Is the World Health Organization's multicentre child growth standard an appropriate growth reference for assessing optimal growth of South African mixed-ancestry children?

L M Arendse,[1] MSc; **D Brits**,[2] PhD; **E V Lambert**,[1,3] PhD; **V E Gibbon**,[1] PhD

[1] *Division of Clinical Anatomy and Biological Anthropology, Department of Human Biology, Faculty of Health Sciences, University of Cape Town, South Africa*

[2] *Human Variation and Identification Research Unit, School of Anatomical Sciences, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, South Africa*

[3] *UCT Research Centre for Health through Physical Activity, Lifestyle and Sport (HPALS), Department of Human Biology, Faculty of Health Sciences, University of Cape Town, South Africa*

Corresponding author: *V E Gibbon (victoria.gibbon@uct.ac.za)*

In South Africa (SA), it has been estimated that one-third of boys and 25% of girls under the age of 5 years are stunted, according to the World Health Organization (WHO) Multicentre Growth Reference Study. During the past decade, research in developed and developing countries has shown that the international growth standard overestimates stunting and/or wasting when compared with population-specific growth references. Population-specific growth references typically incorporate genetic and environmental factors and can therefore better inform public health by identifying children who may be at risk for malnutrition, or who may be ill. Using the universal growth standard in SA may not be accurately assessing growth. In this article, environmental and genetic factors, and their influence on growth, are reviewed. These points are illustrated through a brief history of the peopling of SA, with an understanding of the socioeconomic and political climate – past and present. We discuss the uniqueness of certain population groups in SA, with contributions regarding some of the shortest peoples in the world and a history of sociopolitical inequities, which may mean that children from certain population groups who are perfectly healthy would underperform using the universal growth standard. Therefore, we suggest that a local population-specific growth reference would serve to better inform public health policies, and address childhood health equity and physical developmental pathways to adult health risk status.

S Afr J Child Health 2022;16(2):117-121. https://doi.org/10.7196/SAJCH.2022.v16i2.1805

The World Health Organization (WHO) international growth standard was intended as an indication of how children should be growing under the best possible circumstances, irrespective of genetic influences.[1,2] These circumstances would include: no health, environmental or economic constraints; non-smoking before or after birth; minimum of exclusive 6 months' breastfeeding; term births (≥37 - <42 weeks); and single births.[1] To understand where growth faltering does occur within the growth period, and the explanatory factors that influence the faltering, local research such as that by Norris *et al.*[3] and Schoeman *et al.*[4] is important to understand growth within certain South African (SA) population groups. The current article intends to expand the knowledge base of growth in a different region of SA. The article aims to highlight why there may be plausible reasons (genetic and environmental conditions) to review the WHO growth standard, adopted in SA in 2011,[1] as an appropriate tool to analyse the growth of mixed-ancestry children younger than 5 years in SA. Although many factors influence pre- and postnatal growth, this paper focuses on ancestral genetic influences and environmental living conditions.

Currently, <100 countries worldwide use the WHO Multicentre Growth Reference Study (MGRS), which was developed from longitudinal and cross-sectional data between 1997 and 2003. The aim of the WHO was to provide a universal human growth standard to globally track the general health of children.[2] It was developed using children from six major regions of the world (including the USA, Brazil, Ghana, Oman, India and Norway) to determine whether children grew at the same rate (growth trajectory) under the best possible circumstances (optimal living conditions), irrespective of genetic influences.[2] Although the WHO growth standard is an indication of how children should grow, it is also important to determine how children do grow within a specific set of environmental and genetic influences, i.e. growth reference.[5] It may be the case that many countries, especially developing nations, possibly do not have the necessary resources (money, time, trained personnel) to develop population-specific growth references, and therefore have had to rely on the WHO growth standard.

In 2011, the SA government adopted the MGRS growth standards[1] as part of a new policy called the *Strategic Plan for Maternal, Newborn, Child and Women's Health (MNCWH) and Nutrition in SA 2012 - 2016*.[6] This was to enable fulfilment of some of the key health-related millennium development goals (MDGs),[7] which specifically dealt with health systems, child survival, maternal health, building effective primary health systems and family planning.[7] Therefore, the overarching aim of the 2011 SA policy was to improve primary healthcare for mothers and children, and for the prevention or early diagnosis of diseases/health issues. The revised Road-to-Health Booklet (RtHB) contained the MGRS 2006 growth charts (section D, point 2 of the policy).[6] The RtHB was designed to track the health of mothers and their children more holistically by including all vaccinations, booster shots, HIV and TB testing, and growth tracing.[6] It also includes advice for primary caregivers regarding breastfeeding practices, maternal interaction with children and milestones for cognitive and motor skills development (National Department of Health, 2012). It was created as an all-inclusive summary of a child's development from birth to 59 months (~5 years).

