HUMAN BiOLOGY AND PUBLiC HEALTH
JOURNAL OF THE AUXOLOGICAL SOCIETY

ISSN 2748-9957 | Vol. 3 2022 | pp. 1–13

Effect of body composition in the assessment of growth of Sri Lankan children and need for local references

Vithanage Pujitha Wickramasinghe[1]

[1] Department of Paediatrics, Faculty of Medicine, University of Colombo, Sri Lanka

Citation:

Wickramasinghe, V. (2022). Effect of body composition in the assessment of growth of Sri Lankan children and need for local references, Human Biology and Public Health 3. https://doi.org/10.52905/hbph2022.3.35.

Received: 2022-05-22
Accepted: 2022-12-12
Published: 2023-03-10

Conflict of interest:

There are no conflicts of interest.

Correspondence to:

Vithanage Pujitha Wickramasinghe
email: pujithaw@yahoo.com

Keywords:

assessment of growth, children, Sri Lanka, body composition and anthropometry, growth charts

Abstract

Measuring growth provides the opportunity to assess an individual's health and nutritional status as well as reflect the quality of life and social wellbeing. Global standards and references for child and adolescent growth have been adopted by many countries including Sri Lanka, but it is questionable whether these charts are appropriate. They are known to over-diagnose undernutrition and under-diagnose over-nutrition in many low-and-middle-income countries.
This article reviews the effect of body composition and ethnicity on the assessment of growth of Sri Lankan children.
Growth has been documented since early civilization. Standards and references for assessing intrauterine, infant, child and adolescent growth have evolved for regional, national, and international use. Attention has been focused on socio-economic, political, and emotional (SEPE) factors as primary determinants of growth as well as ethnicity.
Growth charts are based on the distribution of growth parameters in the population. Cut-off values are defined by statistical distributions rather than by the biological meaning of growth measurements. As most of the adverse health outcomes are related to an individual's body composition, anthropometry should correctly reflect body composition and critical cut-off values should help assessing health risks. Yet, the distributions of height, weight, and BMI of healthy children of many low-and-middle-income countries differs from the global growth standards recommended for use by the WHO, and Sri Lankan children differ and show a shift to the left. In 5- to 15-year-old healthy children height, weight, and BMI range between -3SD and +1SD. Thus, applying global standards will often lead to false estimates when defining stunting, thinness, and obesity in these children. This highlights the importance of local rather than universal growth standards. Many countries have meanwhile taken the initiative to develop national growth charts. Further, Sri Lanka needs local growth charts and relevant cut-off values for the correct assessment of height, weight and BMI.

Take-home message for students It is important to develop appropriate cut-off values for the assessment of height, weight, and BMI for Sri Lankan children.

Introduction

Physical growth is a quantitative increase in body size or mass (Bogin 2020). Measurements of growth parameters provide the opportunity to assess an individual's health and nutritional status as well as reflect the quality of life and social wellbeing. Sri Lanka as a middle-income country has shown high achievements in health indices. However, the anthropometric parameters have not improved beyond a certain point over a long period of time and since then have stagnated. The last demographic and health survey (2016) showed stunting (height-for-age) to be 17%, underweight (weight-for-age) to be 21% and wasting (weight-for-height) to be 15% (Department of Census and Statistics, Ministry of National Policies and Economic Affairs 2017). This has puzzled health authorities as well as growth physiologists because of the lack of improvement beyond this point. Many nutrition supplementation programs as well as awareness programs are being conducted to improve these indices in Sri Lanka, but with little success. The reasons for the poor improvement of the nutritional anthropometric indicators have been discussed at many forums, but a proper explanation has not been found. Apart from stunting, overweight and obesity (OW/OB) among children and adults are also increasing in the country as well as its related non-communicable disease (NCD) burden. Doubts have been cast over the use of current anthropometric indices for the diagnosis of OW/OB due to the increasing case load of NCD among metabolically unhealthy non-obese individuals (Wickramasinghe et al. 2013).

Growth assessment is mainly based on anthropometric measurements. However, a stand-alone measurement value is meaningless until it is properly interpreted. Therefore, all anthropometric measurements should be plotted on the appropriate growth charts. The outcome of the interpretation then needs to be addressed and actions should be taken.

The evolution of the Assessment of Growth

Since the early civilizations, body proportions were appreciated with careful measurements of the body at different ages. This is evident in art work, paintings and sculptures (Bogin 2020). Egyptians used a grid system to record body proportions with the help of which they were even able to accurately demonstrate growth disorders. Different stages of life were identified by ancient civilizations. Romans described "seven stages of life" paving the way for current life cycle approaches to an organism's biological development (Bogin 2020). In the 18th century, the interest in studying human growth grew in Europe and the value of collecting data was appreciated. The French Count Philibert Guéneau du Montbeillard (1720–1785) collected longitudinal data of his son born in 1759, at six-monthly intervals until 18 years of age. This is considered the first longitudinal set of human growth data and was published by George-Louie Leclerc de Buffon (1707–1788) in 1777 in the *Histoire Naturelle* (Bogin 2020). Afterwards, more and more people got interested. Tanner used these data to describe both distance charts (size) and velocity charts (growth rates).

