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The age at which adult height is achieved during adolescence in the 'Birth to Twenty Cohort', Johannesburg, South Africa

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Conflict of interest

There is no conflict or competing interests.

Ethics approval

The manuscript is submitted in partial fulfillment of the requirements for the MMed(Paeds) degree at the University of the Witwatersrand. The Graduate Studies Committee and the Human Research Ethics Committee of the University of the Witwatersrand approved this research. Ethics approval number: M160417.

Protection of patients' right to privacy

The subjects were identified by unique study numbers and not by name and address. Participant confidentiality was thus maintained.

Ethnic classification justification

The core of the study involves comparing the secular trends in height among self-reported black and white racial groups in South Africa. The white group represents that part of the population that has always been affluent and thus has growth trends comparable to those of developed nations of the world. In comparing the groups, we wanted to see the extent to which the black population has caught up, if it all, since the introduction of democracy in 1994.

ABSTRACT

Background

Child growth is a sensitive indicator of socio-economic and health conditions in society. Positive secular change in height highlights improvements in these conditions.

Objectives

To establish the age at which linear growth plateaus and to compare the age of growth cessation and the achieved adult height between sexes and racial groups in South Africa.

To compare 'Bone Health Cohort' data with previous similar studies to ascertain the secular trend.

Methods

We analysed prospective data of 569 individuals who had annual anthropometric assessments from age 9 until 20 years (1999 to 2010). The SuperImposition by Translation and Rotation (SITAR) statistical programme was used to model height and age at growth cessation.

Results

There was a total of 183 black females, 93 white females, 205 black males and 88 white males. Black and white females achieved adult height at a similar age (15.1 and 15.3 years), but black females were 5.7 cm shorter. Black and white males achieved their adult height at 17.5 and 16.5 years respectively, black males being 4.6 cm shorter. Mean adult black male height is now 170.7 cm versus 166.9 cm in 1971, while there was no significant secular changes in the other groups.

Conclusions

There has been a positive secular growth trend in height over 30 years among black males, but no changes in the other groups.

Introduction

James Tanner wrote that 'Human growth is a mirror of society; if you want to measure the classlessness of society, and you are not interested in rhetoric but in actual conditions and facts, then looking at the growth of children is perhaps the best way'. [1, 2] Secular growth trends study the change in body size or composition in a given population over a prolonged period.[3, 4] The study of secular trends in growth provides a reliable and an important assessment tool of the physical health of populations. It is also useful in highlighting social disparities between different groups of people.[4] There is a host of factors involved in growth and its cessation in individuals. Secular growth trends therefore, may be negative, positive or unchanged depending on these factors [3,4] These factors can be divided into intrinsic or biological factors and extrinsic or environmental factors. This means that besides having normal genotype, a child should grow in conditions conducive to good health if optimal growth is to be achieved. One biological predictor of an individual's height is mid-parental height. Heterosis, the opposite of inbreeding, refers to increased capacity for growth of an offspring as a result of increased dissimilarity in the genetic makeup of parents.[5] As more and more people from different ethnic and family backgrounds have children together, a positive change in the secular trends occurs. In the South African context, particularly Johannesburg, there is an influx of members of various tribal and ethnic groups. It is possible that heterosis could play some role in changing trends in the South African context.

Extrinsically the potential for growth is strongly influenced by socioeconomic, nutritional and health factors. [4,6] Decreased family size and increased child spacing are associated with better care for the individual child, better maternal nutrition and therefore better chances of survival and growth. Changes in health practices and living conditions have an impact on mortality rates and life expectancy.[5] Although there remains much opportunity for improvement, there have been major decisions taken by the democratic government and civil organisations in South Africa aimed at improving implementation of these health strategies. These include the rolling out of programs addressing household and school sanitation, awareness campaigns and health drives regarding women's rights and family planning, as well as many preventive strategies for diseases such as malnutrition, tuberculosis and HIV infection. Similarly, physical and mental stress can delay adolescence and be

associated with a negative secular trend, a trend that was seen after the recent war in Croatia and Bosnia.[5] Studies have investigated the role of adverse events on the neuroendocrine circuit, the role of adaptive responses to stress and the long-term consequences of stress on the endocrine axes involved in the growth and pubertal development of individuals. [5]

