.3.2 Sample selection

Non-random convenience sampling was used. All patients admitted to the wards mentioned above at the time of data collection (on days and times the researcher was available from November 2016 until December 2017) were invited to participate in the study. The data collection period was extended due to the following problems encountered: delays in obtaining approval to conduct the study, the majority of hospitalised patients turning out to be over the age of 50, and the majority of patients being in feeble health and unable to stand upright without assistance. The deadline for data collection was reached, and after adjusting for patients who did not meet the inclusion criteria (n=3), the final sample included 141 participants.

3.3.2.1 Inclusion criteria

Patients were included in the study if they:

- Were admitted to preselected wards during the period of data collection;
- Spoke English, Afrikaans or Sesotho;
- Were able to stand upright without assistance in order for measurements to be taken accurately;
- Were ≥ 20 years (the age at which long bones have matured in both males and females) and ≤ 50 years (because, after 50 years of age, the extent of bone degeneration may render measurements inaccurate) (Chapman-Novakofski, 2017; Mondal et al., 2012); and
- Gave informed consent.

3.3.2.2 Exclusion criteria

Patients were excluded from the study if they:

- Had (self-reportedly) been on any medication that could have affected bone development;
- Were unable to stand upright and unassisted;

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- Suffered from peripheral oedema, ascites or anasarca, or were on dialysis (as these fluid compartment overloads could complicate the segmental measurements);
- Had visible curvature of the spine or any injuries or deformities affecting their posture or mobility;
- Had any other medical condition that could prevent accurate measurements required for the study; and
- Could not speak English, Afrikaans or Sesotho, as they would be unable to give informed consent.

3.4 Measured variables, operational definitions and techniques

For this study, socio-demographic variables, medical history and anthropometric measurements were recorded. All the data were collected, and all measurements taken, by the researcher, who is a registered dietitian with clinical experience. The information on socio-demographics, medical history and self-reported height was obtained using a questionnaire (Appendix C) administered during a short structured interview.

After completion of the questionnaire, the researcher performed and recorded the anthropometric measurements according to techniques endorsed by the International Society for the Advancement of Kinanthropometry (ISAK) (Stewart et al., 2011) and The Centre for Disease Control and Prevention (Centre for Disease Control and Prevention, 2007), for the more generic measurements (such as height and arm-span). For more specific measurements (such as ulna, tibia and foot length), the procedures were followed as described in the literature describing the compilation of the specific formulas derived from these measurements (see below). If the standardised procedure did not state the number of measurements to take at a specific site, two measurements were taken, and the average value was used. The anthropometric data were recorded on the questionnaire (Appendix C).

The measurements of body segments of the sample were then used in published equations to test how accurate each equation predict height, and were also directly compared to reference height to assess which showed the closest agreement.

3.4.1 Socio-demographic data and medical history

3.4.1.1 Socio-demographic data

3.4.1.1.1 Operational definitions and techniques

Gender, age and ethnicity were recorded as all of these variables may affect the height and length of long bone segments (Anibor et al., 2014; Mondal et al., 2012). The information was collected from the participants' medical files and any outstanding information was obtained and recorded on the data sheet during a structured interview with the participant.

3.4.1.2 Medical history

3.4.1.2.1 Operational definitions and technique

Relevant medical history was recorded from the participants' medical files to establish the presence of any exclusion criteria.

3.4.2 Anthropometric variables

For the study, anthropometry included self-reported height, height recorded in the participant's medical file, measured height, recumbent length, arm-span, demi-span, ulna length, knee height, and tibia, fibula and foot lengths.

Measurements were taken in the ward where the participant was residing. Privacy was ensured by closing curtains or using room dividers where possible. The researcher carefully explained to each participant which measurements were going to be taken and what was expected of them. All measurements were performed on the left side of the body.

3.4.2.1 Self-reported height

3.4.2.1.1 Operational definition and technique

Participants were asked whether they knew their height, and, if so, the height that they reported was recorded as the self-reported height.

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3.4.2.2 Height recorded in the participants' medical files

3.4.2.2.1 Operational definition and technique

The height that was recorded (presumably by nurses or other health care professionals) in the participants' medical files on admission or on the prescription chart, was accessed and recorded.

3.4.2.3 Reference height

3.4.2.3.1 Operational definition

Height is a valuation of maximum vertical size, or the distance between the top of the head and the bottom of the feet, in a human body standing upright, as indicated in Figure 3.1 (Anibor et al., 2014; Stewart et al., 2011). For this study, actual attained height, measured according to standardised techniques, was referred to as the reference height.

3.4.2.3.2 Equipment and technique

Reference height was measured directly, according to standardised techniques (Lee & Nieman, 2013; Stewart et al., 2011; Gibson, 2005) (also referred to as the stretch method, to obtain "stretched height") with a calibrated, mobile, freestanding stadiometer (Seca 213®; Seca GmbH, Hamburg, Germany). The floor, on which participants were measured, was hard and level. The stadiometer was calibrated against a standard height each day on which data was collected, before starting any measurements.

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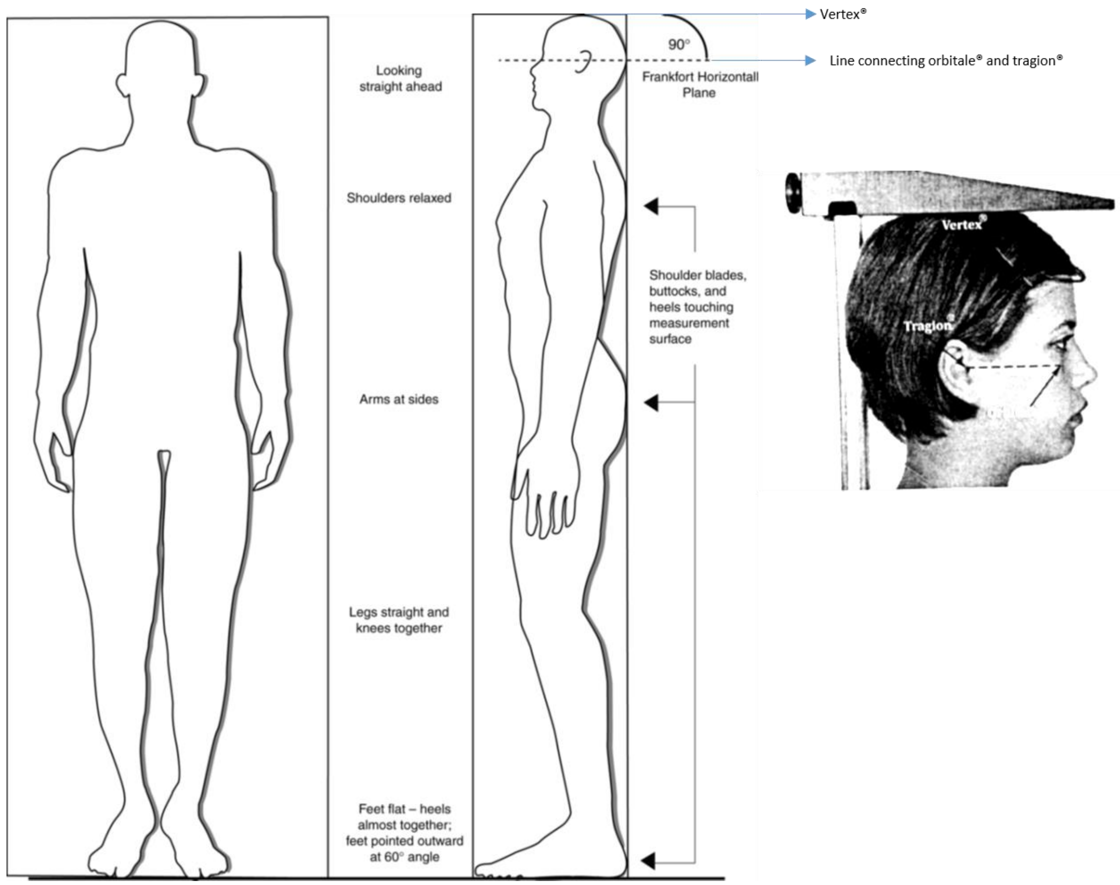

Figure 3.1: Definition and measuring of standing height (Stewart et al., 2011; Centre for Disease Control and Prevention, 2007)

The height of participants was measured using the stretch stature method (Stewart et al., 2011) illustrated in Figure 3.1. The stadiometer was placed on a hard level surface and positioned against a wall to ensure rigidity and stability. Participants were asked to remove any shoes and socks, as well as hats, and to adjust hairstyles that could affect the measurement.

When using this method, participants must stand up fully upright against the backboard of the stadiometer, facing forward, arms relaxed and freely hanging at the sides, palms facing the thighs; knees straight and legs close together and heels, buttocks and upper back in contact with the vertical, and body weight evenly distributed and both feet flat on the platform. As long as the head is in the Frankfort horizontal plane, it is not necessary for it to touch the backboard of the stadiometer (Bjelica et al., 2012). Frankfort horizontal plane, illustrated in Figure 3.1, represents a horizontal line from the lowest point of the bony eye socket to the top notch of the external ear (Lee & Nieman, 2013).

Gentle pressure was applied upwards through the mastoid processes to lift the participant's head. Participants were then asked to take a deep breath and hold this position. The headboard was lowered and firmly placed on the vertex of the head, flattening the hair. The measurement was taken while the participant inhaled, and recorded to the nearest 0.1 cm. The measurement was taken twice and, if the two measurements were not within 0.1 cm of each other, a third measurement was taken. If a third measurement was required, the average was used (Bjelica et al., 2012; Stewart et al., 2011; Centre for Disease Control and Prevention, 2007).

3.4.2.4 Recumbent height

3.4.2.4.1 Operational definition

Recumbent height is defined as the distance from the bottom of the heels to the crown of the head measured while the participant is in the supine position, lying flat on the bed (Gray & Gray, 1980).

3.4.2.4.2 Equipment and technique

The head of the bed was lowered so that participants were lying flat on their backs in the supine position (with no pillow and on the bed sheet with no interfering bedding) (Figure 3.2). A mark was made with a water-soluble seamstress pen on the bedsheet at the bottom of the heels and the top of the crown. The distance between the two marks was measured with a standard, clearly calibrated, non-stretchable anthropometric tape (Butterfly, Shanghai, China), and recorded as the participant's supine length (Gray & Gray, 1980).

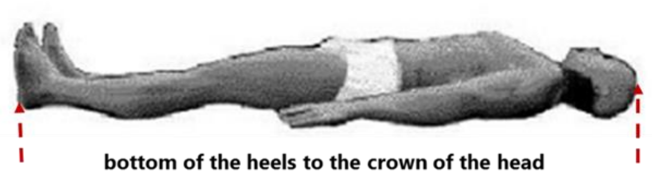

Figure 3.2 Position required to measure recumbent length (Anon, n.d.)**(https://www.flickr.com/photos/64618542@N00/5986241950)**

3.4.2.5 Arm-span

3.4.2.5.1 Operational definition

Arm-span is defined as the maximum distance between the tips of the middle fingers of both hands while both arms are extended sideways and parallel to the ground (Popovic et al., 2013) as depicted in Figure 3.3.

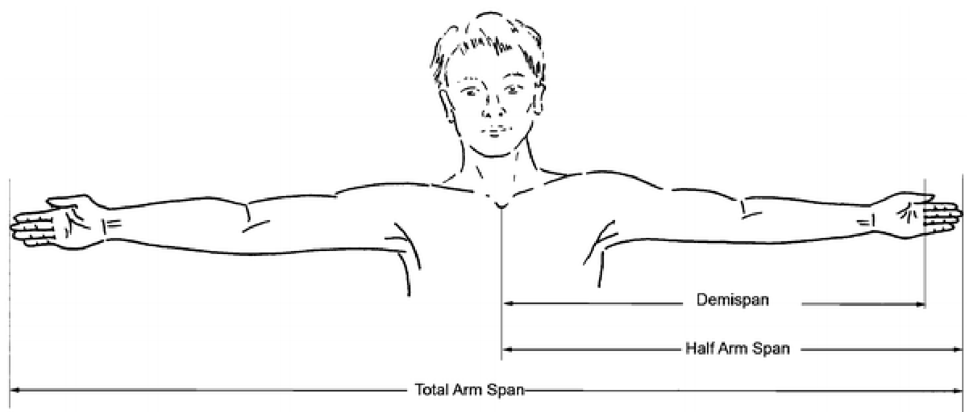

Figure 3.3 Definitions of arm-span and demi-span (Tan & Bansal, 2012)

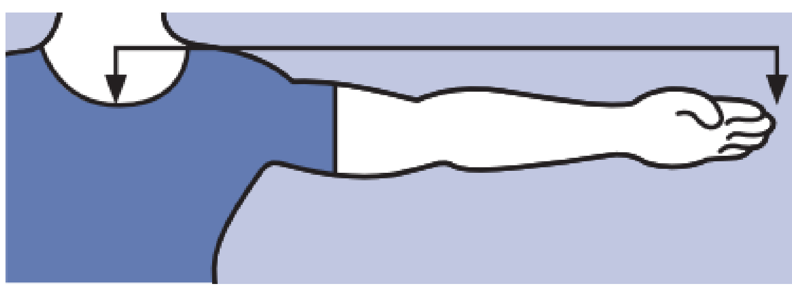

Figure 3.4 Half arm-span (Daradkeh et al., 2016)

3.4.2.5.2 Equipment and technique

Participants were asked to stretch out their arms at 90° angles to their body, parallel to the floor, with their palms facing forward. Participants could stand against a wall for support. Arm-span was measured with a standard, clearly calibrated, non-stretchable anthropometric tape (Butterfly, Shanghai, China). The measurement was taken from the centre of the sternal notch to the tip of either of the middle finger (thus, half arm-span as depicted in Figure 3.4) and multiplied by two to attain total arm-span. Measurements were recorded to the nearest 0.1 cm (Gibson, 2005). If the first two measurements were not within 0.4 cm of each other, a third measurement was taken and the average calculated (Venkataraman et al., 2015; Anibor et al., 2014; Popovic et al., 2013).

3.4.2.6 Demi-span

3.4.2.6.1 Operational definition

Demi-span is defined as the distance from the mid-point of the sternal notch to the middle of the root of the middle and ring finger, when the arm is extended sideways and parallel to the ground (Hirani et al., 2010) as depicted in Figure 3.3.

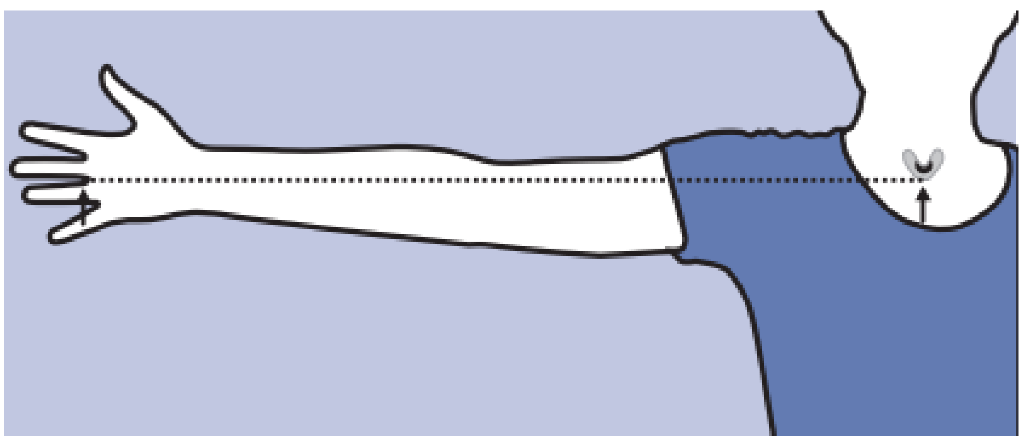

Figure 3.5 Measurement of demi-span (Daradkeh et al., 2016)

3.4.2.6.2 Equipment and technique

Participants were asked to stretch out their right arm at a right angle to their body, parallel to the floor, with their palms facing forward, while standing against a wall. Demi-span was measured from the root of the fingers between the middle and ring finger to the middle of the sternal notch, using a standard, clearly calibrated, non-stretchable anthropometric tape (Butterfly, Shanghai, China). Measurements were taken twice to the nearest 0.1 cm and if the measurements differed, a third measurement was taken (Hirani & Aresu, 2012; Weinbrenner et al., 2006).