Although many countries use the MGRS, several studies in India, Peru and Vietnam,[8] the Czech Republic,[9] Central Europe,[10] China[11] and a number of other countries[12] have shown a significant difference in growth patterns of children from birth to 5 years compared with the MGRS growth standard. Studies have demonstrated that population-specific growth references are more accurate measures of growth.[10] Singhal[13] noted that while the prevention of stunting, as well as the promotion of linear growth in small-for-gestational-age or preterm children, has been shown to be beneficial for neurodevelopmental and other health outcomes, the optimal pattern of infant weight gain is likely to differ depending on the population. Natale and Rajagopalan[12] emphasise that otherwise healthy children who do not conform to the MGRS growth standard have a higher probability of misdiagnosis of malnutrition or growth disorders, and their subsequent treatment may lead to an additional burden of disease later in life. Rapid weight gain and postnatal growth acceleration in healthy, full-term infants, often in low- and middle-income country settings, have been associated with a greater risk for obesity and non-communicable diseases later in life.[13] These findings emphasise the importance of applying an appropriate growth reference for infants and children within a specific set of environmental conditions and genetic influences, to mitigate the risks of stunting and obesity.

Therefore, there may be a case for developing population-specific growth charts to better inform SA's healthcare system and policy development, to optimise child health and future preventive healthcare for at-risk populations. In this article, we address whether the MGRS is an appropriate standard for assessing the optimal growth of mixed-ancestry children younger than 5 years in an SA population group. To provide background and context, we begin with a discussion of the impact of genetic and environmental influences on early childhood growth, followed by a discussion of these factors within SA's mixed-ancestry population.

Factors that affect growth: Genetic and environmental influences

Growth is part of human development and is partly defined as the increase of bone size and body mass.[14] It is influenced by various interrelated factors such as genetics[15,16] and the living environment.[17,18] Genetic influences are the causal mechanisms that influence biological growth, resulting in the expression of certain phenotypic traits such as height and weight. These are the result of generations of factors that affect genetic admixture, including sexual selection, gene flow, genetic drift, intergenerational effects and micro-evolutionary adaptations.[14,19] The ancestral influences include micro-evolutionary causal mechanisms and intergenerational effects that may drive differences in height-for-age and weight-to-height-for-age among population groups in various ecogeographical regions of the world. One major mechanism driving body shape was thermoregulation.[20] In warmer climates, humans have adapted a more linear shape that increases the surface area-to-volume ratio, enabling greater heat dissipation compared with those living in colder climates, where the surface area has been reduced and the volume of the thorax increased to assist in heat retention, i.e. Bergmann's rule.[21] This translates to humans having longer limbs (arms and legs) in warmer climates but a stockier body shape (broader chest and shoulders) in colder climates. Another causal mechanism is the amount of exposure to ultraviolet (UV) radiation, which can affect population groups in the same topographical area. For example, within sub-Saharan Africa, the Maasai (Kenya and Tanzania) are among the tallest people in the world, whereas African pygmies (Cameroon, Gabon, Central African Republic, Democratic Republic of Congo, southern Rwanda and Nigeria) are the shortest.[22-25] According to O'dea,[26] the difference in body size between these two groups is most likely due to UV exposure. Both groups have biological adaptations that improved their survival over generations in a unique ecogeographical habitat.[27] If different population groups have significant variation in adult height,[19,21,28,29] there may be a need to further explore growth within an SA context to expand on the research of Norris *et al.*[3] and Schoeman *et al.*[4] Growth deviation among SA mixed-ancestry children from the WHO growth standard could be informative to the health sector if regression analyses of anthropometrical measurements and explanatory variables can highlight why growth deviations exist within an SA context.