The MRC/Wits Developmental Pathways for Health Research Unit has been recording the growth patterns of children from different racial backgrounds born during the democratic transitional period in the Johannesburg metropolitan region. An earlier study in 2003 by Cameron, concluded that the economic and social transition in the country had not resulted in improved child growth at that time.[7]
Our hypothesis was that although the legacy of inequality still prevails, there has been a change in the disparity in height between the racial groups. We hypothesized that there was an improving secular trend in height among the black population while there was no change among the white population. Furthermore, the white population would achieve adult height earlier and their mean height would be greater than that of their black counterparts. The study also aimed to document the mean age at which adult height was achieved in the different groups

Methods

The study was an analysis of prospectively collected longitudinal data, which was conducted in the MRC/Wits Developmental Pathways for Health Research Unit, Chris Hani Baragwanath Academic Hospital, Soweto, Johannesburg. It used data collected from 569 participants of the Bone Health Cohort, who had annual anthropometric measurements taken from 9 until 20 years of age (1999 to 2010). The 'Bone Health Cohort' is a sub-cohort, which was selected from the 'Birth to Twenty Cohort', when the children were 9 years of age, to study factors influencing pubertal development and bone acquisition during adolescence. The larger 'Birth to Twenty Study', from which the 'Bone Health Cohort' was selected, is a longitudinal study of child health and development and has 2107 participants. The recruitment of eligible neonates (n = 3273) was done within a 7-week period between 23 April and 8 June, 1990.
Because of the demographics of births within the public health sector within Johannesburg, there was an insufficient number of white children in the 'Bone Health

Cohort' to provide adequate power for statistical analyses. To compensate for this, a supplementary sample of 226 white children born during the same period was recruited from Johannesburg schools at age of 10 years. The additional white children did not differ statistically from those enrolled at birth when considering characteristics like maternal age, gestational age and birth weight. All children with chronic diseases (asthma, HIV and rheumatoid arthritis) likely to influence growth were excluded from the study.

All enrolled children were born within the metropolitan area of Johannesburg, South Africa. These children were observed at yearly intervals. Trained research assistants using a stadiometer, which was checked on a regular basis, measured the height of the children in light clothing and without shoes.

The following subject characteristics were extracted from the study records: Study number, sex, ethnic group, yearly height measurements, including date of height measurement and age at height measurement date.

Statistical methods

Sample size was calculated using information obtained from a previous study,[8] which reported the mean height of the South African adult population (see Table 1). That study reported a 6.5cm difference between black and white females, and a 7.8cm difference between black and white males. To be able to detect a difference of 3 cm between black and white females and 5 cm between black and white males, an effective sample size of 104 participants was required for a level of significance of 5% with a power of 80%. The following formula was used :

$n = (Z_{\alpha/2}+Z_{\beta})^2 \text{ x2x}\sigma^2 / d^2$

(where $Z_{\alpha/2}$ is the critical value of the Normal distribution at $\alpha/2$, Z_{β} is the critical value of the Normal distribution at β, σ^2 is the population variance, and d is the difference you would like to detect.)

As the 'Birth to Twenty Cohort' size is over 500, we utilized data from the whole cohort to be able to detect a much smaller difference between the groups.

Annual height measurements were fitted using the SuperImposition by Translation and Rotation (SITAR) in R version 3.3.1 (see Figure 1) . SITAR is a shape invariant model with a single fitted curve that summarises individual growth patterns with three parameters namely tempo (the timing of the onset of the pubertal growth spurt), size

(the size of growth during puberty) and velocity (the rate of growth during the growth spurt).[9]