3.4.2.7 Ulna length

3.4.2.7.1 Operational definition

Ulna length is defined as the distance from the centre of the styloid process (protuberant bone of the wrist) to the olecranon process (the point of the elbow), when the arm is folded across the chest with the hand flat against the chest and the fingers pointed towards the opposing shoulder (Gandy, 2014), as depicted in Figure 3.6.

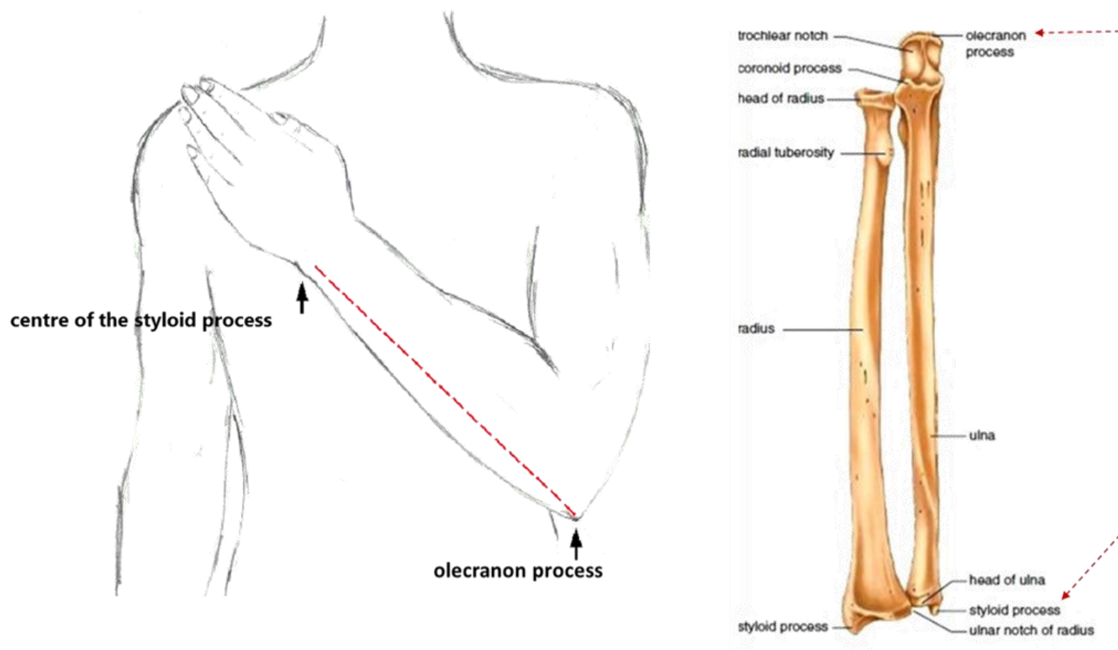

Figure 3.6 Definition and measurement of ulna length (Madden et al., 2012; https://www.hnchawaii.org/anatomy-of-ulnar-bone/)

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3.4.2.7.2 Equipment and techniques

Figure 3.7 Ulna length (Anthropometrical techniques according to ISAK standards; Department of Nutrition and Dietetics, University of the Free State, 2016)

The participant was asked to remove or change the position of any jewellery, bracelets, wristbands, or watches, and to bend the left arm diagonally across the chest, with the palm spread flat and facing inwards, and the fingers pointing towards the opposite shoulder (Figure 3.7). With the elbow fully flexed and the arm semi pronated, ulna length was measured from the tip of olecranon process to the tip of the styloid process (palpable on the dorsum of the wrist) using a standard, clearly calibrated, non-stretchable anthropometric tape (Butterfly, Shanghai, China). The measurement was recorded to the nearest 0.5 cm (Ilayperuma et al., 2010; Shah et al., 2012; Mondal et al., 2012; Madden et al., 2012).

3.4.2.8 Knee height

3.4.2.8.1 Operational definition

Knee height is defined as the distance from the plantar surface of the left foot to the condyles of the femur, just above the patella, when the knee is flexed at 90° (Teichtahl et al., 2012) (Figure 3.8).

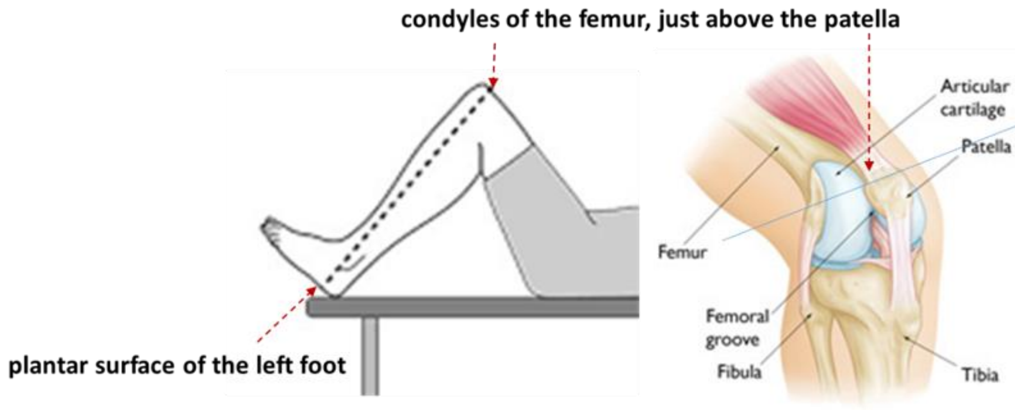

Figure 3.8 Definition and measurement of knee height

(http://www.rxkinetics.com/height_estimate.html)

3.4.2.8.2 Equipment and technique

Knee height was measured with a sliding broad-blade caliper with the participants in a recumbent position. The participants were asked to bend their left knee and ankle at a 90° angle. The moveable blade was placed proximal to the patella, over the condyle of the femur as depicted in Figure 3.9. Pressure was applied to compress soft tissues, and the measurement was recorded to the nearest 0.1 cm (Gavriilidou et al., 2015; Fogal et al., 2015; Marais et al., 2007).

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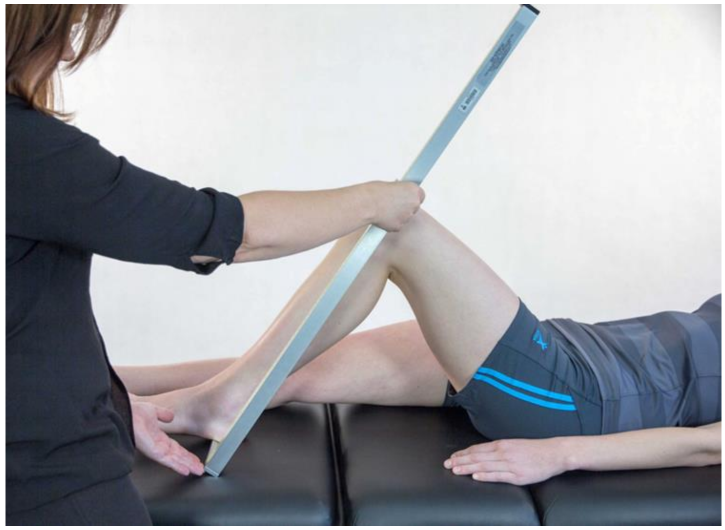

Figure 3.9 Knee height (Anthropometrical techniques according to ISAK standards; Department of Nutrition and Dietetics, University of the Free State, 2016)

3.4.2.9 Tibia length

3.4.2.9.1 Operational definition

Tibia length is defined as the distance between the top of the medial condylar surface and the lowest point of the medial malleolus (Pelin & Duyar, 2003) as depicted in Figure 3.10.

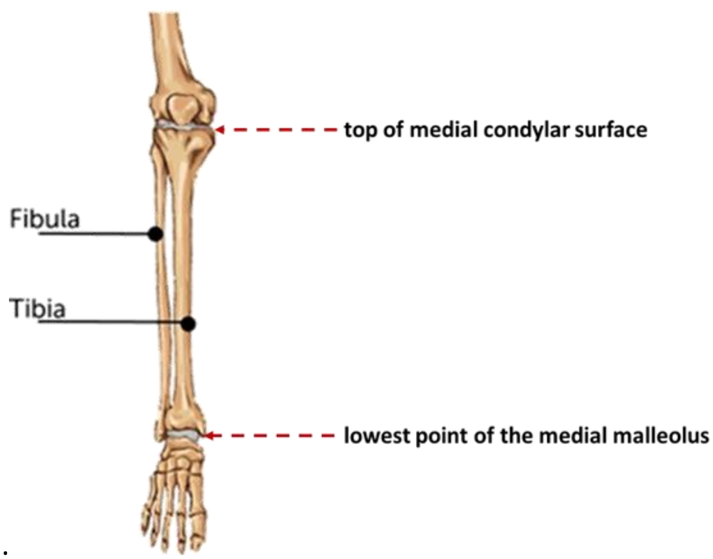

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Figure 3.10 Definition of tibia length

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3.4.2.9.2 Equipment and technique

Participants were helped to seat themselves with their right ankle resting over the left knee to expose the medial aspect of the leg for measurement. The tibia was measured from the superior extremity and the medial border of the head of the tibia (tibiale mediale) to the sphyrion site as depicted in Figure 3.11, using a standard, clearly calibrated, non-stretchable anthropometric tape (Butterfly, Shanghai, China) (Stewart et al., 2011).

Figure 3.11 Measurement of tibia length (ISAK 2001:102)

3.4.2.10 Fibula length

3.4.2.10.1 Operational definition

The length of the fibula is defined as the distance from the proximal end of the fibula to the tip of the lateral malleolar process (Hussein Al-wasfi & Puranik, 2015) as depicted in Figure 3.12

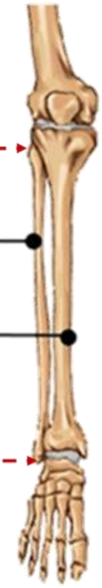

Figure 3.12 Definition of fibula length

3.4.2.10.2 Equipment and technique

Fibula length was measured while participants were seated with their knees flexed at a 90 degree angle, legs hip-width apart, and feet flat on the floor. A standard, clearly calibrated, non-stretchable anthropometric tape (Butterfly, Shanghai, China) was used to measure the fibula length from the head to the lowest point of the lateral malleolus (in other words, between the landmarks depicted in Figure 3.12 (Radoinova et al., 2002; Auyeung et al., 2009).

3.4.2.11 Foot length

3.4.2.11.1 Operational definition

Foot length is defined as the distance from the most posterior part (centre) of the heel to the most anterior part of the longest toe (either the 2nd toe or 1st toe) (Ahmad et al., 2014) as depicted in Figure 3.13.

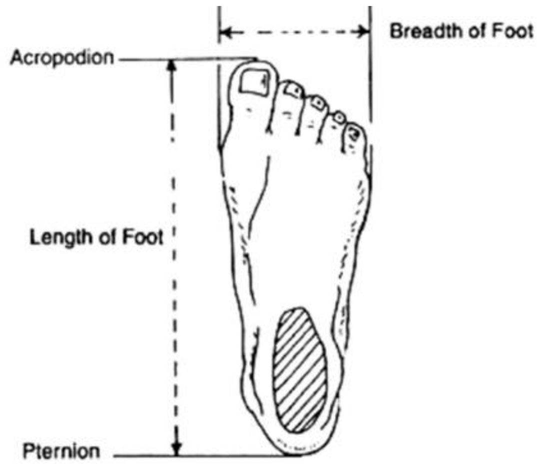

Figure 3.13 Definition of foot length (Kamal & Jadav, 2016)

3.4.2.11.2 Equipment and technique

Foot length was measured from the most posterior part (centre) of the heel to the most anterior part of the longest toe (either 2nd toe or 1st toe), with the participant in the supine position, using a standard, clearly calibrated, non-stretchable anthropometric tape (Butterfly, Shanghai, China) (Ahmad et al., 2014). The measurement was taken while the participants' foot was placed on a flat surface (Figure 3.14).

Figure 3.14 **Measuring foot length (https://www.researchgate.net/figure/The-anthropometric-measurements-foot-length-A-forefoot-width-B-medial-malleolus_fig2_51174793)**

3.4.2.12 Substitution of measurements in published predictive equations

The equations that were used to predict height to test for agreement with standing height, are listed in Table 3.1 Predictive equations to estimate height. Some of the measurements were used as is, such as arm-span, whilst equations were used for others.

Table 3.1 Predictive equations to estimate height

Demi-span (cm)	
Bassey (1986) *(125 normal young to middle-aged adults living in Europe)*	Males: (1.40 X DS) + 57.8
	Females: (1.35 X DS) + 60.1
Hirani et al (2010)*(1421 normal adults aged 25-45 y living in England)*	Males: 65.8 (4.3) + 1.33 (0.05) X DS
	Females: 64.0 (5.1) + 1.31 (0.07) X DS
Ulna length (cm)	
Barbosa (2012) *(Hospitalised adults < 65 y living in England [n=222] and Portugal [36])*	Males: 84.5 + (3.2 X UL)
	Females: 92.0 + (2.9 X UL)
MUST equations (Elia, 2003) *(229 normal adults < 65 y living in Britain)*	Males: 79.2 + (3.60 X UL)
	Females: 95.6 + (2.77 X UL)
Ilayperuma et al (2010) (*258 normal young adults 20-23 y living in Sri Lanka*)	Males: 97.252 + (2.645 X UL)
	Females: 68.777 + (3.536 X UL)

Knee height (cm)	
Chumlea and Guo (1992) *(6672 adults < 65 yrs, living in the USA)*	Males: (2.02 X KH) – (0.04 X age) + 64.19
	Females: (1.83 X KH) – (0.24 X age) + 84.88
Chumlea et al (1994) (*normal adults < 60 yrs; 299 black males, 2177 white males, 402 black females, 2537 white females living in the USA)*	Black males: 73.42 + (179 X KH)
	White males: 71.85 + (1.88 X KH)
	Black females: 68.10 + (1.86 X KH) - (0.06 X age)
	White females: 70.25 + (1.87 X KH) – (0.06 X age)
Tibia length (cm)	
Banerjee et al (2015) *(100 normal adults aged 25-64 y, living in India)*	Males: 71.361 + 2.575 (tibia length)
	For females: 65.344 + 2.691 (tibia length)
Ahmad et al (2014) *(359 medical students in South India)*	46.969 + 2.886 (tibia length)
Fibula length (cm)	
Ahmad et al (2014) *(359 medical students in South India)*	46.881 + 2.847 (fibula length)
Foot length (cm)	
Ahmad et al (2014) *(359 medical students in South India)*	52.255 + 4.519 (foot length)

DS – demispan, UL – ulna length, KH – knee height

3.4.3 Validity, reliability, and measurement and methodology errors

Validity describes the ability of a measurement to achieve the function for which it is intended. It gives an indication of the degree to which a study is free from bias or systematic error (Porta et al., 2014). In order to improve the validity of the study, questions and techniques were based on an in-depth literature study. Validity of the questionnaire was also ensured by including only questions directly related to the aim of the study.

Reliability refers to the degree of similarity between information obtained, when a measurement is repeated under the same circumstances (Porta et al., 2014). Reliability of the questionnaire was improved by conducting a pilot study to identify and correct any ambiguous or misleading questions. To improve communication with Sesotho-speaking participants, health care workers in the wards, who were proficient in the language, were asked to assist as interpreters.

To improve reliability of the anthropometric measurements, standardised methods and calibrated equipment were used. The researcher (a qualified and experienced dietitian) was re-trained by a level 2 ISAK-qualified anthropometrist, prior to commencing with data collection in order to improve the accuracy of locating the anatomical landmarks and the reliable, accurate and precise taking of measurements as prescribed by standardised procedures in the literature.

After data collection, two different individuals, independent of each other, captured the data from the written data sheets onto two separate Excel spreadsheets, which were then compared by the biostatistician to ensure data integrity.

3.5 Pilot study

A pilot study was conducted on the 8th and 10th of November 2016 to ensure that the questions were fully understood during the structured interviews and to determine how long data collection per participant would take. The pilot study included nine patients from the designated study population and various wards who met the inclusion criteria.

The researcher completed the questionnaire on socio-demographics and medical history by means of a structured interview, and anthropometric measurements were performed as outlined above. In order to pilot the data capturing process, the data from the pilot study were captured from the data forms onto the Excel data sheets and checked by the biostatistician. As there were no changes to the methodology, based on the pilot study, the data from the pilot study were included in the final study.

3.6 Procedure

The study was performed according to the following steps:

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Step 1: Approval and permission

- Approval to conduct the study was obtained from the Health Sciences Research Ethics Committee of the University of the Free State (Appendix A).
- Approval to conduct the study was obtained from Free State Department of Health Provincial Research Committee (Appendix B).
- The hospitals and wards were informed of the study and the procedures involved.

