THE ACCURACY OF ARM-ASSOCIATED HEIGHT ESTIMATION METHODS COMPARED TO TRUE HEIGHT IN A MULTI-RACIAL GROUP OF YOUNG SOUTH AFRICAN ADULTS

BY

CHRISTEN RENÉE LAHNER

NOVEMBER 2015

Submitted in fulfilment of the academic requirements for the degree of

MASTER OF SCIENCE IN DIETETICS

in the Discipline of Dietetics and Human Nutrition

School of Agricultural Sciences and Agribusiness

Faculty of Science and Agriculture

University of KwaZulu-Natal

PIETERMARITZBURG

ABSTRACT

Background: Stretch stature is the gold standard for measuring true height, but when this is not possible height estimation methods are used. To date, only two South African studies regarding height estimation techniques have been published.

Objective: To investigate the accuracy of arm-associated height estimation methods used for the calculation of true height compared to stretch stature in young South African adults.

Design: A cross-sectional descriptive design was employed.
Setting: Pietermaritzburg, Westville and Durban, KwaZulu-Natal, South Africa, 2015.
Subjects: Convenience sample (*N*=900) aged 18 to 24 years, which included an equal number of subjects from both genders (n=150 per gender) stratified across race (White, Black and Indian).
Results: Highly significant differences exist between genders ($p<0.001$), where males had larger stretch statures and arm-associated measurements than females ($p<0.001$). Highly significant differences exist between race groups ($p<0.001$), where whites had significantly different stretch statures as well as different arm-associated measurements compared to Blacks and Indians. Some similarities were found between race groups, especially between Blacks and Indians. Arm-associated height estimation methods can be used as estimates of true height in accordance with the following study findings: (i) among Black African males, the World Health Organisation (WHO)-adjusted equation would seem to be the most appropriate, followed by demi-span male equation; (ii) among Black African females, the demi-span female equation would seem to be the most appropriate, followed by total armspan; (iii) among Caucasian males, the total armspan would seem to be the most appropriate, followed by half-armspanx2; (iv) among Caucasian females, the total armspan would seem to be the most appropriate, followed by half-armspanx2; (v) among Indian males, the demi-span male equation would seem to be the most appropriate, followed by the WHO-adjusted equation; and (vi) among Indian females, the WHO-adjusted equation would seem to be the most appropriate,

followed by demi-span female equation.

Discussion:. The anthropometric variation between genders and race groups was linked to the exposure to secular growth conditions, which influences a subject's physiological ability to achieve their maximal height. The Vitruvius theory was proposed where total armspan potentially represents a subject's maximal height, and the ability for them to reach that height is dependent on exposure to consistent ambient secular growth conditions during the window period and beyond.

Conclusion: In conclusion, this study's findings provides a baseline for future height studies to be conducted on the South African population, where each anthropometric method should be validated for each race and gender.

PREFACE

The work described in this dissertation was carried out in the School of Agricultural Sciences and Agribusiness, University of KwaZulu-Natal, Pietermaritzburg under the supervision of Dr Susanna M. Kassier and Professor Frederick J. Veldman.

This study represents the original work by the author and has not otherwise been submitted in any form for any degree or diploma to any University. Where applicable, the work of others is acknowledged in text.

Signed: ....

Christen Renée Lahner (Candidate)

Signed: ....

Dr Susanna M. Kassier (Supervisor)

Signed: ....

Professor Frederick J. Veldman (Co-Supervisor)

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to the following people and organizations who contributed to the completion of this study:

The University of KwaZulu-Natal for affording me the opportunity to complete this dissertation, and providing financial support through the Halley Stott grant.

Dr Susanna M. Kassier for her unwavering support, input, guidance, kindness and humour throughout this research process. You have the innate ability to turn every situation into a learning one, thank-you for showing me that. You are a inspiration to all working women.

Professor Frederick J. Veldman for his expertise, guidance and statistical analysis skills. Thank-you for being the voice of reason, in the abyss of complicated statistics. Your knowledge is invaluable.

Thank-you to all the fieldworkers, who worked tirelessly to achieve my study goals.

Thank-you to all those who participated in this study, without you it would have not been possible.

Thank-you to my family and friends for their loving support and prayers throughout this research process.

CONTENTS **PAGE**

TABLES

FIGURES

APPENDICES

ABBREVIATIONS

BAPEN:	British Association of Parenteral and Enteral Nutrition
BMI:	Body Mass Index
CM:	Centimetres
DS:	Demi-span
DSE:	Demi-span equation
GCS:	Glasgow coma scale
HAS:	Half-armspan
HAS x2:	Half-armspan multiplied by two
ISAK:	International Society for the Advancement of Kinanthropometry
KH:	Knee height
LOS:	Length of hospital stay
MUST:	Malnutrition universal screening tool
MD:	Mean difference
PDC:	Proximal digital crease
RL:	Recumbent length
SD:	Standard deviation
SH:	Standing height
SPSS:	Statistical package for Social Sciences
SRH:	Self reported height
SS:	Stretch stature
TAS:	Total armspan
TEM:	Technical errors of measurement
UKZN:	University of KwaZulu-Natal

UL:	Ulna length
WHO:	World Health Organization

CHAPTER 1: INTRODUCTION, THE PROBLEM AND ITS SETTING

1.1 Importance of the study

The assessment of true height requires a particular dietetic scenario, namely the subject in a *compos mentis* state is required to stand up straight without the constraints of medical equipment, physical disabilities and/or space limitations (Froehlich-Grobe, Nary, Van Sciver, Lee & Little, 2011; Beghetto, Fink, Luft & de Mello, 2006; Shahar & Pooy, 2003). However, clinical environments prevent such idealistic situations (Beghetto et al., 2006). As a result, other estimations of height such as knee height (KH), total armspan (TAS), half-armspan x2 (HAS x2) and recumbent length (RL) are used (Froehlich-Grobe et al., 2011; Shahar & Pooy, 2003). Arm-associated height estimation methods are more commonly used as arm long bones do not change with time (Fatmah, 2009).

Height or estimations thereof, is useful in various clinical settings as an accurate height measurement can be entered into the Body Mass Index (BMI) equation [weight (kg) divided by height $(m)^2$] to obtain a value for estimated weight (Dar & Rather, 2014). In addition, accurate height measurements are necessary when determining Resting Energy Expenditure or Basal Metabolic Rate when calculated for inclusion into the Harris-Benedict equation (Harris & Benedict, 1919); as well as for spirometry, calculating cardiac function indices, drug dose adjustments and the creatinine height index (Freitag, Edgecombe, Baldwin, Cottier & Heland, 2010; Chhabra, 2008; Shahar & Pooy, 2003; Mohanty, Babu & Nair, 2001). Therefore, using an accurate height measurement versus an inaccurate height measurement may have consequences, as illustrated in Figure 1.1.

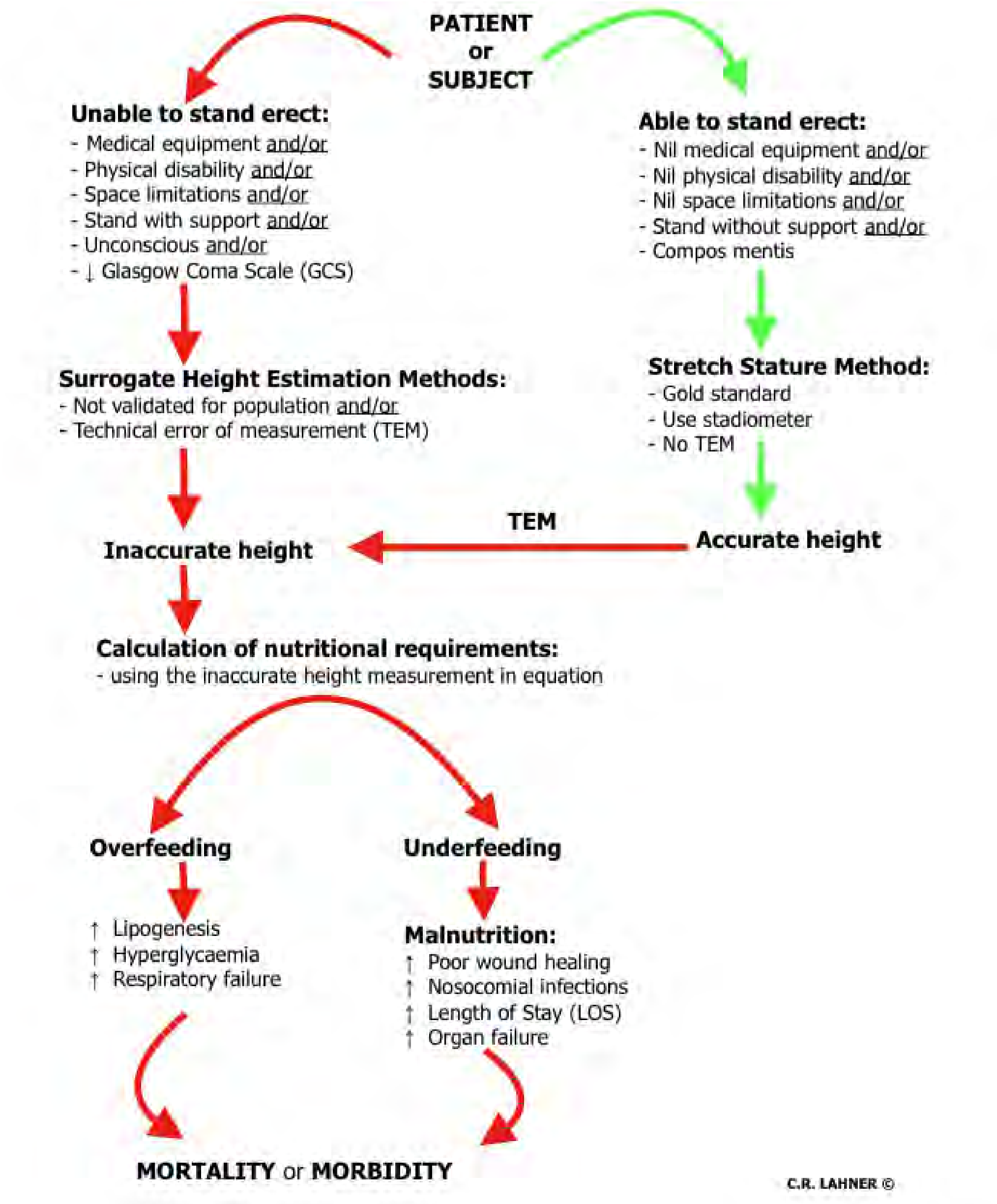

Figure 1.1: Flow diagram illustrating the outcome of using inaccurate height measurements versus accurate height measurements obtained via different assessment methods

Inaccurate measurements can occur when the measuring technique being used was not validated for the population being assessed versus the study population of origin for which the measurement technique was developed or if technical errors of measurement (TEM) process occurred (Ulijaszek & Kerr, 1999). As specified by Walker & Heuberger (2009), inaccurate height measurements results in the inaccurate calculation and misinterpretation of a patient's nutritional requirements. This can lead to over-feeding or under-feeding. Under-feeding initiates the malnutrition cycle, which in-turn increases the risk for medical complications such as poor wound healing, nosocomial infections, organ failure and increased length of hospital stay (LOS). Over-feeding on the other hand, is associated with increased risk for lipogenesis, hyperglycaemia and respiratory failure. These factors facilitate the progression to morbidity and mortality (Walker & Heuberger, 2009).

Dieticians are often faced with the difficult decision of choosing the most appropriate height estimation method, where an incorrect decision could lead to consequences of which the outcome could be fatal (Walker & Heuberger, 2009). To date, only two South African studies regarding height estimation techniques have been published (Lahner, Kassier & Veldman, 2015; Marais, Marais & Labadarios, 2007). Given the need for using appropriate anthropometric methods and the lack of South African population-based studies, determining the accuracy of height estimation methods between variables such as gender and race is of importance. The findings from this study will provide important baseline data for future anthropometric studies, of which the results can facilitate the choice of a more appropriate height estimation equation for patients of different races and genders.

1.2 Aim of this study

The aim of this study was to determine the accuracy of arm-associated height estimation methods [TAS; HAS x2; demi-span equation (DSE) and World Health Organization (WHO) equation] in the calculation of true height compared to stretch stature (SS), the gold standard of measuring true height, in South African born Black, White and Indian adults of both genders aged 18 to 24 years.

1.3 Objectives

The objectives of this study were:

1.3.1 To assess whether current arm-associated height estimation methods accurately calculates true height in young South African adults;

1.3.2 To determine which arm-associated height estimation method accurately calculates true height in Black, Indian and White subjects respectively;

1.3.3 To determine which arm-associated height estimation method accurately calculates true height in male Black, Indian and White subjects respectively; and

1.3.4 To determine which arm-associated height estimation method accurately calculates true height in the female Black, Indian and White subjects respectively.

1.4 Type of study

This study was of a cross-sectional descriptive nature. True height and arm-associated estimates of height were measured and compared in a group of South African born undergraduate and postgraduate students aged 18 to 24 years attending the University of KwaZulu-Natal (UKZN) on the Pietermaritzburg, Howard College and Westville campuses, respectively.

1.5 Hypotheses

For the purpose of the current study, the following null hypotheses were formulated:

1.5.1 There is no relationship between SS and height estimation methods thereof for young South African adults (H_{01});

1.5.2 There is no difference between the height-associated measurements of males and females (H_{02});

1.5.3 There is no difference between SS and height estimation methods thereof for young South African adults of different race groups, irrespective of gender (H_{03});

1.5.4 There is no difference between SS and height estimation methods thereof for males of different race groups (H_{04});

1.5.5 There is no difference between SS and height estimation methods thereof for females of different races (H_{05}); and

1.5.6 There is no difference between SS and arm-associated height estimations thereof, between race groups of both genders (H_{06}).

1.5.7 There is no arm-associated height estimation method predictive of true height for a multi-racial group of young South African adults, of both genders (H_{07}).

1.6 Definition of terms

1.6.1 **Accurate:** For the purpose of this study, accurate refers to measurements that are both reliable and valid.

1.6.2 **Anthropometry:** Anthropometry refers to the measurement of the human body, which can aid in the interpretation of an individual's nutritional status (Mahan, Escott-Stump & Raymond, 2012, p 165).

1.6.3 **Dactylion:** The dactylion is defined as the tip of the middle finger (Marfell-Jones, Olds, Stewart & Carter, 2006, p 23).

1.6.4 **Demi-span:**The demi-span (DS) refers to the measurement from the suprasternal notch to the proximal digital crease (PDC) of the middle finger, measured on the right side of the body to the nearest 0.1 centimetre (cm), and entered into the following equations:

Females: Height (cm) = [1.35 x demi-span (cm)) + 60.1]

Males: Height (cm) = [1.40 x demi-span (cm)) + 57.8]

(Beghetto et al., 2006; Bassey 1986).

1.6.5 **Frankfort plane:** According to Marfell-Jones et al., (2006, p 58), the

Frankfort plane refers to the position the head should be in when measuring height. It is defined as, when the Oribtale (lower edge of the eye socket) is in the same horizontal plane as the Tragion (the notch superior to the tragus of the ear) (Marfell-Jones et al., 2006, p 58).

1.6.6 **Half-armspan:** Half-armspan (HAS) refers to the measurement following the same methodology as TAS. However, the measurement is taken from the suprasternal notch to the dactylion, measured on the right side of the body to the nearest 0.1 cm (Beghetto et al., 2006).

1.6.7 **Half-armspan x2:** The HAS x2 refers to the HAS measurement that is multiplied by two (Beghetto et al., 2006).

1.6.8 **Height estimation methods:** For the purpose of this study, height estimation methods refers to a group of anthropometric methods that are used to estimate height only involving arm measurements namely: (i) armspan; (ii) HAS x2; (iii) DSE; and (iv) WHO equation. These methods use arm-associated measurements, where these values are entered into equations in order to calculate true height.

1.6.9 **International Society for the Advancement of Kinanthropometry:** The International Society for Advancement of Kinanthropometry (ISAK) refers to a set of guidelines that was developed to standardize anthropometric measurements (Marfell-Jones et al., 2006, p v)**.**

1.6.10 **Maximal height:** For the purpose of this study, maximal height refers to the optimum height that one is genetically predisposed to, irrespective of the effects of age or morbidity. This can be collectively termed as an individual's maximal genetic growth potential.

1.6.11 **Oribtale:** The Oribtale refers to the measurement point on the face marked as the lower edge of the eye socket (Marfell-Jones et al., 2006, p 24).

1.6.12 **Phalanx distance:** For the purpose of this study, the phalanx distance refers to the measurement from the right dactylion to the right PDC of the middle finger. This measurement value is subtracted into the HAS measurement to obtain DS.

1.6.13 **Proximal digital crease:** For the purpose of this study, the PDC refers to the anatomical landmark located on the hand surface at the base of right middle finger.

1.6.14 **Secular change:** Secular change refers to the change that occurs within secular trends (Cole, 2002).

1.6.15 **Secular trend:** Secular trend refers to the repetitive and accumulative biological changes represented in humans over centuries (Cole, 2002).

1.6.16 **Secular growth conditions:** For the purpose of this study, secular growth conditions refers to the anthropometric evolution occurring within a population and driven by genetic, nutritional, socio-economic and environmental growth factors.

1.6.17 **Stadiometer:** A stadiometer refers to the instrument used to measure SS. It is composed of a foot board, head board and measuring stick (Marfell-Jones et al., 2006, p 9).

1.6.18 **Standing Height:** For the purpose of this study, the standing height (SH) measurement refers to the measure from the vertex (top of the head) to the floor. This measurement is quantified in metres (m).

1.6.19 **Stretch Stature:** SS is defined by Marfell-Jones et al., (2006, pp 58 - 59) as the gold standard for measuring height whereby the subject stands straight using an instrument known as a stadiometer. The subject's head must be in a the Frankfort horizontal plane, with heels, buttocks and shoulder blades touching the back of the stadiometer. Measurements are read at eye level and taken to the nearest 0.1 cm (Marfell-Jones et al., 2006, pp 58-59).

1.6.20 **Subjects:** For the purpose of this study, subjects refers to the participants of this study on whom anthropometric measurements were measured.

1.6.21 **Technical errors of measurement:** According to Ulijaszek & Kerr (1999), technical errors of measurement (TEM) refers to the degree to which anthropometric data is reliable and valid. Reliability is the number of measurements recurrently giving the same value, whereas validity is determining the true values (unbiased) (Ulijaszek & Kerr, 1999).

1.6.22 **Total armspan:** TAS refers to the measurement taken from the dactylion of the left hand to the dactylion of the right hand, with arms positioned at a 90°

angle to the body and palms facing outwards and measured to the nearest 0.1 cm (Özaslan, Yaşar İşcan, Özaslan, Tuğcu & Koc, 2003).

1.6.23 **Tragion:** The Tragion refers to the measurement point on the face marked as the notch superior to the tragus of the ear (Marfell-Jones et al., 2006, p 24).

1.6.24 **True height:** For the purpose of this study, true height refers to the SH of the subject that was measured using the SS method. It is assumed that this measurement is not influenced by technical errors of measurement.

1.6.25 **Vertex:** The vertex refers to the top of the human head (Marfell Jones et al., 2006, p 24).

1.6.26 **Vitruvius theory:** The Vitruvius theory refers to the hypothesis proposed that opposes Marcus Vitruvius Pollio's ideology that TAS is equal to height (a circle within a square) (Morgan, 1974, pp 72 – 73).

1.6.27 **World Health Organization equation (WHO equation):** The WHO equation refers to the measurement from the suprasternal notch to the dactylion, measured on the right side of the body to the nearest 0.1 cm, and entered into the equation [Height= 0.73×(2×half-armspan)+0.43)] (WHO, 1999).

1.6.28 **World Health Organization adjusted equation (WHO-adjusted equation):** For the purpose of this study, race- and gender-specific adjustments were made to the existing WHO equation following data collection and analysis.

1.6.29 **Young South African adults**: For the purpose of this study, young South African adults refers to Black, White and Indian UKZN students aged 18 to 24 years, of both genders.

1.7 Study parameters

This study had the following delimitations:

1.7.1 South African born undergraduate and postgraduate students aged 18 to 24 years attending the University of KwaZulu-Natal (UKZN) on the

Pietermaritzburg, Howard College and Westville campuses, respectively.

1.7.2 The study population was limited to Black, White and Indian subjects.

1.7.3 The study was limited to subjects without physical disabilities or amputations that would prevent them from standing up straight unaided.

1.8 Study assumptions

This study made the following assumptions:

1.8.1 That the participants were honest about being born in South Africa.

1.8.2 That the participants were honest about being aged 18 to 24 years.

1.8.3 That the participants were students attending UKZN.

1.9 Summary

Anthropometry forms part of an intricate framework to determine a patient's nutritional status. To obtain an accurate measurement of height or an accurate estimation thereof, is required for many important reasons. Certain circumstances call for surrogate measurements and estimations of height to be used. The height estimation methods to date have not been validated for use in the South African population, and therefore their accuracy is questionable. The aim of this study was to determine whether arm-associated height estimation methods can be used to accurately calculate true height in young South African adults aged 18 to 24 years and of different race groups.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Anthropometric measurements collectively help to determine a patient's nutritional status and are fundamental to a dietician's scope of practice (Mahan et al., 2012, p 165). The types of anthropometric measurements available to assess nutritional status are vast, but the most basic and common measurements that are used are weight and height (Sicotte, Ledoux, Zunzunegui, Aboubacrine, Nguyen & ATARAO group 2010).

The literature that follows, will provide background information regarding the importance of the accurate measurement of height for the scientific community, and to investigate the current body of published literature, both globally and within a South African context regarding the accuracy of using height estimation methods to calculate true height, with the focus on arm-associated height estimation methods.

2.2 Standing height

As defined by Marfell-Jones et al. (2006, p 59), standing height (SH) is the absolute goal for determining a subject's true height. The measurement method is called stretch stature (SS), implying the inclusion of an adjustment factor required with diurnal variation (taller in morning and shorter in evening). Stretch stature is determined through the use of a stadiometer, measuring height from the vertex to the floor (Marfell-Jones et al., 2006, p 9). It is most accurate in subjects 18 years and older (Geeta, Jamaiyah, Safiza, Khor, Kee, Ahmad, Suzana, Rahmah & Faudzi, 2009).

As stated by Ulijaszek & Kerr (1999), when height is consistently measured correctly, it produces precise quantitative data. However, there is the possibility for measurement error (TEM) to occur namely: (1) unreliable data where repeated measurements are not generating the same value; (2) biased data representing data that are not true values; and (3) imprecision commonly known as observer error (Ulijaszek & Kerr, 1999). Technical error of measurement can be minimised through training and limiting the number of observers (fieldworkers trained to measure anthropometric measurements accurately) to a smaller rather than larger number (Geeta et al., 2009). When measured correctly, the SS method is the gold standard. However, the observer must analyse the situation pertaining to the subject, as there are many internal and external factors which can impact the validity and reliability of the SH or SS value (Geeta et al., 2009; Marfell-Jones et al., 2006). Hence, these factors will be discussed in the section that follows.

2.3 Factors affecting height

2.3.1 Growth determining factors

According to Black, Victoria, Walker, Bhutta, Christian, Onis, Ezzati, Grantham-Mcgregor, Katz, Martorell, Uauy & the Maternal and Child Nutrition Study Group (2013), life begins from conception and the first thousand days of life (conception until 2 years of age) is considered the most vulnerable growth period. Many factors contribute to optimal growth during this period: (i) maternal health and nutrition (pre-pregnancy, during pregnancy and during lactation); (ii) exclusive breastfeeding; (iii) the duration of breastfeeding; (iv) the appropriate and timely complementary feeding; (v) socio-economic conditions; and (iv) infectious diseases such as diarrhoea. When undernutrition occurs during this growth period, this can have longterm negative effects such as stunting (Black et al., 2013).

Chronic undernutrition in the early life stages can result in stunting, which is defined as when an infant or young child falls below minus two z-score (- 2 z-score) when using height-for-age growth charts (UNICEF, 2015). Stunting is a global problem, and it was estimated in 2011 that approximately 165 million children younger than five years of age were stunted (Black et al., 2013). Stunting has the potential to cause a ripple effect, which can be observed well into adulthood and is especially true for height (Black et al., 2013).

In a retrospective study conducted by Webb, Kuh, Peasey, Pajak, Malyutina, Kubinova, Topor-Madry, Denisova, Capkova, Marmot & Bobak (2008), Russian, Czech and Polish adults (N=29 000) were interviewed to determine the impact their childhood socio-economic status had on their stature. Limited parental education and a limited number of household items were independently associated with each other as well as with a decrease in adult height (Webb et al., 2008). Poor socio-economic status increases the gap between potential chronological skeletal size and actual skeletal size (Nahhas, Sherwood, Chumlea, Towne & Duren, 2013). The impact on stature is described when the optimum growth environment is achieved (Black et al., 2013), as presented in Figure 2.1.