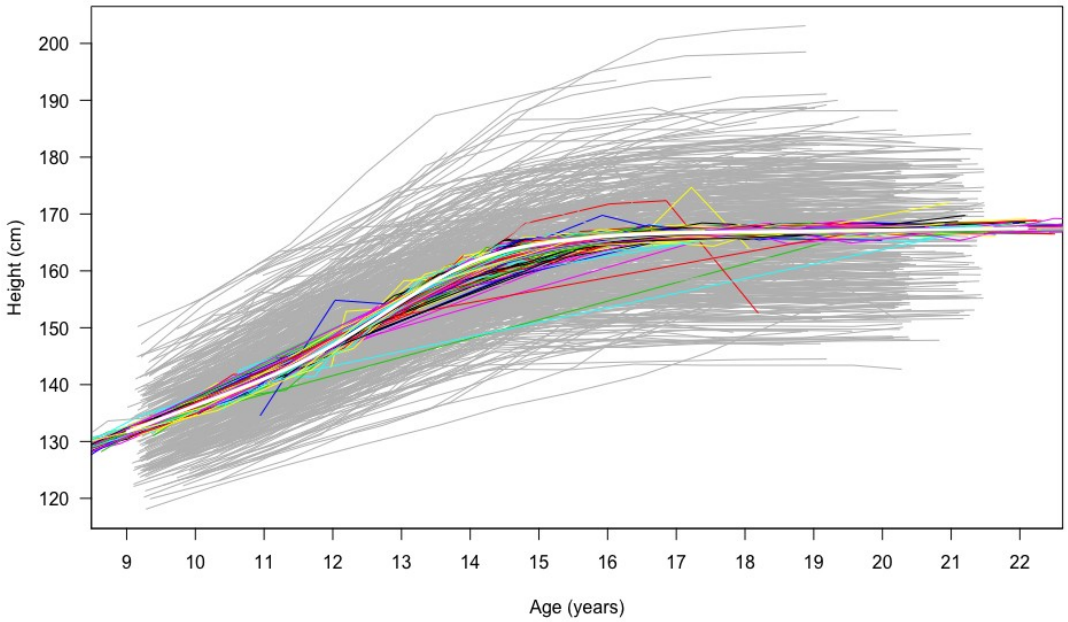


Figure 1. The individual height curves for all the participants, with the mean curve shown as a white line. The coloured lines represent the individual curves adjusted for the SITAR parameters of size, tempo and velocity. The model extrapolates the figures beyond the minimum and maximum ages.

Age at growth cessation was determined as the age at which growth velocity decreased below 0.5cm per annum.[10]

TABLE 1 Mean adult height among adult South Africans in 1971[8]

GROUP	MEAN HEIGHT (cm)	STANDARD DEVIATION (SD)	(n)
Black female	158.9	5.34	165
Black male	166.9	5.93	186
White female	165.4	6.21	151
White male	174.7	5.78	152

Data were analysed using Stata version 13.1 (Stata-Corp LP, College Station, Texas, USA). Tests for normality were performed using skewness and kurtosis tests and were found to be satisfactory. In order to compare the age of growth cessation between sexes and subjects of different racial groups; Analysis of variance (ANOVA) was used to compare the mean ages between the four groups. An independent t-test was used to compare the mean ages between racial groups within the same sex groups and between the sexes of the same racial group. ANOVA was also used to compare the mean heights between the four groups. Where data were not normally distributed, transformation was used. An independent t-test was used to compare the mean heights between racial groups within the same sex groups and between the sexes of the same racial groups.

Ethics

The proposal for this study was approved by the Graduate Studies Committee and ethics approval was obtained from the Human Research Ethics committee (HREC) of the University of the Witwatersrand (Ethics approval number: M160417). All information was obtained from participant records kept within the Research Unit. Written permission to utilize the data was obtained from the Unit Manager of the Research unit. The subjects were identified by unique study numbers and not by name and address, thus maintaining participant confidentiality.

Results

There was a total of 183 black females, 93 white females, 205 black males and 88 white males in the bone health cohort. Table 2 shows the mean height for each group at yearly intervals between 9 and 20 years. Black children were shorter than their white counterparts at all recorded ages. The table also shows the earlier pubertal growth spurt of females compared to males. Males grow for a longer period and reach a greater final height. Figure 1 shows the individual height curves for all the participants, with the mean curve shown as a white line. Figures 2 (a)-(d) show the mean SITAR plots of the individual curves for mean height of participant groups by sex and race. Table 3 shows mean height and age at growth cessation for each group. Black females and white females had similar ages at which adult height was achieved (15.1 years vs. 15.3 years, p=0.1424) (Fig 1 (a) and (b) and Table 3). The difference

in height at growth cessation between black and white females was 5.7 cm (158.2 vs. 163.9, p<0.0001) (Table 3).

