True height and variability in estimates thereof across race and gender

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Abstract

Although standing height is the ideal indicator of a subject's true height, numerous internal and external factors can have an effect on its accuracy. These factors include measurement error, the clinical environment, growth and a secular change in growth, and age. When the measurement of standing height is not possible estimation methods, such as recumbent length, knee height, ulna length, half arm span, total arm span, demi-span equation and the World Health Organization equation have been used as substitutes. However, the accuracy of these methods is questionable.

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Introduction

Anthropometric measurements are vital in determining a patient's nutritional status.[1] In order to assess nutritional status, the types of anthropometric measurements in use are numerous. However, height and weight are the measurements most often used.[2]

Standing height is the gold standard for determining a subject's true height. The measurement method is referred to as stretch stature, implying the inclusion of an adjustment factor required with diurnal variation (taller in the morning, and shorter in the evening).[3] Stretch stature is determined through the use of a stadiometer, measuring the height from the vertex to the floor, and is most accurate in subjects aged ≥ 18 years.[3,4]

Height measurement

True height in adults is influenced by numerous internal and external factors which can have an effect on the validity and reliability of standing height or stretch stature value.[4]

Measurement error

Technical error of measurement (TEM) is defined as an inaccurate measurement caused by inaccurate anthropometric methodology.[4,5] Furthermore, TEM is often the result of a situation when there is a large number of fieldworkers who have not received adequate training prior to data collection.[4,5] The types of TEM are unreliable values, where repeated measurements do not generate the same value; biased values, representing data that are not true values; and imprecision, commonly known as observer error.[4,5]

Clinical environment

The clinical environment needs to be conducive to producing accurate values. Therefore, the patient's health status and the patient environment need to be considered for their impact on the choice of the appropriate anthropometric method.[6]

A poor health status prevents the measurement of stretch stature if the patient is unable to stand upright.[7]

Factors contributing to the latter include:

- Amputations
- Contractures
- Physical deformities, e.g. cerebral palsy, scoliosis or kyphosis
- Muscle weakness, e.g. muscular dystrophy
- Bone conditions, e.g. rickets, osteomalacia or osteoporosis
- Fatigue associated with illness can result in a patient becoming bedridden, or if critically ill, unconscious[6]

It is assumed that a patient environment that is anthropometry friendly has the following characteristics:

- Adequate space
- The patient is not restricted by the medical equipment
- A minimum of two observers are available to conduct the anthropometric measurements
- There is access to the relevant equipment
- There is a low noise level to record the measurements

Growth-determining factors

The most vulnerable period of growth begins at conception until two years of age. Many factors contribute to optimal growth during this

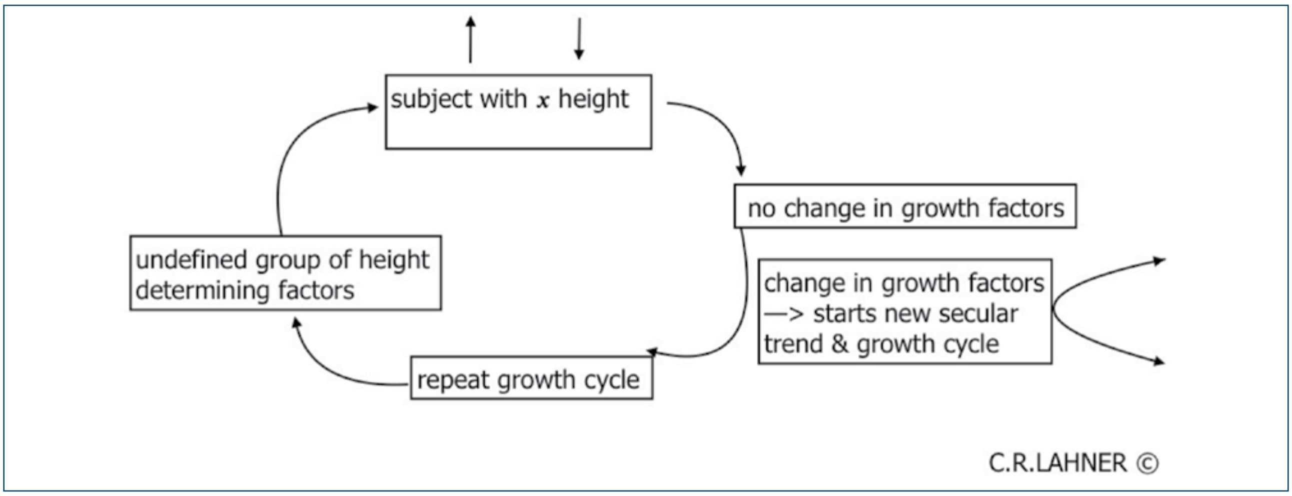

Figure 1: Flow diagram illustrating secular change within a population

period, including:

- Maternal health and nutrition (pre-pregnancy, during pregnancy and during lactation)
- Exclusive breastfeeding
- Breastfeeding duration
- The appropriate and timely introduction of complementary feeding
- Socio-economic factors
- The presence of infectious diseases, such as diarrhoea[8]

Chronic undernutrition during the early life stages can result in stunting, which is defined as a height-for-age that falls below a –2 *z*-score from the reference mean.[9] The bones most affected by chronic undernutrition that relate to a change in height include the long bones, such as the tibia and fibula situated in the lower leg.[8]

Secular change

Secular change refers to a group of undefined height-determining factors that are interrelated, and in so doing, move as a single force, giving rise to a decrease or increase in height,[10,11] as illustrated in Figure 1. Secular trends appear if the growth conditions occur repetitively within the same population, and give rise to the same effect.[10,11]

Ageing process

A decrease in height is part of the ageing process.[12] Height loss occurs from the age of 30 years, with females showing an average decrease in height of 1.25 cm every decade, while males lose an average of 0.75 cm of height per decade.[12] In addition, there is an acceleration in height loss beyond 80 years of age.[12]

The decrease in height can be attributed to the following physiological changes:

- Flattening of the vertebrae
- Vertebral fractures
- Diminution in intervertebral disc thickness
- Scoliosis
- Dorsal kyphosis
- Flattening of the plantar arch
- Bowing of the legs due to osteomalacia
- Osteoporosis
- Postmenopausal hormone imbalances[13–15]

These conditions are exacerbated by mobility-related problems, joint stiffness, arthritis, and postural problems that may impact on the accuracy of anthropometry and the interpretation of body mass index (BMI).[15]

The BMI equation (kg/m^2) does not account for this unavoidable increase in BMI as a result of loss in height, thereby highlighting the need for a correction factor in the BMI classification system, especially for the elderly.[16]

Estimating height

As mentioned, the gold standard for measuring true height is the stretch stature method.[3] When the measurement of stretch stature is not possible, an estimated value is used.[6]

Body parts are often used to estimate height, and include:

- Vertebral column length
- Scapula length
- Trochanteric height
- Leg length
- Thigh length
- Cranial sutures
- Skull circumference
- Facial measurements
- Sitting height
- Knee height
- Ulna length
- Arm measurements, such as arm span
- Recumbent length[17-19]

For the purposes of this paper, the most frequently used methods that are used for the estimation of true height will be discussed.

Recumbent length

To measure recumbent length, a head board, foot board and non-stretch measuring tape are required. The patient is required to lie flat on a mattress, without a pillow or bedding.[20] In an American randomised controlled trial comparing wheelchair-bound patients

(18–65 years, n = 141) versus controls, recumbent length had a variance of 92%. However, 25% of these subjects experienced difficulties lying supine.[6] In another American study conducted on a convenience sample of ambulatory inpatients (18–65 years, n = 108), recumbent length was significantly longer than standing height by 3.68 cm.[21]

Visual height

The visual estimation of height is defined as guessing the subject's standing height through observation. This can result in an overestimation of height in shorter subjects, and is difficult to estimate if the subject is lying in the recumbent position.[22]

Self-reported height

Self-reported height refers to when the subject concerned reports his or her own height, based on his or her knowledge or recall.[23] Self-reported height is useful when no measurements are possible, but has been shown to overestimate standing height.[21,24]

Knee height

Knee height is measured on the left leg from the top of the knee to the heel.[25] It can be challenging to assess knee height in bedridden patients as it requires the patient to bend their knee at a 90˚ angle.[23] Equations for males and females are widely known as the Chumlea equations. The accuracy of the Chumlea equations varies according to age and race. It is for this reason that it has been adapted.[26,27] Knee height, as an alternative measurement of stature, was first assessed in the elderly, and was significantly correlated with standing height in the elderly aged 60–90 years.[25] These findings were supported by another British study investigating the elderly (> 65 years, n = 484), in that knee height was highly significantly (p < 0.001) correlated to standing height (r = 0.89).[28] Similar findings were reported in Indonesian Javanese elderly (55–69 years, n = 812), where knee height was highly significantly (p < 0.001) correlated to standing height in males (r = 0.86) and females (r = 0.75).[29]