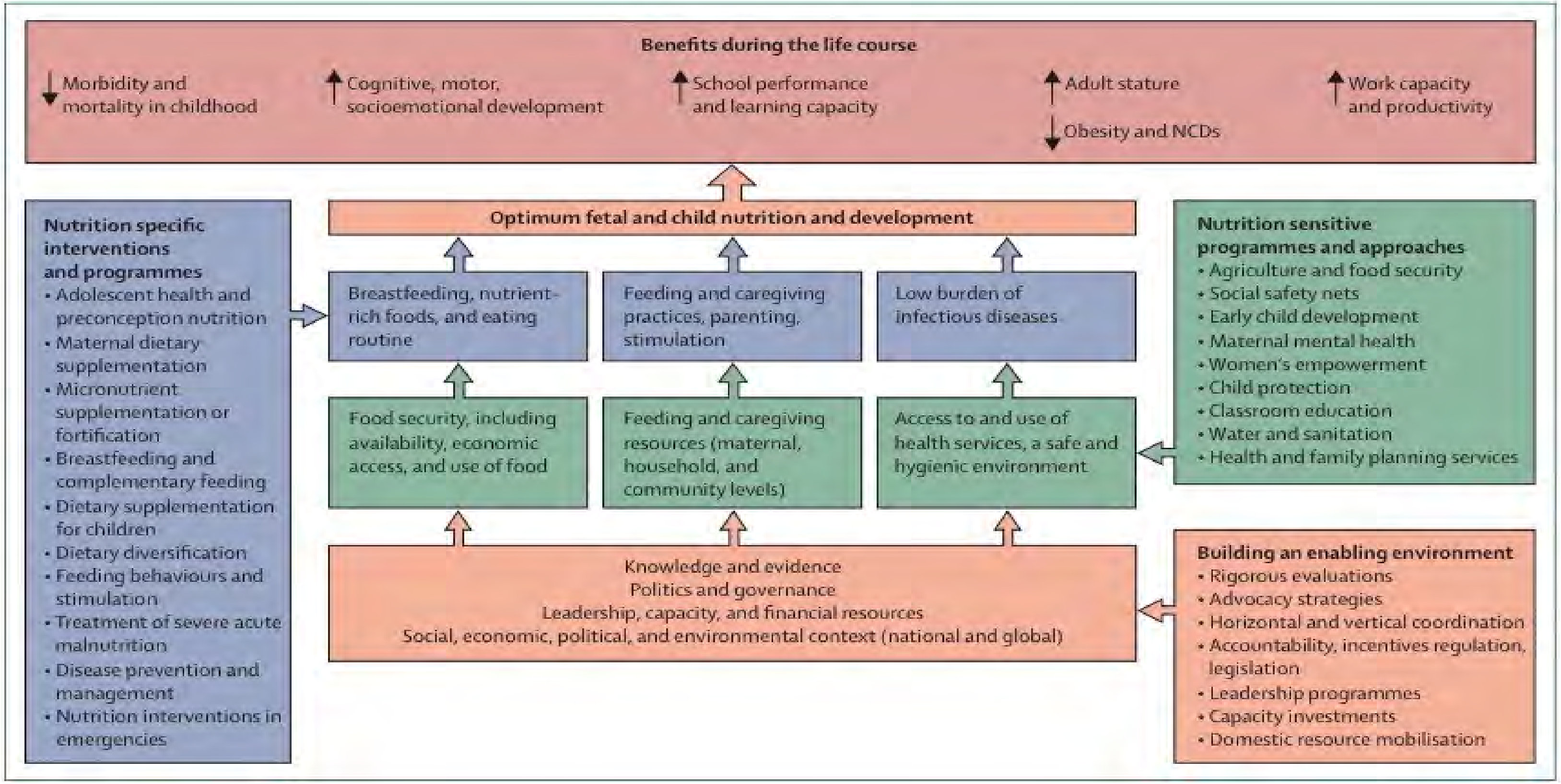

Figure 2.1: The intricate framework to achieve an increase in stature (Source: Black et al., 2013)

According to Black et al. (2013), childhood nutritional, physical and social environments determine adult height. However, there is a window period for children to catch-up to their maximal genetic growth potential. This window period is present when children are younger than two years of age and is related to the long bones in the leg called tibia and fibula that are described to be the rapidly growing bones during this stage of the life span (Black et al., 2013). In addition, it also reflects the secular patterns within generations (Cole, 2000). It is therefore apparent that stunting can be reversed during this window period.

In a South African based study by Nyati (2013, pp 6-7), the racial physical differences in 368 Black and White nine year olds were compared. Findings were that the Black children had longer limbs and shorter trunks. This variation in regional segment length was determined by the growth conditions children were exposed to under two years of age. Nyati (2013, pp 6-7) further explained that childhood growth had a longitudinal impact on their future stature, regional segment length and a limited effect on body proportions. To further describe the impact of environment on height, the term secular change will be discussed (Cole, 2000).

2.3.2 Secular change

The theory of secular trend by Cole (2002), identifies the repetitive and accumulative biological changes represented in humans over centuries. Weight and height are elements reflecting this natural recurrence such as is observed in, for example, the obesity epidemic. Height does not always increase, hence in this instance secular trend is preferably called secular change. This change recurring within populations and ancestral lines is influenced by nutrition, environment and morbidity as well as the potential longitudinal catch-up growth (Cole, 2002). Dutch males displayed secular change, where in 1860, the average height was 165 centimetres (cm) and in 1990 was 181 cm (Cole, 2000). The Dutch are renowned for globally being the tallest nation (Van Wieringen, 1986, p 307). However, this simply could be due to continued ambient conditions allowing the body to evolve and thrive (Cole, 2000).

An understanding of the secular change occurring within the South African population while taking cognisance of the high incidence of stunting, would be that the hypothesis would be a decrease in height (Black et al., 2013).

Secular change is depicted as a group of undefined height determining factors that are interrelated and in so doing, moves as a single force giving rise to a decrease or increase in stature, as illustrated in Figure 2.2 below.

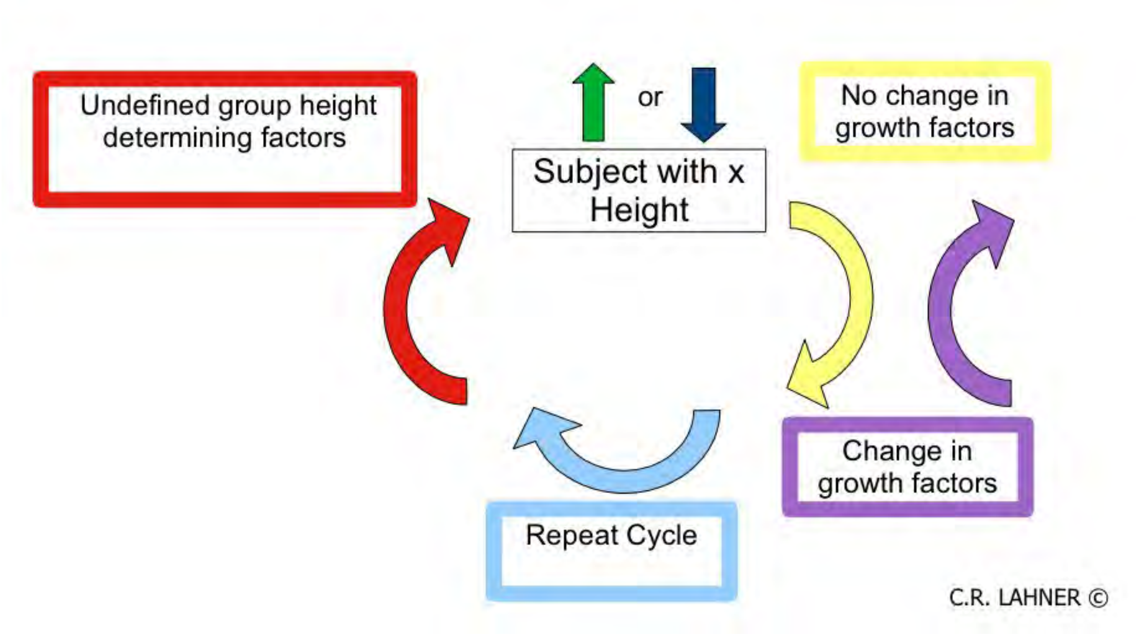

Figure 2.2: Flow diagram illustrating the multiple factors that determine the secular change within a population

Secular trends appears if the growth conditions occur repetitively within the same population and give rise to the same effect. The height determining factors have their greatest influence during the window period as previously described (Cole, 2000). Secular change reveals the network of external factors that determine adult height. The question that arises is what happens when the aging process is added as an additional variable?

2.3.3 The ageing process

A decrease in height is part of the ageing process (Sorkin, Muller & Andres, 1999). The physiological changes in the elderly are linked to a number of skeletal conditions: (i) flattening of the vertebrae; (ii) vertebral fractures; (iii) diminution in intervertebral disc thickness; (iv) scoliosis; (v) dorsal kyphosis; (vi) flattening of the plantar arch; (vii) bowing of the legs; (viii) osteoporosis; and (ix) postmenopausal hormone imbalances (Xu, Perera, Medich, Fiorito, Wagner, Berger & Greenspan, 2011; Perissinotto, Pisent, Sergi, Grigoletto, Enzi, 2002; WHO, 1996). These conditions are exacerbated by: (i) mobility problems; (ii) joint stiffness; (iii) arthritis; and (iv) postural problems which impacts on the accuracy of anthropometry and the interpretation of Body Mass Index (BMI) (WHO, 1996).

According to Sorkin et al. (1999), the degree of height loss will vary between gender, race and age, as presented in Table 2.1.

Table 2.1: Longitudinal height studies showing a decrease in height and increase in BMI with age

Population	N	Measured decrease in height (cm)	Age at onset of height loss (years)	Increase in BMI (kg/m^2) with age	Author
Italian	3356	2-3 per decade	± 40	YES	Perissinotto et al., 2002
Mexican	1968	0.5-1.5 per decade	± 40	YES	Sánchez-Garcia et al., 2007
American	2084	3 in men 5 in females	Cumulative height loss (30 to 70)	YES 0.7 in men 1.6 in females	Sorkin et al., 1999
American	2084	5 in men 8 in females	Cumulative height loss > 80 years	YES 1.4 in men 2.6 in females	Sorkin et al., 1999

In different populations, height loss is measurable (Sorkin et al., 1999) and results in an increase in BMI (Nygaard, 2008). This idea was explored by Sorkin et al. (1999) who suggested that independent of any change in weight, BMI will increase naturally by on average 0.7 kg/m^2 in males and, 1.6 kg/m^2 in females between 30 and 70 years of age. After 80 years of age, BMI increases by 1.4 kg/m^2 in males and 2.6 kg/m^2 in females. The BMI equation (kg/m^2) does not account for this natural increase in BMI due to height loss, thereby highlighting the need for a correction factor in the BMI classification system, especially for the elderly. The ageing process results in height loss and the misclassification of BMI. Furthermore, there are other internal factors such as morbidity that impact on the validity and reliability of height measurements.

As further described by Sorkin et al. (1999), height loss begins at about 30 years of age. This height-loss trend, is illustrated in Figure 2.3.

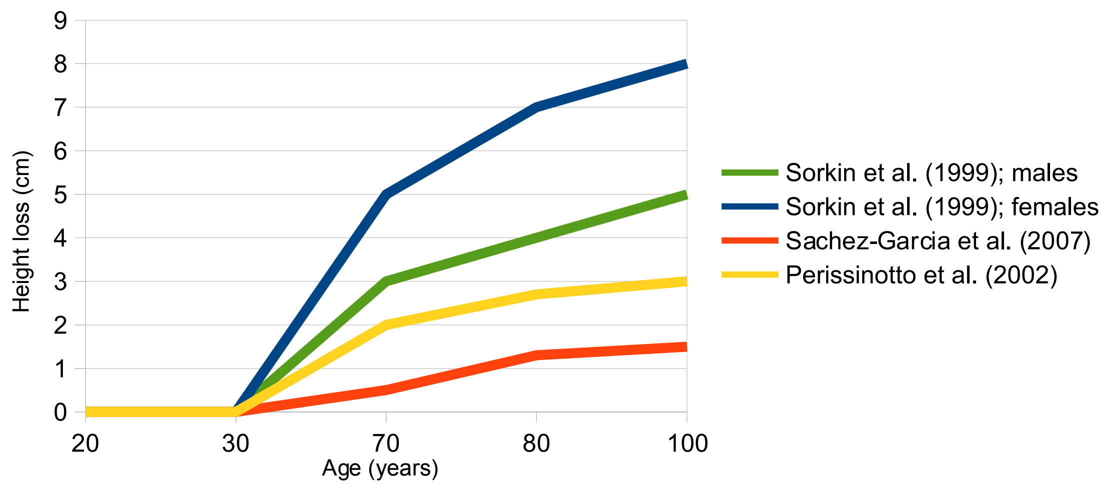

Figure 2.3: Line chart showing the trends of accelerated height loss with age in both genders and different populations

Height loss is continuous and accelerates rapidly after 80 years of age. This skeletal degradation is greater in females than males (Sorkin et al., 1999). Height estimation methods to date, do not take into account the affect these age-related height-loss changes will have on the calculation of estimated SH (Sánchez-Garcia, Garcia-Lopez, Juárez-Cedillo, Cortés-Núñez & Reyes-Beaman, 2007; Perissinotto et al., 2002; Sorkin et al., 1999).

As described by Sorkin et al. (1999), height-loss occurs every decade. It was proposed that females decrease in height by 1.25 cm and for males 0.75 cm (Sorkin et al., 1999). For example if a female is 50 years old, 2.50 cm should be subtracted from her calculated estimated height value. This would be her adjusted age height. The height adjustment factors according to age are presented in Table 2.2.

Table 2.2: Possible age-related height-loss adjustment factors (Adjusted from: Sorkin et al., 1999)

Gender	Age (years)	Adjusted age factor¢
Females	31 - 40	1.25
	41 - 50	2.50
	51 - 60	3.75
	61 - 70	5.0
	71 - 80	6.25
	> 81	8.0
Males	31 - 40	0.75
	41 - 50	1.5
	51 - 60	2.25
	61 - 70	3.0
	71 - 80	3.75
	> 81	5.0

¢ Subtracted from the estimated height value

The adjusted age factor is gender-specific and increases with every decade. Hence, the ageing process results in an overall decrease in true height as well as an increase in BMI.

2.3.4 Clinical environment

The height of a subject is representative of a history of genetic processes, driven by internal and external factors (Froehlich-Grobe et al., 2011). When it comes to the actual measurement procedure, weighing up whether the clinical environment is conducive to producing accurate data is crucial (Froehlich-Grobe et al., 2011). It would therefore seem there are two aspects related to this thought process: (i) what is the state of the patients health?; and (ii) is the patient-environment anthropometry friendly?

A poor health status will prevent the taking of SS if subjects are unable to stand up right (Shahar & Pooy, 2003). As specified by Froehlich-Grobe et al. (2011), these contributing factors include: (i) amputations; (ii) contractures; (iii) physical deformities (cerebral palsy, scoliosis, kyposis); (iv) muscle weakness (muscular dystrophy); and (v) bone conditions (rickets, osteomalacia or osteoporosis). In addition, fatigue associated with illness can cause a patient to become bedridden, or if critically ill, unconscious (Froehlich-Grobe et al., 2011).

It is assumed that an patient-environment that is anthropometry friendly has the following characteristics: (i) adequate space; (ii) patient is not restricted by medical equipment; (iii) minimum of two observers conducting anthropometric measurements; (iv) access to relevant equipment; and (v) low noise level to record data.

It is an essential process to analyse and consider all of the above mentioned factors affecting the measurement of height: (i) first 1000 days of life; (ii) secular change; (iii) the ageing process; and (iv) the clinical environment. When SS is not possible, and considering the patient's comfort and need to obtain accurate data, height estimates are a possible alternative (Froehlich-Grobe et al., 2011;).

2.4 Alternatives to measuring true height

The gold standard for measuring true height is the SS method (Marfell-Jones et al., 2006, p 59). When SS is not possible, the estimated value is used (Froehlich-Grobe et al., 2011). Body parts are often used to estimate height (Özaslan et al., 2003).

These include: (i) vertebral column length; (ii) length of scapula; (iii) trochanteric height; (iv) leg length; (v) thigh length; (vi) cranial sutures; (vii) skull; (viii) facial measurements; (x) sitting height; (xi) knee height (KH); (xii) ulna length (UL); (xiii) arm measurements; and (xiv) recumbent length (RL) (Bjelica, Popović, Kezunović, Petković, Jurak & Grasgruber, 2012; Özaslan et al., 2003; Krishan & Sharma, 2006). The most frequently used methods will be discussed with regards to accuracy in estimating true height.

2.4.1 Recumbent length

According to Freitag, et al. (2010), RL is often used in intensive care units by nursing staff when a patient is unconscious. The RL involves the use of a head board, foot board and non-stretch measuring tape. The patient is required to lie flat on a mattress, without a pillow or bedding (Freitag et al., 2010). In a study comparing 141 wheelchair bound patients versus controls, RL had a variance of 92%. However, 25% of subjects experienced difficulties lying supine (Froehlich-Grobe et al., 2011). In another study conducted on 108 ambulatory inpatients, RL was significantly longer than SH by 3.68cm (Gray, Crider, Kelley & Dickinson, 1985).

2.4.2 Visual and self height estimation

As defined by Coe, Halkes, Houghton & Jefferson (1999), visual estimation of height is defined as guessing the subject's SH through observation. This method results in the overestimation of height in shorter subjects and is difficult to estimate if the subject is lying in the recumbent position (Coe et al., 1999).

Self-reported height (SRH) is when the subject concerned reports their own height, based on their knowledge or recall (Beghetto et al., 2006). The SRH method is useful when no measurements are possible, but has been shown to overestimate SH (Brown, Feng & Knapp 2002; Gray et al., 1985).

2.4.3 Long bone associated measurements: knee height and ulna length

In a study conducted by Chumlea, Roche & Steinbaugh (1985), KH as an alternate for stature was first assessed in the elderly. Subsequently, the author developed equations for males and females widely known as the Chumlea equations. The KH was significantly correlated with SH in the elderly between 60 and 90 years of age (Chumlea et al., 1985). These findings were supported by Hickson & Frost (2003), with a sample size of 484 elderly (>65 years), in that KH was highly significantly ($p < 0.001$) correlated to SH ($r = 0.89$). Similar findings were reported in 812 Indonesian Javanese elderly (55 to 69 years), where KH was highly significantly ($p < 0.001$) correlated to SH in males ($r = 0.855$) and females ($r = 0.754$) (Fatmah, 2009). The KH measurement is a challenging to assess in the bedridden, as it requires the patient to bend their knee at a 90º angle (Beghetto et al., 2006). The accuracy of the Chumlea equations vary with age and race (Beghetto et al., 2006). It is for this reason that it has been adapted (Cereda, Bertoli & Battezzati, 2010; Chumlea, Guo & Steinbaugh, 1994). The relevance of KH to the South African population has been assessed (Marais et al., 2007) and will be discussed in due course.

Ulna length (UL), is measured from the Olecranon process to the Styloid process of the ulna bone situated in the forearm (Vinayachandra, Monteiro, Jayaprakash, Bhagavath & Viveka, 2013). Several studies have identified a potential relationship between ulna length and SH in the Indian population (Al-wasfi & Puranik, 2015; Mehta, Mehta, Gajbhiye & Verma, 2015; Bansal, Vaghela, Lad, Mittal & Kapadiya, 2014; Borkar, 2014; Mohanty, Agrawal, Mishra, Samantsinghar & Chinar, 2013; Prasad, Bhagwat, Porwal & Joshi, 2012; Nagesh & Lovita, 2011; Thummar, Patel, Patel & Rathod, 2011; Mondal, Jana, Das & Biswas, 2009). To date, the only known African study that has investigated the relationship between UL and SH was conducted on Nigerians (N=109) (Ebite, Ozoko, Eweka, Otuaga, Oni & Om'Iniabohs, 2007). Ebite et al. (2007), identified that males had larger ulna lengths than females, but further studies were needed to verify whether UL accurately predicted

SH. Ulna length has been largely used in the British population for screening patients for malnutrition by using the malnutrition universal screening tool (MUST) developed by the British Association of Parenteral and Enteral Nutrition (BAPEN) (Jones, Beech & Wright, 2011). However, this tool should be used with caution in a multi-racial population such as in South Africa (Madden, Tsikoura & Stott, 2012). Although UL has shown to have a significant correlation with SH, population-specific studies need to be conducted as well as population-specific formulas developed (Duyar & Pelin, 2010).

Appropriate height estimation alternatives are essential for assessing nutritional status. The long bones in the legs and arms do not change with age (Pieterse, 1997). Thus, assuming that long bone length remains constant (Fatmah, 2009), height estimation methods using arm measurements such as half-armspan (HAS), demi-span (DS) and total armspan (TAS), may be a viable option (Lahner et al., 2015).

2.4.4 Half-armspan

HAS or mid-armspan was first documented by Kwok and Whitelaw (1991). It is measured from the suprasternal notch to the dactylion (Kwok & Whitelaw, 1991). Assuming that armspan is equal to height, the HAS length value can be doubled to obtain an approximate of true height (Kwok & Whitelaw, 1991). A Malaysian study by Shahar and Pooy (2003), compared the accuracy of height estimated using HAS in 100 adults (30 to 49 years old) and 100 elderly (60 to 86 years old). Half-armspan was more closely correlated ($p<0.05$) to SH in adult females ($r=0.89$) and males ($r=0.84$), than elderly females ($r=0.67$) and males ($r=0.77$). This decrease in correlation with age could be due to age related height-loss (Sorkin et al., 1999). However, height-loss rates will differ within each population as displayed in British inpatients ($n=484$; >65 years old) as the correlation was much higher ($r= 0.87$) (Hickson & Frost, 2003).

The World Health Organization (WHO) (1999), suggested that when a patient is unable to stand, the WHO equation [0.73 x (2x half arm span) + 0.43] should be used to estimate height in adults more than 18 years of age. The equation uses the HAS measurement. The accuracy of this equation has not been validated in various populations. In the elderly it is associated with the underestimation of SH and an increase in BMI (de Oliveira Siqueira, de Lima Costa, Lopes, dos Santos, Lima-Costa & Caiaffa, 2012). It is therefore evident that the ageing effect on SH, diminishes the accuracy of using the HAS and WHO equation.

2.4.5 Demi-span

The DS measurement was first proposed by Bassey (1986) to be entered into the demi-span equation (DSE). It is measured from the suprasternal notch to the base of the middle finger (Bassey, 1986). Bassey (1986) compared SH to DS in 125 Europeans (< 60 year old) with a highly significant correlation (r= 0.74). Those aged younger than sixty were also studied by Shahar & Pooy (2003), with findings generating similar significant correlations in males (r=0.85) and females (r=0.83).

Although, Bassey (1986) initially investigated the DS equations in adults, it has been largely studied in the elderly (Ngoh, Sakinah, Harsa & Amylia, 2012; Hirani & Mindell, 2008; Weinbrenner, Vioque, Barber & Asensio, 2006; Shahar & Pooy, 2003; Bassey, 1986). Correlations between SH and DS has been documented by several studies, as presented in Table 2.3.

Table 2.3: Correlation between standing height and demi-span equations related to different populations and age groups

Population	Sample size (N)	Age (years)	Correlation between DS & SH	Author
European	125	< 60	r= 0.74**	Bassey (1986)
Malays 52 %, Indians 9.5 %, Chinese 38.5 %	100	30 - 49	r= 0.85 in males* r= 0.83 in females*	Shahar & Pooy (2003)
Malays 52 %, Indians 9.5 %, Chinese 38.5 %	100	60 - 86	r= 0.76 in males* r= 0.70 in females*	Shahar & Pooy (2003)
British	484	> 65	r= 0.86**	Hickson & Frost (2003)
Spanish	592	> 65	r= 0.708 in males** r= 0.625 in females**	Weinbrenner et al. (2006)
Health Survey for England (HSE)	3346	≥ 65	r= 0.71 in males* r= 0.72 in females*	Hirani & Mindell (2008)
Malays	328	> 60	r= 0.759 in males** r= 0.803 in females**	Ngoh et al. (2012)

*p <0.05 **p < 0.001

In a longitudinal study with a duration of eight years, DS was resilient to change with an increase in age, and was a reliable measure of true height (Bassey, 1998). The accuracy and precision of using the DSE is affected by age-related height loss, especially in females (Weinbrenner et al., 2006). Consequentially, using DS in the elderly, results in the overestimation of BMI (de Oliveira Siqueira et al., 2012). Adjustments to the DSE have been documented (Hirani, Tabassum, Aresu & Mindell, 2010). The advantage of using the DSE in the context of the South African population is unknown due to a lack of published data.

2.4.6 Total armspan

TAS is the measurement from the dactylion of the right hand to the dactylion of the left hand, with arms outstretched and at a 90º angle to the body (Özaslan, 2003;

Kwok & Whitelaw, 1991). The first known height study to investigate TAS was conducted by Bonomi (1880), whom was also the first to design equipment that would measure height. The study compared SH to TAS in a small sample (n=84), where only six subject's SH was equal to TAS (Bonomi, 1880, pp 20 – 30). Several studies have subsequently tested the relationship between the two variables, as presented in Table 2.4.

Table 2.4: Correlation between standing height and total armspan as per different populations and age groups

Population	Sample size (N)	Age (years)	Correlation between TAS & SH	Author
USA:		23 - 28		Steele & Mattox (1987)
Black	55		r= 0.776** in females	
White	74		r= 0.894** in females	
USA:		35 - 89		Steele & Chenier (1990)
Black	293		r= 0.852** in females	
White	298		r= 0.903** in females	
British	101	> 60	r= 0.93*	Kwok & Whitelaw (1991)
Wheelchair bound patients	119	0.5 - 56	r= 0.989*	Jarzem & Gledhill (1993)
Ethiopian:	1706	18 - 50		de Lucia et al. (2002)
Oromo	260		r= 0.84 in males**	
	204		r= 0.83 in females**	
Amhara	206		r= 0.84 in males**	
	199		r= 0.86 in females**	
Tigre	204		r= 0.84 in males**	
	204		r= 0.84 in females**	
Somali	214		r= 0.86 in males**	
	215		r= 0.80 in females**	
Malays 52 %; Indians 9.5 %; Chinese 38.5 %	100	30 - 49	r= 0.86 in males*	Shahar & Pooy (2003)
			r= 0.90 in females*	
Malays 52 %; Indians 9.5 %; Chinese 38.5 %	100	60 - 86	r= 0.78 in males*	Shahar & Pooy (2003)
			r= 0.72 in females*	

Table 2.4 (continued): Correlation between standing height and total armspan as per different populations and age groups

Population	Sample size (N)	Age (years)	Correlation between TAS & SH	Author
Malawian	289	6 - 15	r= 0.983 in males*	Zverev & Chisi (2005)
	337		r= 0.986 in females*	
Indonesian Javanese	295	55 - 69	r= 0.815 in males**	Fatmah (2009)
	517		r= 0.754 in females**	
Indian (Dhimels)	95	10 - 17	r= 0.97 in males**	Banik (2011)
	97		r= 0.93 in females**	
	132	18 - 59	r= 0.82 in males**	
	126		r= 0.84 in females**	
Nigerian	306	20 - 49	r=0.82*	Goon et al. (2011)
	180		r= 0.77 in males**	
	126		r= 0.72 in females**	
Garo tribal; Bangladeshi	100	25 - 45	r= 0.89 in females**	Hossain et al. (2011)
Montenegrins	178	18 – 36	r= 0.861 in males**	Bjelica et al. (2012)
	107	18 - 37	r= 0.809 in females**	
Indian		21 - 24	r= 0.875 in males*	Singh et al. (2012)
			r= 0.856 in females*	
Serbian	318	19 - 20	r= 0.814 in males**	Popovic et al. (2013)
	76		r= 0.822 in females**	
Nepalese	225	25 - 45	r= 0.682 in males**	Sah et al. (2013)
	175		r= 0.507 in females**	
North Indian	149	18 - 25	r= 0.897 in males*	Chawla et al. (2013)

Table 2.4 (continued): Correlation between standing height and total armspan as per different populations and age groups

Population	Sample size (N)	Age (years)	Correlation between TAS & SH	Author
Indian	77	60 – 64	r= 0.81 in males**	Jamir et al. (2013)
	114		r= 0.79 in females**	
	60	65 – 69	r= 0.72 in males**	
	78		r= 0.85 in females**	
	36	70 – 74	r= 0.79 in males**	
	52		r= 0.89 in females**	
	64	≥ 75	r= 0.80 in males**	
	47		r= 0.84 in females**	

*$p < 0.05$ **$p < 0.001$

Finding's described TAS to overestimate SH (Popovic, Bjelica, Molnar, Jasic & Akpinar, 2013; Sah, Kumar & Bhaskar, 2013; Chawla, Rajkumar, Tomar & Ashoka, 2013; Jamir, Kalaivani, Nongkynrih, Misra & Gupta, 2013; Bjelica et al., 2012; Singh, Kumar, Chavali & Harish, 2012; Banik, 2011; Goon, Toriola, Musa & Akusu, 2011; Hossain, Begum & Akhter, 2011; Fatmah, 2009; Zverev & Chisi, 2005; Shahar & Pooy, 2003; de Lucia, Lemma, Tesfaye, Demisse & Ismail, 2002; Jarzem & Gledhill, 1993; Kwok & Whitelaw, 1991; Steele & Chenier, 1990; Steele & Mattox, 1987). TAS is frequently used as a height estimation method in clinical practice (Froehlich-Grobe et al., 2011). However, there are various factors such as age, gender and race, which may affect the validity of using the armspan measurement.