In addition to genetic influences, environmental (living) conditions can impact the growth trajectory, including nutritional adequacy,[28,29] hygiene and/or exposure to disease.[30,31] During adverse living conditions, physiological maintenance is more important *in lieu* of growth.[32] Most of our height comes from the growth and development of our skeleton. However, when the primary functions of the body are prioritised to sustain life, skeletal growth is retarded, while the individual survives. While accepting the influence of genetic and intergenerational effects on linear growth, Steckel[33] has described stature as a function of access to resources, and human growth as a net measure of nutrient input (food) v. metabolic output (physical activity and disease). It has been shown that in a hostile (nutrient-deficient, disease-prone and/or high metabolic output) environment, the infancy-childhood transitional age (2 - 3 years) is deferred.[32,34,35] During this transitional change, increased growth hormone insulin-like growth factor 1 (IGF1) is released into the body.[32] This growth-stimulating hormone is known to trigger the activity of osteoblasts (bone) and chondrocytes (cartilage) to promote growth.[36] If living conditions are inadequate, the amount of IGF1 for bone and cartilage growth is reduced, negatively impacting skeletal maturation and consequently height potential. If a child's environmental conditions improve before fusion of the epiphyseal plates of their bones, they may still reach their full height potential.[37] This is known as catch-up growth, when the body accelerates growth and the child's growth trajectory is more rapid than average, making up for loss of linear growth during adverse conditions, and hence returning children to their normal growth curve.[13]

SA and the international growth standard: A case study

We explore the implications for discrepancies between the MGRS growth standard and population- or country-specific growth trajectories, particularly for the mixed-ancestry population in SA. Genetic admixture, in combination with unique sociopolitical and socioeconomic conditions, has created a unique population.[38-40] Together, these factors possibly influence growth rates and development patterns of SA children.

Using the WHO growth standard, ~40% of SA children younger than 5 years of age are stunted.[1] Conversely, the percentage of children classified as overweight in SA was twice the international average (6.1%) for the same age group. The specific concern with the use of the international MGRS in SA is the percentage of children younger than 5 years in the middle- and top-wealth quintiles

(24% and 13%, respectively), who are estimated to be stunted (below the 3rd percentile).[41] The latest SA demographic and health survey based on the MGRS growth standard, reported stunted growth for 1 in 3 boys and 1 in 4 girls.[41] It is doubtful that these children do not have access to adequate nutritional resources to sustain their growth, considering that many of them fall in the middle- and upper-wealth quintiles.[42,43] It is also unlikely that stunting in these children can be attributed to daily living conditions, i.e. disease-prone areas, inadequate sanitation/hygiene or limited access to healthcare. Rather, there might be a predisposition for shorter stature in particular population groups in SA.

In contrast to the stunting phenomenon, SA also has one of the highest obesity prevalences (twice the international average) for children younger than 5 years of age.[41] Is this because children eat poorly balanced meals or have a higher intake of energy-dense, nutrient-poor foods? According to Statistics SA, in 2015 two-thirds of the population lived below the upper-bound poverty line of ZAR992 (USD70) per person per month.[40] With such little purchasing power, most would buy cheaper staple foods such as potatoes, rice, wheat and maize products. Could this impact children's and hence adults' rates of obesity? Is there a correlation between the high percentage of obesity and an international growth standard suggesting children are stunted,[44] i.e. are the caregivers of children who are estimated to be stunted advised to increase the children's daily food intake, thus creating a greater weight-to-height-for-age ratio? To shed light on these matters, it is important to consider factors that influence the growth of children in SA.

According to the government classification system, the people of SA are divided into five population groups, i.e. black, coloured, white, Indian/Asian and other.[45] The original inhabitants of southern Africa were click-speaking foragers, generally known today as San and Khoe.[46] These inhabitants were later joined by the southern migrating agropastoral Bantu-speaking peoples (in reference to the Niger-Kordofanian phylum of African languages) from west and central Africa.[39,40,47] Genetic research shows admixture between these migrants and the people from the Niger-Congo, east Africa, the rainforest pygmies, and finally the San and Khoe in southern Africa.[40] Several different population groups reside in SA, and based on their geographical location, they have diverse genetic contributions from these four main groups. A thousand years later, colonialists from Europe (e.g. Dutch, British, French, German, Spanish) joined the genetic melting pot that forms part of the contemporary population of SA.[48]