Differential seasonal variations of height and weight, mid upper arm circumference and ponderal index were described in Europe during the 19th century. Rudolfo Livi defined the ponderal index and Quetelet described the BMI (Bogin 2020). In the second half of the 19th century, Henry

Bowditch gathered height and weight measurements from about twenty-four thousand school children and for the first time constructed percentile growth charts (Bowditch 1891).

During the early 20th century, many longitudinal cohort studies on growth were started in United States and Europe. The Fels Longitudinal Study in Yellow Springs, Ohio, from 1929 to 1970 is one of the earliest and most comprehensive studies. The director of the study, Lester W. Sontag (1901–1991), wrote "… that modern understanding of the growth, health, behavior, and effectiveness of human beings could only be understood if the nature and significance of individual characteristics of each child's physiological, biochemical, nutritional, educational, and environmental characteristics could be assessed and integrated into a total picture" (Sontag 1971). As the need for growth assessment gained importance, Howard Meredith was invited to develop a "Physical Growth Record" in 1947 (Meredith 1949). It included charts for assessing weight and height from 4 to 11 years for boys and girls based on affluent school children from Iowa, USA, in the 1940s (Meredith 1949). In the 1960s and 1970s, this study was followed by several European and US American growth charts, of which the Tanner (Tanner et al. 1966) and the Harvard growth charts (Stevenson and Stuart 1950) may explicitly been mentioned. Based on data collected in the Boston region from 1930 to 1956, sex combined Harvard curves were developed. The WHO used these growth curves later as an international reference (Jelliffe 1966). The US National Academy of Sciences recommended a new set of growth references in 1974 based on cross-sectional data from the US health and examination surveys of the National Centre for Health Statistics (NCHS) and longitudinal data from the Fels Research Institute (Hegsted et al. 1974). The NCHS and CDC joint expert group developed growth charts from birth to 18 years of age (head circumference charts for younger ages and height and weight charts for all ages) (Hamill et al. 1977; Hamill et al. 1979). References for under 2 years of age were developed using reference data produced by the Fels longitudinal study collected from 1929 to 1975 from a selected population in Ohio. Data of 2- to 18-year-old children were cross-sectionally collected in three country-wide surveys carried out in the USA by the NCHS from 1960 to 1975.

In 1975, the WHO recommended to use height and weight reference charts for nutritional surveillance (Waterlow et al. 1977). Countries that did not have local reference charts were advised to create local sets of cross-sectional data. It was recommended to measure at least 200 well-nourished children in each age and sex group and to perform measurements by trained staff using calibrated equipment (Waterlow et al. 1977). Although all of these criteria were not met, new US growth references were published by the National Academy of Science (Hegsted et al. 1974). British references were published by Tanner et al. (1966) and Dutch references by van Wieringen (1972). Nevertheless, the WHO continued to consider the NCHS/CDC charts as the most suitable for international use. Sri Lanka began to use this sex combined, WHO recommended NCHS/CDC weight-for-age chart from birth to 5 years of age for the assessment of weight (growth).

The main limitations of these charts were their confinement to an affluent white Caucasian population and that they were collected at diverse time periods, from predominantly formula fed children who started with complementary food at different ages. In 1970, Gairdner and Pearson revised the Tanner charts in the UK (Gairdner, D., Pearson, J. 1985). The 1990 growth references of the UK replaced all previous charts (Cole 1997). The NCHS/CDC 2000 charts replaced previous charts in the USA (Kuczmarski et al. 2000).

In these years, the variety of European and US American growth charts appeared disadvantageous and a need for an internationally applicable growth standard was discussed to better compare the nutritional status of children across the world. It was stated that height and weight of well-fed healthy children from different ethnic groups and continents showed only little variation in growth. This notion paved the way for the WHO to consider international growth standards based on healthy children raised under most suitable conditions. Such standards were considered to reflect optimum growth in various parts of the world. In 1996, representative samples from USA, Brazil, Oman, India, Ghana and Norway were selected and longitudinally followed up from birth to 24 months of life. Cross-sectional data were added for the ages 25 to 60 months (Borghi et al. 2006). Smoothed height and BMI-for-age growth charts for children and adolescents of both sexes aged 5 to 18 years were developed by WHO based on the 1977 NCHS data (Onis et al. 2007).

In line with adult BMI cut-off values of 25kg/m^2, and 30kg/m^2 for overweight and obesity respectively, the International Obesity Task Force developed sex specific cut-off values at six-monthly intervals for 2- to 18-year old children (Cole et al. 2000). Subsequently, BMI cut-off values to also diagnose three levels of thinness corresponding to adult BMI values of 16kg/m^2, 17kg/m^2 and 18.5kg/m^2 were added (Cole et al. 2007).