Step 2: Pilot study

- The pilot study was conducted on nine patients who met the inclusion criteria and the results were included in the final study.

Step 3: Data collection

- On arrival at the hospital, the staff in charge in the various wards were informed of the research study and what it entailed.
- All equipment were calibrated and checked each day before data collection.
- Prospective participants were greeted, given an information document (Appendix D) and invited to participate. This document communicated details on the information that would be collected in the study, the procedures that would be carried out on the participants and any advantages or disadvantages that the study might expose them to. Participants were informed that participation was voluntary and that they could withdraw from the study at any time without any consequences to them. If participants were illiterate, this document was read to them by the researcher.
- If patients met the inclusion criteria and gave informed consent (Appendix E), they were included in the study.
- Where available, curtains were drawn or room dividers placed to improve privacy. The questionnaire (Appendix C) was completed by making use of the information in the participants file. Any information that could not be obtained from the participants' file was obtained by means of a structured interview. After the interview, participants were measured and measurements were recorded. Once measurements were completed participants were thanked for their cooperation and greeted.

Step 4: Data capturing and analysis

- Data was captured by two individuals onto two separate Excel spreadsheets.
- Data was sent to the Department of Biostatistics of the Faculty of Health Sciences of the University of the Free State where statistical analysis was performed.

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3.7 Statistical analysis

The statistical analysis was performed with the assistance of the Department of Biostatistics at the University of the Free State. Descriptive statistics were expressed as frequencies and percentages for categorical data and medians and interquartile ranges for continuous data, after non-normal distribution of the data was established with the Shapiro–Wilk, Kolmogorov-Smirnov and Anderson-Darling tests for normality. Actual measured height and height predicted by each of the equations, were compared by means of 95% confidence intervals.

Agreement between the directly measured height and indirect determinations of height with each of the 11 equations (Table 3.1), were assessed by means of Bland-Altman analysis. The latter approach is more appropriate than correlation and regression methods for this type of comparison, and entails plotting of the difference between measurements of the same parameter obtained with two different techniques, against the mean of the measurements. For the current study, this entailed plotting the difference between height as predicted by equations and the actual reference height against the mean of the measurements.

In addition, Spearman correlations were done to determine which of the measured body segments had the best association with measured standing (reference) height. Multiple regression analysis was performed to identify which body segments best predicted reference height in this study population.

3.8 Limitations of the study

Several obstacles that were not foreseen, were encountered during the study, which limited the sample size. Firstly, obtaining permission from the Free State Department of Health Provincial Research Committee took much longer than anticipated, thus shortening the anticipated data collection period. Secondly, very few of the hospitalised patients met the inclusion criteria, since the majority were found to be either older than 50 years of age, or too weak or ill to stand independently and unassisted. Thirdly, length of stay was longer than expected from the records, thus, the researcher would return to a hospital within two to three days and find the same patients occupying the beds. Fourthly, data collection per individual participant, on the whole also took

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longer than anticipated from the pilot study. Lastly, on several occasions the patients invited to participate, did not understand the aim of the study and therefore did not give consent to participate.

Another possible limitation that was noticed, was that the hospital mattresses were often prone to indent substantially when a participant was lying down. Thus, the indentation of the bed could have influenced the accuracy of the measurements of recumbent length. This is, however, the standardised way in which recumbent length is measured (Gray & Gray, 1980).

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CHAPTER 4: MANUSCRIPT 1:

AGREEMENT BETWEEN MEASURED HEIGHT, AND HEIGHT PREDICTED FROM PUBLISHED ESTIMATE EQUATIONS, AMONGST ADULTS IN A SOUTH AFRICAN HOSPITALISED POPULATION

Prepared according to the Guidelines for Authors

of the

South African Journal of Clinical Nutrition (Appendix F)

(Note that the numbering and the referencing style of the broader document were maintained for the sake of continuity in the dissertation)

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Agreement between measured height, and height predicted from published estimate equations, amongst adults in a South African hospitalised population

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Keywords: predicted height, predictive equations, hospitalised patients, South Africa

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4.1 Abstract

Objectives: To assess the agreement between measured (reference) height and height predicted from published equations derived from measurement of body segments, in a South African government hospital setting.

Design: Descriptive cross-sectional study

Setting: Medical, surgical, pulmonary, orthopaedic, cardiovascular and general wards at Pelonomi, Universitas and National Hospitals, Bloemfontein.

Subjects: All admitted patients, 20-50 years, who gave written informed consent, could stand upright and unassisted, and were without medical conditions or treatments affecting height between November 2016 and December 2017 (n=141).

Outcome measures: Reference height, recumbent height, arm-span, demi-span, ulna length, knee height, tibia length, fibula length, and foot length were measured according to standardised techniques. Self-reported height and height noted in the medical files, were recorded. Height, predicted by 12 published equations, were compared with reference height by 95% confidence intervals (CI) and Bland–Altman analysis.

Results: Only six (4.3%) participants could self-report their height, and only 16 (11.3%) had height recorded in their medical files. The median reference height of the sample (38.3% female; median age 38.8 years, IQR: 10.1 years) was 165.5 cm (males: 169.3 cm; females: 158.4 cm). Only a set of equations based on knee-height and standardised on a large US population of adults <65 years, estimated height without statistically significant deviance from the reference height.

Conclusions: Most standardised equations tested on South African hospitalised adults resulted in height estimations that were statistically significantly different from reference height. Equations standardised on other populations may not be suitable for the South African population due to differences in genetic and environmental factors.

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4.2 Introduction

Height is a fundamental measurement in hospitalised patients. Amongst many other clinical applications, accurate height measurements are required to calculate body mass index (BMI) and ideal body weight (IBW), which, in turn, are used in nutritional screening and the calculation of nutritional and drug dosage requirements of patients (van den Berg et al., 2016; Venkataraman et al., 2015). Currently, international consensus exist that all patients should be screened for nutritional risk on admission (Cederholm et al., 2017) as malnutrition in hospitalised patients has devastating consequences on clinical outcomes and is associated with increased length of stay (LOS), longer duration of rehabilitation, increased readmission, increased cost of healthcare and increased mortality. Whereas some patients are admitted with malnutrition, others acquire malnutrition during hospitalisation; thus, hospital malnutrition is a prevalent phenomenon worldwide (Souza et al., 2015). Nutritional screening should therefore continue throughout hospital stay and appropriate dietary interventions should be employed to improve nutritional status and prevent malnutrition (Alwarawrah et al., 2018; Cederholm et al., 2018; Cederholm et al., 2017; Allard et al., 2015).

BMI is a principle component of all the screening tools that have traditionally been recommended by the European Society for Clinical Nutrition and Metabolism (ESPEN), including the Malnutrition Universal Screening Tool (MUST), Mini Nutritional Assessment (MNA), and the Nutritional Risk Screening (NRS2002). Recently, the global clinical nutrition community has reached consensus on the core diagnostic criteria for malnutrition in adults in clinical settings. Low BMI is one of phenotypic criterion that a patient may present with to suggest a diagnosis of malnutrition according to the GLIM (Global Leadership Initiative on Malnutrition) criteria (Cederholm et al., 2018; Cederholm et al., 2017).

Accurate measurement of height is required to calculate BMI. Measurement of height in hospitalised patients may be problematic due to patients not being able to stand upright unassisted, including those connected to various lines and monitors, as well as frail, elderly or injured patients. If a patient’s height cannot be measured, the patient or a family member is often asked to report the patient’s height, or the healthcare professional estimates the patient’s height by eyeballing. None of these methods are ideal and often result in inaccurate height recording (Griebeler et al., 2011; Gorber et al., 2007; Hendershot et al., 2006). Patients can also be measured while lying down to obtain the recumbent length, but this requires a standardised technique that is rarely practical in the clinical setting (Barbosa et al., 2012). Also, measurements might not be accurate due to indentation of soft mattresses or a patients' bed being elevated for clinical reasons, such as preventing aspiration.

Indirect methods for determining height may be used and most commonly involve long bone measurements that are substituted into height estimation equations. Equations differ with regard to which body segment is measured. Furthermore, equations also differ based on the age, gender and ethnicity of the population it was standardised on. Numerous predictive equations have been standardised on various populations globally, but none have been developed specifically for the South African population. Only three studies to date have investigated the usefulness of published equations to accurately predict height among South Africans. Marais et al. (2007) compared knee height and arm-span as a proxy for height in the elderly in the Western Cape, and found that knee height only differed from measured height by 2 cm; van den Berg et al. (2016) found that the ulna-based MUST equations overestimated height in Bloemfontein hospitals; and Lahner et al. (2016) reported that arm-based prediction equations do not accurately predict reference height in a group of young adults in KwaZula-Natal. Data are thus currently insufficient to guide health care workers on which equation or method to use to accurately estimate height among hospitalised patients in South Africa when direct measurement is impossible.

This study aimed to determine the agreement between directly measured height and recumbent length, self-reported height, height recorded on admission in the participant's medical file, and height predicted from 12 published prediction equations, in a South African population of hospitalised patients.

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4.3 Methods

4.3.1 Study population and sampling

A descriptive cross-sectional study was conducted in 2016/2017. Ethical approval was obtained from the Health Sciences Research Ethics Committee of the University of the Free State *(125/2016)* and the Free State Department of Health Provincial Research Committee. The study population comprised patients admitted to Universitas, Pelonomi and National Hospitals in Bloemfontein. The study population was limited to patients admitted to the medical, surgical, pulmonary, orthopaedic, cardiovascular and general wards, as patients in these wards are likely to be able to stand upright without assistance. All patients in the mentioned wards admitted during the time of data collection, who met the inclusion criteria and gave informed consent, were included in the study. Inclusion criteria included age between 20 and 50 years (to account for bone maturation and degeneration) and the ability to stand upright without assistance for all measurements to be taken accurately. The final sample comprised 141 participants.

4.3.2 Data collection

Anthropometric variables included height, recumbent length, arm-span, demi-span, ulna length, knee height, tibia length, fibula length, and foot length. All measurements were obtained using standardised techniques. Measurements were taken by the researcher, who has experience in measuring body segments and was trained by an ISAK-qualified anthropometrist before the study. Height was measured using standardised techniques using a calibrated, mobile free-standing stadiometer (*Seca 213®; Seca GmbH, Hamburg, Germany*). Recumbent height, arm-span, demi-span, ulna length, tibia length, fibula length and foot length were measured with a standard, clearly calibrated non-stretchable, steel anthropometric tape (*Butterfly, Shanghai, China*). Knee height was measured with a knee height broad-blade sliding calliper. The same equipment was used for all the measurements and calibrated daily.

Upon rising in the morning, compression of the spine occurs, resulting in the loss of approximately 1% in height (Stewart et al., 2011). The decrease in height occurs rapidly in the first half an hour, and most loss in height occurs in the first two hours of the day (Krishan & Krishan, 2007). Patients

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are woken up before 06:00 am for observations in the wards included in the study. All measurements were taken between 08:30 and 13:30 to avoid discrepancies due to diurnal variation. The stretch stature method was also used to reduce diurnal variation (Stewart et al., 2011).

Socio-demographic information, including date of birth, gender and race, were recorded by the researcher during structured interviews with each participant. Medical diagnoses and treatment were recorded to ensure that these factors did not influence bone development and growth. Height recorded in the participants' medical file was also noted.

The researcher visited the various hospitals and invited patients to participate in the study. If they showed interest in the study, the researcher explained what was expected of them, and that participation was voluntary. Participants were required to sign a written informed consent form after which their medical files were screened to ensure that they met the inclusion criteria. Curtains and room dividers were used where available, to improve privacy. Each participant was assigned a participant number to ensure confidentiality.

4.3.3 Data analysis

Height was predicted by 11 published equations as summarised in Table 4.1.

Table 4.1 Predictive equations to estimate height and population standardised on

Demi-span (cm)	
Bassey (1986) *(125 normal young to middle-aged adults living in Europe)*	Males: (1.40 X DS) + 57.8
	Females: (1.35 X DS) + 60.1
Hirani et al (2010)*(1421 normal adults aged 25-45 y living in England)*	Males: 65.8 (4.3) + 1.33 (0.05) X DS
	Females: 64.0 (5.1) + 1.31 (0.07) X DS
Ulna length (cm)	
Barbosa (2012) *(Hospitalised adults < 65 y living in England [n=222] and Portugal [36])*	Males: 84.5 + (3.2 X UL)
	Females: 92.0 + (2.9 X UL)
MUST equations (Elia, 2003) *(229 normal adults < 65 y living in Britain)*	Males: 79.2 + (3.60 X UL)
	Females: 95.6 + (2.77 X UL)
Ilayperuma et al (2010) (*258 normal young adults 20-23 y living in Sri Lanka*)	Males: 97.252 + (2.645 X UL)
	Females: 68.777 + (3.536 X UL)
Knee height (cm)	
Chumlea and Guo (1992) *(6672 adults < 65 yrs, living in the USA)*	Males: (2.02 X KH) – (0.04 X age) + 64.19
	Females: (1.83 X KH) – (0.24 X age) + 84.88
	Black males: 73.42 + (179 X KH)

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Chumlea et al (1994) (*normal adults < 60 yrs; 299 black males, 2177 white males, 402 black females, 2537 white females living in the USA)*	White males: 71.85 + (1.88 X KH)
	Black females: 68.10 + (1.86 X KH) - (0.06 X age)
	White females: 70.25 + (1.87 X KH) – (0.06 X age)
Tibia length (cm)	
Banerjee et al (2015) *(100 normal adults aged 25-64 y, living in India)*	Males: 71.361 + 2.575 (tibia length)
	For females: 65.344 + 2.691 (tibia length)
Ahmad et al (2014) *(359 medical students in South India)*	46.969 + 2.886 (tibia length)
Fibula length (cm)	
Ahmad et al (2014) *(359 medical students in South India)*	46.881 + 2.847 (fibula length)
Foot length (cm)	
Ahmad et al (2014) *(359 medical students in South India)*	52.255 + 4.519 (foot length)

DS – demispan, UL – ulna length, KH – knee height

Data analysis was performed with the assistance of the Department of Biostatistics of the University of the Free State. The data analysis for this study was generated using SAS software (Copyright, SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA). Categorical data were expressed as frequencies and percentages. The Shapiro–Wilk, Kolmogorov-Smirnov and Anderson-Darling tests for normality indicated that the data was skewed, therefore, continuous data were expressed as medians and ranges.

Bland–Altman analysis was used to assess the 95% limits of agreement between the height predicted from published estimate equations and measured height. The difference between the measurements of the same variable that was obtained through different methods, was plotted against the mean of the measurements. Bland-Altman analysis is better suited to determine agreement than other methods of comparison such as correlation or regression (Giavarina, 2015). The 95% confidence interval for the median difference between predicted and reference heights (paired) were used to assess if the predicted height, obtained with each equation, differed significantly from the measured reference height.

4.4 Results

The sample of 141 included 68 (48.2%) participants from Universitas, 44 (31.2%) participants from Pelonomi and 29 (20.6%) participants from National Hospital in Bloemfontein. The median age of the participants was 38.8 years (interquartile range: 10.1 years). The gender and ethnic distribution of the participants are summarised in Table 4.2.

Table 4.2 Gender and ethnic distribution of participants

Variable	Frequency (n)	Percentage (%)
Gender		
Male	**87**	**61.7**
Female	**54**	**38.3**
Ethnicity		
Black	**119**	**84.4**
Coloured	**5**	**3.6**
Asian	**5**	**2.1**
White	**14**	**9.9**

Only 16 participants (11.3%) had their height recorded in their medical files and only six participants (4.3%) were able to self-report their height, therefore the agreement with reference height could not be determined accurately. Recumbent length overestimated actual height by a median value of 0.3 cm with an interquartile range of 10.0 cm. The median difference between recumbent length and reference height was statistically significant (95% CI [0.2; 0.5]). However, the 95% limits of agreement was -4.0 cm to 1.3 cm (resulting in close clustering of the points around the zero line of perfect agreement in the Bland-Altman plot), indicating that recumbent length (measured according to standardised technique), ranged from underestimating actual height with up to 4 cm, to overestimating actual height with up to 1.3 cm. In a 70 kg individual with a reference height of 175 cm (actual BMI = 22.8 kg/m^2), this will result in a BMI that ranges between 22.5 kg/m^2 and 23.9 kg/m^2.