With the arrival of Europeans and colonial rule, admixture with the local inhabitants was initially not forbidden. Later, racial segregation was introduced – first socially and then by law under apartheid.[49,50] When racial segregation became law (the Prohibition of Mixed Marriages Act No. 55 of 1949 and the Immorality Act No. 21 of 1950), the descendants from this admixture were known as coloured, a term still used by the democratically elected SA government.[45] For the purposes of this discussion, this population group will be referred to as South Africans of mixed ancestry. This term was decided upon, as their genetic heterogeneity is a more recent (*c.* 360 years) result of admixture.[35,40,49,50] Petersen *et al.*[38] described this population group as having the highest (30%) heterozygosity in the world, with the most diverse genetic admixture between individuals within the same population. They have varied genetic contributions from southern Africa – the indigenous San and Khoe, Bantu-speaking Africans, the colonial descendants and the descendants of slaves and indentured labourers brought to the region.[38,40,49,50] Geographically distinct communities also vary in the percentage contribution from the ancestral genetic input.[38,40] Some individuals sampled by Petersen *et al.*[38] showed ~64% San and/or Khoe genes.

Individuals with a high contribution of indigenous San and/or Khoe genes may be predisposed to shorter stature, as genetically these people have short stature, with men reaching an average adult height of 1.5 m.[51,52] Their linear shape and short stature have been described as biological adaptations to their ecogeographical habitat and food availability.[39,46,52,53] Contemporary San and/or Khoe children have a slow growth period in the first 10 years of their life (40% of adult body size), which is said to be a nutritional adaptation, with a notable adolescent growth spurt.[54] Therefore, their growth trajectory would be expected to differ from the MGRS growth standard. In addition to a genetic predisposition to short stature, many people in SA live in poor socioeconomic conditions. From the mid-19th century to its end, sociopolitical circumstances led to severe socioeconomic inequalities between the SA government's bureaucratically classified population groups. Consequently, many people have been impacted regarding, e.g. quality of education, income prospects, healthcare accessibility, spatial restriction and legalised marital segregation between the population groups (i.e. no admixture).[49] Of the 40% of South Africans who lived below the lower-bound poverty line of ZAR647 per person per month in 2015, 23% were individuals of mixed ancestry.[44]

Urbanisation of people may have increased their accessibility to readily available nutrient-rich food and/or medical facilities, but income levels promoting power-of-purchase have not.[55] Currently, health inequities or disparities are still commonly found among South Africans. This situation is due to social determinants of health, including social, environmental, cultural and physical factors that they are born into, grow up in, and function in throughout their lifetimes.[56,57] In summary, the lack of or limited access to resources may have created an intergenerational effect of shorter stature among certain SA population groups, even if at present the children are reared in better living conditions than in the past.[58]

Conclusion

Many factors that affect growth and the use of growth standards or references may not have been included in this article; however, the overarching aim was to stimulate a discussion pertaining to the WHO standards and its use regarding mixed-ancestry children. The data presented show the diversity of the mixed-ancestry population in SA, and that even a single local growth reference to encompass this broad genetic diversity is unlikely to be effective. Implementation of yet another growth reference will be costly; however, we suggest the need to expand the knowledge base of anthropometric data for different regions in SA in addition to factors that contribute to linear growth, and those that negatively affect it, by conducting further research in other ecogeographical areas, as demonstrated by Norris *et al.*[3] and Schoeman *et al.*[4] Such research can inform the health sector as to why, based on specific explanatory variables, children of mixed ancestry, for example, are under-performing in growth – as the MGRS states. Are these children merely predisposed to a normal shorter stature or is it truly a stunting phenomenon? If the former, using the MGRS growth standard, mixed-ancestry children could possibly have a high probability of being diagnosed as undernourished and their parents may be encouraged to increase their food intake, a factor which may contribute to the high percentage of overweight children and the possibility of an increased burden of disease later in life. Each research puzzle piece regarding children's growth can further assist paediatric clinicians and forensic pathologists with their daily duties. All things considered, these data show that investigating the optimal growth of SA mixed-ancestry children and understanding population-specific growth references would serve to better inform public health policies to address childhood health equity and developmental pathways to adult health risk status according to the MDGs in Africa.

Declaration. None.

Acknowledgements. The authors wish to thank the Department of Human Biology, University of Cape Town, for the research grant. The financial assistance of the National Research Foundation (NRF) towards this research is also hereby acknowledged.