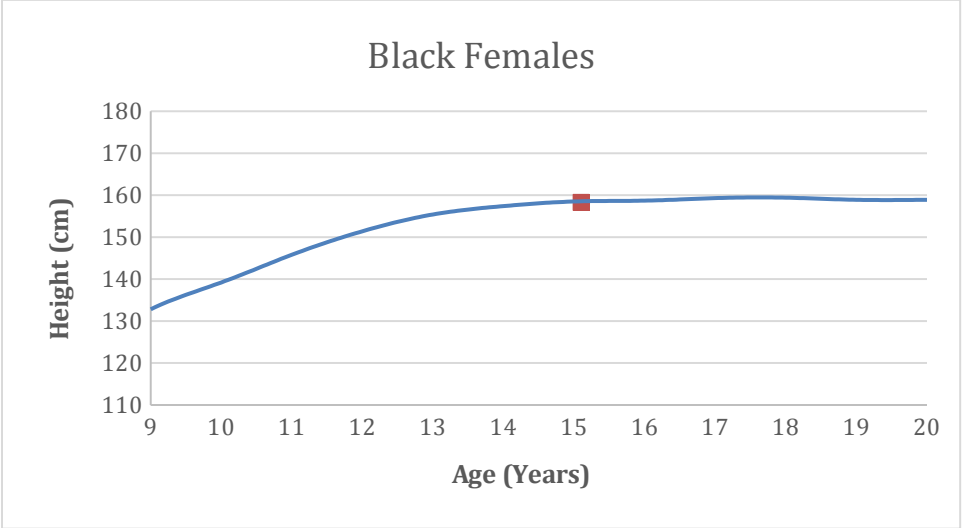
At growth cessation the mean height of white males was 175.3 cm and of black males 170.7 cm (p <0.0001) (Fig 1 (c) and (d) and Table 3). White males achieved adult height at 16.5 years whereas black males achieved adult height at 17.5 years (p < 0.0001). The results of this study show that white children of both sexes reaching maturity were significantly taller by approximately 5 cm than their black counterparts. White males reached their adult height more than a year later than their female counterparts and a year earlier than black males. These differences are statistically significant. Black females and white females had similar ages at which adult height was achieved (15.1 years in blacks and 15.3 years in whites). The decrease in height in the older age groups as seen in Table 2, could be due to the smaller samples at ages 19 and 20, especially in white children. To address this, we combined the ages 18 to 20 into one age group 18+ which has improved the means.

TABLE 2: Height by age in different groups in 'Bone Health Cohort'