The relevance of knee height to the South African population was compared between the elderly (≥ 60 years, n = 1 233) and adults (18–59 years, n = 1 038).[30] Although different race groups were included in the study sample, the majority of the study sample were female and of mixed ancestry. Knee height, total arm span, standing height and weight were measured in all participants. Standing height differed highly significantly (p < 0.001) between the elderly and adult group. In addition, standing height decreased with age, and males were generally taller than females by 10 cm in the adult group and 20 cm in the elderly group. Knee height overestimated standing height by 6 cm in the adult group, and total arm span overestimated standing height by 6 cm in the elderly group. Overestimation of standing height resulted in a decrease in BMI. Consequently, the nutritional status of the participants was incorrectly classified. Therefore, knee height was viewed as the superior height estimation method for use among the elderly in this population.[30]

Ulna length

Ulna length is measured from the olecranon process to the styloid process of the ulna situated in the forearm.[31] Several studies have identified a potential relationship between ulna length and standing height in the Indian population.[32-40] To date, the only known African study that investigated the relationship between ulna length and standing height was conducted on Nigerians (n = 109).[41] In this study, males were identified as having larger ulna lengths than females. However, further studies are required to verify whether ulna length accurately predicts standing height. Ulna length has predominantly been used in the British population for screening patients for malnutrition by using the Malnutrition Universal Screening Tool, developed by the British Association for Parenteral and Enteral Nutrition.[42] However, this tool should be used with caution in a multiracial population, such as in South Africa.[43] Although ulna length was shown to have a significant correlation with standing height, population-specific studies need to be conducted, and population-specific formulas developed.[44]

Half arm span

Half arm span is measured from the suprasternal notch to the dactylion. Assuming that arm span is equal to height, the half arm span length value can be doubled to obtain an approximate of the true height.[45] A Malaysian study compared the accuracy of height estimated using half arm span in adults (30–49 years, n =100) and the elderly (60–86 years, n = 100).[7] Half arm span was more closely correlated (p < 0.050) to standing height in adult females (r = 0.89) and males (r = 0.84), than elderly females (r = 0.67) and males (r = 0.77).[7] The lower correlation with age could be owing to age-related height loss.[12] However, the decrease in height differs among population groups, as displayed in British inpatients (> 65 years, n = 484), where the correlation was higher (r = 0.87, p < 0.001).[28]

World Health Organization equation

The World Health Organization (WHO) has suggested that the WHO equation [0.73 x (2 x half arm span) + 0.43] should be used to estimate height in adults aged ≥ 18 years who are unable to stand.[46] The equation incorporates the half arm span measurement. The accuracy of this equation has not been validated across populations. It is associated with the underestimation of standing height and an increase in BMI in the elderly.[47] Therefore, it is evident that the ageing effect on standing height diminishes the accuracy of using the half arm span and the WHO equation.

Demi-span equation

The demi-span is measured from the suprasternal notch to the base of the middle finger.[48] Standing height was compared to demi-span in Europeans (< 60 years, n = 125), with a highly significant correlation (r = 0.74, p < 0.001).[48] Similar significant correlations were identified in Malaysians (< 60 years, n = 100), comparing males (r = 0.85, p < 0.050) and females (r = 0.83, p < 0.050).[7] Although the demi-span equation was initially studied among adults as a target population, it has predominantly been studied in the elderly.[7,48–51] In a longitudinal study, demi-span was resilient to change with increasing age.[52] However, the accuracy and precision of using the demi-span equation is affected by age-related height loss, especially among females.[51] Consequentially, using demi-span in the elderly results in an overestimation of BMI.[47] Adjustments to the demi-span equation have been documented, such as those developed from a health survey in England in 2007.[53] The advantage of using the demi-span equation in the context of the South African population is unknown because of a lack of published data.

Total arm span

Total arm span is the measurement from the dactylion of the right hand to the dactylion of the left hand, with arms outstretched and at a 90˚ angle to the body.[17,45,54] The first known height study to investigate total arm span compared to standing height was in a small study sample (n = 84), where only six subjects' standing height was equal to total arm span.[54] Several subsequent studies investigated the relationship between the two variables.[7,18,29,45,55–67] Findings have described how total arm span overestimates standing height.[7,18,29,45,55–67] Before puberty, total arm span is closely correlated with standing height. After the onset of puberty (approximately 15 years), the correlation decreases and gender-related variations widen.[59,60,68] In females, the variation between total arm span and standing height is larger than that among males, but increases in both genders with ageing.[60,67,69–71]

Conclusion

Stretch stature, using a stadiometer, is the gold standard for measuring standing height in adults. When the measurement of standing is not possible, height estimation methods, such as visual estimation, self-reported height, recumbent length, knee height, ulna length, half arm span, total arm span and demi-span can be used. However, none of these methods have been validated for use in South Africans, with the exception of knee height in the elderly. Furthermore, clinicians need to consider whether it is important to take cognisance of the fact that estimation methods generate values which are influenced by gender, race, age and the population under investigation. This is especially important in a country like South Africa where the population is made up of numerous race groups.

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