Author contributions. We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us. We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with regard to intellectual property. In so doing, we confirm that we have followed the regulations of our respective institutions with regard to intellectual property. We further confirm that no aspect of the work covered in this manuscript has involved either experimental animals or human patients. We understand that the corresponding author is the sole contact for the editorial process (including Editorial Manager and direct communication with the office). She is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs. We confirm that we have provided a current, correct email address, which is accessible by the corresponding author and which has been configured to accept email from: victoria.gibbon@uct.ac.za

Funding. Department of Human Biology, University of Cape Town – research grant; and the National Research Foundation (NRF) – financial assistance. Opinions expressed and conclusions arrived at are those of the authors and not necessarily those of the NRF.

Conflicts of interest. None.

1. De Onis M, Onyango A, Borghi E, et al. WHO Child Growth Standards: Length/height-for-age, Weight-for-age, Weight-for-length, Weight-for-height, and Body Mass Index-for-age. Methods and Development. Geneva: WHO, 2006.
2. De Onis M, Garza C, Victora CG, et al. WHO Multicentre Growth Reference Study (MGRS): Rationale, planning and implementation. Food Nutr Bull 2004;25(Suppl 1):S1-S89.
3. Norris SA, Griffiths P, Pettifor JM, Dunger DB, Cameron N. Implications of adopting the WHO 2006 child growth standards: Case study from urban South Africa, the birth to twenty cohort. Ann Hum Biol 2009;36(1):21-27. https://doi.org/10.1080/03014460802620694
4. Schoeman S, Faber M, Adams V, et al. Adverse social, nutrition and health conditions in rural districts of the KwaZulu-Natal and Eastern Cape provinces, South Africa. S Afr J Clin Nutr 2010;23(3):140-147. https://doi.org/10.1080/16070658.2010.11734328
5. Cole TJ. The development of growth references and growth charts. Ann Hum Biol 2012;39(5):382-394. https://doi.org/10.3109/03014460.2012.694475
6. National Department of Health. Strategic Plan for Maternal, Newborn, Child and Women's Health (MNCWH) and Nutrition in South Africa 2012 - 2016. Pretoria: NDoH, 2011.
7. Millennium Development Goals (MDG) Africa Steering Group. Achieving the Millennium Development Goals in Africa: Recommendations of the MDG Africa Steering Group. New York: United Nations, 2008.
8. Fenn B, Penny ME. Using the new World Health Organization growth standards: Differences from 3 countries. J Pediatr Gastroenterol Nutr 2008;46(3):316-321. https://doi.org/10.1097/mpg.0b013e31815d6968
9. Vignerová J, Shriver L, Paulová M, et al. Growth of Czech breastfed infants in comparison with the World Health Organization standards. Cent Eur J Public Health 2015;23(1):32-38. https://doi.org/10.21101/cejph.a4204
10. Christesen HT, Pedersen BT, Pournara E, Petit IO, Júlíusson PB. Short stature: Comparison of WHO and national growth standards/references for height. PLoS ONE 2016;11(6):e0157277. https://doi.org/10.1371/journal.pone.0157277
11. Ya-Qin Z, Hui L, Hua-Hong W, et al. The 5th national survey on the physical growth and development of children in the nine cities of China: Anthropometric measurements of Chinese children under 7 years in 2015. Am J Phys Anthropol 2017;163:497-509. https://doi.org/10.1002/ajpa.23224
12. Natale V, Rajagopalan A. Worldwide variation in human growth and the World Health Organization growth standards: A systematic review. BMJ Open 2014;4:e003735. https://doi.org/10.1136/bmjopen-2013-003735
13. Singhal A. Long-term adverse effects of early growth acceleration or catch-up growth. Ann Nutr Metab 2017;70:236-240. https://doi.org/10.1159/000464302
14. Bogin B. The evolution of human growth. In: Cameron N, Bogin B, eds. Human Growth and Development. 2nd ed. Amsterdam: Elsevier, 2012:287-324.
15. Moore DD, Walker MD, Diamond DJ, Conkling MA, Goodman HM. Structure, expression, and evolution of growth hormone genes. Recent Progr Hormone Res 1982;38:197-225.
16. Weedon MN, Frayling TM. Reaching new heights: Insights into the genetics of human stature. Trends Genet 2008;24(12):595-603. https://doi.org/10.1016/j.tig.2008.09.006
17. Cowgill LW, Eleazer CD, Auerbach BM, Temple DH, Okazaki K. Developmental variation in ecogeographic body proportions. Am J Phys Anthropol 2012;148:557-570. https://doi.org/10.1002/ajpa.22072