Before puberty, TAS is at its closest correlation to SH, while after the onset of puberty (± 15 years), the correlation decreases and the gap between genders widens (Banik, 2011; Nwosu & Lee, 2008; Zverev & Chisi, 2005). In females, the gap between TAS and SH is larger than males (Jamir et al., 2013; Banik, 2011; Grimberg & Lifshitz, 2007; Manonai, Khanacharoen, Theppisai & Chottacharoen, 2001), but increases in both genders with the ageing process (Ofluoglu, Unlu & Akyuz, 2008).

The SH to TAS correlation varies between different race groups. Hence, one height estimation method cannot be used in all cases, but rather each height estimation method should be validated for accuracy in accordance with a particular population group and gender (Bjelica et al., 2012; Singh et al., 2012; de Lucia et al., 2002; Reeves, Varakamin & Henry, 1996; Steele & Chenier, 1990). An example of the outcome of using the TAS measurement as an unvalidated substitute for SH in a clinical setting is if used in spirometry studies, resulting in misclassifications of pulmonary function which is a common error (Chhabra, 2008; Golshan, Amra & Hoghoghi, 2003; Aggarwal, Gupta & Jindal, 1999). Therefore, the relationship between TAS and SH is questionable and will be further discussed in the next section.

2.4.7. The Vitruvian man

The relationship between TAS and SH exists throughout art and science history (Aggarwal, Gupta, Ezekiel & Jindal, 2000). A Roman architect by the name Marcus Vitruvius Pollio, published his book series called De Architectura in first century BC (McEwen 2003, pp 1 - 2). This was later translated into English by Morgan (1914). According to Morgan (1914, pp 72 – 73), Vitruvius described the human body in terms of symmetry and proportions. If the navel is the central point, in supine position with arms and legs outstretched, the body forms a circle. This circle is drawn within a perfect square: this is where the idea that armspan is equal to height originated from (Morgan, 1914, pp 72 – 73), and this theory is illustrated in Figure 2.4 below.

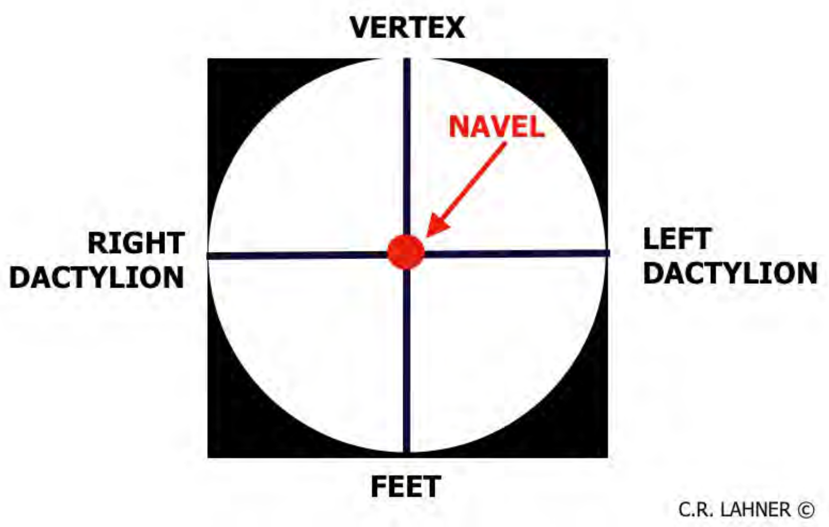

Figure 2.4: Diagrammatic illustration of man, based on the Vitruvias's ideology+

+ Vitruvius's ideology is described as a circle within a square, where the navel is the central point of measurement (Morgan, 1974, pp 72 – 73).

Vitruvius's ideology was later illustrated by Leonardo da Vinci (1452-1519) in a drawing called the Vitruvian man in 1490 (George, 2014), as illustrated in Figure 2.5 below.

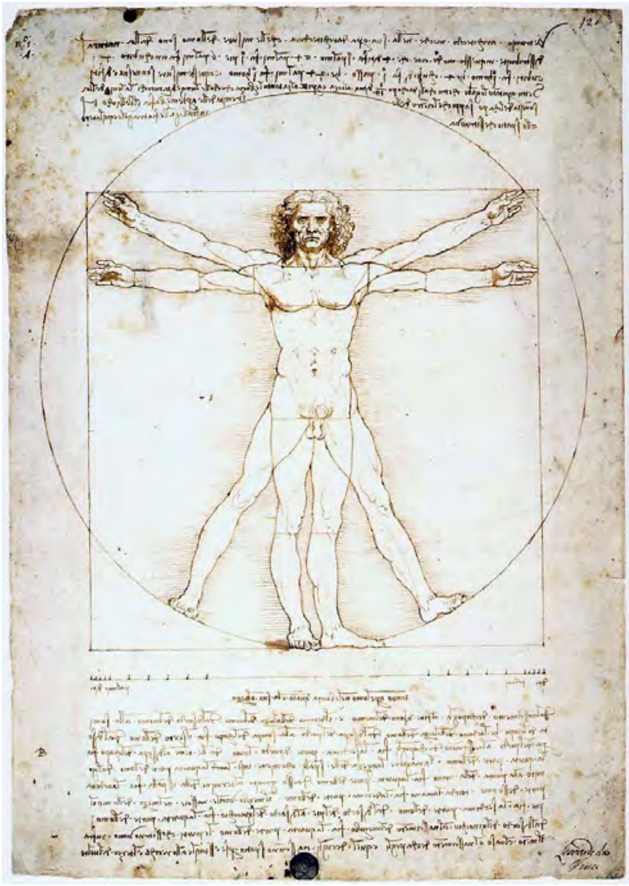

Figure 2.5: The Vitruvian man drawn by da Vinici in 1490 (Source: Wikimedia Commons, 2015)

The diagrammatic illustration reflects the hypothesis that armspan is equal to height. This hypothesis has been proven as inaccurate by several studies (Popovic et al., 2013; Sah et al., 2013; Chawla et al., 2013; Jamir et al., 2013; Bjelica et al., 2012; Singh et al., 2012; Banik, 2011; Goon et al., 2011; Hossain et al., 2011; Fatmah, 2009; Zverev & Chisi, 2005; Shahar & Pooy, 2003; de Lucia et al., 2002; Jarzem & Gledhill, 1993; Kwok & Whitelaw, 1991; Steele & Chenier, 1990; Steele & Mattox, 1987). However, there is the possibility that the Vitruvius traits may occur occasionally within a population despite being unlikely for the majority of populations (Aggarwal et al., 2000; Schott, 1992).

Every effort should be made to ensure that SS is measured (Marfell-Jones et al., 2006, pp 58 – 59). When the measurement of true height is not possible, SH can be estimated (Froehlich-Grobe et al., 2011). Several methods have been documented using different body parts. The methods least affected by the ageing process include those using lone bones namely KH, TAS, HAS and DS (Fatmah, 2009), of which TAS is the most frequently used and was first described by Vitruvius. The use of arm-associated height estimation methods in the context of the South African population, is yet to be fully understood and investigated. However, there are two studies to date that have explored the use of height estimation methods in the South African population. The latter will be further discussed in the section that follows.

2.5 South African studies using height estimation methods

South African studies that have investigated SH and height estimation methods are limited. However, two have been conducted over the last decade. The first study was conducted by Marais et al. (2007), that compared elderly (≥ 60 years, n= 1233) to adults (18- 59 years, n=1038). Although different ethnic groups were included in the study sample, the majority of the subjects surveyed were female and of mixed ancestry (Coloured), as presented in Table 2.5.

Table 2.5: South African height study sample characteristics (Source: Marais et al., 2007)

Variable	Category	N= 2 271
Race group	Black	168
	Coloured[¥]	1344
	White	759
Gender	Male	582
	Female	1689
Location	Clinic	1123
	Old-age home	1149
Age (years)	18 – 59	1038
	≥ 60	1233

¥ Coloured participants have a mixed ancestry.

KH, TAS, SH and weight were measured in each subject. Standing height differed highly statistically ($p<0.0001$) between the elderly and adult group. In addition, SH decreased with age and males were generally taller than females by ten cm in the adult group and 20 cm in the elderly group.

Knee height and TAS overestimated SH by six cm in the adult group and TAS overestimated SH by six cm in the elderly group. Overestimation of SH resulted in a decrease in BMI. Consequently, subjects were classified to be of a poorer nutritional status. Therefore, KH was seen as the superior height estimation method in the elderly (Marais et al., 2007).

Subsequently, a study was conducted on young adults (Lahner et al., 2015) to investigate the accuracy of arm-associated height estimates compared to SS namely TAS, DS, HAS and the WHO equation. The study characteristics are presented in Table 2.6.

Table 2.6: South African height study sample characteristics (Source: Lahner et al., 2015)

Variable	Category	Sample size (N= 200)
Race group	Black	100
	White	100
Gender	Male	100
	Female	100
Location	UKZN, PMB	200
Age (years)	18 – 24	200

No height estimate assessed was significantly predictive of SH in the study sample ($p<0.001$). Standing height differed significantly between genders and race groups ($p<0.001$). Height estimation measurements were compared to SS for the study sample (N=200), as presented in Table 2.7.

Table 2.7: Comparison between measured height and estimates thereof according to subject race and gender (Source: Lahner et al., 2015)

Variable (cm)	Mean± SD	*P-value	↓ or ↑
Black Males (n=50)			
Standing height minus armspan	-4.96 ± 3.13	.000	↑
Standing height minus half-armspan x 2	-8.17 ± 4.54	.000	↑
Standing height minus WHO equation	39.92 ± 3.89	.000	↓
Standing height minus male demi-span equation	-0.60 ± 4.10	.306	↑
Black Females (n= 50)			
Standing height minus armspan	-3.34 ± 4.14	.000	↑
Standing height minus half-armspan x 2	-7.25 ± 3.95	.000	↑
Standing height minus WHO equation	37.22 ± 2.99	.000	↓
Standing height minus female demi-span equation	-3.03 ± 3.06	.000	↑
White Males (n=50)			
Standing height minus armspan	0.00 ± 4.97	0.995	-
Standing height minus half-armspan x 2	-4.04 ± 5.43	.000	↑
Standing height minus WHO equation	45.05 ± 4.40	.000	↓
Standing height minus male demi-span equation	4.57 ± 4.42	.000	↓
White Females (n=50)			
Standing height minus armspan	2.00 ± 4.39	.002	↓
Standing height minus half-armspan x 2	-1.91 ± 4.99	.009	↑
Standing height minus WHO equation	43.04 ± 4.10	.000	↓
Standing height minus female demi-span equation	2.81 ± 4.14	.000	↓

*Independent samples t-test, ↑ Overestimates height compared to standing height, ↓ Underestimates height compared to standing height

DS was the most predictive of SH in black males and TAS was the most predictive of SH in White males. None of the estimates assessed were accurately predictive of SH in females of both genders. This emphasised the importance of using height estimation methods that have been assessed in the South African population, with consideration for gender, race and age (Lahner et al., 2015).

2.6 Conclusion

SH is a basic anthropometric measurement (Sicotte et al., 2010). Where possible, SS is the gold standard, with careful consideration of TEM (Marfell-Jones et al., 2006, p 59; Ulijaszek & Kerr, 1999). Many factors can influence the maximal genetic growth potential for height in adults. These include nutrition during 'first 1000 days of life', secular trend and the ageing process (Black et al., 2013; Cole, 2002; Sorkin et al., 1999). Practicality of measuring height can be influenced by the clinical environment and disease profile of the subject (Froehlich-Grobe et al., 2011). When SH is not possible, height estimation methods are used by measuring body parts (Özaslan et al., 2003). Alternative height estimation measurements include: (i) RL; (ii) visual; (iii) self-estimated; (iv) KH; (v) HAS; (vi) DS; and (vii) TAS (Freitag et al., 2010; Özaslan et al., 2003; Kwok & Whitelaw, 1991; Bassey, 1986; Chumlea et al., 1985).

Vitruvius proposed that TAS and SH are equal, in his circle within a square ideology (McEwen, 2003, pp 72-73). Leonardo da Vinci mirrored this in his drawing called the Vitruvian man (George, 2014). In the last century the accuracy of height estimates have been questioned.

In the South African context, to date two studies have researched SH compared to height estimation methods (Lahner et al., 2015; Marais et al., 2007). Findings suggest that KH can be used in the South African elderly (Marais et al., 2007). Demi-span can be used in Black males and TAS in White males. However, no height estimate accurately predicts height in Black and White females (Lahner et al., 2015).

There is a clear gap in the published literature regarding research conducted in the South African population and using height estimates to obtain accurate data. No research has been conducted on South African Indians in this area. Research into the South African population by taking cognisance of age, gender and race groups would be most beneficial to understand the unique height profile. The findings of this research will provide vital insight into the secular trends of South Africans, as well as which height estimation method would be best suited for everyday clinical use.

CHAPTER 3: METHODOLOGY

3.1 Introduction

In this chapter, an overview is given of the study design, the sampling procedure as well as the methods and measuring instruments that were used for data collection in the current study. The sections on study population and sample selection and the inclusion and exclusion criteria, provides an overview of eligibility for participation and the criteria that was used to select subjects. This is followed by the methods and materials which includes a detailed description of how the data was collected. These methods were validated by fieldworkers receiving anthropometric training prior to the pilot study and data collection for the current study. This was followed by how the data was statistically analysed. Lastly, the reliability and validity of the data was discussed in addition to ethical considerations.

3.2 Study design

Data was collected using a cross-sectional descriptive survey.

3.2.1 Advantages of using a cross-sectional descriptive survey

According to Levin (2006), cross-sectional studies are appropriate where there are monetary limitations and time constraints, this was desirable for this study as data was collected over a two month period (February to March, 2015) and limited funds were available for research purposes. Hence, the design provided an 'snapshot' of the current height status and arm-associated anthropometrics of young South African adults (Grimes & Schulz, 2002). As the study was over a short period of time, there was no loss to follow-up (Levin, 2006; Grimes & Schulz, 2002).

3.2.2 Disadvantages of using a cross-sectional descriptive survey

A cross-sectional descriptive survey represents a situation at one particular point in time and it is therefore difficult to make informal inferences about the topic matter (Levin, 2006).

3.3 Study population

Various race groups were selected for participation in this study which included Blacks, Whites and Indians, of which typically inhabit KwaZulu-Natal and Southern Africa at large (Relethford, 2000). Both males and females between the ages of 18 and 24 years were eligible for the study. As proof of their South African heritage, the subjects had to be in possession of a South African identification document. Furthermore, the subjects had to be registered students attending the University of KwaZulu-Natal (UKZN) from either Howard College, Westville campus or Pietermaritzburg campus.

3.4 Sample selection

A study sample (N=900) was selected by means of convenience sampling. As a result, fieldworkers approached prospective subjects on respective campuses. If they met the inclusion criteria, they were asked whether they were willing to participate. As the sample was stratified by both race and gender, the study sample consisted of 300 Black, White and Indian subjects respectively with each race group being represented by 150 males and 150 females. As a result, convenience sampling took place until the proposed quota of male and female subjects per each race stratum was filled.

3.5 Inclusion and exclusion criteria

Subject's were eligible for participation provided that the inclusion and exclusion criteria was met, as reported in Table 3.1 below.

Table 3.1: Inclusion and exclusion criteria of study sample

Inclusion Criteria:	Exclusion criteria:
1. Black, White or Indian 2. Male and female 3. UKZN students from Howard College, Westville or Pietermaritzburg campus 4. 18 to 24 years 5. South African born citizens 6. Able to stand without assistance	1. Mixed ancestry (Coloured) 2. Students from the Nelson Mandela Medical School 3. Students older than 24 years 4. Students who were not born in South Africa, despite South African citizenship. 5. Physical disabilities 6. Amputations 7. Assistance needed to stand 8. Unwilling to remove outer layers of clothing and/or shoes.

Subjects had to be registered students from the University of KwaZulu-Natal and born in the Republic of South Africa, i.e. be in possession of an identity document from the Republic of South Africa. In addition, the study sample was limited to subjects without physical disabilities or amputations, as that would prevent the subject from standing up straight.

3.6 Study methods and materials

This section describes the methods and materials that were used to obtain the study data.

3.6.1 Data collection stations

Fieldworkers set up mobile data collection stations on the grounds of various UKZN campuses in high traffic areas where many students would be walking to and from lectures. Stations were set up in close proximity to an even surfaced wall with a 90º angle level to the floor surface. There were a minimum of three fieldworkers at each station at any given time. In addition, the data collection period was specifically planned to take place during February and March 2015 (late summer), as this would allow subjects to be more likely to agree to removing shoes, socks and outer layers of clothing such as jackets and jerseys, as this was essential for the accurate measurement of height.

3.6.2 Height measurement

Height was measured using stretch stature (SS), the gold standard of measuring true height (Marfell-Jones et al., 2006, p 58). The instrument used to measure height was a portable stadiometer (Seca) with a sliding head board, that was manufactured according to the International Society for the Advancement of Kinanthropometry (ISAK) guidelines (Marfell-Jones et al., 2006, p 9). The height measurements were measured three times to one decimal place and the mean of two closest values calculated. The procedure for measuring height is described in the next section.

3.6.3 Procedure for measurement of height

Height measurements were taken using a portable stadiometer with a sliding headpiece and foot board. The procedure for measuring height was as follows:

i. The stadiometer was placed on a level even surface and against a wall that was at a 90º angle to the floor.
ii. Subjects were asked to remove shoes, socks and outer layers of clothing such as a jacket.
iii. Subjects were asked to untie their hair if it was tied up. In the case of

traditional hairstyles such as braids and weaves typically seen in the Black South African females, a knitting needle was gently inserted through the hairstyle in order to give an indication of where the skull was. Then a ruler was used to accurately appraise height by reading it from the stadiometer.

iv. Subjects were then asked to stand on the foot board of the stadiometer, positioned as follows: (i) the subject facing outwards; with their (ii) hands placed to their sides; (iii) legs straight; (iv) feet together; and (v) head in a Frankfort plane, as illustrated below in Figure 3.1.

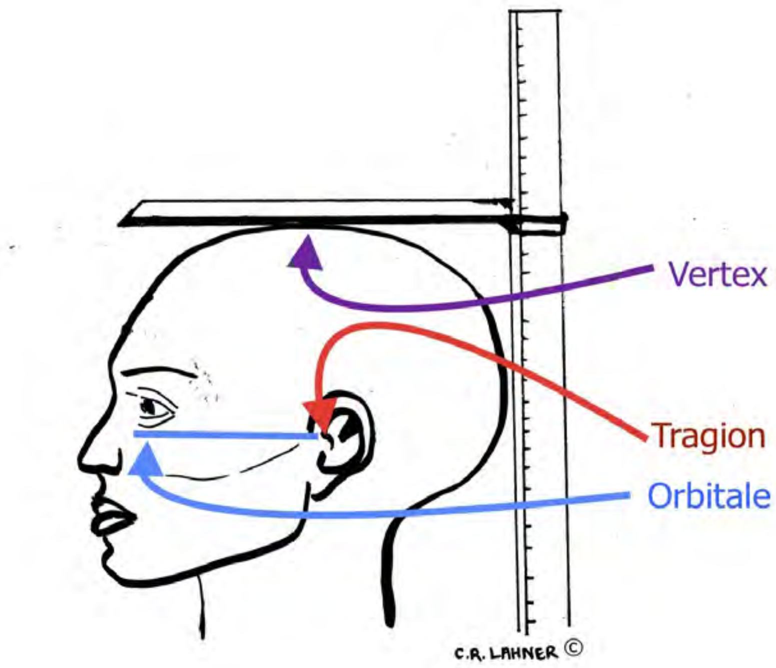

Figure 3.1: The head positioned in the Frankfort plane¶

The Frankfort plane is achieved when the orbitale is in the same horizontal plane as the tragion.

v. The back of the heels, buttocks and upper back had to be touching the stadiometer.

¶ The Tragion and Orbitale are in the same horizontal plane and the sliding head board touching the vertex.

vi. Observer A placed one hand on either side of the subjects jawline, as illustrated below in Figure 3.2.

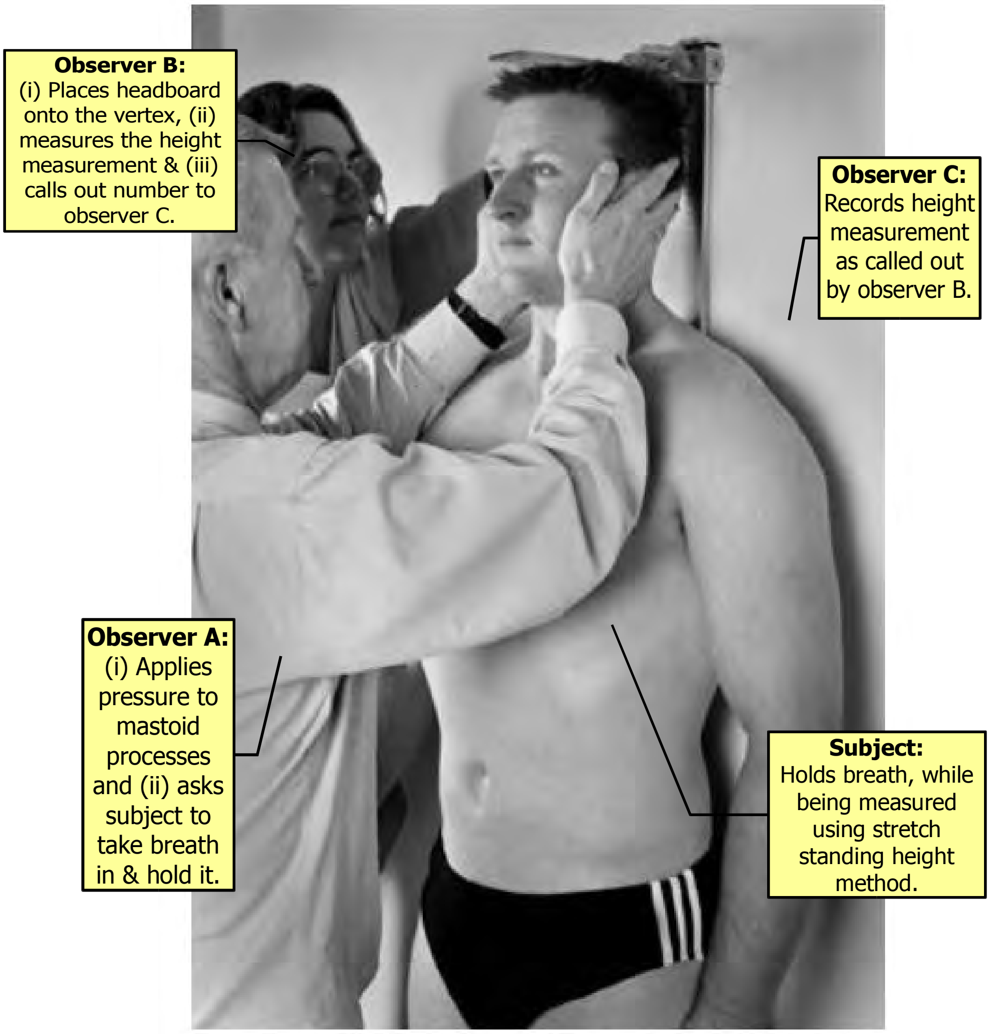

Figure 3.2: The function of observers (A, B & C) when conducting the 'stretch stature' height measurement
Adapted from: Marfell-Jones et al. (2006, p 58)

Observer A positioned the head and applied 'upward pressure' into the mastoid processes. The same observer asked the subject to inhale and hold their breath.

vii. The second observer (observer B) placed the sliding head board onto the vertex of the subject and read the height measurement out loud to the third observer (observer C) who recorded the height to one decimal place on the data recording sheet (see Appendix 1). When reading the measurement, observer B called out each number one at a time. For example, 186.2 centimetres (cm) would be called out as one, eight, six, point, two, etc.

viii. The height of each subject was taken three times and recorded to the nearest 0.1 cm. The mean of the two closest values was captured as the subject's height.