Table 4.3 summarises the difference between reference height and the height predicted by means of the various estimate equations. Of the 11 equations tested, only two were able to predict height with no statistically significant difference from the reference height. The first was the set of knee

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height-based equations by Chumlea et al. (1994), which have been standardised based on the measurements of thousands of healthy USA adults under the age of 60 (95% CI [-0.9; 0.2]; 95% limits of agreement: -5.8 cm to 7.2 cm). Of the equations that use demi-span, the equations by Bassey (1986), that were standardised based on measurements of 125 normal young to middle-aged adults living in Europe, best predicted height (95% limits of agreement: -7.8 cm to 9.4 cm). Ulna length, as part of the MUST equations (Malnutrition Advisory Group et al., 2011) resulted in the widest 95% limits of agreement (-20.4 cm to 0.5 cm).

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Table 4.3: Agreement between height predicted by equations based on body segments and reference height measured by stadiometer

	Minimum	Lower Quartile	Median	Upper Quartile	Maximum	95% Confidence interval for the median difference between predicted and reference heights (paired)	95% Limits of agreement (cm) by Bland Altman analysis
Reference height (measured via standardised stadiometer technique) (cm) (n=141)	144.3	159.2	165.5	171.5	184.1		
Recumbent length							
Recumbent length (cm) (n=139)	**143.9**	**159.5**	**166.0**	**172.0**	**185.5**	**[0.2; 0.5]***	**-4.0 to 1.3**
HEIGHT PREDICTED BY PUBLISHED EQUATIONS (cm)							
Height predicted by demi-span-based equation (n=141)							
Bassey (1986)	**149.9**	**160.7**	**166.6**	**171.4**	**185.5**	**[0.2; 1.5]***	**-7.8 to 9.4**
Hirani et al (2010)	**151.1**	**161.7**	**168.7**	**173.5**	**187.1**	**[1.8; 3.1]***	**-9.4 to 6.9**
Height predicted by ulna length-based equations (n=141)							
Barbosa (2012)	**156.4**	**168.6**	**172.2**	**176.0**	**190.4**	**[5.6; 7.4]***	**-17. 8 to 4.5**
MUST equations (Elia, 2011)	**157.1**	**169.6**	**177.1**	**181.8**	**198.4**	**[9.6; 11.9]***	**-20.4 to 0.5**

Ilayperuma et al (2010)	**147.3**	**163.2**	**169.5**	**172.6**	**184.8**	**[1.1; 3.5]***	**-12.7 to 6.3**
Height predicted by knee height-based equations (n=141)							
Chumlea & Guo (1992)	**156.8**	**164.6**	**169.3**	**172.4**	**188.5**	**[2.5;4.5]***	**-13.2 to 7.0**
Chumlea et al (1994)	**147.9**	**159.7**	**165.4**	**170.6**	**184.6**	**[-0.9; 0.2]**	**-5.8 to 7.2**
Height predicted by tibia length-based equations (n=141)							
Banerjee et al (2015)	**150.4**	**166.4**	**171.5**	**177.5**	**201.5**	**[5.1; 6.8]***	**-17.3 to 4.3**
Ahmad et al (2014)	**138.2**	**154.2**	**160.1**	**165.9**	**193**	**[-6.5; -4.4]***	**-7.9 to 16.5**
Height predicted by fibula length-based equation (n=141)							
Ahmad et al (2014)	**144.5**	**157.4**	**163.9**	**167.6**	**189.8**	**[-3.5; -1.1]***	**-6.5 to 13.0**
Height predicted by foot length-based equation (n=140)							
Ahmad et al (2014)	**139.5**	**157.9**	**162.7**	**170.7**	**187.4**	**[-3.6; -1.4]***	**-11.5 to 14.2**

*** indicates that the mean predicted height differed significantly from the paired mean reference height**

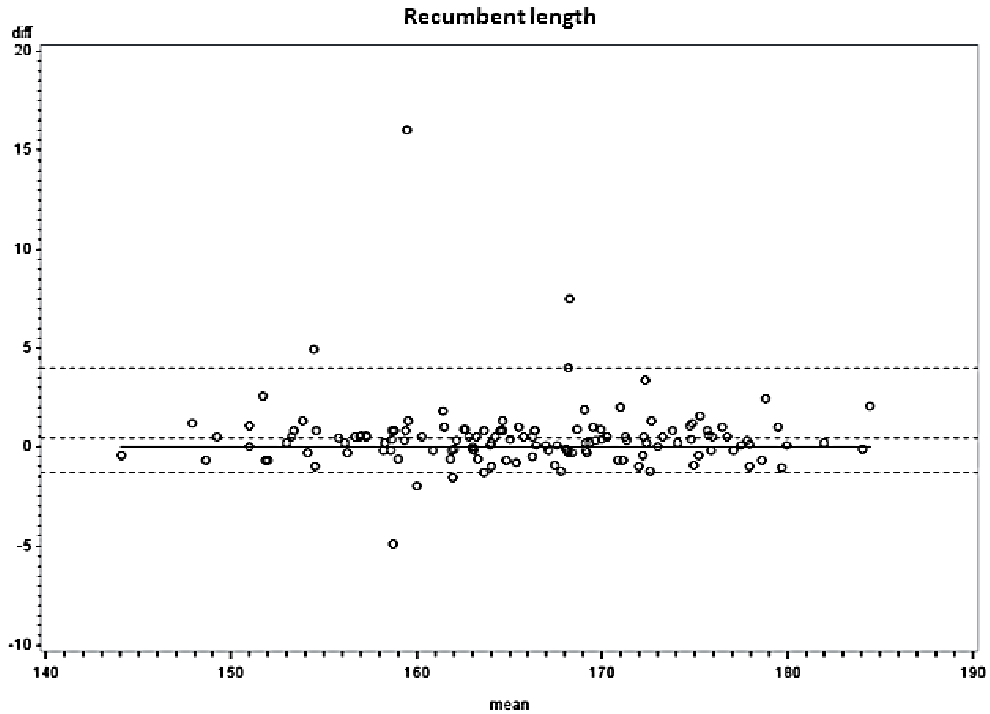


Figure 4.1: Bland–Altman plot depicting the level of agreement between recumbent length and reference height (x-axis: degrees of freedom; y-axis: difference between the mean of recumbent length and reference height for each participant)

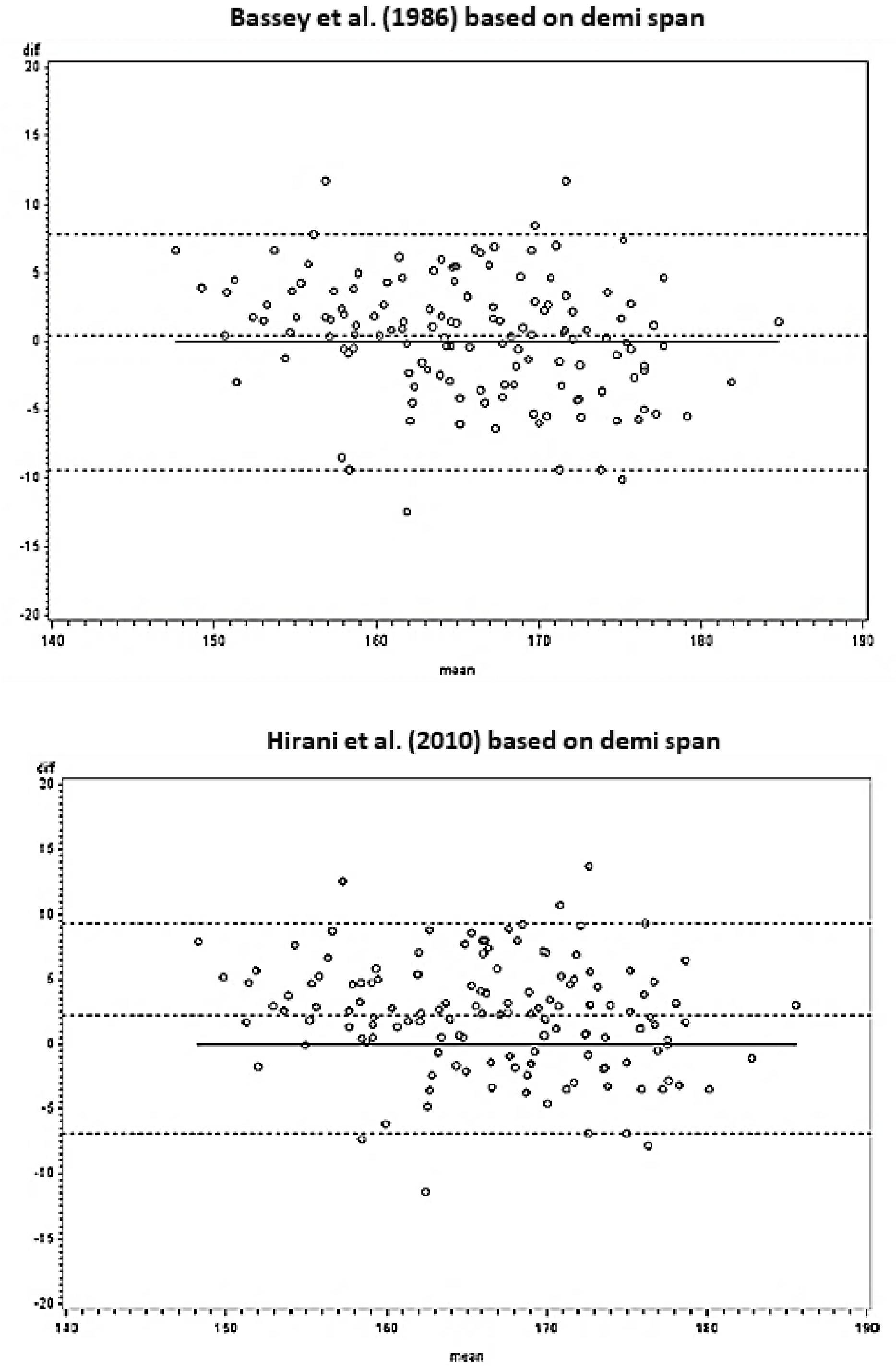


Figure 4.2 Bland–Altman plots depicting the levels of agreement between reference height and height predicted from equations based on demi-span (x-axis: degrees of freedom; y-axis: difference between the mean of predicted height and reference height for each participant)

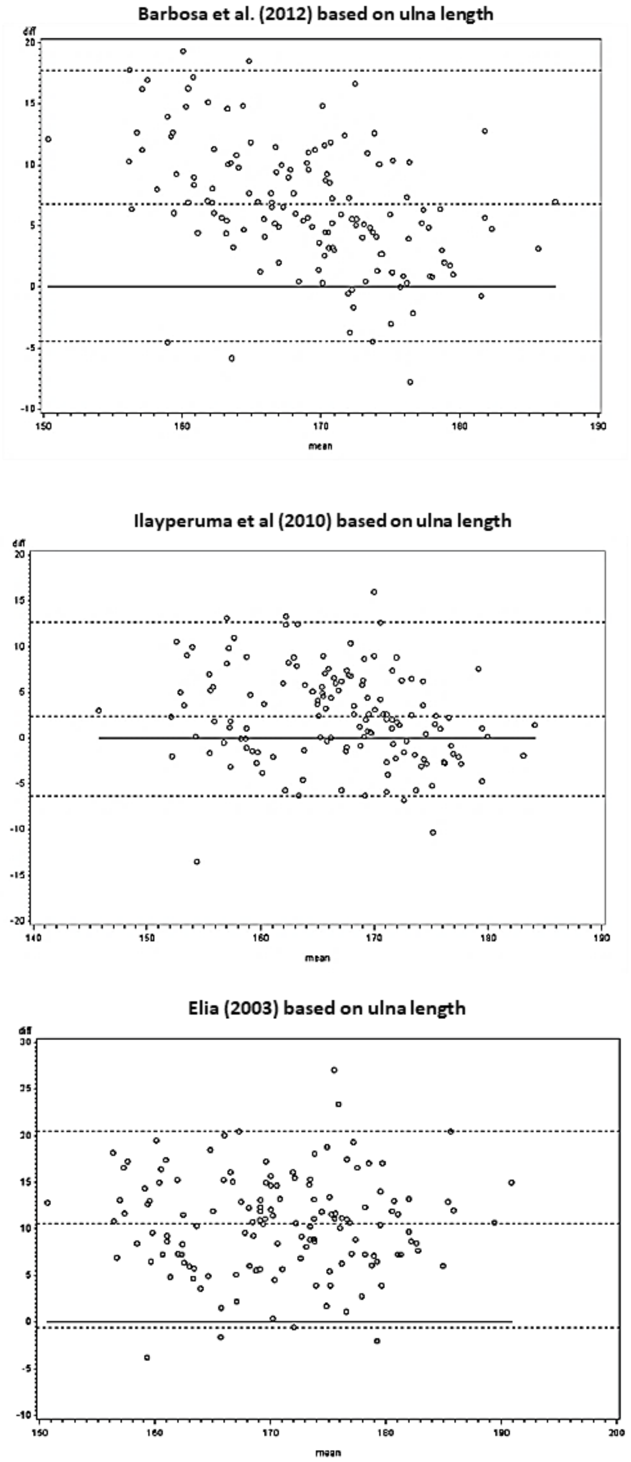
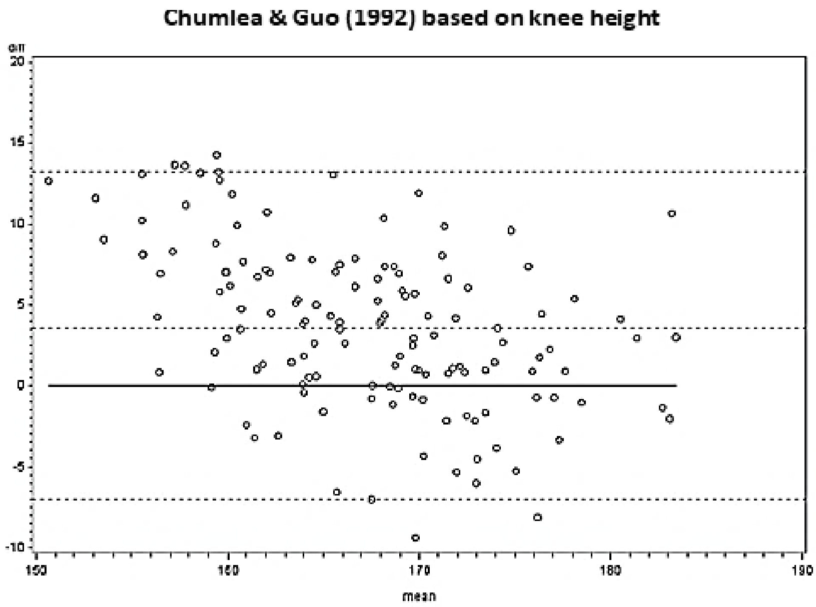


Figure 4.3: Bland–Altman plots depicting the levels of agreement between reference height and height predicted from equations based on ulna length (x-axis: degrees of freedom; y-axis: difference between the mean of predicted height and reference height for each participant)



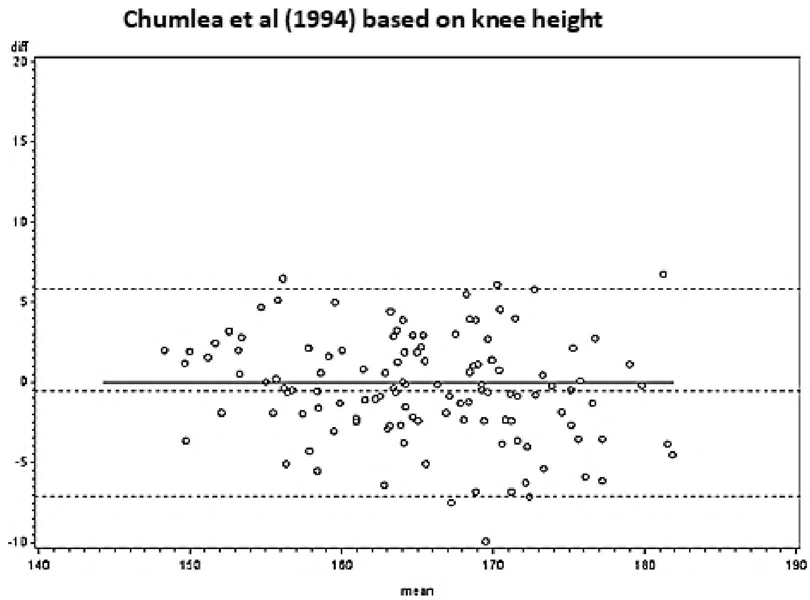


Figure 4.4: Bland–Altman plots depicting the levels of agreement between reference height and height predicted from equations based on Knee height (x-axis: degrees of freedom; y-axis: difference between the mean of predicted height and reference height for each participant)