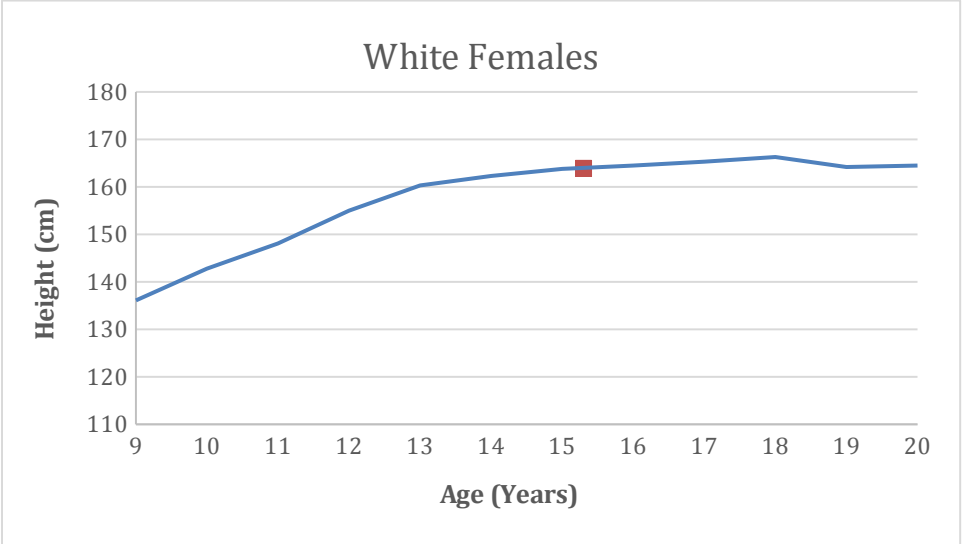
Age in years	**Mean Height in cm (SD) [n(%)]**			
	Black females	**White females**	**Black males**	**White males**
9	132.8 (5.6) [131 (39.6)]	136.1 (6.8) [28 (8.4)]	132.2 (5.9) [146 (44.1)]	137.2 (6.0) [26 (7.9)]
10	139.2 (6.2) [156 (34.2)]	142.8 (7.6) [61 (13.4)]	137.4 (6.2) [177 (38.8)]	143.3 (7.2) [62 (13.6)]
11	145.8 (7.6) [156 (33.3)]	148.1 (8.0) [64 (13,7]	142.7 (6.8) [179 (38.3)]	148.2 (7.7) [69 (14.7)]
12	151.4 (6.8) [161 (33.9)]	155.0 (7.9) [68 (14.3)]	147.4 (7.8) [183 (38.5)]	155.9 (9.1) [63 (13.3)]
13	155.4 (6.4) [150 (35.0)]	160.3 (6.8) [60 (14.0)]	153.7 (8.4) [170 (39.6)]	164.0 (9.9) [49 (11.4)]
14	157.4 (6.0) [165 (34.8)]	162.3 (8.0) [72 (15.2)]	160.1 (8.6) [184 (38.8)]	170.0 (9.1) [53 (11.2)]
15	158.5 (6.2) [149 (34.9)]	163.8 (6.9) [56 (13.1)]	165.6 (7.9) [167 (39.1)]	174.8 (8.4) [55 (12.9)]
16	158.7 (6.4) [164 (35.5)]	164.5 (6.6) [62 (13.4)]	168.6 (7.2) [183 (39.6)]	176.9 (7.7) [53 (11.5)]
17	159.3 (6.3) [146 (34.7)]	165.3 (6.8) [57 (13.5)]	170.3 (6.7) [172 (40.9)]	178.0 (8.7) [46 (10,9)]
18	159.4 (6.1) [124 (37.9)]	166.3 (7.1) [30 (9.2)]	171.2 (6. 6) [137 (41.9)]	178.0 (8.0) [36 (11.0)]
19	158.9 (6.5) [50 (30.3)]	164.2 (6.9) [32 (19.4)]	170.0 (6.8) [55 (33.3)]	177.2 (9.1) [28 (17.0)]
20	158.9 (5.9) [127 (43.0)]	164.5 (6.7) [15 (5.1)]	171.3 (6.9) [136 (46.1)]	174.3 (6.8) [17 (5.8)]

TABLE 3 Mean Height and Age at growth cessation of 'Bone Health Cohort'

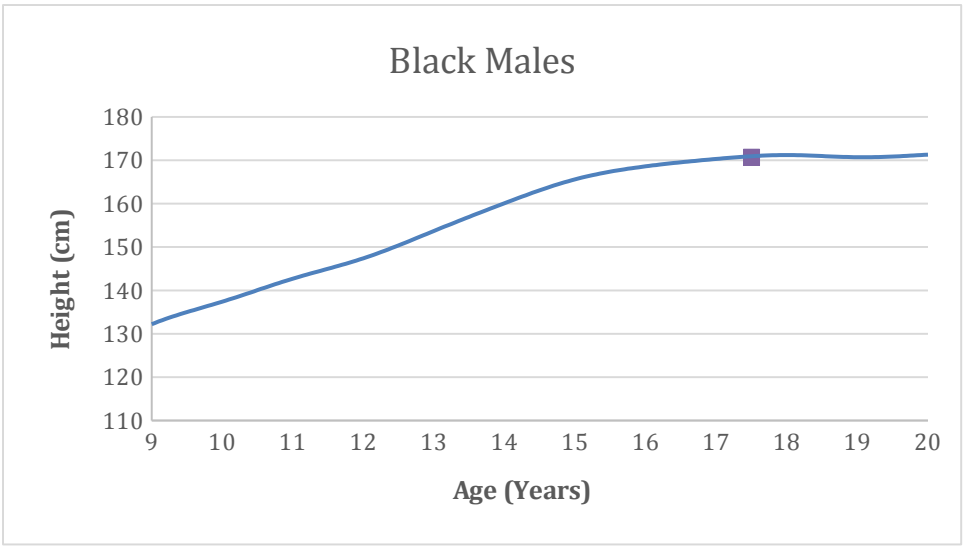
	Black females	White females	Black males	White males
No. of participants/observations	183/1679	93/605	205/1889	88/557
Mean height at growth cessation (cm) (SD)	158.2 (6.1)	163.9 (7.0)	170.7 (6.7)	175.3 (8.4)
Mean age at growth cessation (years) (SD)	15.1 (1.1)	15.3 (1.0)	17.5 (1.3)	16.5 (1.1)