3.6.4 Arm-associated height estimation measurements

Arm-associated height estimation methods were measured in all subjects. These included (i) total armspan (TAS); (ii) half-armspan (HAS); and (iii) demi-span (DS), as illustrated below in Figure 3.3.

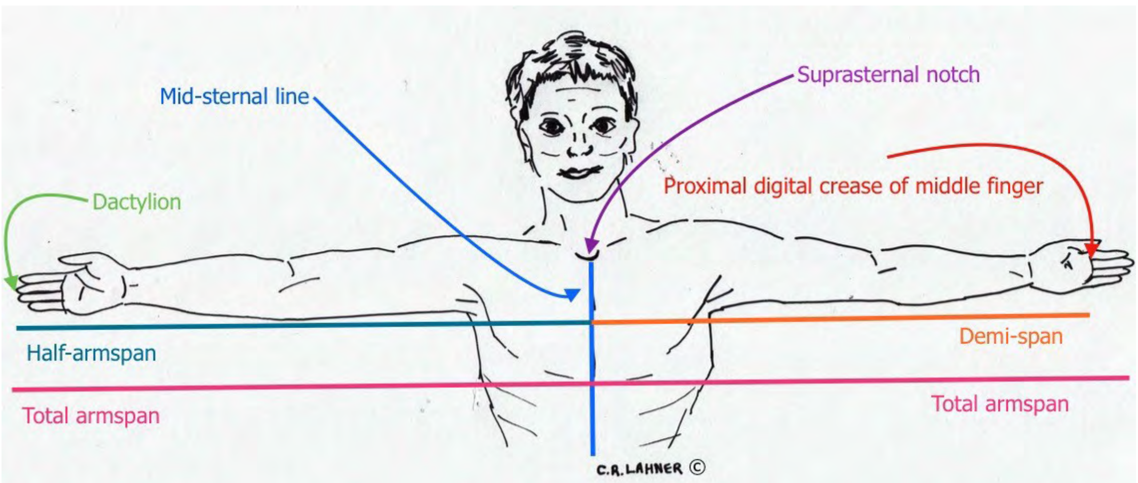

Figure 3.3: Figure illustrating arm-associated height estimation methods, with measurement landmarks

The arm-associated measurements were measured three times to one decimal place. The actual procedure for each measurement is described in the sections that follow.

3.6.5 Procedure for measuring total armspan

The TAS measurements were taken using a stainless steel measuring tape, calibrated in cm (Özaslan et al., 2003). The following method was used:

i. The subject was asked to remove outermost layers of clothing such as a jacket, that could restrict the free movement of the arms.
ii. The subject was then asked to stand against the wall with: (i) the arms outstretched in a horizontal plane to the floor; (ii) palms facing outwards; and (iii) the arms placed at a 90º angle to the subject's body.
iii. The 90º angle was verified using a triangle protractor.
iv. Observer A and observer B stood on either side of the participant, while observer C recorded the measurement, as illustrated below in Figure 3.4.

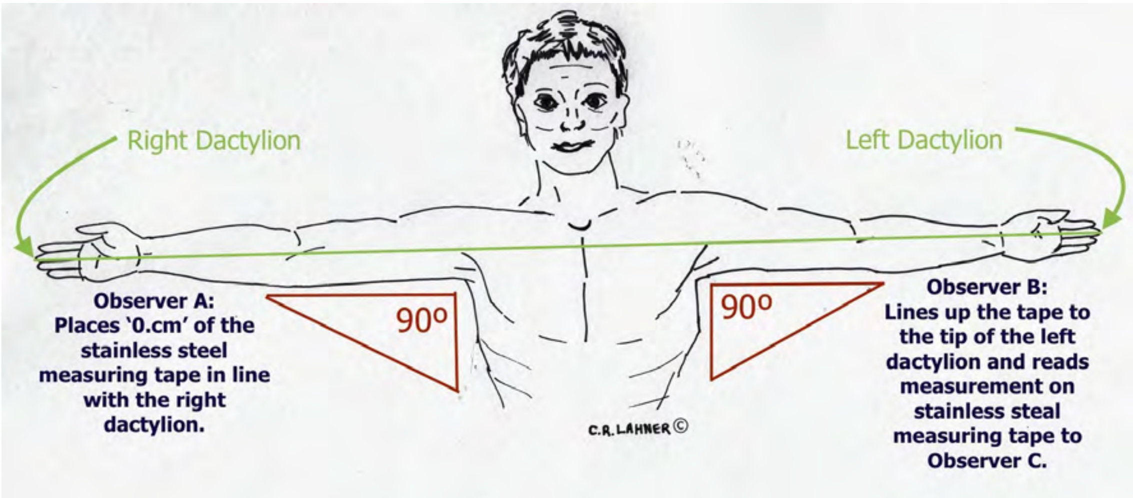

Figure 3.4: Figure illustrating how to measure total armspan

v. A stainless steel metal measuring tape was used to measure TAS from the right dactylion to the left dactylion.
vi. The measurement was taken in three times and recorded to the nearest 0.1 cm. The mean of the two closest values was captured.

3.6.6 Procedure for measuring half-armspan

The HAS measurements were taken using a stainless steel measuring tape, calibrated in cm (Beghetto et al., 2006). The measurements were conducted on the right hand-side of the body in accordance with ISAK guidelines (Marfell-Jones et al., 2006, p 55). The following method was used:

i. The subject was asked to remove outermost layers of clothing such as a jacket, that could restrict the free movement of the arms.
ii. The subject was then asked to stand against the wall with: (i) the right arm outstretched in a horizontal plane to the floor; (ii) the palm facing outwards; and (iii) the arm placed at a 90º angle to the subject's body.
iii. The 90º angle was verified using a triangle protractor.
iv. Observer A stood at the suprasternal notch while observer B stood on right side of the subject. Observer C recorded the measurement, as illustrated below in Figure 3.5.

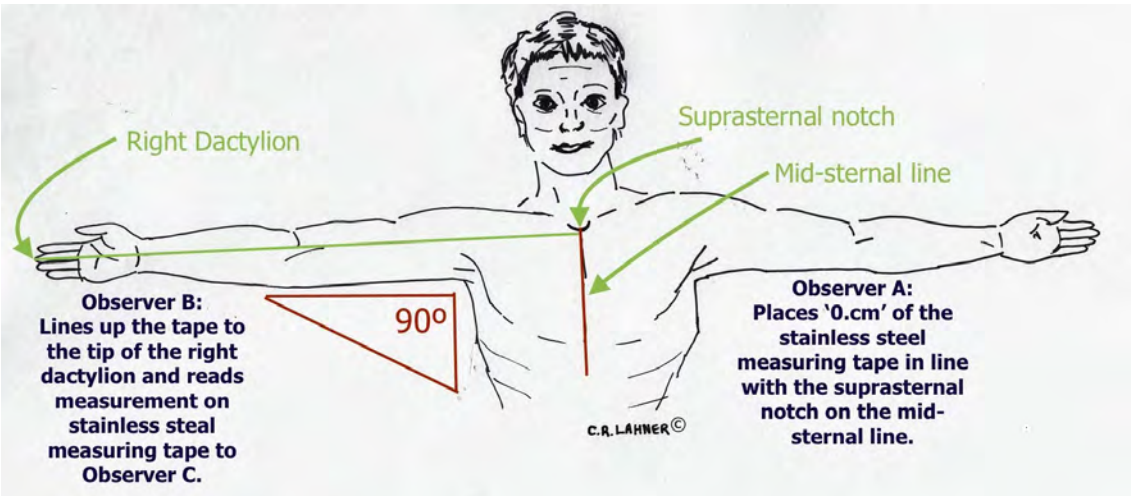

Figure 3.5: Figure illustrating how to measure half-armspan

v. A stainless steel metal measuring tape was used to measure HAS from the suprasternal notch to the right dactylion.
vi. The measurement was taken in three times and recorded to the nearest 0.1

cm. The mean of the two closest values was captured.

3.6.7 Procedure for measuring demi-span

The DS measurements were measured from the suprasternal notch to the proximal digital crease (PDC) of the middle finger. For the purpose of this study, DS was calculated by measuring the Phalanx distance, as illustrated below in Figure 3.6.

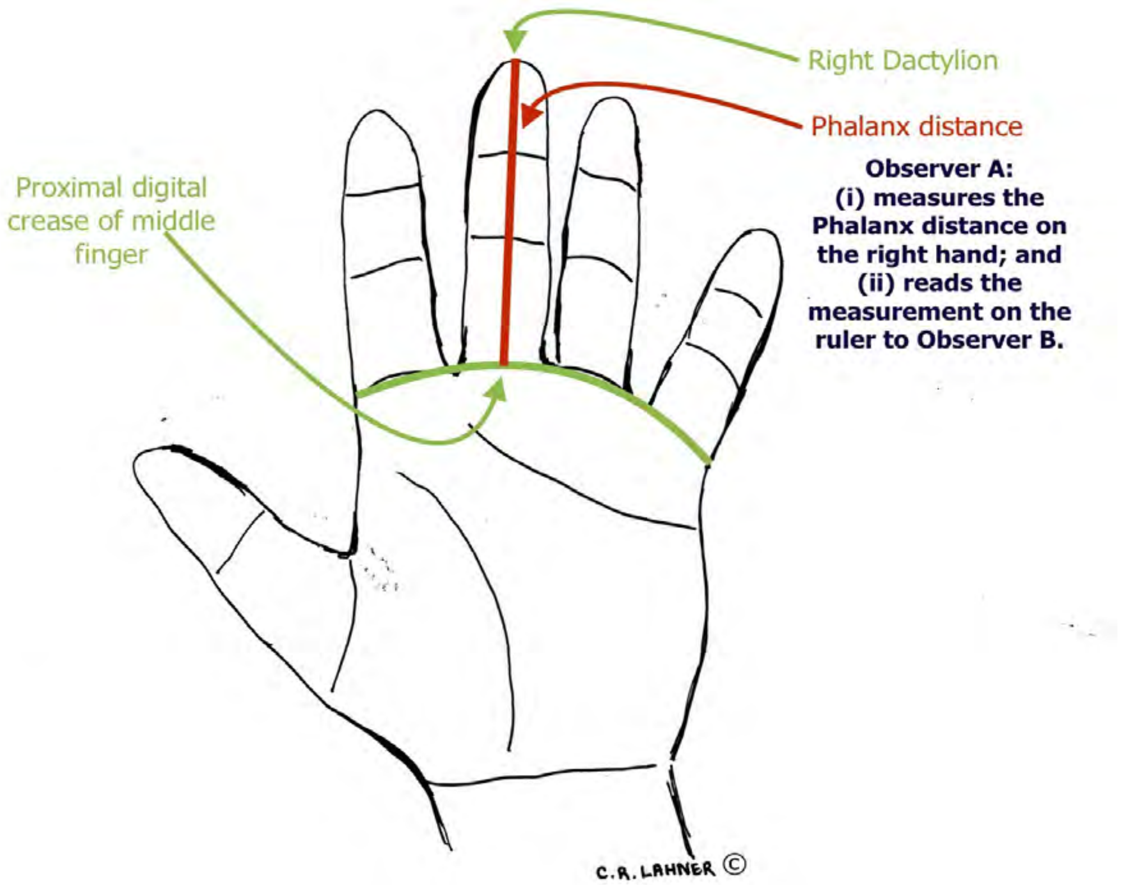

Figure 3.6: Figure illustrating the alternative method to measure demi-span, with anatomical landmarks

Phalanx distance is measured from the right dactylion to the PDC of the middle finger. This measurement is then subtracted from the HAS measurement. A ruler, calibrated in cm, was used to measure the Phalanx distance. The measurements were conducted on the right hand-side of the body in accordance with ISAK guidelines (Marfell-Jones et al., 2006, p55). The original method for measuring DS, is illustrated below in Figure 3.7.

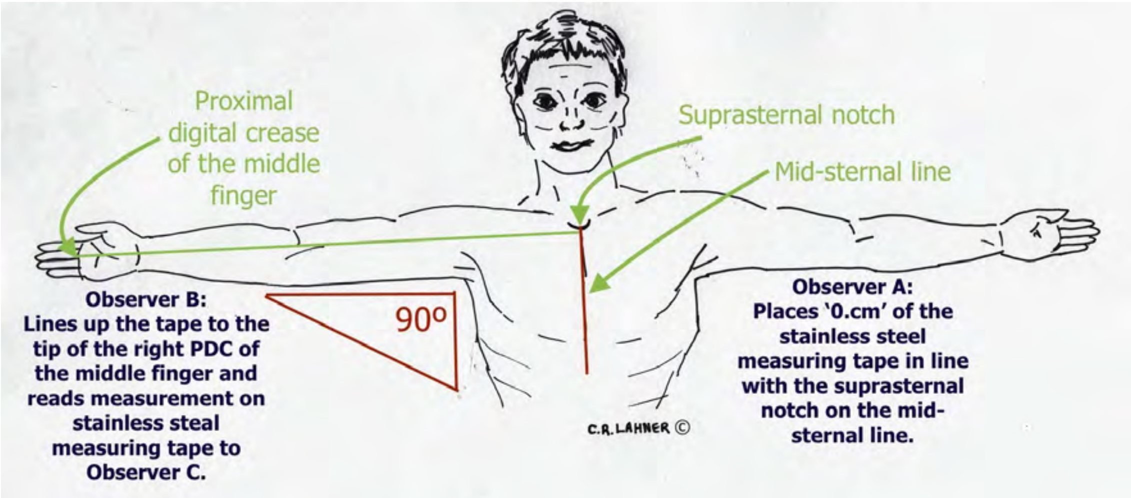

Figure 3.7: Figure illustrating how to measure demi-span measurement, using the original method

Original method for measuring DS included the following steps:

i. The subject was asked to open their right hand and extend the fingers outwards.
ii. Observer A measured from the right PDC to the right dactylion, as is illustrated in Figure 3.6. Observer B recorded the measurement.
iii. The measurement was taken three times and recorded to the nearest 0.1 cm. The mean of the two closest values was captured.

3.6.8 The joint motion important for measurement of arm-associated anthropometry

The position of the hand, wrist and arm are vital for the accurate measurement of arm-associated measurements. For the purpose of this study, guidelines were designed to determine whether the measurements were being measured accurately. Hence, the following guidelines were adhered to:

i. Ensured that the wrist was in a neutral position, as illustrated below in Figure 3.8.

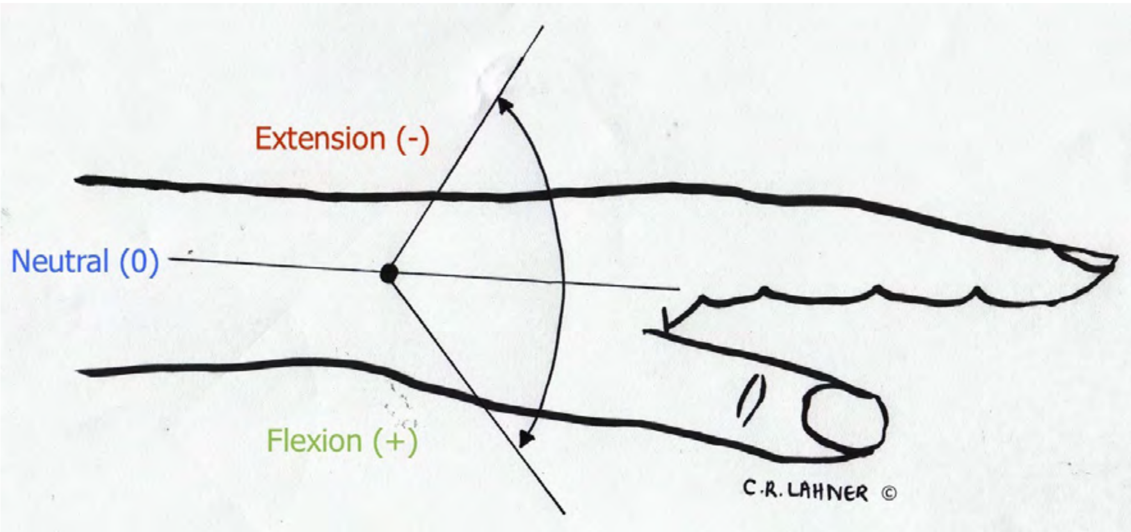

Figure 3.8: Figure illustrating showing the wrist in a neutral position

The subject should avoid extension and flexion movements in the wrist. Extension refers to negative angle movements while flexion refers to positive angle movements.

ii. Ensured that the wrist was in a neutral position, as illustrated in Figure 3.9.

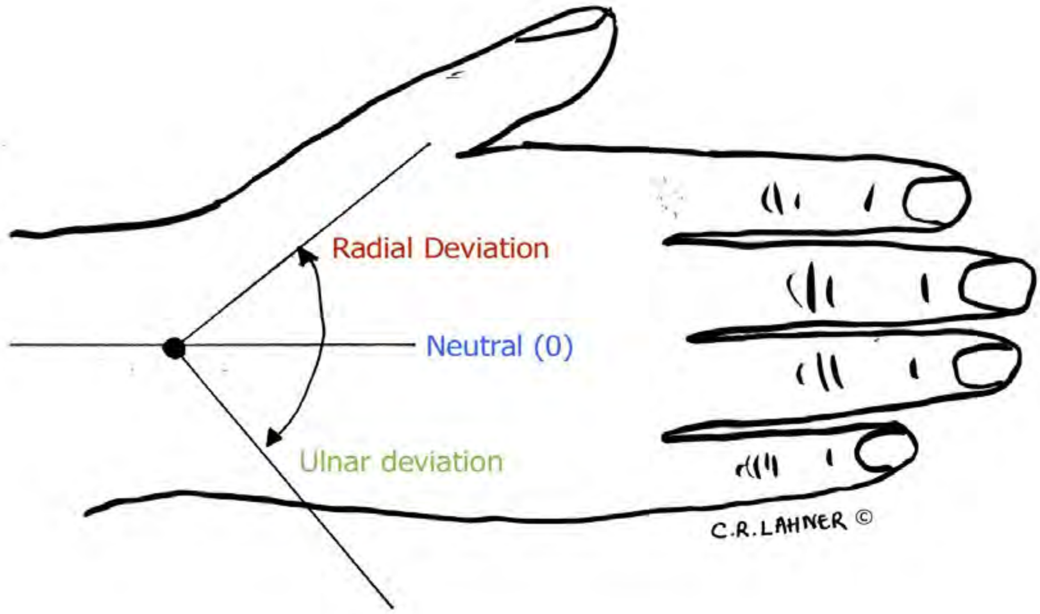

Figure 3.9: Figure illustrating the wrist in a neutral position

The subject should avoid radial deviation and ulnar deviation movements in the wrist.

iii. Ensured that when measurements are being taken that the arm is extended at a 90º angle to the body, with elbows straightened and not bent.
iv. The subject was asked to place their fingers together (small, ring, middle, and index fingers together) with their thumb pointing upwards, as is illustrated in in Figure 3.9 (see above).

3.6.9 Equations

The measurements obtained from data collection were then entered into two equations namely, the DSE (Bassey, 1986) and the World Health Organisation (WHO) equation (WHO, 1999).

The equations were then applied accordingly and values were calculated to one decimal place:

i. The demi-span equations:
   - Females: Height (cm) = [1.35 x demi-span (cm) + 60.1]
   - Males: Height (cm) = [1.40 x demi-span (cm) + 57.8]
ii. The WHO equation:
   - Height = [0.73 × (2 × half-armspan) + 0.43]

3.7 Fieldworker recruitment and training

Twelve observers (fieldworkers) were recruited on a volunteer basis, provided that they were dietetic- or human nutrition students studying Dietetics or Human Nutrition at UKZN and were willing to undergo training. Prior to data collection taking place, observers were trained by the researcher on how to conduct the anthropometric measurements according to ISAK guidelines. Training of the fieldworkers was vital for the collection of accurate data (Welman & Kruger, 1999, p 95). Fieldworkers were given a handout (see Appendix 2) containing instructions regarding the study objectives and methods. They were given the opportunity to practice the anthropometric measurements on each other in order to perfect their technique prior to data collection. Any problems with their technique or misunderstandings regarding the content were clarified.

The objectives of the training session included the gaining of an understanding regarding the following:

i. The importance of the study in the context of dietetics and human nutrition;
ii. The qualities of a good observer (fieldworker);
iii. How to measure accurate measurements according to ISAK guidelines; as well as
iv. Gaining experience in measuring height; and
v. Clarifying any misunderstandings in content of the data collection methods employed.

3.8 Pilot study

Piloting of the study was conducted prior to the commencement of data collection on the Pietermaritzburg campus of UKZN where three trained fieldworkers (postgraduate dietetic students) compared the accuracy of standing height (SH) to the calculation of true height using arm-associated height measurements such as, TAS, HAS, DS on 5.8% (n=52) of the total study sample (N=900) on Black (n=26) and White students (n=26) of both genders (n=13), respectively. The data of these subjects were not included in the final study sample (N=900).

The aim of this pilot study was to identify any problems that may occur during the data collection process (Nelson & Margetts, 1997, p 45). Hence, during piloting the following problems were identified:

i. The measuring tape was changed from a non-stretch SECA tape to a stainless steel hardware measuring tape. This allowed for the tape to stay rigid, making the measuring procedure easier during the actual data collection process.
ii. Piloting was conducted during the winter months of the previous year where it was noted that subjects were hesitant to remove outer layers of clothing before anthropometric measurements could be conducted. Therefore, the current study was conducted during late summer (February – March).

3.9 Statistical analysis

A spreadsheet was created using the Statistical Package for Social Sciences (SPSS) computer package version 21 (SPSS, Chicago, USA) in which data was captured and subsequently analysed. For the purpose of this study, continuous variables included: (i) SS (dependent); (ii) TAS; (iii) HAS; (iv) HAS x2; (v) DS; (vi) DSE; (vii) WHO equation; and (viii) WHO-adjusted equation; as well as the inclusion of categorization by gender and race, as presented in Table 3.2.

Table 3.2: Study objectives with corresponding variables that were statistically analysed

Objectives	Variables
Arm-associated height estimation methods accurately calculates true height in young South African adults.	SS, TAS, HAS, HAS x2, DS, DSE, WHO equation and WHO-adjusted equations.
Arm-associated height estimation methods accurately calculates true height in different race groups.	SS, TAS, HAS, HAS x2, DS, DSE, WHO equation, WHO-adjusted equations and race groups (Blacks, Whites & Indians).
Arm-associated height estimation methods accurately calculates true height in females of different race groups.	SS, TAS, HAS, HAS x2, DS, DSE, WHO equation, WHO-adjusted equations, race groups (Blacks, Whites & Indians) and females.
Arm-associated height estimation methods accurately calculates true height in males of different race groups.	SS, TAS, HAS, HAS x2, DS, DSE, WHO equation, WHO-adjusted equations, race groups (Blacks, Whites & Indians) and males.

These variables were used in statistical analysis. The statistical tests that were applied included: (i) descriptive statistics, described the study sample characteristics; (ii) chi-square test, investigated the comparison between categorises; (iii) Pearson correlation coefficient, identified the strength of association between variables; (vi) one sample T-test, investigated the comparison between two continuous variables; and (v) independent samples T-test, investigated the comparison between two categories within the same variable.

3.10 Reliability and validity of data

Anthropometric studies commonly involve the measurement of body parts (Ulijaszek & Kerr, 1999). These measurements should be measured using anthropometric methods that are both valid and reliable (Ehrlich, 2007; Ulijaszek & Kerr, 1999). Hence, reliability and validity with regards to the current study's methodology will be discussed in this section.

3.10.1 Reliability

Reliability refers to whether a particular method applied repeatedly to the same object, would yield similar results every time (Babbie, 2015; Katzenellenbogen & Joubert, 2007). However, it does not ensure accuracy or validity (Katzenellenbogen & Joubert, 2007). In the current study, internal reliability was determined by the quality of the anthropometric measurements collected which were dependent on the skills of the trained observers and the use of appropriate equipment that had perfectly fixed stability reliability (Babbie, 2015; Katzenellenbogen & Joubert, 2007; Ulijaszek & Kerr, 1999).

Therefore the following measures were employed to ensure that the data generated by this study were reflective of accurate anthropometric measurements: (i) the researcher was trained on ISAK level one principles and practices, by a level three ISAK accredited Biokineticist; (ii) Dietetic students were used as fieldworkers; (iii) fieldworkers were kept to a minimum of 12 (Geeta et al., 2009); (vi) the fieldworkers were trained on how to accurately measure the height and height estimation measurements according to ISAK guidelines; (v) a pilot study was conducted; (vi) the appropriate measuring equipment was used and was manufactured according to ISAK guidelines (Seca Stadiometer) (Marfell-Jones et al., 2006, p 9); (vii) all anthropometric measurements were repeated three times and the mean value of the two closest values calculated and captured to one decimal place; and (viii) subjects were recruited according to the stipulated inclusion and exclusion criteria, so that the subjects closely reflected the target group, namely young South African adults.

3.10.2 Validity

Validity refers to the extent to which research conclusions are sound, as well as the level to which documented data adequately reflects the actual meaning of the concept under investigation (Babbie, 2015; Katzenellenbogen & Joubert, 2007). Validity in one group does not necessarily mean validity in another, and the data generated by these anthropometric methods need to be interpreted in the context of these limitations (Babbie, 2015). Therefore in this current study, SH and height estimation methods were validated for use in young South African adults of whom were either Black, White or Indian. Assuming that the methods employed to obtain the anthropometric data were reliable and accurate, as discussed above in reliability, SH measurement of the subjects were compared to the estimated height calculated using arm-associated measurements.

Construct, content, and face validity of the anthropometric data was ensured through: (i) the use of appropriate anthropometric equipment; (ii) a pilot study was conducted; and (iii) the fieldworkers were trained according to ISAK guidelines.

Instrumental validity was ensured by using anthropometric equipment manufactured according to ISAK guidelines as well as using trained fieldworkers that were trained on how to measure height measurements according to ISAK guidelines, in order to investigate whether there was a valid correlation between the true height and the estimated height calculated using arm-associated measurements.