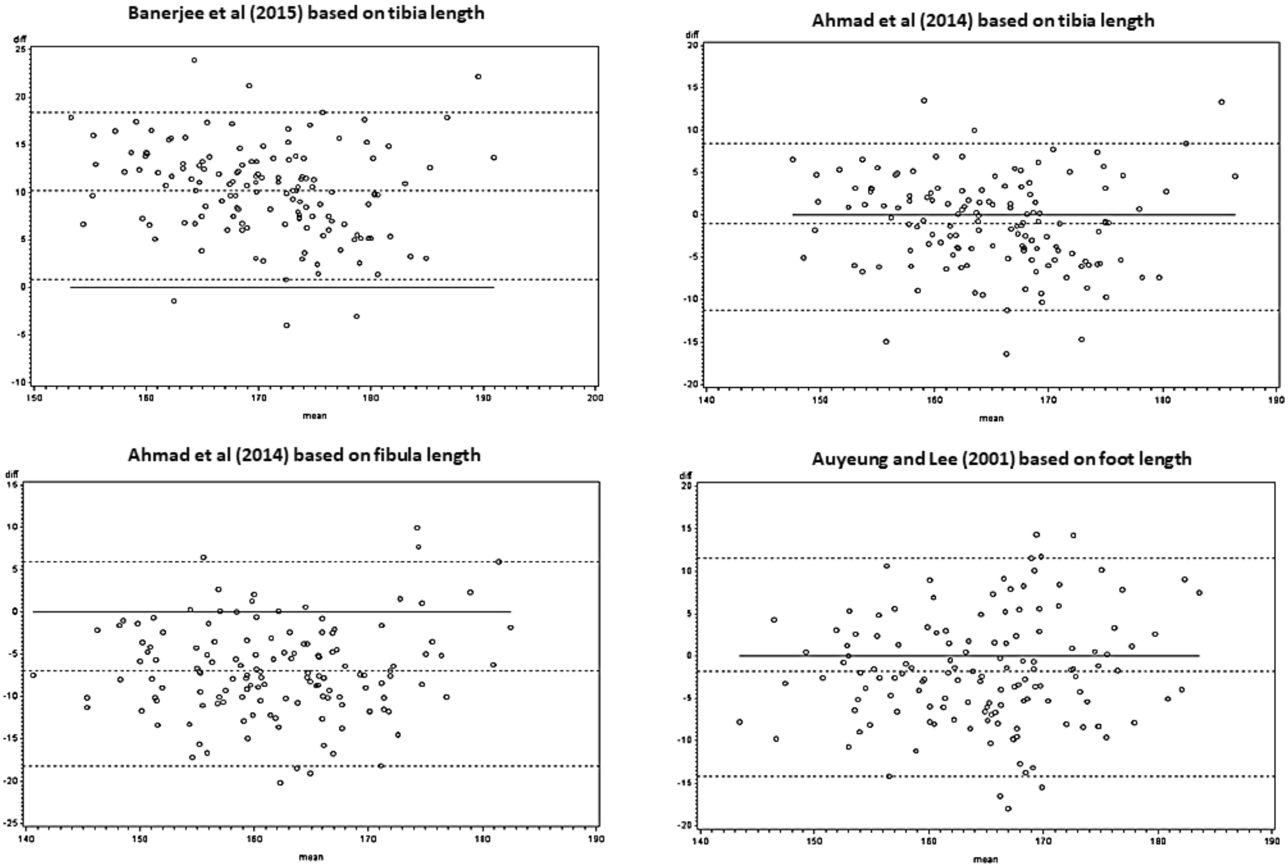


Figure 4.5 Bland–Altman plots depicting the levels of agreement between reference height and height predicted from equations based on tibia, fibula and foot length (x-axis: degrees of freedom; y-axis: difference between the mean of predicted height and reference height for each participant)

4.5 Discussion

In this study, less than 5% of participants from a population of hospitalised patients admitted to government hospitals in Bloemfontein, South Africa, could self-report their height and only 11.3% had their height recorded in their medical files. Moreover, the study found that among 11 published equations, standardised on adult <65 years, and standardised per gender, only one knee height-based set of predictive equations could predict height within acceptable limits in the study population. These equations were standardised for males and females, and black and white ethnicities by Chumlea et al. (1994) on 5415 normal US adults under 60 years old.

The fact that so few participant files had height measurements noted seems to indicate that healthcare practitioners in the government hospitals in Bloemfontein do not seem to consider height as an important measurement when assessing a patient in hospital. Even though the admission form and prescription chart require measurement of height; all participants were able to stand unassisted for accurate height measurement, and stadiometers were available in all the wards where participants were recruited, height was only recorded in a small minority of participant files. Moreover, if patients cannot be measured standing upright, healthcare workers may not always have the necessary equipment, knowledge or skills needed to measure body segments and apply predictive equations, which makes self-reported height seem like a practical solution. The current study, however, confirms the experience of dietitians that most patients in the South African government setting do not know their height (or weight). Bloomfield et al. (2006) state that, due to the various uses of height in the treatment of patients, actual measurements are preferred to estimates to limit error. Considering the multiple clinical uses of height in the treatment of hospitalised patients, this calls for further investigation and intervention.

The results of the current study show that recumbent length, although significantly different from reference height, could be a reasonable alternative to use when actual height cannot be measured. Measuring recumbent height is relatively easy and does not require expensive equipment, but does however, require the patient to lie straight and perfectly flat. Many patients who are critically ill are in semi-Fowler's position due to the effects on haemodynamic parameters (Anchala, 2016) or attached to various lines, making it difficult to measure recumbent height accurately. Even with patients lying down, the firmness of the mattress may affect measurement. Hendershot et al. (2006) emphasise the need for accurate height measurements in hospitalised patients to optimise patient care.

Even if the necessary equipment was available to measure various body segments and all healthcare workers in South African hospitals were trained to do so, no study to date has identified a reliable method of predicting height in the South African population. The current study found that most published predictive equations did not yield reliable results in this population. The difference between reference height and height estimated from many of the equations are considered clinically significant as some equations underestimated height by median values of up to 5.8 cm while others overestimated height by median values of as much as 10.9 cm. The 95% limits of agreement, calculated in the Bland–Altman analysis, indicated underestimation of almost 20.4 cm to overestimation of 16.5 cm. Other studies have also found variable accuracy in height prediction equations between ethnic groups (Fogal et al., 2015; Bjelica et al., 2012; Barbosa et al., 2012). These major discrepancies may be attributed to the fact that the equations were standardised on different populations, ethnicities, and age groups.

The current study did, however, identify the knee height-based equations by Chumlea et al. (1994) as the best to predict height in South African hospitalised patients. The fact that these equations were standardised on a large population (albeit from the US) of more than 5000, whereas other equations were typically standardised on much smaller populations, may contribute to its higher level of agreement. On the other hand, Marais et al. (2007) also found that knee-height measurements substituted in the equations developed by Chumlea & Guo (1992), were more closely related to the standing height than arm-span. In KwaZulu Natal, published arm-based equations did not accurately predict height in a sample of 200 younger adults and the study concluded that gender and race-specific equations are needed (Lahner et al., 2016). This concurs with the findings of van den Berg et al. (2016) that the ulna-based MUST equations overestimated height and were unreliable in individuals aged 20 to 60 years in a hospitalised population in Bloemfontein. In the South African setting, the high prevalence of stunting could play a role in the finding that knee height-based equations deliver better predictions than arm-based equations.

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The World Health Organization (WHO) Multicentre Growth Reference Study (MGRS) was designed to develop growth references standards for infants and children. To obtain reference data, the growth patterns of 8 500 children living in ideal conditions with regards to infant feeding and healthcare in Brazil, Ghana, India, Norway, Oman, and the United States, were followed. The study aimed to provide the best conditions for growth and development and to limit sources of bias. The MGRS found that infants and children from around the world experience similar linear growth when important health and environmental needs are met (de Onis, 2007). This begs the question of whether differences in skeletal proportions that were previously attributed to ethnicity, might perhaps rather be due to environmental factors.

As different bones grow faster during different life stages, different proportions could reflect less than optimal environmental conditions. Some evidence exist that stunting affects the long bones in the lower extremities more than in the upper extremities, which would explain the superiority of age and sex appropriate equations based on knee-height to predict height in the South African population of patients that represent the lower socio-economic strata (Pomeroy et al., 2012; McIntyre, 2011; Lorentzon et al., 2011; Bogin & Varela-Silva, 2010). Knee height measurement requires specialised equipment and knowledge and skill regarding the standardised technique and appropriate predictive equations to use, which complicates the ideal that all patients in whom reference height cannot be determined should be screened for nutritional risk on admission by nursing staff (Cederholm et al., 2018).

Stunting is a public health concern in South Africa where 27.4 % of children under the age of 5 are stunted. The prevalence in the Free State is even higher at 33.5% (SADHS, 2019). As a result of stunting, children do not reach their genetic height potential, which may influence body segment ratios. Finding the most reliable and practical way of determining height of patients who are unable to stand upright in the South African population may prove to be a very complicated task.

4.6 Limitations

The size of the study is considered a limitation. A much larger study population would have been ideal, but fewer patients than anticipated could be included in the study due to the advanced age of hospital patients, few patients who were able to stand upright without assistance and time constraints placed on the data collection period. The results of the study are still considered meaningful as no similar study has previously been conducted and the results provide valuable insight into the reliability of various standardised equations in height estimation.

A source of (probably slight) bias might have occurred due to some patients staying in bed and others walking around prior to taking measurements which could result in some diurnal variation between patients.

The researcher was well trained and practised in the anthropometric techniques, and used validated, standardised techniques and high-quality, calibrated equipment in order to obtain valid and reliable anthropometric measurements.

4.7 Conclusion and recommendations

Equations standardised on different populations may not be suitable to estimate height in the South African population due to differences in environmental factors. The importance of obtaining accurate height measurements, especially in screening for malnutrition in hospitalised patients, should not be underestimated. Hospital staff should be educated on the importance of a comprehensive patient assessment, including measuring patients' height and recording it in the files.

Currently, global consensus emphasises that all patients admitted to hospital must be screened for nutritional risk, which requires accurate height measurement to calculate BMI, while accurate height measurements are also required for various other clinically important calculations. The current study identified various obstacles to accurate height recording in the South African government hospital setting, ranging from the fact that patients and their families do not know their height; admission personnel generally do not record height on admission in the patients' medical files; and no guidelines currently exist on the most reliable measure to use to accurately estimate the height of the many patients who cannot stand upright and unassisted. The current study suggests that the set of knee height based equations of Chumlea et al (1994) may be useful for the South African population, but the

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measurement requires special equipment, knowledge and skill that admission personnel may not have.

The short-term solution may be to standardise equations on the South African population, based on more easily measured long bones, such as the ulna length, but the high prevalence of stunting in South Africa may mean that this measure may not be applicable to persons from all social classes. The ultimate solution would involve addressing the high prevalence of stunting in the country.

4.8 Acknowledgements

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CHAPTER 5: MANUSCRIPT 2:

CORRELATION BETWEEN BODY SEGMENTS AND HEIGHT AMONGST ADULTS IN A SOUTH AFRICAN HOSPITAL POPULATION

Prepared according to the Guidelines for Authors

of the

South African Journal of Clinical Nutrition (Appendix F)

(Note that the numbering and the referencing style of the broader document were maintained for the sake of continuity in the dissertation)

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Correlation between body segments and height amongst adults in a South African hospital population

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Keywords: predicted height, demi-span, ulna, knee height, tibia, fibula, foot, South Africa

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5.1 Abstract

Objectives: To determine the correlation between body segments and standing (reference) height in patients in a South African government hospital setting.

Design: Descriptive cross-sectional study

Setting: Medical, surgical, pulmonary, orthopaedic, cardiovascular and general wards at Universitas, Pelonomi and National Hospitals in Bloemfontein.

Subjects: Patients, 20 to 50 years of age, admitted at the time of data collection and able to stand upright without assistance (n=141).

Outcome measures: Spearman correlations were assessed between reference height and arm-span, demi-span, ulna length, knee height, tibia length, fibula length and foot length (measured by standardised techniques). Multiple regression analysis was performed to identify the segment that is most closely associated with reference height in the study population.

Results: The median height of 141 participants (61.7 % male, median age 38.8 years; lower quartile: 34.3 years; IQR: 10.1 years) was 165.5 cm (males: 169.3 cm; females: 158.4 cm). All body segment measurements were statistically significantly correlated with reference height, the strongest association being with knee height in both males (R^2:0.77) and females (R^2:0.86). Foot length and ulna length had the weakest correlation with reference height in males and females, respectively. Multiple regression analysis identified knee height as having the best predictive value in determining reference height.

Conclusions: Measurements of the lower leg, particularly knee height, showed better correlation with measured standing (reference) height, while regression analysis also identified knee height as superior in its ability to predict height in a South African hospitalised population with a high prevalence of stunting.

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5.2 Introduction

Height is a necessary measurement in determining drug dosage, vital capacity, and nutritional status (Bjelica et al., 2012). Determining the nutritional status of hospitalised individuals is vital in improving patient outcomes and preventing, as far as possible, hospital acquired malnutrition or worsening of existing malnutrition. Malnutrition has been associated with increased morbidity and mortality, increased length of hospital stay (LOS) and increased medical expenses (Souza et al., 2015).

Height should be measured in ambulatory patients upon admission to hospital. In many instances height cannot be measured in hospitalised patients, such as is in cases where patients are too ill or weak to stand, patients admitted to the intensive care unit are sedated, unconscious or connected to various lines, or elderly patients unable to stand (Venkataraman et al., 2015). Under these circumstances, various methods have been employed to estimate height. Most commonly a patient's height will be estimated via visual observation by a health care worker. The reliability of this method has been questioned in many studies (Venkataraman et al., 2015; Maskin et al., 2010; Hendershot et al., 2006).

According to the literature, indirect measurement to estimate height yields more accurate results than estimating height via observation (Bojmehrani et al., 2014). Indirect measurement of height involves measuring long bones in the body and making use of equations that include these measurements to predict height. This can be accomplished by substituting long bone measurements into standardised equations or using fixed body segment ratios (Chhabra, 2008). These equations and ratios have been standardised on various population groups, most of which differ extensively.

The difference in body segments in relation to height were originally thought to be due to ethnicity. It is now well known that there are many other factors that contribute to attained height in adults (Gaur et al., 2016; Perkins et al., 2016; Bogin & Varela-Silva, 2010). Studies have investigated how various genetic and environmental factors may influence the development and growth of the various long bones, which can affect body proportions (Bogin & Varela-Silva, 2010). Environmental stress may have a different impact on the growth of various bones (even in the same limb) (Pomeroy et al., 2012). Zeugopods, which include the ulna, radius, tibia and fibula, may be more sensitive to environmental stressors than stylopods (the femur and humerus). Lower limb length shows a greater degree of proportionality to height, especially the tibia (Pomeroy et al., 2012).

The South African setting is unique, including multiple ethnicities and the occurrence of a nutrition transition. This transition from healthier traditional diets to more unhealthy Western diets has contributed significantly to the high rates of obesity on the one hand and micronutrient deficiency and stunting on the other, that are evident in the South African context (Popkin et al., 2012; Abrahams et al., 2011). No study to date has investigated which body segment measurement is most closely associated with height in the unique South African setting. The aim of this study was to determine which of the body segment measurements, namely arm-span, demi-span, ulna length, knee height, tibia length, fibula length, and foot length best correlate with actual or reference height, and regression analysis was done to determine the most reliable body segment to use when estimating height.

5.3 Methods

5.3.1 Study population and sampling

Approval was obtained from the Health Sciences Research Ethics Committee of the Faculty of Health Sciences, University of the Free State (125/2016) and the Free State Department of Health Provincial Research Committee to conduct the current descriptive cross-sectional study. The study population included patients admitted to Universitas, Pelonomi and National Hospital in Bloemfontein. Patients in the medical, surgical, pulmonary, orthopaedic, cardiovascular and general wards formed the study population, as patients in these wards are likely to be able to stand upright without assistance. All patients who were in the above-mentioned wards of the three hospitals during the time of data gathering were included in the study, provided that they met the inclusion criteria and gave written informed consent. Participants had to be between 20 and 50 years of age (to account for bone maturation and degeneration) and able to stand upright without assistance in order for all measurements to be taken accurately. The final sample comprised 141 participants.