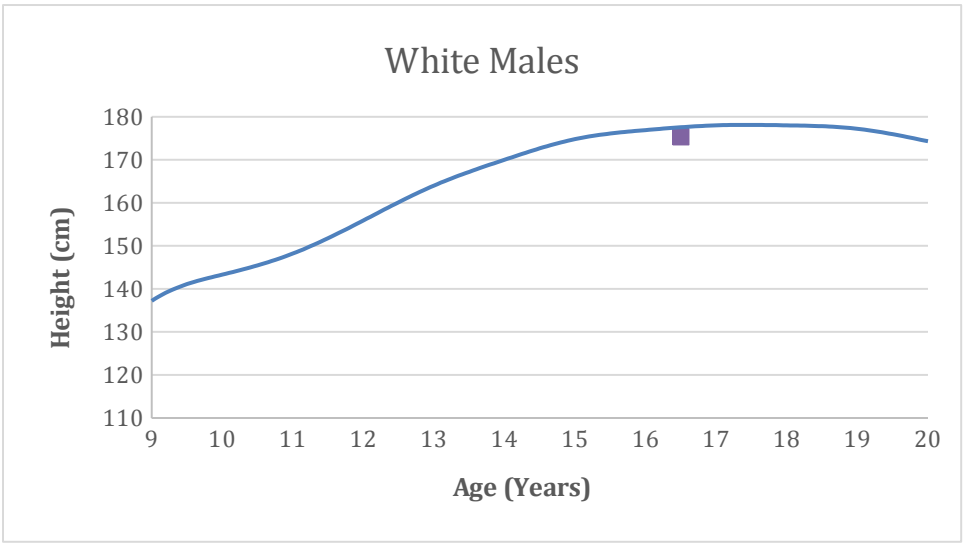
(a)



(b)



(c)



(d)

Figure 2. Mean curve for height showing maximum height and age at growth cessation for (a) black females, (b) white females, (c) black males, (d) white males.

Discussion

The pattern of secular changes in growth during childhood and adolescence has generally been positive during the past 50-100 years in Europe and in the United States of America. Large increases in final adult height have occurred in all developed countries, but not in many developing countries.[11, 12] South Africa, being a developing country with a long history of socio-economic and political inequalities, has trends that have shown patterns of both developed and developing regions. The section of the population that was always affluent has maintained a positive trend similar to that of countries where there are no socio-economic constraints.

In 1978, Richardson et al reviewed data on the physical size of 14,087 children from a variety of South African studies.[13] The mean heights and weights of white children began to diverge from those of their non-white peers by 2 years of age. The poorest growth was seen amongst rural black children, and the best amongst white urban children. There was some variation by age, but the consistent hierarchy, from smallest to largest, was black rural, black urban, mixed ancestry urban, Indian urban and white urban.[14]

The previously oppressed population, which has always lagged behind, has in recent years shown an improving growth trend. A recent review found significant secular advances in skeletal maturity between 1962 and 2001 in urban black South African male children.[14] No noteworthy change was seen among white children over the same period. The secular advances in skeletal maturity in black children were consistent with increases in their height and adiposity.[14] The authors concluded that the increase in skeletal maturity might be the result of the removal of growth constraint in black children.[14]

Adult black males are now on average 3.8 cm taller than in 1971 (170.7 cm compared to 166.9.0 cm in 1971) ($p < 0.0001$), while there is only a non-significant difference of 0.6 cm in height between the present cohort of adult white males and those measured in 1971 (175.3 cm compared to 174.7 cm in 1971) ($p= 0.5141$) (Table 1 and 3). No change in height was found in black or white females between the current cohort and those measured over 40 years previously (black females currently 158.2 cm vs. 158.9 cm in 1971) ($p=0.2578$) (white females currently 163.9 cm vs. 165.4 cm in 1971) ($p=0.0814$) (Table 1 and 3). Thus, there has only been a positive secular trend in the black male group.