3.11 Ethical considerations

Ethics approval was granted by the UKZN Human and Social Sciences Research Ethics Committee (Protocol reference number HSS/0271/013D). Prior to data collection, each subject was requested to read and sign an informed consent form, stating the purpose of the study as well as what participation in the study will entail (see Appendix 3). In addition, participation was voluntary and the subjects were guaranteed confidentiality and anonymity. Data sets were kept anonymous as subjects were only identified by means of a code. Permission to collect data on the respective campuses was obtained from Risk Management Services on the respective UKZN campuses prior to data collection (Appendix 4). Raw data will be stored in a secure location for a minimum of five years.

3.12 Summary

The aim of this study was to assess the accuracy of arm-associated height estimation methods in the calculation of true height compared to SS in young South African adults. The sample was selected according to an inclusion and exclusion criteria. Data was collected through a cross-sectional descriptive survey from a total of 900 UKZN students between the ages of 18 and 24 years.

Fieldworkers were trained on how to measure accurate anthropometric measurements according to ISAK guidelines. Prior to data collection, ethical approval was granted as well as a pilot study was conducted.

Data collection stations were designed for the data collection process, where a minimum of three observers (fieldworkers) were working at any given time, in order to measure and record anthropometric measurements. The anthropometric measurements that were recorded included SS, TAS, HAS and DS. These measurements were then entered into equations to calculate estimated height.

The data collected from this study was statistically analysed using SPSS software. Considerations were made to ensure that the data collected were both valid and reliable. In the next chapter (Chapter 4), the results of the study will be presented.

CHAPTER 4: RESULTS

4.1 Introduction

This chapter presents the results of the study, of which the aim was to determine whether arm-associated height estimation methods accurately estimate true height in young South African adults of various race groups, as well as determine whether there were statistically significant differences between genders and race groups for a particular height estimation method.

4.2 Characteristics of the study sample

The characteristics of the study sample are presented in Table 4.1 below.

Table 4.1: Characteristics of the study sample in terms of race, gender and age (N=900)

Race	Gender	n	Age (years)		
			Minimum value	**Maximum value**	**Mean ±SD**
Black	Male	150	18	24	20.5 ± 1.9
	Female	150	18	24	20.6 ± 1.9
White	Male	150	18	24	20.8 ± 1.7
	Female	150	18	24	20.3 ± 1.6
Indian	Male	150	18	24	19.7 ± 1.6
	Female	150	18	24	19.9 ± 1.6

SD= Standard deviation

The study sample (N=900) consisted of equal numbers of three race groups and both genders: (i) Black (n=300); (ii) White (n=300); and (iii) Indian (n=300). The mean age of the study sample was 20.3 years. The mean age of Blacks and Whites was 20.6 years while the mean age for Indians was 19.8 years.

4.3 Height patterns of the study sample

Within the study sample of young South African adults, differences in height were evident between genders and race groups. These differences are presented in Table 4.2 below.

Table 4.2: Stretch stature categorized by race and gender (N=900)

Race	Gender	n	Minimum SS (cm)	Maximum SS (cm)	Mean SS (cm) ±SD
Black	Male	150	153.0	187.0	170.5 ± 6.6
	Female	150	140.8	173.0	158.7 ± 6.1
White	Male	150	161.1	198.0	179.3 ± 6.7
	Female	150	148.4	189.2	165.9 ± 6.8
Indian	Male	150	158.6	198.8	172.0 ± 6.5
	Female	150	143.6	173.3	159.0 ± 5.9

SS = Stretch stature; cm= SS measured in centimetres; SD= Standard deviation

The White population was the tallest with the highest mean stretch stature (SS) recorded for both the males (179.3 cm) and females (165.9 cm). The Indians were the second tallest race group with the mean value for males and females being 172.0 cm and 159.0 cm respectively. Overall, the Black race group was the shortest, as well as the shortest among males (170.5 cm) and females (158.7 cm).

4.4 Comparison of the relationship between race and gender for stretch stature and various height estimation measurement (H_{01})

SS and all arm-associated estimates thereof were used to calculate true height, as presented in Table 4.3.

<u>Table 4.3:</u> Comparison of the relationship between race, gender and height estimation methods

Race and gender	SS & estimations thereof	p-value¶
Race (Black, White & Indian)	Stretch stature	0.119
	Total arm-span	0.194
	Demi-span	0.751
	Demi-span equation	0.777
	Half-arm span	0.971
	Half-arm span x 2	0.971
	WHO-equation	0.971
Gender	Stretch stature	0.000
	Total arm-span	0.000
	Demi-span	0.000
	Demi-span equation	0.000
	Half-arm span	0.000
	Half-arm span x 2	0.000
	WHO-equation	0.000

¶ Chi square test. Association is significant at the 0.05 level

SS= Stretch Stature

From the above, it is was evident that there was a highly statistically significant association ($p<0.001$) between SS and, estimations thereof with gender but not a significant association with race. The correlations between SS and height estimation methods thereof were compared, as presented in Table 4.4.

Table 4.4: Correlation between stretch stature and height estimation methods thereof

Race, gender & SS	SS & height estimations thereof	r value	p value¶
Stretch Stature	Total arm-span	0.887	0.000
	Demi-span	0.843	0.000
	Demi-span equation	0.851	0.000
	Half-arm span	0.856	0.000
	Half-arm span x 2	0.856	0.000
	WHO-equation	0.856	0.000
	WHO-adjusted equation	0.186	0.000

¶ Pearson's correlation coefficient. Correlation is significant at the 0.01 level (2-tailed)

SS= Stretch Stature

SS was highly statistically significantly correlated ($p<0.001$) with all the arm-associated estimation methods. Total armspan (TAS) ($r=0.887$, $p<0.001$) had the strongest correlation when compared to SS, whereas the World Health Organisation (WHO) equation was the weakest ($r=0.186$, $p<0.001$). These relationships will be further investigated when each height estimation method will be compared to both genders within each race.

4.5 Comparison of height-associated measurements and gender (H_{02})

SS and height estimation methods thereof were compared between genders, and are presented in Table 4.5.

Table 4.5: The difference between gender, irrespective of race, and height estimation method (N=900)

Variable	Gender	n	Mean (cm) ± SD	MD (cm)	p value¶
Stretch stature	Male	450	173.9 ± 7.6	12.7	0.000
	Female	450	161.2 ± 7.1		
Total armspan	Male	450	179.7 ± 8.1	15.3	0.000
	Female	450	164.4 ± 7.7		
Demi-span	Male	450	82.1 ± 4.1	6.7	0.000
	Female	450	75.4 ± 3.7		
Demi-span gender specific equation	Male	450	172.8 ± 5.7	10.9	0.000
	Female	450	161.9 ± 5.0		
Half-armspan	Male	450	90.3 ± 4.3	7.4	0.000
	Female	450	82.9 ± 3.9		
Half-armspan x2	Male	450	180.6 ± 8.6	14.7	0.000
	Female	450	165.9 ± 7.9		
WHO-equation	Male	450	132.3 ± 6.3	10.7	0.000
	Female	450	121.5 ± 5.8		
WHO-adjusted equation	Male	450	169.5 ± 10.2	3.9	0.000
	Female	450	165.6 ± 8.0		

¶ Independent samples t-test. Difference is significant at the 0.05 level

MD = Mean difference; cm= height estimates measured in centimetres; SD= Standard deviation

There was a highly statistically significant difference ($p<0.001$) for all height estimation measurements between males and females, irrespective of race. Across all height estimation measurements, males had higher values than females ($p<0.001$), suggesting that the young South African adult males in the study sample are anatomically larger than the young South African adult females surveyed. Stretch stature and height estimation methods thereof, were compared between genders for the Black subjects, as presented in Table 4.6.

Table 4.6: The difference between gender for the height estimation methods, for the Black race group (n=150)

Variable	Gender	n	Mean (cm) ± SD	MD (cm)	p value¶
Stretch stature	Male	150	170.5 ± 6.6	11.8	0.000
	Female	150	158.7 ± 6.1		
Total armspan	Male	150	177.9 ± 7.7	13.7	0.000
	Female	150	164.2 ± 8.1		
Demi-span	Male	150	81.6 ± 3.6	6.2	0.000
	Female	150	75.4 ± 3.6		
Demi-span gender specific equation	Male	150	172.0 ± 5.1	10.1	0.000
	Female	150	161.9 ± 4.9		
Half-armspan	Male	150	89.7 ± 3.8	6.7	0.000
	Female	150	83.0 ± 3.9		
Half-armspan x2	Male	150	179.4 ± 7.7	13.4	0.000
	Female	150	166.0 ± 7.7		
WHO-equation	Male	150	131.4 ± 5.6	9.8	0.000
	Female	150	121.6 ± 5.7		
WHO-adjusted equation	Male	150	170.5 ± 5.6	4.6	0.000
	Female	150	165.9 ± 5.9		

¶ Independent samples t-test. Difference is significant at the 0.05 level

MD = Mean difference; cm= height estimates measured in centimetres; SD= Standard deviation

Within the Black race group, there was a highly statistically significant difference ($p<0.001$) for all height estimation measurements between males and females. Stretch stature and height estimation measurements thereof, were compared between genders for the White race group, as presented in Table 4.7.

Table 4.7: The difference between genders for the height estimation methods, for the White race group (n=150)

Variable	Gender	n	Mean (cm) ± SD	MD (cm)	p value¶
Stretch stature	Male	150	179.3 ± 6.7	13.4	0.000
	Female	150	165.9 ± 6.7		
Total armspan	Male	150	182.0 ± 8.0	15.9	0.000
	Female	150	166.0 ± 7.7		
Demi-span	Male	150	83.2 ± 4.1	7.0	0.000
	Female	150	76.2 ± 3.8		
Demi-span gender-specific equation	Male	150	174.3 ± 5.8	11.3	0.000
	Female	150	163.0 ± 5.2		
Half-armspan	Male	150	91.4 ± 4.3	7.7	0.000
	Female	150	83.8 ± 4.1		
Half-armspan x2	Male	150	182.9 ± 8.6	15.3	0.000
	Female	150	167.5 ± 8.1		
WHO-equation	Male	150	133.9 ± 6.3	11.2	0.000
	Female	150	122.7 ± 5.9		
WHO-adjusted equation	Male	150	158.7 ± 5.7	-13.3	0.000
	Female	150	172.0 ± 6.6		

¶ Difference is significant at the 0.05 level

MD = Mean difference; cm=height estimates measured in centimetres; SD= Standard deviation

Within the White race group, there was a highly statistically significant difference ($p<0.001$) for all height estimation methods between males and females. Stretch stature and height estimation methods thereof, were compared between genders for the Indian race group, as presented in Table 4.8.

Table 4.8: The difference between genders for the height estimation methods, for the Indian race group (n=150)

Variable	Gender	n	Mean (cm) ± SD	MD (cm)	p value¶
Stretch stature	Male	150	172.0 ± 6.5	12.9	0.000
	Female	150	159.0 ± 5.9		
Total armspan	Male	150	179.3 ± 8.2	16.3	0.000
	Female	150	163.1 ± 7.1		
Demi-span	Male	150	81.6 ± 4.2	7.0	0.000
	Female	150	74.6 ± 3.5		
Demi-span gender-specific equation	Male	150	172.0 ± 5.9	11.2	0.000
	Female	150	160.8 ± 4.7		
Half-armspan	Male	150	89.8 ± 4.5	7.7	0.000
	Female	150	82.1 ± 3.7		
Half-armspan x2	Male	150	179.6 ± 9.0	15.4	0.000
	Female	150	164.2 ± 7.4		
WHO-equation	Male	150	131.5 ± 6.6	11.2	0.000
	Female	150	120.3 ± 5.4		
WHO-adjusted equation	Male	150	179.3 ± 6.3	20.2	0.000
	Female	150	159.0 ± 5.4		

¶ Difference is significant at the 0.05 level

MD = Mean difference; cm= height estimates measured in centimetres; SD= Standard deviation

Within the Indian race group, there was a highly statistically significant difference ($p<0.001$) for all height estimation methods between males and females.

4.6 Comparison of height estimation methods and race, irrespective of gender (H_{03})

The three race groups were compared against SS and arm-associated height estimation methods that were used to calculate true height, irrespective of gender. The difference between Black and White subjects was compared for height estimation methods, irrespective of gender, as presented in Table 4.9.

Table 4.9: The difference between Black and White subjects for height estimation methods, irrespective of gender (n=600)

Variable	Race	n	Mean (cm) ± SD	MD (cm)	p value¶
Stretch stature	Black	300	164.6 ± 8.7	-7.9	0.000
	White	300	172.6 ± 9.5		
Total armspan	Black	300	171.0 ± 10.5	-2.9	0.001
	White	300	174.0 ± 11.2		
Demi-span	Black	300	78.5 ± 4.7	-1.2	0.004
	White	300	79.7 ± 5.3		
Demi-span gender-specific equation	Black	300	167.0 ± 7.1	-1.6	0.007
	White	300	168.6 ± 7.9		
Half-armspan	Black	300	86.3 ± 5.1	-1.2	0.005
	White	300	87.6 ± 5.7		
Half-armspan x2	Black	300	172.7 ± 10.2	-2.5	0.005
	White	300	175.2 ± 11.3		
WHO-equation	Black	300	126.5 ± 7.5	-1.8	0.005
	White	300	128.3 ± 8.3		
WHO-adjusted equation	Black	300	168.2 ± 6.2	2.8	0.000
	White	300	165.4 ± 9.0		

¶ Independent samples t-test. Difference is significant at the 0.05 level

MD = Mean difference; cm= height estimates measured in centimetres; SD= Standard deviation

There was a statistically significant difference ($p<0.05$) in height estimation measurements between Blacks and Whites for demi-span (DS), the demi-span equation (DSE), half-armspan (HAS) and half-armspan x2 (HAS x2). However, there was a highly significant difference ($p<0.001$) for SS, TAS, and the WHO-adjusted equation. The difference between Black and Indian subjects was compared for height estimation methods, irrespective of gender, as presented in Table 4.10.

Table 4.10: The difference between Black and Indian subjects for height estimation methods, irrespective of gender (n=600)

Variable	Race	n	Mean (cm) ± SD	MD (cm)	p value[¶]
Stretch stature	Black	300	164.6 ± 8.7	-0.9	0.216
	Indian	300	165.5 ± 9.0		
Total armspan	Black	300	171.0 ± 10.5	-0.1	0.878
	Indian	300	171.2 ± 11.2		
Demi-span	Black	300	78.5 ± 4.7	0.4	0.320
	Indian	300	78.1 ± 5.2		
Demi-span gender-specific equation	Black	300	167.0 ± 7.1	0.5	0.367
	Indian	300	166.4 ± 7.7		
Half-armspan	Black	300	86.3 ± 5.1	0.4	0.353
	Indian	300	85.9 ± 5.6		
Half-armspan x2	Black	300	172.7 ± 10.2	0.8	0.353
	Indian	300	171.9 ± 11.3		
WHO-equation	Black	300	126.5 ± 7.5	0.6	0.353
	Indian	300	125.9 ± 8.2		
WHO-adjusted equation	Black	300	168.2 ± 6.2	-0.9	0.213
	Indian	300	169.1 ± 11.7		

¶ Difference is significant at the 0.05 level

MD = Mean difference; cm= height estimates measured in centimetres; SD= Standard deviation

The Indian and Black race groups were compared to determine the difference in height estimation methods. Across all height estimation measurements, there was no statistically significant difference between Blacks and Indians. The difference between Indian and White subjects were compared for height estimation methods, irrespective of gender, as presented in Table 4.11.

Table 4.11: The difference between White and Indian subjects for height estimation methods, irrespective of gender (n=600)

Variable	Race	n	Mean (cm) ± SD	MD (cm)	p value¶
Stretch stature	White	300	172.6 ± 9.5	7.0	0.000
	Indian	300	165.5 ± 9.0		
Total armspan	White	300	174.0 ± 11.2	2.8	0.002
	Indian	300	171.2 ± 11.2		
Demi-span	White	300	79.7 ± 5.3	1.6	0.000
	Indian	300	78.1 ± 5.2		
Demi-span gender-specific equation	White	300	168.6 ± 7.9	2.2	0.001
	Indian	300	166.4 ± 7.7		
Half-armspan	White	300	87.6 ± 5.7	1.6	0.000
	Indian	300	85.9 ± 5.6		
Half-armspan x2	White	300	175.2 ± 11.3	3.3	0.000
	Indian	300	171.9 ± 11.3		
WHO-equation	White	300	128.3 ± 8.3	2.4	0.000
	Indian	300	125.9 ± 8.2		
WHO-adjusted equation	White	300	165.4 ± 9.0	-3.8	0.000
	Indian	300	169.1 ± 11.7		

¶ Difference is significant at the 0.05 level

MD = Mean difference; cm= height estimates measured in centimetres; SD= Standard deviation

When the Indian and White subjects were compared to determine the difference in height estimation methods, there was a highly statistically significant difference ($p<0.001$) across all height estimation measurements, between Whites and Indians.

4.7 Comparison of height estimation methods and race according to gender

The three race groups surveyed, were compared against SS and arm-associated height estimation methods used to calculate true height according to gender.

4.7.1 Comparison of height estimation methods and race for males (H_{04})

The differences between White and Indian males were compared for height estimation methods, as presented below in Table 4.12.

Table 4.12: The difference between White and Indian males for height estimation methods (n=300)

Variable	Race	n	Mean (cm) ± SD	MD (cm)	p value¶
Stretch stature	White	150	179.3 ± 6.7	7.3	0.000
	Indian	150	172.0 ± 6.5		
Total armspan	White	150	182.0 ± 8.0	2.6	0.005
	Indian	150	179.3 ± 8.2		
Demi-span	White	150	83.2 ± 4.1	1.6	0.001
	Indian	150	81.6 ± 4.2		
Demi-span gender-specific equation	White	150	174.3 ± 5.8	2.2	0.001
	Indian	150	172.0 ± 5.9		
Half-armspan	White	150	91.4 ± 4.3	1.6	0.001
	Indian	150	89.8 ± 4.5		
Half-armspan x2	White	150	182.9 ± 8.6	3.3	0.001
	Indian	150	179.6 ± 9.0		
WHO-equation	White	150	133.9 ± 6.3	2.4	0.001
	Indian	150	131.5 ± 6.6		
WHO-adjusted equation	White	150	158.7 ± 5.7	-20.5	0.000
	Indian	150	179.3 ± 6.3		

¶ Independent samples t-test. Difference is significant at the 0.05 level

MD = Mean difference; cm= height estimates measured in centimetres; SD= Standard deviation

When White and Indian males were compared, highly statistically significant differences ($p<0.001$) were identified across all height estimation measurements, except for TAS where the outcome was a significant difference ($p<0.05$). The difference between Black and Indian males was compared for height estimation methods, as presented in Table 4.13.

<u>Table 4.13:</u> The difference between Black and Indian males for height estimation methods (n=300)

Variable	Race	n	Mean (cm) ± SD	MD (cm)	p value¶
Stretch stature	Black	150	170.5 ± 6.6	-1.5	0.05
	Indian	150	172.0 ± 6.5		
Total armspan	Black	150	177.9 ± 7.7	-1.4	0.126
	Indian	150	179.3 ± 8.2		
Demi-span	Black	150	81.6 ± 3.6	-0.0	0.994
	Indian	150	81.6 ± 4.2		
Demi-span gender-specific equation	Black	150	172.0 ± 5.0	-0.0	0.994
	Indian	150	172.0 ± 5.9		
Half-armspan	Black	150	89.7 ± 3.8	-0.1	0.852
	Indian	150	89.8 ± 4.5		
Half-armspan x2	Black	150	179.4 ± 7.7	-0.2	0.852
	Indian	150	179.6 ± 9.0		
WHO-equation	Black	150	131.4 ± 5.6	-0.1	0.852
	Indian	150	131.5 ± 6.6		
WHO-adjusted equation	Black	150	170.5 ± 5.6	-8.7	0.000
	Indian	150	179.3 ± 6.3		

¶ Independent samples t-test. Difference is significant at the 0.05 level

MD = Mean difference; cm= height estimates measured in centimetres; SD= Standard deviation

When the Black and Indian male subjects were compared, the only statistically significant differences were identified between SS ($p<0.05$) and the WHO-adjusted equation ($p<0.001$). However, there were no statistically significant differences between TAS, DS, DSE, HAS and HAS x2. The difference between Black and White males was compared for height estimation methods, as presented in Table 4.14.

Table 4.14: The difference between Black and White males for height estimation methods (n=300)

Variable	Race	n	Mean (cm) ± SD	MD (cm)	p value¶
Stretch stature	Black	150	170.5 ± 6.6	-8.7	0.000
	White	150	179.3 ± 6.7		
Total armspan	Black	150	177.9 ± 7.7	-4.0	0.000
	White	150	182.0 ± 8.0		
Demi-span	Black	150	81.6 ± 3.6	-1.6	0.000
	White	150	83.2 ± 4.1		
Demi-span gender-specific equation	Black	150	172.0 ± 5.1	-2.2	0.000
	White	150	174.3 ± 5.8		
Half-armspan	Black	150	89.7 ± 3.8	-1.7	0.000
	White	150	91.4 ± 4.3		
Half-armspanx2	Black	150	179.4 ± 7.7	-3.5	0.000
	White	150	182.9 ± 8.6		
WHO-equation	Black	150	131.4 ± 5.6	-2.5	0.000
	White	150	133.9 ± 6.3		
WHO-adjusted equation	Black	150	170.5 ± 5.6	11.8	0.000
	White	150	158.7 ± 5.7		

¶ Independent samples t-test. Difference is significant at the 0.05 level

MD = Mean difference; cm= height estimates measured in centimetres; SD= Standard deviation

When comparing Black and White males, highly statistically significant differences ($p<0.001$) were identified across all height estimation measurements.

4.7.2 Comparison of height estimation methods and race for females (H_{05})

The difference between White and Indian females was compared for height estimation methods, as presented in Table 4.15.

Table 4.15: The difference between White and Indian females for height estimation methods (n=300)

Variable	Race	n	Mean (cm) ± SD	MD (cm)	p value¶
Stretch stature	White	150	165.9 ± 6.7	6.8	0.000
	Indian	150	159.0 ± 5.9		
Total armspan	White	150	166.0 ± 7.7	3.0	0.001
	Indian	150	163.1 ± 7.1		
Demi-span	White	150	76.2 ± 3.8	1.6	0.000
	Indian	150	74.6 ± 3.5		
Demi-span gender-specific equation	White	150	163.0 ± 5.1	2.1	0.000
	Indian	150	160.8 ± 4.7		
Half-armspan	White	150	83.7 ± 4.1	1.7	0.000
	Indian	150	82.1 ± 3.7		
Half-armspan x2	White	150	167.5 ± 8.1	3.3	0.000
	Indian	150	164.2 ± 7.4		
WHO-equation	White	150	122.7 ± 5.9	2.4	0.000
	Indian	150	120.3 ± 5.4		
WHO-adjusted equation	White	150	172.0 ± 6.6	13.0	0.000
	Indian	150	159.0 ± 5.4		

¶ Independent samples t-test. Difference is significant at the 0.05 level.

MD = Mean difference; cm= height estimates measured in centimetres; SD= Standard deviation

When Indian and White females were compared, there was a highly statistically significant difference ($p<0.001$) for all height estimation measurements. The difference between Black and Indian females was compared for height estimation methods, as presented in Table 4.16.

Table 4.16: The difference between Black and Indian females for height estimation methods (n=300)

Variable	Race	n	Mean (cm) ± SD	MD (cm)	P value¶
Stretch stature	Black	150	158.7 ± 6.1	-0.3	0.663
	Indian	150	159.0 ± 5.9		
Total armspan	Black	150	164.2 ± 8.1	1.1	0.198
	Indian	150	163.1 ± 7.1		
Demi-span	Black	150	75.4 ± 3.6	0.8	0.048
	Indian	150	74.6 ± 3.5		
Demi-span gender-specific equation	Black	150	161.9 ± 4.9	1.1	0.048
	Indian	150	160.8 ± 4.7		
Half-armspan	Black	150	83.0 ± 3.9	0.9	0.039
	Indian	150	82.1 ± 3.7		
Half-armspanx2	Black	150	166.0 ± 7.7	1.8	0.039
	Indian	150	164.2 ± 7.4		
WHO-equation	Black	150	121.6 ± 5.6	1.3	0.039
	Indian	150	120.3 ± 5.4		
WHO-adjusted equation	Black	150	165.9 ± 5.9	6.8	0.000
	Indian	150	159.0 ± 5.4		

¶ Independent samples t-test. Difference is significant at the 0.05 level

MD = Mean difference; cm= height estimates measured in centimetres; SD= Standard deviation

When Black and Indian females were compared, there were statistically significant differences ($p<0.05$) between DS, DSE, HAS, HAS x2, WHO equation and WHO-adjusted equation ($p<0.001$). There were no statistically significant differences between TAS and SS. The difference between Black and White females was compared for height estimation methods, as presented in Table 4.17.

Table 4.17: The difference between Black and White females for height estimation methods (n=300)

Variable	Race	n	Mean (cm) ± SD	MD (cm)	p value¶
Stretch stature	Black	150	158.7 ± 6.1	-7.1	0.000
	White	150	165.9 ± 6.7		
Total armspan	Black	150	164.2 ± 8.1	-1.8	0.045
	White	150	166.0 ± 7.7		
Demi-span	Black	150	75.4 ± 3.6	-0.8	0.073
	White	150	76.2 ± 3.8		
Demi-span gender-specific equation	Black	150	161.9 ± 4.9	-1.0	0.073
	White	150	163.0 ± 5.1		
Half-armspan	Black	150	83.0 ± 3.9	-0.8	0.098
	White	150	83.8 ± 4.1		
Half-armspanx2	Black	150	166.0 ± 7.7	-1.5	0.098
	White	150	167.5 ± 8.1		
WHO-equation	Black	150	121.6 ± 5.6	-1.1	0.098
	White	150	122.7 ± 5.9		
WHO-adjusted equation	Black	150	165.9 ± 5.9	-6.1	0.000
	White	150	172.0 ± 6.6		

¶ Independent samples t-test. Difference is significant at the 0.05 level

MD = Mean difference; cm= height estimates measured in centimetres; SD= Standard deviation

When comparing Black and White females, highly statistically significant differences ($p<0.001$) were identified for SS and the WHO-adjusted equation. Statistically significant differences ($p<0.05$) were also identified for TAS. However, no statistically significant differences were identified for DS, DSE, HAS and HAS x2.