18. Wells JCK. Ecogeographical associations between climate and human body compositions: Analyses based on anthropometry and skinfolds. Am J Phys Anthropol 2012;147:169-186. https://doi.org/10.1002/ajpa.21591
19. Giuliani C, Bacalini MG, Sazzini M, et al. The epigenetic side of human adaptation: Hypotheses, evidences and theories. Ann Hum Biol 2015;42(1):1-9. https://doi.org/10.3109/03014460.2014.961960
20. Lomolino MV, Sax DF, Riddle BR, Brown, JH. The island rule and a research agenda for studying ecogeographical patterns. J Biogeography 2006;33:1503-1510. https://doi.org/10.1111/j.1365-2699.2006.01593.x
21. Wells JCK. Ecogeographical associations between climate and human body compositions: Analyses based on anthropometry and skinfolds. Am J Phys Anthropol 2012;147:169-186. https://doi.org/10.1002/ajpa.21591
22. Galvin KA, Thornton PK, Boone RB, Sunderland J. Climate variability and impacts on east African livestock herders: The Maasai of Ngorongoro conservation area, Tanzania. Afr J Range Forage Sci 2004;21(3):183-189.
23. Jarvis JP, Scheinfeldt LB, Soi S, et al. Patterns of ancestry, signatures of natural selection, and genetic association with stature in Western African pygmies. PLoS Genet 2012;8(4):e1002641. https://doi.org/10.1371/journal.pgen.1002641
24. Patin E, Laval G, Barreiro LB, et al. Inferring the demographic history of African farmers and pygmy hunter-gatherers using a multilocus resequencing data set. PLoS Genet 2009;5(4):e1000448. https://doi.org/10.1371/journal.pgen.1000448
25. Galvin KA, Beeton TA, Boone RB, BurnSilver SB. Nutritional status of Maasai pastoralists under change. Hum Ecol 2015;43:411-424. https://doi.org/10.1007%2Fs10745-015-9749-x
26. O'Dea JD. Possible contribution of low ultraviolet light under the rainforest canopy to the small stature of pygmies and negritos. Homo 1994;44(3):284-287.
27. Dickens TE, Rahman Q. The extended evolutionary synthesis and the role of soft inheritance in evolution. Proc Royal Soc B 2012;279:2913-2921. https://doi.org/10.1098/rspb.2012.0273
28. Steckel RH. Biological measures of the standard of living. J Econ Perspect 2008;22(1):129-152. https://doi.org/10.1257/jep.22.1.129
29. Stulp G, Barrett L. Evolutionary perspectives on human height variation. Biol Rev 2016;91:206-234. https://doi.org/10.1111/brv.12165
30. Walker ARP. Nutrition-related diseases in southern Africa: With special reference to urban African populations in transition. Nutr Res 1995;15(7):1053-1094.
31. Akachi Y, Canning D. The height of women in sub-Saharan Africa: The role of health, nutrition, and income in childhood. Ann Hum Biol 2007;34(4):397-410. https://doi.org/10.1080/03014460701452868
32. Hochberg Z. Evo-devo of child growth II: Human life history and transition between its phases. Eur J Endocrinol 2009;160:135-141. https://doi.org/10.1530/eje-08-0445
33. Steckel RH. Biological measures of the standard of living. J Econ Perspect 2008;22(1):129-152. https://doi.org/10.1257/jep.22.1.129
34. Hochberg Z. Evolutionary perspective in child growth. Rambam Maimonides Med J 2011;2(3):e0057. https://doi.org/10.5041%2FRMMJ.10057
35. German A, Livshits G, Peter I, et al. Environmental rather than genetic factors determine the variation in the age of the infancy to childhood transition: A twins study. J Pediatr 2015;166:731-735. https://doi.org/10.1016/j.jpeds.2014.11.047
36. Bogin B. Background to the study of human growth. In: Bogin B, ed. Patterns of Human Growth. 2nd ed. Cambridge. Cambridge University Press, 1999:18-19.
37. Tanner JM. Catch-up growth in man. Br Med Bull 1981;37(3):233-238.
38. Petersen DC, Libiger O, Tindall EA, et al. Complex patterns of genomic admixture within southern Africa. PLoS Genet 2013;9(3):e1003309. https://doi.org/10.1371/journal.pgen.1003309
39. Busby GBJ, Band G, Si Le Q, et al. Admixture into and within sub-Saharan Africa. eLife 2016;5:e15266. https://doi.org/10.7554/elife.15266
40. Montinaro F, Busby GBJ, Gonzalez-Santos M, et al. Complex ancient genetic structure and cultural transitions in southern African populations. Genetics 2017;205:303-316. https://doi.org/10.1534/genetics.116.189209
41. National Department of Health (NDoH), Statistics South Africa (Stats SA), South African Medical Research Council (SAMRC), ICF. South Africa Demographic and Health Survey 2016: Key Indicator Report. Pretoria: NDoH, 2017.
42. Statistics South Africa. Living Conditions Survey: Living Conditions of Households in South Africa – an Analysis of Household Expenditure and Income Data using the LCS 2014/2015. Pretoria: Stats SA, 2017.