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5.3.2 Data collection

The researcher completed a structured interview with each participant. Socio-demographic information including date of birth, gender and race were recorded. Medical diagnosis and treatment were recorded to ensure that these factors did not influence bone development and growth and in turn the measurements taken. Anthropometric variables included weight, height, arm-span, demi-span, ulna length, knee height, tibia length, fibula length, and foot length. Measurements were taken by the researcher, who has experience in measuring body segments and was trained by a qualified anthropometrist prior to the study.

Height was measured by means of standardised techniques using a calibrated, mobile, free-standing stadiometer (*Seca 213®; Seca GmbH, Hamburg, Germany*). Arm-span, demi-span, ulna length, tibia length, fibula length and foot length were measured using a standard, clearly calibrated non-stretchable, steel anthropometric tape (*Butterfly, Shanghai, China*). Knee height was measured with a knee height broad-blade sliding calliper.

During the data collection period, the researcher visited the selected hospitals and invited patients to participate in the study. If they showed interest in the study, the researcher explained what was expected of them and that participation was voluntary. Participants were required to sign a consent form after which their medical files were screened to ensure that they met the inclusion criteria. To improve privacy, curtains and room dividers were used where available and to ensure confidentiality each participant was assigned a number instead of noting names.

5.3.3 Data analysis

Data analysis was completed with the assistance of the Department of Biostatistics of the University of the Free State. The data analysis for this study was generated using SAS software (Copyright, SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA). Categorical data were expressed as frequencies and percentages, and continuous data as ranges, medians and percentiles.

Spearman correlation coefficient was calculated for the variables and p-values to determine the correlation between body segments and actual height. Scatter plots were constructed to display correlation between variables. R^2 was calculated to determine which variable had the strongest correlation with height. Multiple regression analysis was applied to determine the predictive value of body segments to estimate height.

5.4 Results

The sample of 141 included 68 (48.2%) participants from Universitas, 44 (31.2%) participants from Pelonomi and 29 (20.6%) participants from National Hospital in Bloemfontein. The median age of the participants was 38.8 years (inter quartile range: 10.1 years). Table 5.1 depicts the gender and ethnic distribution of the study population.

Table 5.1: Gender and ethnic distribution of participants

Variable	Frequency (n)	Percentage (%)
Gender		
Male	**87**	**61.7**
Female	**54**	**38.3**
Race		
Black	**119**	**84.4**
Coloured	**5**	**3.6**
Asian	**5**	**2.1**
White	**14**	**9.9**

The median reference height was 169.3 cm and 158.4 cm for males and females, respectively. Although all the body segments were statistically significantly correlated with height ($p<0.05$) based on Spearman correlations, the strongest correlation coefficient (R^2) was with knee height, particularly amongst the women ($R^2 = 0.86$) (Table 5.2). Foot length, followed by ulna length, had the weakest correlation coefficient with height among males. In females it was reversed, with ulna length having the weakest correlation with height and foot length the second weakest (Figure 5.1 and Figure 5.2).

Arm-span (SD = 4.2 cm in males, 4.3 cm in females) and demi-span (SD = 3.9 cm in males and females) showed the greatest variation between participants. Tibia length showed a stronger correlation with height than the fibula length in females. Conversely, the fibula length was better correlated with height in males when compared to the tibia. In general, measurements of the lower leg were more closely correlated with height than measurements of the arms, in both genders.

Table 5.2: Spearman correlations of body segments with reference (measured standing) height

Measurement	Minimum (cm)	Median (cm)	Maximum (cm)	R^2	p-value
MALES (n=87)					
Measured standing height	156.0	169.3	184.1		
Arm-span	77.0	88.0	101.3	0.71	<0.0001*
Demi-span	68.5	80.0	91.2	0.71	<0.0001*
Ulna length	28.3	28.3	33.1	0.63	<0.0001*
Knee height	46.8	53.4	62.1	0.77	<0.0001*
Tibia length	35.1	41.6	50.2	0.72	<0.0001*
Fibula length	34.2	40.4	48.3	0.73	<0.0001*
Foot length	22.6	25.6	29.9	0.40	<0.0001*
FEMALES (n=54)					
Measured standing height	144.3	158.4	172.3		
Arm-span	72.5	81.2	90.3	0.77	<0.0001*
Demi-span	66.5	73.5	83.5	0.75	<0.0001*
Ulna length	22.2	25.6	29.5	0.59	<0.0001*
Knee height	43.6	49.4	56.3	0.86	<0.0001*
Tibia length	34.3	39.4	48.0	0.80	<0.0001*
Fibula length	31.6	37.4	50.6	0.77	<0.0001*
Foot length	19.3	23.1	26.2	0.64	<0.0001*

*** Statistically significant**

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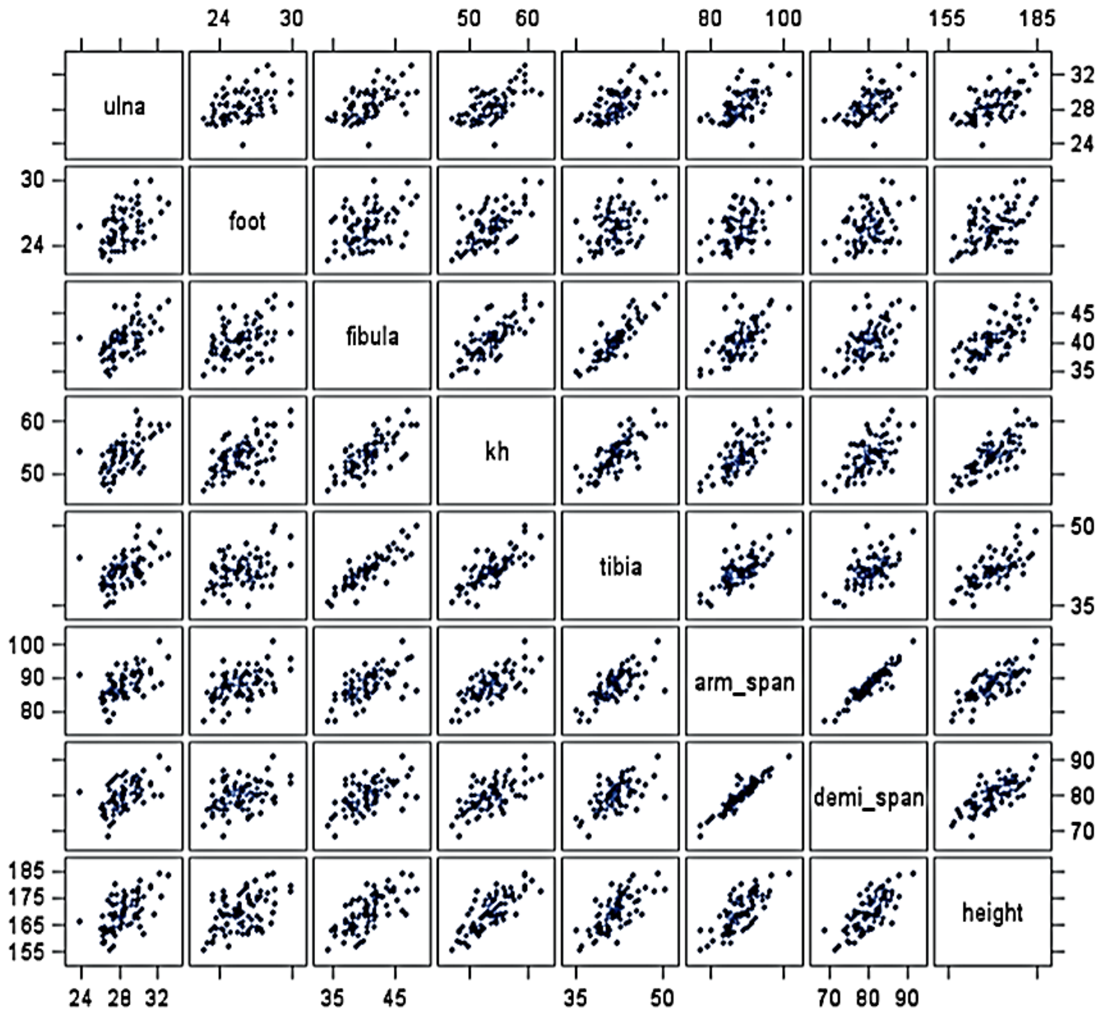

Figure 5.1: Scatter plot of predicted height over reference height in males

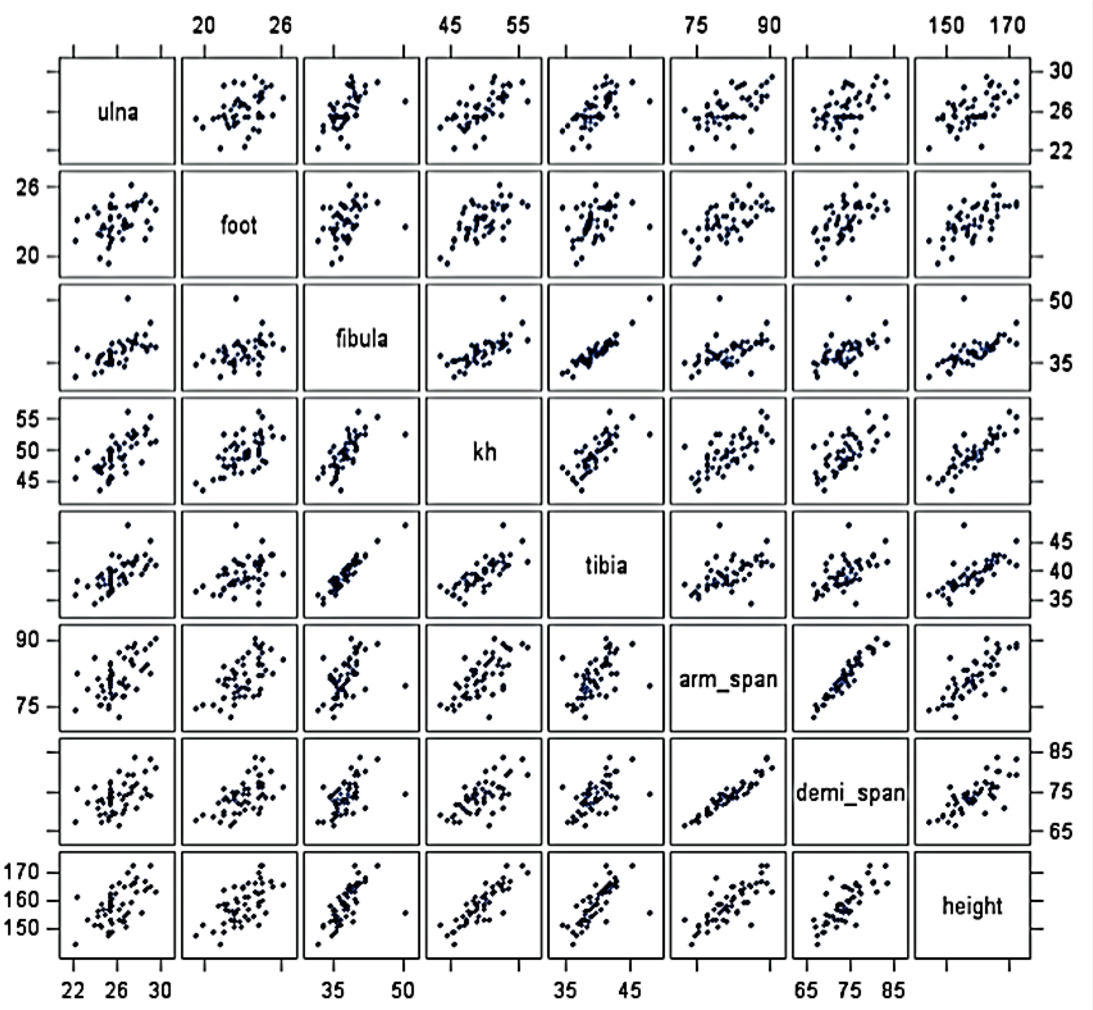

Figure 5.2: Scatter plot of predicted height over reference height in females

A t-test with the significant level (α) equal to 0.10 (Table 5.3) indicated that the p-values for knee height and demi-span were <0.10, signifying sufficient evidence to use these measurements in the estimation of height. Knee height indicated the greatest predictive value in both men and women and is thus most strongly associated with height.

Arm-span and demi-span were highly correlated, and since the one can accurately be predicted linearly from the other, a severe multi-co-linearity problem may exist. Thus, one of these correlated independent variables was removed from the model, in this case arm-span. Data from two participants were identified as outliers and removed from the model.

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Table 5.3: Multiple regression analysis indicating level of significance between variables

MALES	DF	Parameter estimate	Standard error	t-value	Pr>[t] (level of significance)
Demi-span	1	0.45	0.13	3.58	0.0006*
Ulna length	1	0.54	0.31	1.76	0.08
Knee-height	1	0.96	0.23	4.27	<0.0001*
Tibia length	1	0.09	0.29	0.30	0.77
Fibula length	1	0.31	0.25	1.24	0.22
Foot length	1	-0.24	0.29	-0.83	0.41
FEMALES	**DF**	**Parameter estimate**	**Standard error**	**t-value**	**Pr>[t] (level of significance)**
Demi-span	1	0.38	0.12	3.10	0.003*
Ulna length	1	-0.37	0.29	-1.26	0.21
Knee-height	1	1.15	0.25	4.56	<0.0001*
Tibia length	1	0.53	0.43	1.23	0.23
Fibula length	1	0.45	0.35	1.28	0.21
Foot length	1	0.26	0.33	0.81	0.43

*** Statistically significant**

Mallows's C(p) statistic, displayed in table 5.4, found that knee-height delivered the smallest C(p) (although not close to 1) and the highest value for R^2, indicating that it had the strongest association with height, especially amongst females. Demi-span was more closely associated with height in males than in females. Mean square error (MSE) indicating the goodness of fit of the regression line, is also specified in table 5.4.

Table 5.4: Regression model to assess which body segment is best at predicting actual height

MALES	R^2	C(p)	MSE
Demi-span	0.53	74.24	19.48
Ulna length	0.41	112.44	24.24
Knee-height	0.65	32.59	14.29
Tibia length	0.53	72.20	19.23
Fibula length	0.51	78.37	19.99
Foot length	0.22	175.26	32.07
FEMALES	**R^2**	**C(p)**	**MSE**
Demi-span	0.59	104.29	17.69
Ulna length	0.36	190.59	27.71
Knee-height	0.80	28.22	8.85
Tibia length	0.70	64.65	13.08
Fibula length	0.67	74.02	14.17
Foot length	0.40	173.74	25.75

R^2 coefficient of multiple correlation measures the accuracy with which the variables approximate reference height. If $R^2 = 1$, the variable perfectly predicts height.
MSE assesses the quality of an estimator/ predictor, values closer to zero indicates a better association with height.
C(p) value indicates which variable is best able to predict reference height. A small C(p) value indicates a more precise predictor of height.

The overall F statistics (Pr>F) of the respective models for males and females were both significant ($p<0.0001$), indicating that the models explain a significant portion of the variation in the data (Table 5.5).

Table 5.5 Analysis of variance

	Model for males	Model for females
DF (degrees of freedom)	6	6
Sum of squares	2625.0	1899
Mean of squares	437.5	316.5
F-value	41.8	54.5
Pr>F	<0.0001	<0.0001
Root of MSE (mean square error)	3.24	2.41
R^2	0.76	0.88
Dependent mean	169.8	158.6
Adjusted R2	0.74	0.86
Coefficient of variance	1.91	1.52

Males presented an R^2 value of 0.76 which indicates that approximately 76% of the variation in height amongst males in this sample, was explained by the independent variables. The root MSE of 3.24, indicates that approximately 95% of the sample's height values fell within 6.48 cm (two standard deviations) of their respective predicted values.

The R^2 value for females was 0.88, indicating that approximately 88% of the variation of height amongst females in this sample is explained by the independent variables. The root MSE of 2.41 indicates that approximately 95% of the sample height values fell within 4.82cm (two standard deviations) of their respective predicted values.

5.5 Discussion

This study found that knee height has the strongest correlation with height in both males and females. Regression analysis revealed knee height to be most predictive of actual height. Overall, measurements of the lower leg were better correlated with height than measurements of the upper extremities.

All body segment measurements were statistically significantly correlated with height ($p<0.05$). While this, on face value, seems to suggest that any one of the measurements could be used to predict height, accuracy is required in order to best assess nutritional status and provide quality individualised interventions (Venkataraman et al., 2015).