4.8 The adaptation of the WHO equation to the WHO-adjusted equation

The WHO equation was further scrutinized to determine whether there was a highly statistically significant difference ($p<0.001$) between SS and the estimated height value obtained from the WHO equation. The difference between SS and the WHO equation was compared, as presented in Table 4.18.

Table 4.18: The difference between stretch stature and the WHO equation

Race	Gender	n	Mean (cm) ± SD	MD (cm)	p value¶
Black, White, Indian	Male	450	41.6 ± 5.3	2.0	0.000
	Female	450	39.7 ± 4.5		
Black	Male	150	39.1 ± 3.7	2.0	0.000
	Female	150	37.1 ± 3.3		
White	Male	150	45.3 ± 5.6	2.2	0.000
	Female	150	43.2 ± 4.5		
Indian	Male	150	40.5 ± 4.3	1.7	0.000
	Female	150	38.8 ± 3.3		
Black	Male	150	39.1 ± 3.7	-6.2	0.000
White		150	45.3 ± 5.6		
Black	Female	150	37.1 ± 3.3	-6.0	0.000
White		150	43.2 ± 4.5		
Black	Male	150	39.1 ± 3.7	-1.3	0.004
Indian		150	40.5 ± 4.3		
Black	Female	150	37.1 ± 3.3	-1.6	0.000
Indian		150	38.8 ± 3.3		
White	Male	150	45.3 ± 5.6	4.9	0.000
Indian		150	40.5 ± 4.3		
White	Female	150	43.2 ± 4.5	4.4	0.000
Indian		150	38.8 ± 3.3		

¶ Independent samples t-test (2-tailed). Difference is significant at the 0.01 level.

≠ Stretch stature minus WHO equation

MD = Mean difference; cm= height estimates measured in centimetres; SD= Standard deviation

Across all genders and race groups, there was a highly statistically significant difference ($p<0.001$) between SS and WHO equation, where the WHO equation significantly ($p<0.001$) underestimated height. Based on the differences identified, the the WHO equation was adjusted to develop the WHO-adjusted equations, as seen in Table 4.19.

<u>Table 4.19:</u> WHO-adjusted equations according to race and gender

Race	Gender	Height estimation equations[Ö]
Black	Male	Height (cm) = [0.73 × (2×right half-armspan(cm)) + 0.43) + 39.1246]
	Female	Height (cm) = [0.73 × (2×right half-armspan(cm)) + 0.43) + 37.1299]
White	Male	Height (cm) = [0.73 × (2×right half-armspan(cm)) + 0.43) + 45.3405]
	Female	Height (cm) = [0.73 × (2×right half-armspan(cm)) + 0.43) + 43.1595]
Indian	Male	Height (cm) = [0.73 × (2×right half-armspan(cm)) + 0.43) + 40.4746]
	Female	Height (cm) = [0.73 × (2×right half-armspan(cm)) + 0.43) + 38.7598]

Ö Standing height calculated in centimetres (cm)

The equations were categorized according to Indian, White and Black subjects as well as according to gender. Since the WHO-equation was the least accurate measurement to serve as an estimate of SH, it was replaced with the WHO-adjusted equation in the statistical tests that followed.

4.9 Comparison of arm-associated height estimation methods against stretch stature, in terms of race and gender (H_{06})

Each of the arm-associated height estimation measurements used to calculate true height including TAS, DSE, HAS x2, and WHO-adjusted equation were compared against the gold standard i.e. SS.

4.9.1 Total armspan

Total armspan was compared to SS by determining the mean difference (MD) between the two variables, as presented in Table 4.20.

Table 4.20: The difference between stretch stature and the total armspan#

Race	Gender	n	Mean (cm) ± SD	MD# (cm)	p value¶
Black, White, Indian	Male	450	-5.8 ± 4.9	-2.6	0.000
	Female	450	-3.2 ± 4.9		
Black	Male	150	-7.4 ± 4.2	-4.7	0.000
White		150	-2.7 ± 5.0		
Black	Female	150	-5.4 ± 4.3	-5.3	0.000
White		150	-0.1 ± 5.1		
Black	Male	150	-7.4 ± 4.2	-0.1	0.877
Indian		150	-7.3 ± 3.9		
Black	Female	150	-5.4 ± 4.3	-1.4	0.002
Indian		150	-4.0 ± 3.7		
White	Male	150	-2.7 ± 5.0	4.6	0.000
Indian		150	-7.3 ± 3.9		
White	Female	150	-0.1 ± 5.1	3.9	0.000
Indian		150	-4.0 ± 3.7		

¶ Independent samples t-test (2-tailed). Difference is significant at the 0.01 level.

Stretch stature minus armspan

MD = Mean difference; cm= height estimates measured in centimetres; SD= Standard deviation

It was identified that there were highly statistically significant differences ($p<0.001$) between genders regardless of race. However, when race was taken into consideration, similarities as well as variations were documented. There were highly statistically significant differences for TAS length when White subjects were compared to Blacks ($p<0.001$) and Indians ($p<0.001$) respectively, if categorized according to gender. However, Indian and Black males had similar TAS lengths ($p=0.877$), but significant differences were identified between Black and Indian females ($p=0.002$).

4.9.2 Demi-span gender-specific equation

The DSE was compared to SS by determining the MD between the two variable, as presented in Table 4.21.

Table 4.21: The difference between stretch stature and the demi-span equation§

Race	Gender	n	Mean (cm) ± SD	MD§ (cm)	p value¶
Black, White, Indian	Male	450	1.1 ± 5.4	1.8	0.000
	Female	450	-0.7 ± 4.6		
Black	Male	150	-1.5 ± 4.0	-6.5	0.000
White		150	5.0 ± 5.6		
Black	Female	150	-3.2 ± 3.5	-6.1	0.000
White		150	2.9 ± 4.6		
Black	Male	150	-1.5 ± 4.0	-1.5	0.002
Indian		150	-0.0 ± 4.3		
Black	Female	150	-3.2 ± 3.5	-1.4	0.000
Indian		150	-1.8 ± 3.4		
White	Male	150	5.0 ± 5.6	5.0	0.000
Indian		150	-0.0 ± 4.3		
White	Female	150	2.9 ± 4.6	4.7	0.000
Indian		150	-1.8 ± 3.4		

¶ Independent samples t-test (2-tailed). Difference is significant at the 0.01 level.

§ Stretch stature minus demi-span equation

MD = Mean difference; cm= height estimates measured in centimetres; SD= Standard deviation

Highly statistically significant differences were identified ($p<0.001$) between male and female subjects. However, when race was included, the same statistically significant differences ($p<0.05$) were identified between Black, Indian and White subjects of both genders. Therefore, the DS measurement differed for each race and gender respectively.

4.9.3 Half-armspan x2

HAS x2 was compared to SS by determining the difference between the two variables, as presented in Table 4.22.

Table 4.22: The difference between stretch stature and the half-armspan x2‡

Race	Gender	n	Mean (cm) ± SD	Md‡ (cm)	p value¶
Black, White, Indian	Male	450	-6.7 ± 6.1	-2.0	0.000
	Female	450	-4.7 ± 5.1		
Black	Male	150	-8.9 ± 4.4	-5.3	0.000
White		150	-3.6 ± 6.8		
Black	Female	150	-3.2 ± 3.5	-6.1	0.000
White		150	2.9 ± 4.6		
Black	Male	150	-8.9 ± 4.4	-1.3	0.027
Indian		150	-7.6 ± 5.7		
Black	Female	150	-3.2 ± 3.5	-1.4	0.000
Indian		150	-1.8 ± 3.4		
White	Male	150	5.0 ± 5.6	5.0	0.000
Indian		150	-0.0 ± 4.3		
White	Female	150	2.9 ± 4.6	4.7	0.000
Indian		150	-1.8 ± 3.4		

¶ Independent samples t-test (2-tailed). Difference is significant at the 0.01 level.

‡ Stretch status minus half–armspanx2

MD = Mean difference; cm= height estimates measured in centimetres; SD= Standard deviation

Highly statistically significant differences ($p<0.001$) were identified between gender regardless of race. However, when race was taken into consideration, similar statistically significant differences ($p<0.05$) were identified between Blacks, Indians and Whites for both genders. Therefore the HAS measurement differed for each race and gender respectively.

4.9.4 WHO-adjusted equations

The WHO-adjusted equation was compared to SS by determining the difference between the two variables, as presented in Table 4.23.

<u>Table 4.23:</u> The difference between stretch stature and the WHO-adjusted equation[℧]

Race	Gender	n	Mean (cm) ± SD	MD[℧] (cm)	p value[¶]
Black, White, Indian	Male	450	4.4 ± 13.9	8.8	0.000
	Female	450	-4.4 ± 8.1		
Black	Male	150	0.0 ± 3.7	20.5	0.000
White		150	20.5 ± 8.7		
Black	Female	150	-7.1 ± 8.8	-1.0	0.322
White		150	-6.1 ± 9.0		
Black	Male	150	0.0 ± 3.7	7.3	0.000
Indian		150	7.3 ± 8.5		
Black	Female	150	-7.1 ± 8.8	-7.1	0.000
Indian		150	0.0 ± 3.3		
White	Male	150	20.5 ± 8.7	27.8	0.000
Indian		150	-7.3 ± 8.5		
White	Female	150	-6.1 ± 9.0	-6.1	0.000
Indian		150	0.0 ± 3.3		

¶ Independent samples t-test (2-tailed). Difference is significant at the 0.01 level.

℧ stretch stature minus WHO-adjusted equation

MD = Mean difference; cm= height estimates measured in centimetres; SD= Standard deviation

Highly statistically significant differences (p<0.001) were identified between all race groups for both genders, except between Black and White female subjects (p=0.322). Therefore, the WHO-adjusted equation generated significant variation in height among the majority of race and gender groups surveyed.

4.9.5 Comparison of the differences between each arm-associated height estimation method

Arm-associated height estimation methods used to calculate true height were compared to SS by determining the difference between the two variables, as presented in Table 4.24.

Table 4.24: Differences between the mean height estimation method outcomes in the study sample (N=900)

Pairs of variables	MD (cm)	Correlation*	p value¶
(Stretch stature minus total armspan) versus (stretch stature minus demi-span equation)	-4.7	0.558	0.000
(Stretch stature minus total armspan) versus (stretch stature minus halfarmspan x2)	1.2	0.746	0.000
(Stretch stature minus total armspan) versus (stretch stature minus WHO-adjusted equation)	-4.5	0.156	0.000
(Stretch stature minus halfarmpsan x2) versus (stretch stature minus WHO-adjusted equation)	-5.7	0.192	0.000
(Stretch stature minus demi-span equation) versus (stretch stature minus half-armspan x2)	5.9	0.792	0.000
(Stretch stature minus WHO-adjusted equation) versus (stretch stature minus half-armspan x2)	5.7	0.192	0.000

¶ Paired samples t-test (2 tailed)

*Pearson's Correlation Coefficient (Correlation significant at the 0.01 level)

MD = Mean difference; cm= height estimates measured in centimetres

Highly statistically significant differences ($p<0.001$) were identified between all arm-associated height estimation methods, suggesting that each method had different predictive values for the study sample under investigation (N=900).

4.10 Accuracy of arm-associated height estimation methods for the calculation of true height, in terms of race and gender (H_{07})

The arm-associated height estimation methods used to calculate true height, were assessed to determine whether they were able to make statistically significant accurate predictions for SH. The following methods were tested: (i) TAS; (ii) DSE; (iii) HAS x2; and (iv) the WHO-adjusted equation.

4.10.1 Black males

The arm-associated height estimation methods used to calculate true height were compared to SS by determining the difference between the mean values of the two variables, as presented below in Table 4.25.

Table 4.25: Difference between stretch stature (SS) and the height estimation methods thereof for Black males (n=150)

Variable	MD (cm) ± SD	P value¶	↑ or ↓
Stretch stature minus total armspan	-7.4 ± 4.2	0.000	↑
Stretch stature minus demi-span equation	-1.5 ± 4.0	0.000	↑
Stretch stature minus halfarmspanx2	-8.9 ± 4.4	0.000	↑
Stretch stature minus WHO-adjusted equation	0.0 ± 3.7	1.000	-

¶ One sample t-test (2 tailed) (significant at 0.01 level), ↓= Underestimates SS, ↑ Overestimates SS

MD = Mean difference; cm= height estimates measured in centimetres; SD = Standard deviation

Highly statistically significant differences (p<0.001) were identified for HAS x2 (MD=-8.9), TAS (MD=-7.4) and DSE (MD=-1.5). This suggests that these height estimation methods consistently over-estimated SS in Black males. However, the WHO-adjusted equation (MD=0.0; p=1.0) was the most predictive of SS, followed by DSE.

4.10.2 Black females

The arm-associated height estimation methods used to calculate true height were compared to SS by determining the difference between the mean values of the two variables, as presented in Table 4.26.

Table 4.26: Difference between stretch stature and the height estimation methods thereof amongst Black females (n=150)

Variable	MD (cm) ± SD	P value¶	↑ or ↓
Stretch stature minus Total armspan	-5.4 ± 4.3	0.000	↑
Stretch stature minus demi-span equation	-3.2 ± 3.5	0.000	↑
Stretch stature minus half-armspan x2	-7.3 ± 4.2	0.000	↑
Stretch stature minus WHO-adjusted equation	-7.1 ± 8.8	0.000	↑

¶ One sample t-test (2-tailed). Difference is significant at 0.01 level. ↓= Underestimates SS, ↑ Overestimates SS

MD = Mean difference; cm= height estimates measured in centimetres; SD = Standard deviation

Statistically significant differences (p<0.001) were documented for HAS x2 (MD=-7.3), the WHO-adjusted equation (MD=-7.1), TAS (MD=-5.4), and DSE (MD=-3.2). This suggests that these height estimation methods consistently overestimate SS amongst Black females in the study sample. Therefore, in Black females the DSE was the the most predictive of SH, followed by TAS.

4.10.3 White males

The arm-associated height estimation methods used to calculate true height were compared to SS by determining the difference between the mean values of the two variables, as presented below in Table 4.27.

Table 4.27: Difference between stretch stature and the height estimation methods thereof for White males (n=150)

Variable	MD (cm) ± SD	p value¶	↑ or ↓
Stretch stature minus total armspan	-2.7 ± 5.0	0.000	↑
Stretch stature minus demi-span equation	5.0 ± 5.6	0.000	↓
Stretch stature minus halfarmspanx2	-3.6 ± 6.8	0.000	↑
Stretch stature minus WHO-adjusted equation	20.5 ± 8.7	0.000	↓

¶ One sample t-test (2-tailed). Difference is significant at 0.01 level. ↓= Underestimates SS, ↑ Overestimates SS

MD = Mean difference; cm= height estimates measured in centimetres; SD = Standard deviation

Highly statistically significant differences (p<0.001) were documented for the WHO-adjusted equation (MD=20.5), DSE (MD=5.0), HAS x2 (MD=-3.6), and TAS (MD=-2.7). Therefore, in White males the TAS was the the most predictive of SH, followed by HAS x2.

4.10.4 White females

The arm-associated height estimation methods used to calculate true height were compared to SS by determining the difference between the mean values of the two variables, as presented below in Table 4.28.

Table 4.28: Difference between stretch stature and the height estimation methods thereof for young White females (n=150)

Variable	MD (cm) ± SD	P value¶	↑ or ↓
Stretch stature minus total armspan	-0.1 ± 5.1	0.719	↑
Stretch stature minus demi-span equation	2.9 ± 4.6	0.000	↓
Stretch stature minus halfarmspanx2	-1.6± 5.4	0.000	↑
Stretch stature minus WHO-adjusted equation	-6.1 ± 9.0	0.000	↑

¶ One sample t-test (2-tailed). Difference is significant at 0.01 level. ↓= Underestimates SS, ↑ Overestimates SS
MD = Mean difference; cm= height estimates measured in centimetres; SD = Standard deviation

Highly statistically significant differences ($p<0.001$) were documented for the WHO-adjusted equation (MD=-6.1), DSE (MD=2.9), HAS x2 (MD=-1.6), and TAS (MD=-0.1). This suggests that the DSE consistently underestimates SH, while HAS x2 and TAS consistently over-estimate SS. However, TAS (MD= -0.1; p=0.719) was identified to be the most predictive of SH, followed by HAS x2.

4.10.5 Indian males

The arm-associated height estimation methods used to calculate true height were compared to SS by determining the difference between the mean values of the two variables, as presented in Table 4.29.

Table 4.29: Difference between stretch stature and the height estimation methods thereof for Indian males (n=150)

Variable	MD (cm) ± SD	p value¶	↑ or ↓
Stretch stature minus total armspan	-7.3 ± 3.9	0.000	↑
Stretch stature minus demi-span equation	-0.0 ± 4.3	0.922	↑
Stretch stature minus halfarmspanx2	-7.6 ± 5.7	0.000	↑
Stretch stature minus WHO-adjusted equation	-7.3 ± 8.5	0.000	↑

¶ One sample t-test (2-tailed). Difference is significant at 0.01 level. ↓= Underestimates SS, ↑ Overestimates SS

MD = Mean difference; cm= height estimates measured in centimetres; SD = Standard deviation

Highly statistically significant differences ($p<0.001$) were documented for HAS x2 (MD = -7.6), TAS (MD = -7.3), and the WHO-adjusted equation (MD = -7.3). This suggests that these height estimation methods consistently over-estimated SS amongst young Indian males. However, the DSE (MD= -0.0; p=0.922) was the most predictive of SS. Therefore, in Indian males the DSE was the most predictive estimate of SH, followed by the WHO-adjusted equation.

4.10.6 Indian females

The arm-associated height estimation methods used to calculate true height were compared to SS by determining the difference between the mean values of the two variables, as presented below in Table 4.30.

Table 4.30: Difference between stretch stature and the height estimation methods thereof amongst young Indian females (n=150)

Variable	MD (cm) ± SD	p value¶	↑ or ↓
Stretch stature minus total armspan	-4.0 ± 3.7	0.000	↑
Stretch stature minus demi-span equation	-1.8 ± 3.4	0.000	↑
Stretch stature minus halfarmspanx2	-5.1 ± 4.1	0.000	↑
Stretch stature minus WHO-adjusted equation	0.0 ± 3.3	0.996	↓

¶ One sample t-test (2-tailed). Difference is significant at 0.01 level. ↓= Underestimates SS, ↑ Overestimates SS

MD = Mean difference; cm= height estimates measured in centimetres; SD = Standard deviation

Highly statistically significant differences ($p<0.001$) were identified for HAS x2 (MD = -5.1), TAS (MD= -4.0), and DSE (MD = -1.8). This suggests that these height estimation methods consistently over-estimated SS amongst Indian females. However, the WHO-adjusted equation (MD= 0.0; $p=0.996$) was the most predictive of SS. Therefore, amongst young Indian females the WHO-adjusted equation was the most predictive height estimation method of SH, followed by the DSE.

4.11 Summary

This chapter presented the results of the study, of which the relationship between arm-associated height estimation methods and true height in young South African adults of various race groups and between genders was investigated. Whites were the tallest race group in the study sample, followed by Indians and Blacks. Males had statistically significantly larger height-associated measurements than females, across all race groups. The Whites differed from that of Blacks and Indians for the majority of height-associated estimation measurements, whereas there were similarities between these measurements for Blacks and Indians. The WHO equation was the least accurate method for calculating true height in the study sample and based on the differences identified, the WHO equation was adjusted to formulate the WHO-adjusted equations.

For young Black males, the WHO-adjusted equation was most predictive of true height. Among young Black females, the female DSE was the most predictive of true height. For young White males and females, TAS was the most predictive of true height. While young Indian males, the male DSE was the most predictive of true height. For young Indian females, the WHO-adjusted equation was the most predictive of true height.

The results in this chapter will be discussed in chapter five in accordance with the literature documented in chapter two and the study objectives and hypotheses presented in chapter one.

CHAPTER 5: DISCUSSION

5.1 Introduction

In South Africa, little is known about the relationship between height and arm-associated measurements (Lahner et al., 2015). The purpose of this study was to determine the accuracy of arm-associated height estimation methods (total armspan (TAS), half-armspan x2 (HAS x2), demi-span (DS) gender-specific equations (DSE), and World Health Organization (WHO) equations used for the calculation of true height compared to the stretch stature (SS) in young South African adults. This was a cross-sectional descriptive survey, with a study sample (N=900) made up of equal numbers of Black, White and Indian young South African adults and of both genders.

In this chapter the results are discussed, highlighting the key finding which include: (i) the relationship between SS and arm-associated height estimation methods; (ii) the differences between genders; (iii) the differences between race groups, irrespective of gender; (iv) differences between race groups of the same gender; (v) differences between SS and arm-associated height estimation methods between race groups of both genders; (vi) arm-associated height estimation methods for use in young South African adults; and (vii) the plausible causes for anatomical variation in a multi-racial population.

5.2 Comparison of the relationship between SS and arm-associated height estimation methods thereof

A highly statistically significant association ($p<0.001$) was found between SS and all arm-associated height estimation methods, irrespective of race and gender. This correlation identifies a strong relationship between SS measurement and the height estimates thereof, which further suggests that the height estimation methods investigated in the current study could be used to calculate true height.

As a result, H_{01}, namely that there is no relationship between SS and height estimation methods thereof for young South African adults can be rejected.

5.3 Differences between males and females

Highly statistically significant (p<0.001) relationships and correlations were identified between genders and height estimation measurements, with males having highly statistically significant (p<0.001) larger SS and arm-associated measurements than females. Similar findings were documented by Lahner et al. (2015); Jamir et al. (2013); Banik (2011); Grimberg & Lifshitz (2007); Marais et al. (2007), thereby supporting that males are anatomically larger than females. For example, males were the tallest when compared to females in the same race group namely, White males (179.3 centimetres (cm)) and females (165.9 cm), followed by Indians for both males (172.0 cm) and females (159.0 cm) and then Blacks both males (170.5 cm) and females (158.7 cm).

Moreover, highly statistically significant (p<0.001) differences were identified between males and females within the same race group. Hence, these findings are indicative of the fact that gender-specific height estimation methods should be used when estimating height (Bjelica et al., 2012; Singh et al., 2012; de Lucia et al., 2002; Reeves et al., 1996; Steele & Chenier, 1990).

Consequently, H_{02}, namely that there is no difference between the height-associated measurements of males and females can be rejected.

5.4 Differences between race groups, irrespective of gender

The race groups that were considered for this study included: (i) Blacks; (ii) Whites; and (iii) Indians. Non-significant relationship was identified between height estimation measurements and race. However, significant differences were identified when the study subjects were categorized according to race and gender, of which these findings are supported by several studies (Bjelica et al., 2012; Singh et al., 2012; de Lucia et al., 2002; Reeves et al., 1996; Steele & Chenier, 1990).

Highly statistically significant ($p<0.001$) differences where identified between Blacks (n=450) and Whites (n=450) for all height estimation measurements. Similar findings were documented when comparing Whites (n=450) and Indians (n=450). However, non-significant differences were identified between Blacks (n=450) and Indians (n=450) for all height estimation measurements. Findings suggest that the Whites differed from that of Blacks and Indians in terms of height estimation measurements. Whereas there were similarities between these height estimation measurements for Blacks and Indians. Therefore, it is possible that anatomical similarities exist between Blacks and Indians, irrespective of gender.

Based on the above findings it can be said that Whites are anatomically different in comparison to the other race groups by both SH and arm-associated measurements. However, Indians and Blacks are similar in terms of all arm-associated measurements, especially when comparing males of both races.

Therefore, H_{03}, namely that there is no difference between SS and height estimation methods thereof for young South African adults of different race groups, irrespective of gender can be rejected.

5.5 Differences between race groups of the same gender

Race groups were categorized by gender and comparisons were made between SS and height estimation methods thereof.

5.5.1 Males

White males were highly statistically significantly ($p<0.001$) different for SS and all height estimation measurements thereof compared to Indians and blacks. Therefore, White males had different to SH and arm-associated measurements, compared to Black and Indian males.

As a result, H_{04}, which states that there is no difference between SS and height estimation methods for males of different race groups can be rejected.

However, similarities due exist between Black and Indian males where the only statistically significant differences were identified between SS ($p<0.05$) and the WHO-adjusted equation ($p <0.001$). However, there were no statistically significant differences between TAS, DS, DSE, HAS and HAS x2. Hence, Indian and Black males are anatomically different in terms of the SH measurement but have similar arm-associated measurements.

5.5.2 Females

Highly statistically significant differences ($p<0.001$) were identified for all height estimation measurements between White and Indian females. These findings suggest that White and Indian females were anatomically different with regards to SH measurement as well as arm-associated measurements.

Hence, H_{05}, which proposes that there is no difference between SS and height estimation methods thereof for females of different races can be rejected.

But, similarities were identified between Black and Indian females as there were no statistically significant differences between TAS and SS. Furthermore, when comparing Black and White females no statistically significant differences were identified for DS, DSE, HAS and HAS x2. These findings identify possible anatomical similarities for the SH measurement and TAS measurement between Black and Indian females, as well as anatomical similarities for arm-associated measurements between Black and White females.

5.6 Differences between SS and arm-associated between race groups of both genders

When SS is not viable, height estimation methods could be used (Froehlich-Grobe et al., 2011; Shahar & Pooy, 2003). For the purpose of this study, arm-associated height estimation methods were used to calculate true height and were investigated to determine whether they could be validated for everyday use in young South African adults. The height estimation methods investigated included: (i) HAS x2; (ii) DSE; (iii) WHO equation; and (iv) TAS.

The differences between SS and these arm-associated height estimation methods were able to identify whether the arm-associated height estimation method was able to accurately estimate true height, as well as determine the extent of under- or over-estimation of SH.

5.6.1 Half-armspan x2

Highly statistically significant differences ($p<0.001$) were identified for comparison of HAS x2 and SS for all race groups of both genders, of which these findings were supported by Lahner et al. (2015). Furthermore, HAS x2 overestimated SS in the calculation of true height, for all race groups of both genders. These findings were supported by Lahner et al. (2015). Therefore, it is possible that anatomical variations exist in the HAS measurement for the study subject's race groups and between genders.

5.6.2 Demi-span gender-specific equation

Highly statistically significant differences ($p<0.001$) were identified for comparison of DSE and SS between all race groups of both genders in accordance with the findings by Lahner et al. (2015). Therefore, it is possible that anatomical variations exist in the DS measurement for the study subject's race groups and between genders.