43. Rutstein SO, Johnson K. The DHS Wealth Index. DHS Comparative Reports No. 6. Maryland: ORC Macro, 2004. http://www.dhsprogram.com/topics/wealth quintiles (accessed 22 July 2020).
44. Steyn NP, Labadarios D, Maunder E, Nel J, Lombard C. Secondary anthropometric data analysis of the National Food Consumption Survey in South Africa: The double burden. Nutrition 2005;21(1):4-13. https://doi.org/10.1016/j.nut.2004.09.003
45. Statistics South Africa. Poverty Trends in South Africa: An Examination of Absolute Poverty between 2006 and 2015. Pretoria: Stats SA, 2017.
46. Morris AG, Heinze A, Chan EKF, Smith AB, Hayes VM. First ancient mitochondrial human genome from a prepastoralist southern African. Genome Biol Evol 2014;6(10):2647-2653. https://doi.org/10.1093%2Fgbe%2Fevu202
47. Liebenberg L, L'Abbè EN, Stull KE. Population differences in the postcrania of modern South Africans and the implications for ancestry estimation. Forens Sci Int 2015;257:522-529. https://doi.org/10.1016/j.forsciint.2015.10.015
48. Quintana-Murci L, Harmant C, Quach H, et al. Strong maternal Khoisan contribution to the South African coloured population: A case of gender-biased admixture. Am J Hum Genet 2010;86:611-620. https://doi.org/10.1016%2Fj.ajhg.2010.02.014
49. Petrus T, Isaacs-Martin W. The multiple meanings of coloured identity in South Africa. Africa Insight 2012;42(1):87-102.
50. Inwood K, Masakure O. Poverty and physical well-being among the coloured population in South Africa. Econ Hist Dev Regions 2013;28:2:56-82. https://doi.org/10.1080/20780389.2013.866382
51. Eideh H, Jonsson B, Hochberg Z. Growth of the Kalahari desert's bushman – the Ju/'hoansi San. Acta Pædiatr 2012;101:528-532. https://doi.org/10.1111/j.1651-2227.2011.02573.x
52. Rosa A, Brehm A. African human mtDNA phylogeography at-a-glance. J Anthropol Sci 2011;89:25-58. https://doi.org/10.4436/jass.89006
53. Uren C, Kim M, Martin AR, et al. Fine-scale human population structure in southern Africa reflects ecogeographic boundaries. Genetics 2016;204(1):303-314. https://doi.org/10.1534/genetics.116.187369
54. Walker RS, Gurven M, Hill K, et al. Growth rates and life histories in twenty-two small-scale societies. Am J Hum Biol 2006;8:295-311. https://doi.org/10.1002/ajhb.20510
55. Temple NJ, Steyn NP, Fourie J, de Villiers A. Price and availability of healthy food: A study in rural South Africa. Nutrition 2011;27:55-58. https://doi.org/10.1016/j.nut.2009.12.004
56. Statistics South Africa. Mortality and Causes of Death in South Africa, 2015: Findings from Death Notifications. Pretoria: Stats SA, 2017.
57. South Africa. National Health Act No. 61 of 2003.
58. Cole TJ. The secular trend in human physical growth: A biological view. Econ Hum Biol 2003;1:161-168. https://doi.org/10.1016/s1570-677x(02)00033-3

Accepted 28 May 2021.