Arm-span showed the lowest predictive value among participants, and demi-span the second greatest. In females, the ulna length showed the weakest correlation with height and the second weakest in males. A South African study investigating the agreement between measured height and height predicted from ulna length found that when using ulna length in the Malnutrition Universal Screening Tool (MUST) equations, height was significantly overestimated (van den Berg et al., 2016).

Knee height measurements (together with tibia and fibula length) were more closely correlated with height than measurements of the upper body. This could be due to the high prevalence of stunting in South Africa, where 23.9% of children under 5 years of age are stunted (World Health Organization, 2017). A study in Turkey (with lower prevalence of stunting of 9.5% of children under 5 years) undertaken in 779 male and 755 female children also found lower limb length to be better correlated with height (Tacar et al., 1999; World Health Organization, 2017).

Early growth and development (especially from birth to two years of age) is a period during which children are considered exceptionally vulnerable to a harmful environment. This susceptible period overlaps with a period during which leg length increases (grows) at a relatively faster rate than the trunk. Relative leg length could be considered indicative of environmental factors during the early growth period, as environmental factors tend to have a greater impact on the growth of leg length than other body segments (Bogin & Rios, 2003; Wadsworth et al., 2002). Adults who grew up in less than optimal environments, for example those who had a poor nutritional intake and inadequate access to healthcare, may therefore have relatively shorter legs in relation to their height. Developmental plasticity in response to environmental stress might explain this phenomenon. In response to an adverse environment, such as inadequate nutrition, mammals may compromise the growth of tissues in order to protect the brain. As mentioned, the tibia is thought to be particularly vulnerable to adverse environmental conditions (Pomeroy et al., 2012).

Knee height had the best predictive value with measured height in this study, but knee height measurement is not always possible. Measuring knee height requires the patient to bend their knee and foot at a 90-degree angle and requires a calliper for measurement. Knee height measurement may thus not be possible in resource limited settings or in patients with knee

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or ankle deformities, tight adductor spasms, fixed flexion deformities or painful arthritis. Given such circumstances, tibia or fibula length may be more suitable. Some studies suggest better results when using tibia length (Gaur et al., 2016). Sensitivity of different limb segments to environmental influences remains to be studied comprehensively, and would aid in understanding how growth adapts under conditions of stress (Gaur et al., 2016; Auyeung et al., 2009).

The thrifty phenotype hypothesis proposes that the growth rate of certain organs or tissues (such as the lower limbs) is reduced during periods of environmental stress in order to maintain function of more important tissues and organs (such as the brain). It is also proposed that trunk height may be spared, as the trunk accommodates major organs. Growth of the hands and feet are suggested to be spared due to the important functions that these body parts perform. Foot length had the poorest correlation with height in males and the second poorest in females in this study. This poor correlation between foot length and height could be due to the growth of the foot being spared during stunted growth in order to maintain functionality or possibly due to changes in growth rate after maturation of the bones in the foot, as maturation of bones take place in the foot before the long bones (Patel et al., 2007; Pomeroy et al., 2012).

The distal blood flow hypothesis is an additional theory suggested to contribute to this phenomenon. The theory suggests that the greater reduction in tibia length (relative to the length of the upper limbs and trunk height) of foetuses exposed to hypoxia as a result of maternal smoking could be explained by the fact that the tibia is the last to receive oxygenated blood. It is important to consider that different environmental stressors (e.g. hypoxia vs nutrition) may result in different developmental adaptations and may thus have different effects on body segment ratios (Payne et al., 2018; Pomeroy et al., 2012).

In this study, tibia length had a stronger correlation to female height when compared to fibula length, and the opposite was true for males. This conflicts with findings by Gaur et al (2016) who reported that all body segment measurements had a stronger correlation with height in females than in males, with the exception of the ulna length. This could be due to sex differences in response to an adverse environment. Studies suggesting that the growth of males is more vulnerable to adverse environmental conditions date back to 1951 to studies on Guamanian children and in 1953 on children who survived the Nagasaki and Hiroshima atomic bombs. Subsequent studies have also stated that adverse environmental conditions have a greater impact on the growth of males. The theory behind the differences between the sexes is that the growth of females may be protected as the female's body has to sustain pregnancy and lactation, the female's development thus plays an important role in reproduction (Cole et al., 2015; Stinson, 1985).

If growth and development of the lower leg is more susceptible to adverse environmental conditions (due to accelerated growth of the legs during early development), measurement of long bones in the lower leg to predict reference height may be more appropriate in the South African population which has a high prevalence of stunting from birth to 5 years of age. Due to the specialised equipment required to measure knee height, measurement of this segment might not be possible under all circumstances in which case the tibia or fibula length would be a more practical measure to use.

5.6 Limitations

The size of the study is considered a limitation. A much larger study population would have been ideal, but fewer patients than anticipated could be included in the study. This was due to the advanced age of hospital patients, few patients who were able to stand upright without assistance and time constraints placed on the data collection period. The results of the study are still considered meaningful as no similar study has previously been conducted and the results provide valuable insight into the potential relationship between body segments and height.

5.7 Conclusion and recommendations

As so few patients were able to stand upright without assistance to be measured, this study emphasises the need to determine the agreement between measurements of body segments and standing height in the South African population. Accurate determination of height is essential in assessing nutritional status and improving clinical outcomes. Various environmental factors may have different impacts on the growth and development of bones and thus on body segment ratios. As the long bones of the lower limbs would be most affected during stunting, measurements of the lower limbs may be more appropriate to estimate actual height in population groups with a high prevalence of stunting, such as in South Africa.

5.8 Acknowledgements

The authors would like to thank the, participants for their co-operation and assistance.

5.9 Funding

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CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

In this final chapter, the limitations of the study, as well as the conclusions and recommendations, are discussed.

6.1 Limitations of the study

The size of the study is a limitation as a larger sample size would be more representative. The initial aim for sample size was not reached due to limited time for data collection, the advanced age of hospital patients, and few patients who were able to stand upright without assistance. The results of the study are still considered meaningful as some of the few previous South African studies comprised similar sample sizes and significant results were obtained from this study.

6.2 Conclusion and recommendations

Conclusions and recommendations are summarised in terms of the research objectives.

6.2.1 Socio-demographic information

The study population (n=141) with a median age of 38.8 years old, consisted of mostly black South Africans (84.4%) and included more men (61.7%) than women. In this study, it was challenging to find hospitalised patients that could stand up straight and unassisted for accurate height measurements as required. Although the wards included in the study were purposefully selected for the likelihood of including patients that can stand in the required stretch height posture, most patients in the selected wards were found to be in feeble health and were unable to stand upright without assistance. Therefore, the need to determine the agreement between measurements of body segments and standing height in the South African population is emphasised. Participant age was another major limitation as most patients encountered in the hospital during data collection were over 50 years of age and therefore did not meet the inclusion criteria.

Recommendation: Future studies should have an extended data collection period to include a larger sample size and more patients from the various ethnic groups. Data should also be

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included from clinics where a younger patient population is more likely to be younger than 50 years. Future studies should perhaps be performed on patients in public and private hospitals and comparisons drawn between the two.

6.2.2 Reference height, self-reported height; and height recorded in the participant's medical file on hospital admission

The median reference height of the study population was 165.5cm (IQR 12.3cm). Most participants did not know how tall they were and only six could report their height. Out of the 141 participants' medical files, only 16 had the height recorded (although there is no way of knowing if the height was measured or guessed by the admission staff). Overall, it seems that medical staff in the targeted hospitals, did not consider height as important in patient assessment.

Recommendation: Hospital staff should be educated on the importance of a comprehensive patient assessment upon admission to the hospital or the ward, which includes measuring patients who are able to stand and recording their height in the files.

6.2.3 Height estimated by equations based on measures of body segments

Among 11 equations based on different body segments, including , demi-span and ulna length, knee height, tibia length, fibula length, and foot length, as well as recumbent length, only a set based on knee height that was standardised on more than 5000 participants, for males and females and for black and white ethnicities, were able to predict height without significant difference from reference height. Recumbent length yielded a median difference that was significantly different from reference height, but with within 95% limits of agreement (-4 to 1.3 cm). Clinical studies commonly suggest that body segment-based equations for predicting height, need to be standardised for each population, and suggested ethnic differences as the reason. The findings of this study, however, support evidence from forensic science, anthropology and growth studies that environmental stresses, including disease load and dietary niche, influence the development and growth of the various long bones in ways that affect the body proportions. This developmental plasticity differs across different body segments, causing lower limb length to show a greater proportionality to height. Relative leg growth is accelerated during the early years of life; thus, stunting seems to have a more pronounced effect on the length of the lower leg long bones. Thus, the high prevalence of stunting among South Africans may explain why knee height, outperformed upper body measurements in this population of patients admitted to public hospitals in a South African city.

Recommendation: Equations standardised on a specific population might not accurately predict height of all patients (even within the population on which it was standardised) due to varying environmental factors. More extensive studies across different South African populations are needed to confirm the findings, better the current understanding of the effects of environmental stressors on body proportion, and to develop accurate height-prediction equations that may be used in South African populations. Stunting in South Africa should also be addressed.

6.2.4 Body segments best correlated with height and best predictors of height

All body segments measured in this study, namely , demi-span and ulna length, knee height, tibia length, fibula length or foot length, were statistically significantly correlated with height. Knee height was most strongly correlated with reference height in this study population. Lower leg measurements showed better correlation with reference height in comparison to measurements of upper limbs, with arm-span and demi-span showing the greatest variability.

Recommendation: When considering the accuracy of estimation, it is important to bear in mind the amount of error that is acceptable in clinical practice; therefore, in order to obtain the best results, not all measurements can be used. Knee height and measurements of the lower leg may be more closely correlated with reference height and should preferably be used.

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APPENDICES

Appendix A – Approval from University of the Free State, Health Sciences Research Ethics Committee

Appendix B – Approval from the Free State Department of Health Provincial Research Committee

Appendix C – Questionnaire

Appendix D – Information document

Appendix E – Consent form

Appendix F – South African Journal of Clinical Nutrition author instructions

7.1 APPENDIX A:

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA

UFS·UV
HEALTH SCIENCES
GESONDHEIDSWETENSKAPPE

IRB nr 00006240
REC Reference nr 230408-011
IORG0005187
FWA00012784

17 November 2016

MRS HANNA EUGENIE ERASMUS
DEPT OF NUTRITION AND DIETETICS
FACULTY OF HEALTH SCIENCES
UFS

Dear Mrs Hanna Eugenie Erasmus

HSREC 125/2016
PROJECT TITLE: MEASURED HEIGHT AND HEIGHT ESTIMATED FROM BODY SEGMENTS IN HOSPITALISED ADULTS IN BLOEMFONTEIN, SOUTH AFRICA

1. You are hereby kindly informed that the Health Sciences Research Ethics Committee (HSREC) approved this protocol after all conditions were met. This decision will be ratified at the next meeting to be held on 29 November 2016.

2. The Committee must be informed of any serious adverse event and/or termination of the study.

3. Any amendment, extension or other modifications to the protocol must be submitted to the HSREC for approval.

4. A progress report should be submitted within one year of approval and annually for long term studies.

5. A final report should be submitted at the completion of the study.

6. Kindly use the **HSREC NR** as reference in correspondence to the HSREC Secretariat.

7. The HSREC functions in compliance with, but not limited to, the following documents and guidelines: The SA National Health Act. No. 61 of 2003; Ethics in Health Research: Principles, Structures and Processes (2015); SA GCP(2006); Declaration of Helsinki; The Belmont Report; The US Office of Human Research Protections 45 CFR 461 (for non-exempt research with human participants conducted or supported by the US Department of Health and Human Services- (HHS), 21 CFR 50, 21 CFR 56; CIOMS; ICH-GCP-E6 Sections 1-4; The International Conference on Harmonization and Technical Requirements for Registration of Pharmaceuticals for Human Use (ICH Tripartite), Guidelines of the SA Medicines Control Council as well as Laws and Regulations with regard to the Control of Medicines, Constitution of the HSREC of the Faculty of Health Sciences.

Yours faithfully

DR SM LE GRANGE
CHAIR: HEALTH SCIENCES RESEARCH ETHICS COMMITTEE

7.2 APPENDIX B

health

Department of Health

FREE STATE PROVINCE

21 September 2016

Mrs. HE Erasmus
Department of Nutrition and Dietetics
Faculty of Health Science
UFS

Dear Mrs. HE Erasmus

Subject: Measured height and height estimated from body segments in hospitalised adults in Bloemfontein, South Africa

- Permission is hereby granted for the above – mentioned research on the following conditions:
- Participation in the study must be voluntary.
- A written consent by each participants must be obtained
- Serious adverse events to be reported and/or termination of the study.
- Ascertain that your data collection exercise neither interferes with the day to day running of Pelonomi, National and Universitas Hospital nor the performance of duties by the respondents or health care workers.
- Confidentiality of information will be ensured and no names will be used.
- Research results and a complete report should be made available to the Free State Department of Health on completion of the study (a hard copy plus a soft copy).
- Progress report must be presented not later than one year after approval of the project to the Ethics Committee of the University of the Free State and to Free State Department of Health.
- Any amendments, extension or other modifications to the protocol or investigators must be submitted to the Ethics Committee of the University of the Free State and to Free State Department of Health.
- **Conditions stated in your Ethical Approval letter should be adhered to and a final copy of the Ethics Clearance Certificate should be submitted to khusemj@fshealth.gov.za or sebeelats@fshealth.gov.za before you commence with the study**
- No financial liability will be placed on the Free State Department of Health
- Please discuss your study with the institution managers/CEOs on commencement for logistical arrangements
- Department of Health to be fully indemnified from any harm that participants and staff experiences in the study
- Researchers will be required to enter in to a formal agreement with the Free State department of health regulating and formalizing the research relationship (document will follow)
- You are encouraged to present your study findings/results at the Free State Provincial health research day
- Future research will only be granted permission if correct procedures are followed see http://nhrd.hst.org.za

Trust you find the above in order.

Kind Regards

Dr D Motau
HEAD: HEALTH
Date: 21/9/16

Head : Health
PO Box 227, Bloemfotein, 9300
4th Floor, Executive Suite, Bophelo House, cnr Maitland and, Harvey Road, Bloemfotein
Tel: (051) 408 1527Fax: (051) 408 1556 e-mail:sebeelats@fshealth.gov.za@fshealth.gov.za/chikobvup@fshealth.gov.za

www.fs.gov.za

7.3 APPENDIX C:

Agreement between measured height and height estimated from body segments in hospitalised adults in Bloemfontein, South Africa

QUESTIONNAIRE						
1. Date	dd	mm	yyyy			
2. Hospital	Universitas	Pelonomi	National			
3. Ward						
4. Respondent number						
5. Time						
6. What is your date of birth?	dd	mm	yyyy			
7. What is your gender?	M	F				
8. What is your race?	Black	White	Coloured	Asian	Indian	Other:

9. What medication do you use at home and are you currently using? ____________________

____

10. What medical conditions have you been diagnosed with? ____________________

____

11. What is your height? (Self-reported height)	______ cm		
12. Height recorded in file	______ cm		
13. Measured height	______ cm	______ cm	______ cm
14. Weight	______ kg	______ kg	______ kg
15. Knee height	______ cm	______ cm	
16. Tibia length	______ cm	______ cm	
17. Fibula length	______ cm	______ cm	
18. Foot length	______ cm	______ cm	
19. Arm span	______ cm	______ cm	______ cm
20. Demi-span	______ cm	______ cm	
21. Ulna length	______ cm	______ cm	
22. Recumbent length	______ cm	______ cm	

FOROMO

1. Letsatsi | dd | mm | yyyy |

2. Sepetlele | Universitas | Pelonomi | National |

3. *Ward* ____________

4. Nomoro ya ya nkang karolo ____________

5. Nako ______

6. Letsatsi la hao la tswalo le neneng? | dd | mm | yyyy |

7. Bong ba hao ke bo feng? | M | F |

8. Mmala wa hao ke o feng? | Black | White | Coloured | Asian | Indian | Other: |

9. O sebedisa meriana efeng hae le ha jwale? ____________

10. O na le mafu a feng? ____________

11. Botelele ba mmele wa hao ke bokae? ______ cm

12. Botelele ba mmele ho ya ka faele ______ cm

13. Botelele bo methuweng ______ cm ______ cm ______ cm

14. Boima ______ kg ______ kg ______ kg

15. Botelele ba lengwele ______ cm ______ cm

16. Botelele ba 'Tibia' ______ cm ______ cm

17. Botelele ba 'Fibula' ______ cm ______ cm

18. Botelele ba Leoto ______ cm ______ cm

19. Botelele ba Sephaka ______ cm ______ cm ______ cm

20. 'Demi-span' ______ cm ______ cm

21. Botelele ba 'Ulna' ______ cm ______ cm

22. Botelele o kakalletse ______ cm ______ cm

VRAELYS

1. Datum [dd | mm | yyyy]

2. Hospitaal [Universitas | Pelonomi | National]

3. Saal [ ]

4. Nommer van deelnemer [ ]

5. Tyd [ ]

6. Wat is u geboortedatum? [dd | mm | yyyy]

7. Wat is u geslag? [M | F]

8. Wat is u ras? [Black | White | Coloured | Asian | Indian | Other:]

9. Watter medikasie gebruik u by die huis en tans? ________________________________

____

10. Met watter mediese toestand is u gediagnoseer? ________________________________

____

11. Hoe lank is u? ________ cm

12. Lengte in lêer aangeteken ________ cm

13. Lengte ________ cm ________ cm ________ cm

14. Gewig ________ kg ________ kg ________ kg

15. Knie hoogte ________ cm ________ cm

16. Tibia lengte ________ cm ________ cm

17. Fibula lengte ________ cm ________ cm

18. Voet lengte ________ cm ________ cm

19. Arm reikwydte ________ cm ________ cm ________ cm

20. Demi-reikwydte ________ cm ________ cm

21. Ulna lengte ________ cm ________ cm

22. Lengte gemeet terwyl deelnemer lê ________ cm ________ cm

`

7.4 APPENDIX D

Dear participant

This letter invites you to participate in the following research study:

Measured height and height estimated from body segments in hospitalised adults in Bloemfontein, South Africa

The height of patients in hospital is used to determine how much medication to give, how much oxygen they need and for many other things. Hospitalised patients cannot always stand for their height to be measured; sometimes they are unconscious or injured. In these cases different methods are used to estimate their height. Patients can be measured while lying down; bones in the arm and leg can be measured and used in equations to estimate height. This research study aims to investigate how accurate these other methods are at estimating patients' height in the South African population.