The results of the study raise some interesting questions. Why do black and white females have the same age at height cessation, a finding not present in black and white males? If females stop growing at the same age, why are females of the two racial groups not the same size? The answers may lie in differences in the interplay between a number of factors including onset and duration of puberty, skeletal maturation, menarche, heredity and poverty.

Age at growth cessation

Establishing the age at which growth ceases highlights an important landmark in human development and provides a reference for historic and future comparisons for a population. In humans, longitudinal bone growth and, hence, linear growth ceases in late adolescence.[15] The cessation of growth marks the biological onset of adulthood. It is however not the end of development; development of physical prowess, skill and mental processes continues for many years.[16] Females stop growing earlier than males and this sex difference in the age of growth cessation is common across many populations.

The pubertal growth spurt is characterized by rapid changes in bone length, mass and structure as adolescents undertake the final stretch to adult height. During this time growth in height accelerates, then peaks and finally falls to zero.[17] The timing and rate of this pubertal growth spurt is highly variable between individuals and is partially determined by heredity.[18] I Hawley et al [14] found that skeletal maturation can be a useful tool in comparing and predicting growth as the secular trends in skeletal maturation were concordant with secular change in stature. They also found that there has been a positive secular trend in skeletal maturation amongst the black male group compared to older studies even though skeletal maturation was delayed amongst the black male group compared to their white counterparts. In a South African study published in 2015, skeletal maturity was reached 1.9 years earlier in girls than boys, and the pattern of maturation differed between the sexes. Within girls, there were no ethnic differences in the pattern or timing of skeletal maturity. Within boys, however, skeletal maturity was delayed by 7 months in black compared with white ethnicity.[19] Males tend to grow for longer as they start their height acceleration later than females. As Table 2 illustrates, there is a significant catch up growth from age of 14 to 17 in males while females stop growing at 15 years of age.

A study done in the same cohort looking at age at menarche found that the median menarcheal age for blacks was 12.4 years (95% confidence interval (CI) 12.2 - 12.6) and 12.5 years (95% CI 11.7 - 13.3) for whites.[20] There was no difference in the age of onset of puberty and menarche between black and white females. Black females enter puberty and menarche with a shorter stature, as compared to their white counterparts (Table 2, figures 1(a) and 1(b)). There is no catch-up growth during the pubertal growth spurt in black females (Table 2). The final result is a shorter height at growth cessation for black females. In the end, black and white females have the same age at height cessation because of similar age at menarche yet, their final sizes differ as black females were consistently shorter than white females in the prepubertal period.

Height at growth cessation

The significance of adult height has been studied extensively in various disciplines. It has far reaching consequences relating to the health, economic, psychological and social aspects of an individual.

Many studies find a positive correlation between short stature and the prevalence of cardiovascular disease while others find evidence that taller people have a higher risk for cancer.[21] The adverse effects of short stature during pregnancy, child birth and child rearing are well established.[22] There is no consensus about the effect of height on longevity.

Tall stature is also a proxy for social status and leadership in both men and women, which includes a higher earning potential, dominance in interpersonal interactions and success in attracting a desired partner in the case of males.[22]

On the other hand, the positive secular change in height highlights improvements in health and social conditions in transitional countries like South Africa. In a neighbouring country, significant positive changes in growth and nutritional status were observed among Mozambican youth from 1992 to 2012, which were associated with economic, social and cultural developments.[23] Another study that analysed youths at age 15.5 years in Seychelles in 2005/6 found a positive secular trend in final height when compared to published data from 1956/7.[24] Both studies concluded that the change in trends was due to the general improvement of the living conditions of the population.[23,24]

Study Limitations

Because of the demographics of births within Johannesburg, there was an insufficient number of white children in the smaller cohort to provide adequate power for statistical analyses. To compensate for this, a supplementary sample of 226 white children born during the same period was recruited from Johannesburg, at age of 10 years. Furthermore, as race was self-declared, heterosis, which has been occurring for the last few centuries in SA may have a genetic influence on cessation of growth and final height and that is difficult to measure.

Conclusion

The age at which adult height is reached amongst both black and white females in Johannesburg South Africa is just over 15 years. Amongst males, adult height is achieved at means of 16.5 and 17.5 years respectively, with white males reaching it earlier than black males. Secular growth trends in height in South Africa show a positive change amongst black males. Future studies may ascertain the continuation of the positive secular trend changes in height among the black section of the population.

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