5.6.3 WHO-equation

Highly statistically significant differences ($p<0.001$) were identified for the comparison of WHO-equation and SS between all race groups of both genders, of which these findings substantiated by Lahner et al. (2015). The WHO (1999), recommended that the WHO equation should be used as a universal tool to calculate estimated height. However, in the current study the WHO equation was identified to be the least predictive height estimation method in the calculation of true height as it statistically significantly underestimated height for all race groups of both genders. These findings were confirmed by other studies (Lahner et al., 2015; de Oliveira Siqueira et al., 2012).

5.6.4 Total armspan

Highly statistically significant differences ($p<0.001$) were identified for TAS measurement compared to SS between all race groups of both genders, however, non-significant differences were identified between Indians and Blacks. Therefore, it is possible that anatomical variations exist in the TAS measurement, among the study subject's race groups and between genders. However, Blacks and Indians have similar TAS measurements. Overall, TAS highly statistically significantly ($p<0.001$) overestimated height in all race groups of both genders. These findings were supported by several studies (Lahner et al., 2015; Popovic et al., 2013; Sah et al., 2013; Chawla et al., 2013; Jamir et al., 2013; Bjelica et al., 2012; Singh et al., 2012; Banik 2011; Goon et al., 2011; Hossain et al., 2011; Fatmah, 2009; Zverev & Chisi, 2005; Shahar & Pooy, 2003; de Lucia et al., 2002; Jarzem & Gledhill, 1993; Kwok & Whitelaw, 1991; Steele & Chenier, 1990; Steele & Mattox, 1987).

Based on these above mentioned findings it is therefore evident that, H_{06}, which proposed that there is no difference between SS and height estimation methods thereof between race groups of both genders can be rejected. Importantly, although significant differences due exist, anatomical similarities were also identified between

Blacks and Indians.

5.7 Arm-associated height estimation methods for use in young South African adults

Anthropometric methodology should be validated before it is applied (Singh et al., 2012, Bjelica, 2012; Lucia et al., 2002; Reeves et al., 1996; Steele & Chenier, 1990). Therefore, arm-associated height estimation measurements were investigated, to determine which of the height estimation measurements were accurately predictive of calculating true height for the study sample, which were categorized as: (i) Black males; (ii) Black females; (iii) White males; (iv) White females; (v) Indian males; and (vi) Indian females.

5.7.1 Black males

A non-statistically significant difference was identified for the comparison of WHO-adjusted equation (p=1.00; MD=0.0000) and SS for Black males. Consequently, the WHO-adjusted equation was the most predictive height estimation method for the calculation of true height for the Black male subject, followed by the DSE (p=0.000; MD=-1.5113). Similar findings were documented by Lahner et al. (2015), where the male DSE was accurately predictive of calculating true height for Black males.

5.7.2 Black females

It was found that a highly statistically significant difference documented for the comparison of female DSE (p=0.000; MD= -3.1889) and SS for Black females. Therefore, the female DSE was the most predictive height estimation method for the calculation of true height for the Black female subject, followed by the TAS (p=0.000; MD=-5.4540).

5.7.3 White males

A statistically significant difference exists for the comparison of TAS (p=0.000; MD= -2.7093) and SS for White males. Therefore, TAS was the most predictive height estimation method for the calculation of true height for the Black female subject, followed by the HAS x2 (p=0.000; MD=3.6009).

5.7.4 White females

A non-statistically significant difference identified for the comparison of TAS (p=0.719; MD= -0.1509) and SS for White females. Therefore, the TAS was the most predictive height estimation method for the calculation of true height for the White female subject, followed by the HAS x2 (p=0.000; MD=-1.6405).

5.7.5 Indian males

A non-statistically significant difference was documented for the comparison of male DSE (p=0.922; MD= -0.0346) and SS for Indian males. Therefore, the male DSE was the most predictive height estimation method for the calculation of true height for the Indian male subject, followed by the WHO-adjusted equation (p=0.000; MD=-7.2602).

5.7.6 Indian females

A non-statistical significant difference exists for the comparison of WHO-adjusted equation (p=0.996; MD=-0.0013) and SS for Indian females. Hence, the WHO-adjusted equation was the most predictive height estimation method for the calculation of true height for the Indian female subject, followed by the female DSE (p=0.000; MD=-1.7867).

Therefore, it is possible that SH can be estimated using height estimations methods such as the ones described in this study. Consequently, H_{07}, namely that there is no arm-associated height estimation method predictive of true height for a multi-racial group of young South African adults, of both genders can be rejected.

The importance of these findings will be discussed in correlation with the plausible causes that result in anatomical variation for a multi-racial population such as for South Africans, which will be discussed in the next section.

5.8 The plausible causes for anatomical variations in a multi-racial society

The current study's findings have identified statistically significant differences between races as well as between genders. These anatomical variations in the SH measurement and arm-associated measurements, could be driven by various height determining factors. Thus, these height determining factors will be explained in terms of the maximal height theory as well as by the Vitruvius theory.

5.8.1 The maximal height theory

Adult height is a reflection of a collection of determining height factors unique to each population (Black et al., 2013). This was supported by this study's findings where anthropometric variation was identified in accordance to race and gender. As mentioned by Cole (2002), secular change is the accumulative and repetitive biological changes that may occur within a subject to give rise to an effect, and in this case an increase or decrease in stature as well as variability in arm-associated measurements (Cole, 2002).

The secular trends that have occurred within the South African population is unknown as there is a lack of available data regarding height estimation studies. However, the current study has shed light on the possible height profiles of young South African adults of Black, White and Indian race groups of both genders. The differences or similarities between these height profiles could be due to the exposure of different secular growth conditions, specific to each race group. For the purpose of this study, secular growth conditions refers to the anthropometric evolution occurring within a population which is driven by genetic, nutritional, socio-economic and environmental growth factors, as illustrated in diagram Figure 5.1.

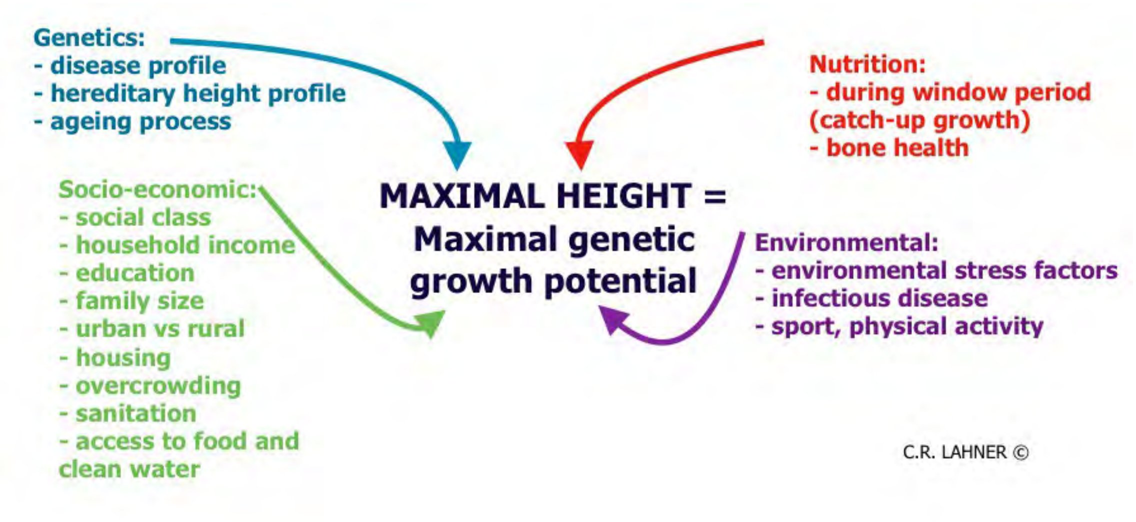

Figure 5.1: Diagram defining the possible factors that determine maximal height

The genetic-related height determining factors is related to the subject's genetic profile, which may influence the height variables genetically expressed in adulthood. The hereditary height profile refers to the subject's maternal and paternal height profiles, which were inherited through their parents and thus potentially has the ability to influence the subjects skeletal size. However, regardless of our adult skeletal size, over time humans are genetically predisposed to height-loss with age and SH will decrease (Sorkin et al., 1999).

The nutrition-related height determining factors refer to the adequate delivery of nutrients during the window period, which support skeletal development especially important for the the prevention of stunting (Black et al., 2013) including: (i) maternal health and nutrition (pre-pregnancy, during pregnancy and during lactation); (ii) exclusive breastfeeding; (iii) duration of breastfeeding; as well as (iv) appropriate and timely complementary feeding (Black et al., 2013).

Based on the literature it would seem that the socio-economic related height determining factors comprises of the following: (i) social class; (ii) household income; (iii) education level; (iv) family size; (v) urban versus rural living conditions; (vi) access to appropriate housing; (vii) overcrowding; (viii) sanitation; and (x) access to food and clean water.

With reference to the literature the environmental-related height determining factors refers to external factors such as: (i) pollution; (ii) environmental stress factors; (iii) modifiable lifestyle behaviors like smoking, infectious illness and diseases; as well as (iv) physical activity which influences the skeletal development.

Hence, the above mentioned factors have the possibility of influencing a subject's physical ability to achieve their maximal genetic height potential, which for the purpose of this study is referred to as maximal height.

The maximal height theory highlights the possible factors that determine adult height, but the Vitruvius theory will discuss the correlation between maximal height and TAS.

5.8.2 The Vitruvius theory

Marcus Vitruvius Pollio, described the body as a circle within a square (Morgan, 1914, pp 72 – 73). Vitruvius was ascribing to the ideal that body dimensions are made up of exactly similar parts around an axis such as the navel (Morgan, 1914, pp 72 – 73). His depiction of body symmetry, led to the understanding that the human height would be equal to the TAS. The current study findings are in accordance with that of several studies which have identified that TAS is not equal to SS and overestimates

SH (Lahner et al., 2015; Popovic et al., 2013; Sah, Kumar & Bhaskar, 2013; Chawla et al., 2013; Jamir et al., 2013; Bjelica et al., 2012; Singh et al., 2012; Banik, 2011; Goon et al., 2011; Hossain et al., 2011; Fatmah, 2009; Zverev & Chisi, 2005; Shahar & Pooy, 2003; de Lucia et al., 2002; Jarzem & Gledhill, 1993; Kwok & Whitelaw, 1991; Steele & Chenier, 1990; Steele & Mattox, 1987).

Nevertheless, this phenomenon can occur within a population (Aggarwal et al., 2000; Schott, 1992). According to the current study findings, the most likely race group for this phenomenon to occur would be for Whites. Although, highly statistically significant differences were identified between SS and TAS in White males (p=0.000, MD= -2.7093), non-significant differences were identified between SS and TAS in White females (p= 0.719, MD= -0.1509). As a result, this anatomical phenomenon is more likely to occur within White females than White males.

Based on these above mentioned findings and for the purpose of this study, the Vitruvius theory that was proposed can be explained as follows: within a subject of a particular population there exists a gender- and race-specific group of unique secular growth conditions. These conditions influence the subject's ability to achieve their maximal height i.e. the height at which they were genetically predisposed to reach. Provided that the optimum secular growth conditions were consistently available during the window period between conception and two years of life.

It is therefore hypothesized that these secular growth height determining factors potentially impact on the leg long bones, especially the tibula and fibula. This hypothesis is illustrated in Figure 5.2.

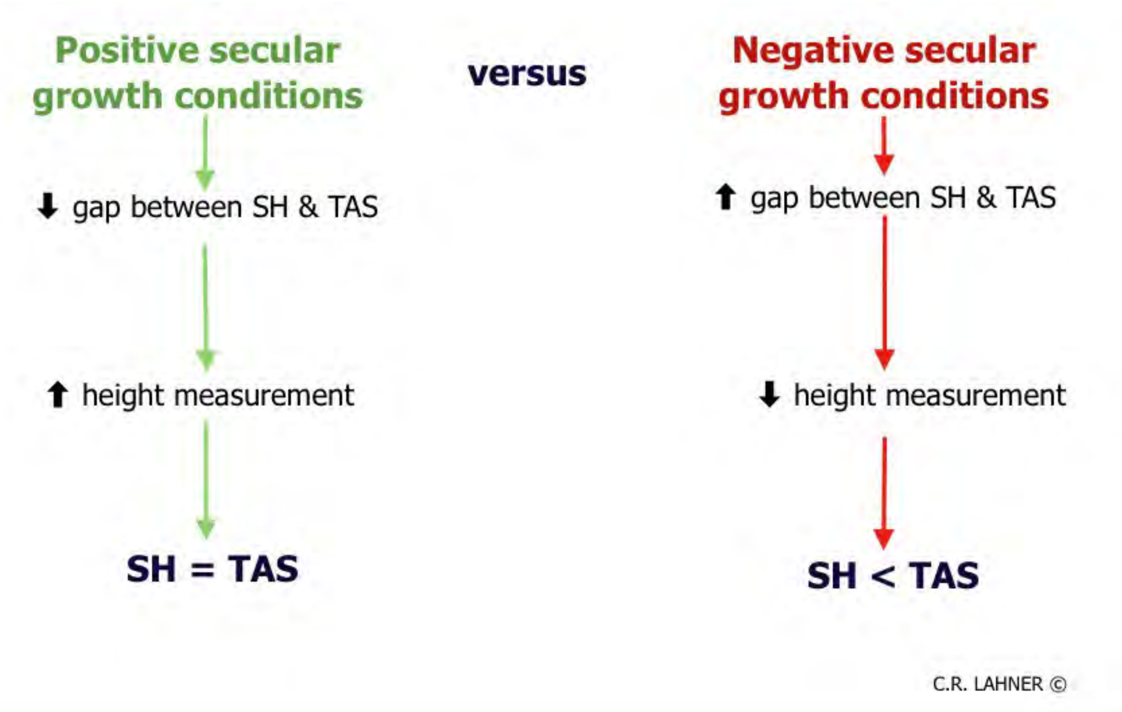

Figure 5.2: Diagram illustrating the effects of positive and negative secular growth conditions on the SH to TAS ratio

Negative secular growth conditions may cause the difference between maximal height and actual skeletal height to differ significantly and as a result cause a potential decrease in long bone length i.e. decrease of height measurement. Whereas, positive secular growth conditions may cause the difference between maximal height and actual skeletal height to decrease and as a result cause a potential increase in long bone length i.e. increase of height measurement.

Since the long bones in the arm are not affected by age-related height-loss, they are potentially not influenced by the other secular growth conditions. Therefore based on this study's findings, it is hypothesized that TAS represents the subjects maximal height or genetically-intended height. Furthermore, when TAS is equal to SS it means that in that particular subjects, have had consistent exposure to positive secular growth conditions during the window period and beyond.

5.9 Summary

Findings from this cross-sectional descriptive survey, were discussed in terms of the relationship of arm-associated height estimation methods and SS with young Blacks, Whites and Indians of both genders. The arm-associated methods that were compared included TAS, HAS x2, DSE and WHO-adjusted equation.

Males and females were statistically significantly different to each other, where males had larger arm-associated measurements and SH measurements.

Findings suggest that the Whites differed from that of Blacks and Indians. However, there were anatomical similarities between these height estimation measurements of Blacks and Indians.

Possible anatomical variations were identified between all race groups and for both genders for the HAS measurement, DS measurement as well as for TAS measurement.

The WHO equation was the least predictive height estimation method for the calculation of true height, and as a result it was adjusted to develop the WHO-adjusted equations.

The plausible causes for anatomical variation in the SH measurement and the arm-associated height estimation methods were described by the maximal height theory as well as by the Vitruvius theory. These theories were formulated to propose that TAS was not equal to SH and that in order for a subject to attain this perfect ratio, otherwise known as maximal height, they would need to be exposed to appropriate genetic, nutritional, environmental and socio-economical factors during the growth window period and beyond.

Findings identified that arm-associated height estimation methods could be used to accurately estimate true height and was specific for each race and gender. WHO-adjusted equation was the most predictive of calculating true height for Black males. Female DSE was the most predictive of calculating true height for Black females. TAS was the most predictive of calculating true height for White males and females. Male DSE was the most predictive of calculating true height for Indian males. WHO-adjusted was the most predictive of calculating true height for Indian females.

Therefore, based on this study's results and discussion, conclusions and recommendations will be discussed in the next chapter.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

The aim of this study was to determine the accuracy of arm-associated height estimation methods used in the calculation of true height (total armspan (TAS); half-armspan x2 (HAS X2); demi-span equations (DSE) and World Health Organization (WHO) equations) compared to the stretch stature (SS), the gold standard of measuring true height, in young South African born Black, White and Indian adults of both genders aged between 18 to 24 years. From this study's findings conclusions and recommendations have been made about the relationship between standing height (SH) and arm-associated measurements.

6.2 Conclusions of the current study's findings

Stretch stature is the gold standard for measuring true height, but when this is not possible, height estimation methods such as those tested in this study can be used to calculate estimated true height. Not one arm-associated height estimation method used in the calculation of true height tested yielded exactly the same results, with statistically significant differences identified between all race and gender groups.

Significant differences exist between genders, where males have larger SS and arm-associated measurements than females. Significant differences exist between race groups, where Whites have statistically significant different SS as well as different arm-associated measurements compared to Blacks and Indians.

Some similarities were identified between genders and race groups, such as those in Black females which have similar arm-associated measurements to White females and Indian females, as well as between Black and Indian males having similar overall arm measurements. Whites were the tallest race group followed by Indians and Blacks, respectively.

The anthropometric variation between genders and race groups was potentially linked to the exposure to variation of secular growth conditions, which relates to the anthropometric evolution that occurs within a population and may be driven by genetic, nutritional, socio-economic and environmental growth factors. These factors may influence a subject's physical ability to achieve their maximal genetic height potential, which is known as maximal height.

The Vitruvius theory was proposed where TAS potentially represents an subject's maximal height, and the ability for them to reach that SH is dependent on exposure to consistent ambient secular growth conditions during the growth window period and beyond.

Arm-associated height estimation methods can be used in the South African young adult population to calculate true height. However, each height estimation method is race- and gender-specific: (i) Black males the WHO-adjusted equation is most predictive, followed by male DSE; (ii) Black females the female DSE is most predictive, followed by TAS; (iii) White males the TAS is most predictive, followed by HAS x2; (iv) White females TAS is most predictive, followed by HAS x2; (v) Indian males the male DSE is most predictive, followed by the WHO-adjusted equation; and (vi) Indian females the WHO-adjusted equation is most predictive, followed female DSE.

Age-related height-loss was not tested in this study, but a possible adjustment factor of 1.25 cm and 0.75 cm for every decade after 30 years of age for females and males respectively could be subtracted from the calculated estimate height value.

Findings highlight possible breakthrough ideas about maximal height in the form of the Vitruvius theory. Furthermore, this study has emphasized the importance for gender- and race-specific equations such as arm-associated height estimation measurements that were used to calculate true height, of which have been investigated for use in Blacks, Whites and Indians of both genders.

It is clear that throughout this study's findings, race and gender related anthropometric differences exist and that not all arm-associated height estimations methods used to calculate true height yield the same height value. In addition each race and gender should be assessed with their individual anthropometric variations in mind. Young South African adults SH could be estimated using the height estimation equations proposed in the current study's findings.

Overall, this study's findings provides a foundation for future height studies of a similar nature, as well as provide a template from which others can replicate. This study provided extensive understanding into the methodology required for accurate height anthropometry.

6.3 Critique of the study

This study was a cross-sectional descriptive survey of Black, White and Indian South African adults (N=900) of both genders aged 18 to 24 years, studying at University of KwaZulu-Natal. Thus based on the above and together with consideration of the current study's findings, various critiques were be made.

6.3.1 Study limitations

For the purpose of this study the following study limitations were identified:

i. A larger sample size should have been included, so that the height estimation methods recommended could be validated for use in young South African adults.
ii. There was a lack of local South African based anthropometric studies which investigated the use of arm-associated height estimation methods for the calculation of true height in young South African adults.

6.3.2 Recommendations for improvement of the study

For the purpose of improving future study designs the following recommendation were identified:

i. A larger sample size should have been used.
ii. Coloureds (mixed ancestry) should have been included in the study sample.
iii. Different age categories should have been included.

6.4 Recommendations for clinical practice

6.4.1 Height estimation equations

Based on the findings of the current study, the recommendations were made for health professionals such as Dieticians, who in clinical practice may require surrogate height estimation methods when SS is not a viable option. These recommendations are summarized below in Table 6.1.

Table 6.1: Summary of study findings describing the height estimation methods that are most predictive of stretch stature, according to race and gender

Race	Gender	Height estimation equations$
Black	Male	Height (cm) = [0.73 × (2× right half-armspan (cm)) + 0.43) + 39.1246]
	Female	Height (cm) = [(1.35 x right demi-span (cm)) + 60.1)]
White	Male	Height (cm) = [total armspan (cm)]
	Female	Height (cm) = [total armspan (cm)]
Indian	Male	Height (cm) = [(1.40 x right demi-span (cm)) + 57.8]
	Female	Height (cm) = [0.73 × (2× right half-armspan (cm)) + 0.43) + 38.7598]

$ Height estimates measured in centimetres (cm)

The height estimation methods that were recommended were both race- and gender-specific: (i) for Black males the WHO-adjusted equation; (ii) for Black females the female DSE; (iii) for White males TAS; (iv) for White females TAS; (v) for Indian males the male DSE; and (vi) for Indian females the WHO-adjusted equation.

6.4.2 The WHO equation

The universal height equation proposed by the World Health Organisation (WHO) called the WHO equation, was the least predictive height estimation method for the study sample. Therefore, it stands to reason that this no longer can be called an universal tool, consequently the equation should be revised by the WHO. Furthermore academic institutions should revisit existing health science curricula, which are still making reference to the use of the WHO equation for the prediction of height.

6.5 Implications for further research

The recommendations made in this section are based on the overall results and conclusions of this study.

6.5.1 Age-related height-loss adjustment factor

The findings of this study identified the relationship between true height and arm-associated measurements in young South African adults, but did not address actual height-loss that occurs with age. It would be recommended that a longitudinal height study be conducted to track the actual height difference that occurs specifically in males and females of different race groups. These measurements can then challenge the age-related height-loss adjustment factors that have been proposed in this study i.e. 1.25 cm for females and 0.75 cm for males for every decade after 30 years of age which could be subtracted from the calculated estimate height value.

6.5.2 Validation of height estimation methods

The current study's methodology should be replicated in a larger sample size of young South African adults i.e. for the validation of using arm-associated height estimation methods in young South African adults.

6.5.3 Longitudinal study

It would be recommended to conduct a longitudinal study within a population, whereby the effect of the secular growth conditions are measured in correlation with its effect on maximal height. Furthermore, the results from the study could either support or reject the Vitruvius theory proposed in this study.

REFERENCES

Aggarwal AN1, Gupta D, Jindal SK (1999). Interpreting spirometric data: impact of substitution of arm span for standing height in adults from North India. **Chest** 115 (2): 557 – 562.

Aggarwal AN, Gupta D, Ezekiel LMK, Jindal SK (2000). Statistical estimation of height from arm span in North Indian subjects. **Indian Journal of Physiology and Pharmacology** 44(3): 329 – 334.

Al-wasfi AAH, Puranik MG (2015). Estimation of height from length of ulna and length of fibula in Indian and Iraqi population. **International Journal of Information Research and Review** 2 (7): 904 – 908.

Babbie E. (2015). **The practice of social research**. Cengage Learning.

Banik SD (2011). Arm span as a proxy measure for height and estimation of nutritional status: A study among Dhimals of Darjeeling in West Bengal India. **Annals of Human Biology** 38(6): 728 – 735.

Bansal AK, Vaghela PC, Lad KS, Mittal P, Kapadiya KI (2014). A study of relation between stature and ulnar length. **International Journal of Research in Medical Sciences** 3 (4): 137 – 139.

Bassey EJ (1986). Demi-span as a measure of skeletal size. **Annals of Human Biology** 13 (5): 499 – 502.

Bassey EJ (1998). Longitudinal changes in selected physical capabilities: muscle strength, flexibility and body size. **Age and Ageing** 27-S3: 12-16.

Beghetto MG, Fink J, Luft VC, de Mello ED (2006). Estimates of body height in adult inpatients. **Clinical Nutrition** 25: 438–443.

Black RE, Victoria CG, Walker SP, Bhutta ZA, Christian P, Onis MD, Ezzati M, Grantham-Mcgregor S, Katz J, Martorell R, Uauy R & the Maternal and Child Nutrition Study Group (2013). Maternal and child undernutrition and overweight in low-income and middle-income countries. **The Lancet** 371: 1 – 25.

Bonomi J (1880). **The proportion of the human figure**, 5th ed. London: Charles

Robertson.

Borkar M (2014). To find height of individual from the length of ulna in western Maharashtrian population. **International Journal of Medical Science and Clinical Inventions** 1 (7): 367 – 370.

Bjelica D, Popović S, Kezunović M, Petković J, Jurak G, Grasgruber P (2012). Body height and its estimation utilising arm span measurements in Montenegrin adults. **Anthropological Notebooks** 18(2): 69-83.

Brown JK, Feng JY, Knapp TR (2002). Is self-reported height or arm span a more accurate alternative measure of height? **Clinical Nursing Research** 11 (4): 417 – 432.

Cereda E, Bertoli S, Battezzati A (2010). Height prediction formula for middle-aged (30-55y) caucasians. **Nutrition** 26: 1075 – 1081.

Chawla M, Rajkumar, Tomar S, Ashoka R (2013). The relationship between arm span and height in adult males of North Indian Punjabi population. **Journal of evolution of medical and dental sciences** 1: 1-9.

Chhabra SK (2008). Using arm span to derive height: Impact of three estimates of height on interpretation of spirometry. **Annals of Thoracic Medicine** 3(3): 94 – 99.

Chumlea WC, Roche AF, Steinbaugh ML (1985). Estimating stature from knee height for persons 60 to 90 years of age. **Journal of American Geriatrics Society** 33 (2): 116 – 120.

Chumlea WMC, Guo SS, Steinbaugh ML (1994). Prediction of stature from knee height for black and white adults and children with application to mobility-impaired or handicapped persons. **Journal of the American Dietetic Association** 94 (12): 1385 – 1391.