You are free to choose whether you want to take part in the study and you may withdraw at any time if you feel that you want to. Information such as your date of birth and medication that you are taking will be taken from your file. If you agree to participate in the study, you will be asked questions on your medical history, your height will be measured while standing up and lying down on the bed. You will be weighed and your arms, leg and foot will be measured with a measuring tape. These measurements will not hurt and will take 15-20 minutes.

You are eligible to participate in this study if you are between 20 and 50, can stand upright by yourself to be measured, and you do not suffer from any medical condition that could affect the measurements. These exclusions are based on factors that will alter the results of the study.

All information collected will be treated as strictly confidential. Results of the study may be published and presented a congress. Participation will not cost you anything and there will be no payment for participation. This research study has been approved by the Free State

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Department of Health Provincial Research Committee and the Health Sciences Research Ethics Committee of the University of the Free State.

The study will be done by Hanna Erasmus from the University of the Free State. For more information on the study please feel free to contact the Department of Nutrition and Dietetics, University of the Free State on 051 401 2894 or the Health Sciences Research Ethics Committee on 051 401 7795.

`

Ho monka karolo

Lengolo lena le o memela ho nka karolo dipatlisisong tsena tse latelang:

Botelele bo methuweng le bo lekantshitsweng ho tswa ho dikarolo tsa mmele ho bakudi ba baholo ba robaditsweng sepetlele Bloemfontein, Afrika Borwa.

Botelele ba bakudi bo sebeditswa ho lekantsha hore na ho fanwe ka meriana e mekae, moya o hemuwang, le dintho tse ding tse ngata. Ha se ka mehla moo bakudi ba robaditsweng sepetlele ba kgonang ho ema hore ba methuwe botelele; hangata ba ba be ba idibetse kapa ba lemetse haholo. Maemong ana ho hlokeha mekgwa e meng ho lekantsha botelele ba bona. Bakudi ba ka methwa ba robetswe; masapo a diphaka le a maoto a ka methwa mme a sebediswa ho lekantsha botelele. Dipatlisiso tsena di etswa ka maikemisetso a ho lekola ka mokgwa oo meralo ena e nepahetseng ka teng ho lekantsheng botelele ba bakudi setjhabeng sa Afrika Borwa.

O lokolehile ho nka karolo kapa ho se nke karolo dipatlisisong tsena ebile o ka itokolla nako e nngwe le e nngwe ha o ikutlwa ho etsa jwalo. Ha o dumela ho nka karolo dipatlisisong tsena, o tla botswa dipotso ka histori ya hao ya bophelo, botelele ba hao bo tla methwa o eme, bo boele bo methuwe o robetse betheng. Boima ba mmele wa hao le bona botla methwa, mme diphaka le maoto a hao a tla methuwa ka theipi. Tsena tsohle di ke ke tsa o hlokofatsa mme di tla nka metsotso e 15 – 20.

O dumellwa ho nka karolo dipatlisisong tsena ha e be o na le dilemo tse 20 ho isa ho tse 50, ha o kgona ho ema ka bo wena, le ha o sa tshwarwa ke mafu a ka amang ditekanyo tsena. Di kgethollo tsena tsa ho nka karolo di beilwe hoya ka dintlha tse ka amang sephetho sa dipatlisiso.

Dintlha tsohle tse bokellwetswang e tla ba lekunutu ka hohle-hohle. Ha hona ditjeho ho wena ha o nka karolo mme o ke ke wa lefuwa ha o nka karolo.

Dipatlisiso tsena di dumelletswe ke Komiti ya Dipatlisiso ya Lefapha la tsa Bophelo la Profinsi ya Foreisitata le ke Komiti ya Dipatlisiso la Disaense tsa Bophelo Yunivesithing ya Foreisitata.

`

Dipatlisiso di tla etswa ke Hanna Erasmus ya tswang Yunivesithing ya Foreisitata. Bakeng sa tlhahiso leseding ka dipatlisiso tsena, o lokolllehile ho ikopanya le Lefapha la tsa Phepo le Dietetics, Yunivesithing Foreisitata mohaleng wa 051 401 2894 kapa Komiti ya Etiki ya Lefapha la tsa Bophelo ho 051 401 7795.

`

Geagte deelnemer

Met hierdie brief word u uitgenooi om aan die volgende navorsingstudie deel te neem:

Gemete lengte en lengte geskat van liggaamsdeel-lengtes by gehospitaliseerde volwassenes in Bloemfontein, Suid-Afrika

In hospitale word pasiënte se lengte vir verskeie doeleindes gebruik, soos byvoorbeeld om te bepaal hoeveel suurstof, medikasie of voedingstowwe hulle liggame benodig. Partykeer is dit nie moontlik vir pasiënte om te staan sodat hulle lengte gemeet kan word nie, byvoorbeeld as hulle beseer of bewusteloos is. Indien 'n pasiënt nie kan staan om gemeet te word nie, word verskeie metodes gebruik om lengte te skat. Pasiënte kan gemeet word terwyl hulle lê; en die lengtes van hul, bene, arms en voete kan gemeet word, en gebruik word om lengte te skat. Hierdie navorsingstudie se doel is om te bepaal hoe akkuraat hierdie ander metodes in die Suid-Afrikaanse bevolking is om pasiënte se lengte te skat.

U deelname aan die studie is vrywillig en u mag enige tyd tydens die studie onttrek. Sekere inligting, byvoorbeeld u geboortedatum en watter medikasie u gebruik, sal uit u lêer verkry word. Indien u instem om aan die studie deel te neem, sal u vrae gevra word oor u mediese geskiedenis, en u lengte sal gemeet word terwyl u staan asook terwyl u lê. U sal geweeg word en metings sal van u arms, bene en voete met 'n maatband geneem word. Hierdie neem van u mates sal nie seer wees nie en sal 15-20 minute neem.

U sal in aanmerking kom vir die studie indien u tussen 20 en 50 jaar oud is, self kan regop staan om gemeet te word en nie aan enige mediese toestand lei wat die mates kan beïnvloed nie. Hierdie uitsluitings is gebaseer op faktore wat die uitkoms van die studie kan beïnvloed.

Alle inligting wat ingesamel word, sal as streng vertroulik hanteer word. Die resultate van die studie kan moontlik gepubliseer word en voorgedra word by 'n kongres, sonder om individuele deelnemers te identifiseer. Deelname is gratis en u sal ook geen vergoeding ontvang vir deelname nie. Hierdie studie is goedgekeur deur die Vrystaatse Departement van Gesondheid Provinsiale Navorsingskomitee, asook die Gesondheidswetenskappe Navorsingsetiek-komitee van die Universiteit van die Vrystaat.

Die studie gaan deur Hanna Erasmus van die Universiteit van die Vrystaat gedoen word. Vir verdere inligting oor die studie kan u die Departement van Voeding en Dieetkunde aan die

`

Universiteit van die Vrystaat kontak by 051 401 2894 of die Gesondheidswetenskappe se Navorsingsetiek-komitee by 051 401 7795.

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7.5 APPENDIX E

Measured height and height estimated from body segments in hospitalised adults in Bloemfontein, South Africa

You have been asked to participate in the abovementioned study. It will take approximately 15-20 minutes of your time. If you agree to participate in the study, information about your age, gender, race and medical history will be recorded. You will be weighed and measured. Bones in your feet, legs and arms will also be measured. All the information collected will be treated as confidential.

Please ask questions if there is anything you do not understand or are unsure of.

Signing this document means that you have read the information document and understand what this study is about. That you know what is required of you and that you may withdraw from the study at any time, even after you have signed this document. Withdrawal from the study will not have any consequences.

Date: ___________________________________

Signature of participant: __________________________________

Signature of witness:

(If patient is illiterate or cannot sign)

Signature of researcher: ___________________________________

`

Botelele bo methuweng le bo lekantshitsweng ho tswa ho dikarolo tsa mmele ho bakudi ba baholo ba robaditsweng sepetlele Bloemfontein, Afrika Borwa.

O kopuwe ho nka karolo dipatlisisong tse boletsweng ka hodimo. Ho tla bonyane metsotso e 15-20 ya nako ya hao. Ha o dumela ho nka karolo dipatlisisong, dintlha tse kang dilemo, bong, mmala le histori ya hao ya bophelo di tla ngolwa fatshe. O tla methwa boima le tse ding. Masapo a maoto a hao le diphaka tsa hao a tla methwa. Dintlha tsena tsohle di tla bolokwa e le lekunutu.

Botsa dipotso ka kopo ha ho na le hoo o sa ho utliwisising kapa ha o se na bonnete.

Ho saena ho bolela hore o badile tokomane ya tlhahiso leseding e bile o utlwisisa hore na dipatlisiso di mabapi le eng. Ho bolela hape hore o tseba se batlahalang ho wena le hore o ka ikgula dipatlisisong nako e nngwe le e nngwe, le ka mora hore o saene tokomane ena. Ho ikgula ha hao ho ke ke be ha e ba le ditlamorao.

Letsatsi: ___________________________________

Tshaeno ya ya nkang karolo: ___________________________________

Tshaeno ya paki:

(Ha mokodi a sa kgone ho ngola kapa ho bala)

Tshaeno ya mobatlisisi: ___________________________________

`

Gemete lengte en geskatte lengte van liggaamsdele by gehospitaliseerde volwassenes in Bloemfontein, Suid-Afrika

U is gevra om aan die bogenoemde studie deel te neem. Dit sal ongeveer 15-20 minute van u tyd in beslag neem. Indien u instem om deel te neem, sal inligting met betrekking tot u ouderdom, geslag, ras en mediese geskiedenis aangeteken word. U sal gemeet en geweeg word. U voete, bene en arms sal ook gemeet word. Alle inligting wat ingesamel word sal as vertroulik hanteer word.

Vra asseblief as u onseker is oor iets of as u iets nie verstaan nie.

Wanneer u hierdie dokument onderteken, beteken dit dat u die inligtingsdokument gelees het en verstaan waaroor die studie gaan. Dit beteken ook dat u weet wat van u verwag word en dat u enige tyd tydens die studie mag onttrek, selfs nadat u die dokument onderteken het. Onttrekking van die studie sal geen nagevolge vir u inhou nie.

Datum: ___________________________________

Handtekening van deelnemer: ___________________________________

Handtekening van getuie:

(Indien pasiënt ongeletterd is of nie kan teken nie)

Handtekening van navorser: ___________________________________

7.6 APPENDIX F

ISSN 003-8-2469 S Afr J Clin Nutr 2008 volume 23 number 4 (December)

SAJCN

THE SOUTH AFRICAN JOURNAL OF CLINICAL NUTRITION

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Short items are more likely to appeal to our readers and therefore to be accepted for publication. ***Manuscript should not exceed 4000 words in total all contents inclusive.***

Original articles of 4 000 words or less, with up to 6 tables or illustrations, should normally report observations or research of relevance to the field of nutrition. References should preferably be limited to no more than 25.

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Editorials, Opinions, Issues in the field of nutrition. should be about 1000 words and are welcome, but unless invited, will be subjected to the SAJCN peer review process.

Review articles are rarely accepted unless invited.

Letters to the editor, if intended for the correspondence column, should be marked 'for publication', signed by all authors and presented in triple spacing. Letters should be no longer than 400 words with only one illustration or table.

Obituaries should not exceed 400 words and may be accompanied by a photograph.

Manuscript preparation

- Please submit your manuscript electronically at www.sajcn.co.za. (Register as an author, log in and follow the 5 steps to upload your manuscript.)
- Please submit the manuscript as a MS Windows Word document.
- Please have your manuscript edited by a language expert or colleague proficient in English prior to submission. Articles must be in UK English.
- All manuscripts must include an abstract (50-250 words).
- Research articles should have a structured abstract not exceeding 250 words (50 for short reports) comprising: Objectives, Design, Setting, Subjects, Outcome measures, Results and Conclusions.
- Refer to articles in recent issues for guidance on the presentation of headings and subheadings.
- Abbreviations should be spelt out when first used in the text and thereafter used consistently.
- Scientific measurements should be expressed in SI units except: blood pressure should be given in mmHg and haemoglobin values in g/dl.

If in doubt, refer to www.icmje.org/index.html

Illustrations

1. All illustrations must be submitted electronically. High resolution (300dpi) .jpg or .tiff files are preferred.
2. Figures consist of all material that cannot be set in type, such as photographs and line drawings.
3. Tables and legends for illustrations should appear on separate sheets and should be clearly identified.
4. Line drawings should be arranged to conserve vertical space. Note that reduction to 80 mm for a single column or 170 mm for double columns should not render lettering illegible. Explanations should be included in the legend and not on the figure itself.
5. Figure numbers should be clearly marked on the back of prints and the top of illustrations should be indicated.
6. If any tables or illustrations submitted have been published elsewhere, written consent to republication should be obtained by the author from the copyright holder and the author(s).
7. A limited number of illustrations are free at the discretion of the editor. Colour illustrations are encouraged but are charged to the author.

References

References should be inserted in the text as superior numbers and should be listed at the end of the article in numerical and not in alphabetical order.

Authors are responsible for verification of references from the original sources.

References should be set out in the Vancouver style and approved abbreviations of journal titles used; consult the List of Journals in Index Medicus for these details.

Names and initials of all authors should be given unless there are more than six, in which case the first three names should be given followed by et al. First and last page numbers should be given.

Journal references should appear thus:

1. Price NC. Importance of asking about glaucoma. BMJ 1983; 286: 349-350. Book references should be set out as follows:

1. Jeffcoate N. Principles of Gynaecology. 4th ed. London: Butterworth, 1975: 96-101.
2. Weinstein L, Swartz MN. Pathogenic properties of invading microorganisms. In: Sodeman WA jun, Sodeman WA, eds. Pathologic Physiology: Mechanisms of Disease. Philadelphia: WB Saunders, 1974: 457-472.

Manuscripts accepted but not yet published can be included as references followed by (in press).

Unpublished observations and personal communications may be cited in the text, but not in the reference list.

Manuscript revisions

In the event of a manuscript needing revision following the peer review process, all revision changes to the original manuscript should be made using the "track changes" function in Microsoft Word, or in any other such similar format so as to facilitate the speedy completion of the review process. In the event of an "author-reviewer" difference of opinion, the author(s) should state their opinion in writing in the text, which should be bracketed. Revised manuscripts which do not conform to this revision format will be returned to the authors for editing.

Revised manuscript should be resubmitted electronically within 3 weeks of receipt thereof.

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