Coe TR, Halkes M, Houghton K, Jefferson D (1999). The accuracy of visual estimation of weight and height in pre-operative supine patients. **Anaesthesia** 54(6): 582 – 586.

Cole TJ (2000). Secular trends in growth. **Proceedings of the Nutrition Society** 59: 317 – 324.

Cole TJ (2002). The secular trend in human physical growth: a biological view.

Economics and Human Biology 1: 161- 168.

Dar RA, Rather GM (2014). Research article spatial variation in malnutrition grades using Body Mass Index (BMI)- a comparative study among kashmiri and Gujjar adults of south Kashmir Himalayas, J&K-India. **International of Journal Recent Scientific Research** 5(12): 2260 – 2265.

da Vinici L (1490). Vitruvian man. Gallerie dell'Accademia, Venice.

de Lucia E, Lemma F, Tesfaye F, Demisse T, Ismail S (2002). The use of armspan measurement to assess the nutritional status of adults in four Ethiopian ethnic groups. **European Journal of Clinical Nutrition** 56: 91 – 95.

de Oliveira Siqueira V, de Lima Costa BV, Lopes ACS, dos Santos LC, Lima-Costa MF, Caiaffa WT (2012). Different equations for determining height among the elderly: the Bambui cohort study of aging. **Cadernos de Saúde Pública** 28 (1): 125 – 134.

Duyar I, Pelin C (2010). Estimating body height from ulna length: need of a population-specific formula. **Eurasian Journal of Anthropology** 1 (1): 11 – 17.

Ebite L, Ozoko T, Eweka A, Otuaga P, Oni A, Om'Iniabohs F (2007). Height: Ulna ratio: A method of stature estimation in a rural community in Edo state, Nigeria. **The Internet Journal of Forensic Science** 3 (1): 1 – 4.

Ehrlich R (2007). **Epidemiology: a research manual for South Africa**. Oxford University Press Southern Africa.

Fatmah F (2009). Predictive equations for estimation of stature from knee height, arm span, and sitting height in Indonesian Javanese elderly people. **International Journal of Medicine and Medical Sciences** 1 (10): 456 – 461.

Freitag E, Edgecombe G, Baldwin I, Cottier B, Heland M (2010). Determination of body weight and height measurement for critically ill patients admitted to the intensive care unit: A quality improvement project. **Australian Critical Care** 23: 197 – 207.

Froehlich-Grobe K, Nary DE, Van Sciver A, Lee J, Little TD (2011). Measuring Height without a Stadiometer: Empirical Investigation of Four Height Estimates Among Wheelchair Users. **American Journal of Physical Medicine and Rehabilitation** 90(8): 658-666.

Geeta A, Jamaiyah H, Safiza MN, Khor GL, Kee CC, Ahmad AZ, Suzana S, Rahmah R, Faudzi A (2009). Reliability, technical error of measurements and validity of instruments for nutritional status assessment of adults in Malaysia. **Singapore Medical Journal** 50 (10): 1013 – 1018.

George H (2014). **The elements of sculpture: A viewers guide**. London: Haddon Press.

Golshan M, Amra B, Hoghoghi MA (2003). Is arm span an accurate measure of height to predict pulmonary function parameters?. **Monaldi archives for chest disease** 59 (3): 189 – 192.

Goon DT, Toriola AL, Musa DI, Akusu S (2011). The relationship between arm span and stature in Nigerian adults. **Kinesiology** 43(1): 38-43.

Gray DS, Crider JB, Kelley C, Dickinson LC (1985). Accuracy of Recumbent height measurement. **Journal of Parenteral and Enteral Nutrition** 9 (6): 712 – 715.

Grimberg A & Lifshitz F. **Worrisome growth: Growth, adrenal, sexual, thyroid, calcium, and fluid balance disorders,** Vol 2. 5th ed. New York: Informs Healthcare USA, Inc, 2007:163-194.

Grimes DA, Schulz KF (2002). Descriptive studies: what they can and cannot do. **The Lancet** 359 (9301): 145-149.

Harris JA, Benedict FG (1919). A Biometric Study of the Basal Metabolism in Man. **Washington, DC: Carnegie Institution of Washington** (279).

Hickson M, Frost G (2003). A comparison of three methods for estimating height in the acutely ill elderly population. **Journal of Human Nutrition and Dietetics** 16: 13-20.

Hirani V, Mindell J (2008). A comparison of measured height and demi-span equivalent height in the assessment of body mass index among people aged 65 years and over in England. **Age and Ageing** 37: 311–317.

Hirani V, Tabassum F, Aresu M, Mindell J (2010). Development of New Demi-Span Equations from a Nationally Representative Sample of Adults to Estimate Maximal Adult Height. **The Journal of Nutrition** 140(8):1475 – 1480.

Hossain S, Begum JA, Akhter Z (2011). Measurement of stature from arm span- an anthropometric study on Garo Tribal Bangladeshi females. **Bangladesh Journal of Anatomy** 9(1): 5-9.

Jamir L, Kalaivani M, Nongkynrih B, Misra P, Gupta SK (2013). Relationship between arm span and height among persons in a rural area of Ballabgarh, Haryana. **Indian Journal of Medical Specialities** 4(2): 248 – 253.

Jarzem PF, Gledhill RB (1993). Predicting height from arm measurements. **Journal of Pediatric Orthopaedics** 13(6): 761 – 765.

Jones GE, Beech SJ, Wright C (2011). Estimation of stature from ulna length and demispan in healthy adults (18 – 64 yrs). **Proceedings of the Nutrition Society** 70: 1.

Katzenellenbogen JM, Joubert G (2007). **Data collection and measurement**, in Joubert G, Erlich R, Katzenellenbogen JM, Abdool Karim SS (eds.), Epidemiology: a manual for South Africa, 2nd ed, pp. 106–122, Oxford University Press, Cape Town.

Krishan K, Sharma A (2006). Estimation of stature from dimensions of hands and feet in a North Indian population. **Journal of Forensic and Legal Medicine** 14: 327 – 332.

Kwok T, Whitelaw MN (1991). The use of armspan in nutritional assessment of the elderly. **Journal of the American Geriatrics Society** 39 (5): 492 – 496.

Lahner CR, Kassier SM, Veldman FJ (2015). **The accuracy of arm-associated height estimation methods compared to standing height in Black and White South African born students from the University of KwaZulu-Natal aged 18 – 24 years**. In press article. Public Health Sciences Journal.

Levin KA (2006). Study design III: Cross-sectional studies. **Evidence-based Dentistry** 7: 24-25.

Madden AM, Tsikoura T, Stott DJ (2012). The estimation of body height from ulna length in healthy adults from different ethnic groups. **Journal of Human**

Nutrition and Dietetics 25: 121 – 128.

Mahan LK, Escott-Stump S, Raymond JL (2012). Krause's Food and the Nutrition Care Process, 13th ed. **USA: Saunders**.

Manonai J, Khanacharoen A, Theppisai U, Chottacharoen A (2001). Relationship between height and arm span in women of different age groups. **Journal of Obstetrics and Gynaecology Research** 27(6): 325 – 327.

Marais D, Marais ML, Labadarios D (2007). Use of knee height as a surrogate measure of height in older South Africans. **South African Journal of Clinical Nutrition** 20 (1): 39 – 44.

Marfell-Jones M, Olds T, Stewart A, Carter JL (2006). International Standards for Anthropometric Assessment. Australia: **International Society for the Advancement of Kinanthropometry**.

McEwen IK (2003). Vitruvius: writing the body of architecture. London: MIT press.

Mehta AA, Mehta AA, Gajbhiye VM, Verma S (2015). Estimation of stature from ulna. **International Journal of Anatomy and Research** 3 (2): 1156 – 1158.

Mohanty SP, Babu SS, Nair NS (2001).The use of arm span as a predictor of height: A study of South Indian women. **Journal of Orthopedic Surgery and Research** 9: 19-23.

Mohanty BB, Agrawal D, Mishra K, Samantsinghar P, Chinara PK (2013). Estimation of height of an individual from forearm length on the population of Eastern India. **Journal of Medical and Allied Sciences** 3 (2): 72 – 75.

Mondal MK, Jana TK, Das J, Biswas S (2009). Use of length of ulna for estimation of stature in living adult male in Burdwan district and adjacent areas of West Bengal. **Journal of Anatomical Society of India** 58 (1): 16 – 18.

Morgan MS (1914). **Vitruvius: the ten books on architecture.** London: Oxford University Press.

Nagesh KR, Lovita MA (2011). Tibia, ulna and radius in South Indian population. **Indian Journal of Forensic Medicine and Pathology** 4 (1): 9 – 14.

Nelson M, Margetts BM (1997). **Design Concepts in Nutritional Epidemiology**, 2nd ed. New York: Oxford University Press.

Nahhas RW, Sherwood RJ, Chumlea WC, Towne B, Duren DL (2013). Predicting the timing of maturational spurts in skeletal age. **American Journal of Physical Anthropology** 150: 68 – 75.

Nyati HL (2000). Racial differences in the growth of axial and appendicular skeleton and bone mass in 11 year old South African children. Unpublished Masters thesis, University of Witwatersrand, Johannesburg, Gauteng Province, South Africa.

Nygaard HA (2008). Measuring body mass index (BMI) in nursing home residents: The usefulness of measurement of arm span. **Scandinavian Journal of Primary Health Care** 26: 46 – 49.

Ngoh HJ, Sakinah H, Harsa Amylia MS (2012). Development of demi-span equations for predicting height among the Malaysian elderly. **Malaysian of Journal Nutrition** 18(2): 149 – 159.

Nwosu BU, Lee MM (2008). Evaluation of short and tall stature in children. **American Academy of Family Physicians** 78(5): 597 – 604.

Ofluoglu D, Unlu F, Akyuz G (2008). Relationship between arm span and height in postmenopausal osteoporotic women. **Rheumatology International** 28: 737 – 741.

Özaslan A, İşcan MY, Özaslan İ, Tuğcu H, Koç S (2003). Estimation of stature from parts. **Forensic Science International** 132: 40- 45.

Perissinotto E, Pisent C, Sergi G, Grigoletto F, Enzi G (2002). Anthropometric measurements in the elderly: age and gender differences. **British Journal of Nutrition** 87: 177- 186.

Pieterse S (1997). Anthropometric measurement results. **HelpAge Symposium report** 1: 13 – 18.

Popovic S, Bjelica D, Molnar S, Jasic D, Akpinar S (2013). Body height and its estimation utilizing arm span measurements in Serbian adults. **International Journal of Morphology** 31(1): 271 -279.

Prasad A, Bhagwat B, Porwal S, Joshi DS (2012). Estimation of human stature from length of ulna in Marathwada region of Maharashtra. **International Journal of Biological & Medical Research** 3 (4): 2337 – 2341.

Reeves SL, Varakamin C, Henry CJ (1996). The relationship between arm-span measurement and height with special reference to gender and ethnicity. **European Journal of Clinical Nutrition** 50(6): 398-400.

Relethford JH (2000). Human skin color diversity is highest in sub-Saharan African populations. **Human Biology** 72(5): 773 – 780.

Sah RP, Kumar A, Bhaskar RK (2013). Body height and its estimation utilizing arm span measurements in population of Birgunj Area of Nepal: An Anthropometric study. **Journal of College of Medical Sciences Nepal** 9(4): 9-14.

Sánchez-Garcia S, Garcia-Lopez MX, Juárez-Cedillo T, Cortés-Núňez AR, Reyes-Beaman S (2007). Anthropometric measures and nutritional status in a healthy elderly population. **BioMed Central Public Health** 7 (2): 1-9.

Schott GD (1992). The extent of man from Vitruvius to marfan. **The Lancet** 340: 1518 – 1520.

Shahar S, Pooy NS (2003). Predictive equations for estimation of stature in Malaysian elderly people. **Asia Pacific Journal of Clinical Nutrition** 12 (1): 80- 84.

Sicotte M, Ledoux M, Zunzunegiu M, Aboubacrine SA, Nguyen VK, the ATARAO group (2010). Reliability of anthropometric measures in a longitudinal cohort of patients initiating ART in West Africa. **BioMed Central Medical Research Methodology** 10 (102): 1 – 9.

Singh A, Kumar A, Chavali KH, Harish D (2012). Use of arm-span and foot length fro estimation of height of the person. **Journal of Punjab Academy of Forensic Medicine & Toxicology** 12(2): 87- 91.

Sorkin JD, Muller DC, Andres R (1999). Longitudinal change in height of men and women: Implications for interpretation of body mass index. **American Journal of Epidemiology** 150: 969 – 977.

Steele MF, Chenier TC (1990). Arm-span, height, and age in Black and White women. **Annals of Human Biology** 17(6): 533 – 541.

Steele MF, Mattox JW (1987). Correlation of arm-span and height in young women of two races. **Annals of Human Biology** 14(5): 445-7.

Thummar B, Patel ZK, Patel S, Rathod SP (2011). Measurement of ulnar length for estimation of stature in Gujarat. **National Journal of Integrated Research**

in Medicine 2 (2): 36 – 40.

Ulijaszek SJ, Kerr DA (1999). Anthropometric measurement error and the assessment of nutritional status. **British Journal of Nutrition** 82: 165–177.

UNICEF (2015). Nutrition: Definition of the indicators. Available at: http://www.unicef.org/infobycountry/stats_popup2.html (date accessed 01/04/2015).

Van Wieringen JC (1986). **Secular growth changes**. In: Falkner F, Tanner JM (Eds). Human Growth: A comprehensive treatise, vol 3. Prenum Press, New York.

Vinayachandra P H, Monteiro FNP, Jayaprakash K, Bhagavath P, Viveka S (2013). Estimating stature from percutaneous length of ulna in South Indian population. **Medico-Legal update** 13 (1): 74 – 77.

Walker RN, Heuberger RA (2009). Predictive Equations for Energy Needs for the Critically Ill. **Respiratory Care** 54: 509-521.

Webb E, Kuh D, Peasey A, Pajak A, Malyutina S, Kubinova R, Topor-Madry R, Denisova D, Capkova N, Marmot M, Bobak M (2008). Childhood socioeconomic circumstances and adult height and leg length in central and eastern Europe. **Journal of Epidemiology and Community Health** 62: 351 – 357.

Weinbrenner T, Vioque J, Barber X, Asensio L (2006). Estimation of Height and Body Mass Index from Demi-Span in Elderly Individuals. **Gerontology** 52: 275 – 281.

Wikimedia Commons (2015). **Leonardo da Vinci – Vitruvian Man.** (http://upload.wikimedia.org/wikipedia/commons/a/a5/Leonardo_da_Vinci-_Vitruvian_Man.JPG) (accessed 16 April 2015).

Welman JC, Kruger SJ (1999). **Research Methodology for the Business and Administrative Sciences.** Cape Town: Oxford University Press.

World Health Organization (WHO) (1996). Physical status: the use and interpretation of anthropometry. Report of a WHO report expert committee. WHO Technical report series 854. Geneva: **World Health Organization**.

World Health Organization (1999). Management of severe malnutrition: a manual for physicians and other senior health workers. Geneva: **World Health Organization**.

Xu W, Perera S, Medich D, Fiorito G, Wagner J, Berger LK, Greenspan SL (2011). Height loss, vertebral fractures, and the misclassification of osteoporosis. **Bone** 48: 307 – 311.

Zverev Y, Chisi J (2005). Estimating height from arm span measurement in Malawian children. **Collegium Anthropologicum** 29(2): 469 – 473.

Sociodemographic Data and Anthropometric Measurements:

Standing Height Estimation Study

Start off by confirming whether they meet the following criteria. If not, they are not eligible for participation :

- Born in South Africa
- Aged 18 to 24 years
- Black, White or Indian
- UKZN student

Subject Code:…………………………………..

Gender				
Male	1			
Female	2			
Race				
Black	1			
White	2			
Indian	3			
Age (years):				
Undergraduate year of study				
First	1			
Second	2			
Third	3			
Fourth	4			
Other	5			
Standing height	**Measure 1**	**Measure 2**	**Measure 3**	**Mean**
Arm span	**Measure 1**	**Measure 2**	**Measure 3**	**Mean**
Mid-arm span	**Measure 1**	**Measure 2**	**Measure 3**	**Mean**
Demi-span	**Measure 1**	**Measure 2**	**Measure 3**	**Mean**

RESEARCH BRIEF:

THE ACCURACY OF COMMON HEIGHT ESTIMATION METHODS COMPARED TO STANDING HEIGHT

UNIVERSITY OF KWAZULU-NATAL
PIETERMARIZBURG CAMPUS

DISCIPLINE OF HUMAN NUTRITION &
DIETETICS

FEBRUARY 2015

Height study specifics:

Please see the details as follows:

Aim:	To determine which height estimation method when compared to standing height, has the smallest % error.
Subjects:	• UKZN students (PMB/HOWARD/WESTVILLE) • 18 – 24 years • Healthy, able to stand ○ Free from physical disabilities preventing one being able to stand erect
Number of subjects:	N = 900: • 150 White Males • 150 White Females • 150 Black Males • 150 Black Females • 150 Indian Males • 150 Indian Females
Height estimations methods to screen:	• Standing height (gold standard) • Total Arm Span • Half Arm span • Demi- span
Readings:	• Take two ○ if the two are more than 0.1 different then repeat a 3rd time • Measure on right side
Data:	• The data collected will be filled into a spreadsheet

Height study methods:

Height Estimation Method:	Instruction:
Standing Height: [4]	This is the golden standard for measuring height. 'A stadiometer is used to measure stature or use a right-angled headboard and a non- stretchable tape measure with 1mm increments fixed to a vertical surface. Platform scales with moveable measuring rods are not indicated because of inaccuracy. Subject is measured with minimal clothing and no shoes and socks must be worn. Feet must be together, arms to the side, legs straight and shoulders relaxed. The head must be in the Frankfort horizontal plane (looking straight ahead). Heels, buttocks, shoulder blades and back of the head must be against the vertical board of the stadiometer. Measurement is taken at maximum inspiration. An average of 3 readings is taken and read to the nearest 0.1cm. To avoid errors of parallax, the measurer's eyes should be level with the headboard. ' • Use Stadiometer
Total Arm Span (TAS): [14]	'The maximal distance between the tips of the two middle fingers. The subjects is upright with his or her back against the wall.The arms are fully abducted, with straight elbows, at 90° from the torso...The measurement is made with a rigid extended calibrated rule, a flexible metal tape or an adapted stadiometer'. • Use Protractor triangle and stainless steal tape
Half Arm Span: [3, 10, 12]	'This estimate is obtained by measuring the extension from the tip of the middle finger to the

	sternal furcula, maintaining the superior limb at 90º to the body. The value found can be simply multiplied by two to provide the estimate of height based on TAS'.[3,10, 12] • Use Protractor triangle and stainless steal tape
Demi-span:[15,3]	'The distance between the suprasternal notch and the root of the middle finger is measured'. [15, 3] Females: Height (cm) = (1.35 x demispan (cm)) + 60.1 Males: Height (cm) = (1.40 x demispan (cm)) + 57.8 • Arm span - (Measure from root of middle finger to tip of middle finger)
WHO height equation:[18]	'This is the distance from the middle of the sternal notch to the tip of the middle finger with the arm held out horizontally to the side. Both sides should be measured. If there is a discrepancy, the measurements should be repeated and the longest one taken. The height (in metres) can then be calculated as follows [18]: Height= 0.73×(2×half arm span)+0.43

References

1. Aggarwal AN, Gupta D, Jindal SK (1999). Interpreting Spirometric Data: Impact of Substitution of Arm Span for Standing Height in Adults From North India. **Chest** 115:557–562.
2. Bassey EJ (1986). Demi-span as a measure of skeletal size. Annals of Human Biology.
3. Beghetto MG, Fink J, Luft VC, de Mello ED (2006). Estimates of body height in adult inpatients. **Clinical Nutrition** 25: 438–443.
4. Cape Town Metropole Paediatric Interest Group (2009). **Anthropometry guideline Paediatrics** 1: 1- 25.
5. de Lucia E, Lemma F, Tesfaye F, Demisse T, Ismail S (2002). The use of armspan measurement to assess the nutritional status of adults in four Ethiopian ethnic groups. **European Journal of Clinical Nutrition** 56: 91–95.
6. de Oliveira Siqueira V, Vieira de Lima Costa B, Lopes ACS, dos Santos LC, Lima-Costa MF, Teixeira Caiaffa W (2012). Different equations for determining height among the elderly: the Bambuí Cohort Study of Aging. **Cad. Saúde Pública** 28(1):125-134.
7. Freitag E, Edgecombe G, Baldwin I, Cottier B, Heland M (2010). Determination of body weight and height measurement for critically ill patients admitted to the intensive care unit: A quality improvement project. **Australian Critical Care** 23: 197—207.
8. Froehlich-Grobe K, Nary DE, Van Sciver A, Lee J, Little, TD (2012). Measuring Height without a Stadiometer: Empirical Investigation of Four Height Estimates Among Wheelchair Users. **American Journal Phys Med Rehabil** 90(8): 658–666.
9. Hirani V, Mindell J (2008). A comparison of measured height and demi-span equivalent height in the assessment of body mass index among people aged 65 years and over in England . **Age and Ageing** 37: 311–317.

10. Hickson M, Frost G (2003). A comparison of three methods for estimating height in the acutely ill elderly population. **J Hum Nutr Dietet** 16: 13–20.

11. Jamaiyah H, Geeta A, Safiza MN, Wong NF, Kee CC, Ahmad AZ, Suzana S, Rahmah R ,Khor GL, Ruzita AT, Chen WS, Rajaah M, Faudzi A (2008). Reliability and Technical Error of Calf Circumference and Mid-half Arm Span Measurements for Nutritional Status Assessment of Elderly Persons in Malaysia. **Mal J Nutr** 14(2): 137 – 150.

12. Kwok T, Whitelaw MN (1991). The use of armspan in nutritional assessment of the elderly. J Am Geriatr Soc. 39(5):492-6.

13. Mahan LK, Escott-Stump S (2004). **Krause's food, nutrition and diet therapy**. Tenth edition. Philadelphia: WB Saunders Company.

14. Özaslan A, Yaşar İşcan M, Özaslan I, Tuğcu Hd, Koç S (2003). Estimation of stature from body parts. **Forensic Science International** 132: 40–45.

15. Preddy VR (2012). **Handbook of Anthropometry: Physical measures of Human form in Health and Disease**, Volume 1: Part 1-6. New York: Springer.

16. Mohanty SP, Babu SS, Nair NS (2001). The use of arm span as a predictor of height: A study of South Indian women. **Journal of Orthopaedic Surgery** 9(1):19–23.

17. Shahar S, Pooy NS (2003). Predictive equations for estimation of stature in Malaysian elderly people. **Asia Pacific Journal of Clinical Nutrition** 12 (1):80-84.

18. **World Health Organization** (1999). Management of severe malnutrition: a manual for physicians and other senior health workers. Geneva: World Health Organization.

INFORMED CONSENT FORM

Dear Subject

I am a Masters student studying towards my MSc Dietetics at the University of KwaZulu-Natal (UKZN), Pietermaritzburg Campus. My contact details as well as that of my supervisors at Dietetics are indicated below, should you wish to contact us.

You are hereby invited to participate in a research project where the accuracy of arm span and mid-arm span as an estimation of standing height will be determined.

STUDY INFORMATION

Study aim: To determine the accuracy of armspan, half-armspan and demi-span as an estimate of standing height among undergraduate male and female students studying at UKZN.

Procedures: The study will involve the collection of basic information from you such as age, race and gender. Standing height; arm span and mid-arm span measurements will be taken by trained field workers.

Duration: The duration of data collection should not take longer than 5 - 10 minutes.

Risk: There are no foreseen risks involved in the participation of this study.

Participation: Your participation in this study is voluntary and you have the right to withdraw from participating at any stage without giving a reason and any negative consequences.

Confidentiality: All personal information will be stored and used confidentially and no names will be used in the analysis of any results as you will be allocated a subject code.

Findings: The information collected will be used by the researcher for the write up of a MSc dissertation and publishing the results in a peer reviewed scientific journal. .

If you are willing to participate in the study, please consent by signing the informed consent form below.

CONTACT DETAILS

Researcher:	**Email addresses**
Christen Lahner	lahnerchristen@gmail.com
Supervisors: Prof. Frederick Veldman	veldmanf@ukzn.ac.za
Mrs. Suna Kassier kassiers@ukzn.ac.za	kassiers@ukzn.ac.za

CONSENT FORM TO PARTICIPATE IN THE STUDY

I, ____ declare that the purpose of the study and methods used to collect study data have been explained to me by the researcher/fieldworkers. I fully understand the study aim and what is required of me. In addition, I have been given the opportunity to ask questions. I understand that my participation is entirely voluntary and I may exit the study at any point, should I wish to. I am aware that I can contact the researcher or study supervisors at any time for clarification regarding queries I may have related to the study. Should I have any concerns about my rights as a participant, I can contact either the researcher or the supervisor.

I hereby consent to voluntary participation in the above mentioned study.

Participant name (optional):____

Participant signature: ______________________ Date: _______________________________

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

23 September 2014

Professor Frederick Veldman &
Ms Suna Kassier
School of Agricultural, Earth & Environmental Sciences
College of Agriculture, Engineering & Science
Pietermaritzburg Campus
UKZN
Email: kassiers@ukzn.ac.za
veldmanf@ukzn.ac.za

Dear Professor Veldman & Ms Kassier

RE: PERMISSION TO CONDUCT RESEARCH

Gatekeeper's permission is hereby granted for you to conduct research at the University of KwaZulu-Natal (UKZN) provided Ethical clearance has been obtained. We note the title of your project is:

"Investigation of the accuracy of arm span, demi-span and 2x mid arm span to predict standing height among undergraduate male and female students on the Pietermaritzburg Campus, UKZN".

It is noted that you will be constituting your sample by accessing data from UKZN.

Please note that the data collected must be treated with due confidentiality and anonymity.

Yours sincerely

MR MC BALOYI
REGISTRAR

Office of the Registrar
Postal Address: Private Bag X54001, Durban, South Africa
Telephone: +27 (0) 31 260 8005/2206 **Facsimile:** +27 (0) 31 260 7824/2204 **Email:** registrar@ukzn.ac.za
Website: www.ukzn.ac.za