The assessment of growth in Sri Lankan children spans several decades, and it was mostly done using WHO recommended standards. Island wide uniform growth monitoring began in the 1970s with a weight-for-age chart without sex discrimination. The 50th centile for boys and 3rd centile for girls up to 5 years of age were based on WHO/NCHS standards. It aimed at detecting under-nutrition rather than over-nutrition. With the development of WHO 2006 standard, Sri Lanka incorporated the weight-for-age and length/height-for-age charts of each sex based on SD scores for under 5 growth monitoring. Head circumferences for age charts based on centiles from birth to 3 years of age also included. For children above 5 years, sex specific WHO/NCHS references were used with height-for-age charts for 5 to 11 years of age and weight-for-height charts for those who were 90 to 145cm in height. In 2014, above 5-year growth charts were replaced with height-for-age and BMI-for-age charts for monitoring of growth in 5- to 18-year-old children for each sex based on WHO 2007 references. In 2019, the centile values for occipital frontal circumference/head circumference for age was replaced by SD score.

Advances in neonatal care enabled many preterm babies to survive and grow, but the available infant growth charts were inappropriate for these babies. With an increased understanding of the impact of early growth on later health and the impact of the first 1000 days of life, growth monitoring during early days became important in the management of preterm infants. Barker's hypothesis on the fetal origin of adult disease describes the association between adverse fetal environment and the prevalence of non-communicable disease in adulthood (Barker et al. 1993; Barker and Osmond 1986; Barker et al. 1989). The "accelerated growth hypothesis" by Singhal and Lucas postulates that rapid excess growth during first year of life can lead to adverse health outcomes later (Singhal et al. 2007). The concept highlighted the importance of close monitoring of preterm growth in order to prevent the development of NCD later in life. Using North American data, Babson and Benda developed graphs for the assessment of preterm infants from

26 weeks of gestation till one year of age post term (Babson and Benda 1976). These were updated in 2003 extending to the age from 22 to 50 weeks of gestational age (Fenton 2003).

Nutrition, maternal and fetal disease, intra- as well as extra-uterine environment, and the genetic potential affect fetal growth and contribute to the differences in birth weights world-wide. Most of the prenatal growth references were developed on small samples of local populations. The INTERGROWTH-21st (Villar et al. 2014) project aimed at assessing fetal growth and newborn size using an international representative sample. Pregnant women from Brazil, Italy, Oman, UK, and USA, China, India and Kenya were recruited for a multi-center fetal growth study. This study showed similar fetal growth and birth size in the different geographical settings as long as mothers' nutrition and health are at a high level with minimum environmental constraints. Combining these data with the WHO growth standards allow for international standards from conception to birth including the assessment of preterm babies up to 6 months of post term age. Sri Lanka uses these preterm charts since 2017.

Yet, recent evidence suggests that prenatal growth of Indian children and gestational weight gain (GWG) which is the proxy measure of intrauterine growth differs from the INTERGROWTH-21st reference (Thiruvengadam et al. 2022). 26% of the mothers had a GWG <10th centile at 18–20 weeks, and 45% at time of delivery. Ethnic differences in GWG should be considered when making clinical decision (Hermanussen 2022).

Reference selection and application

Growth references are statistical summaries of anthropometry, conditioned (usually) on age and sex. References describe how children do grow, in contrast to growth standards that prescribe how children should grow (Khadilkar and Khadilkar 2011). References are descriptive and show how the children are growing according to their prevailing situation. References relate health, nutrition, and the social-economic-political-emotional situation to the reference population (Bogin 2021). International charts help to compare between different countries, socio-economic and ethnic groups, but they may over-report stunting, wasting, and underweight in many developing countries such as Sri Lanka.

It is important to consider that stunting is not a synonym of malnutrition (Scheffler et al. 2020). Thus, growth references and standards must not be used to define malnutrition (Bhutta et al. 2017; Bogin et al. 2022; Hermanussen and Wit 2017; Mumm et al. 2017). This also applies for the population of Sri Lanka. If we want to focus on malnutrition, it is important to stress that assessing an individual's health status needs specific information on nutrition. This includes information on food availability, on diet diversity, and also on body composition and measurements of body fat. The diagnosis of malnutrition cannot be based on a single anthropometric measure (Lara-Pompa et al. 2020). It should be noted that during the initial stages of life body weight often increases rapidly with notable upward crossings of several centiles. This does not necessarily reflect pathological weight gain and later risk of obesity but may rather be part of a proportionate increase of weight and height to find the correct "growth channel" particularly in children with low birth weight. Therefore, looking at the broader picture is more important rather than drawing conclusions on limited number of anthropometric measures.

Population specific growth charts are appropriate instruments for screening and diagnosing growth impairments which under certain circumstances may also reflect the nutritional status. However, this is not easy and quite an ardent and costly task for many developing countries (Sullivan et al. 1991). Population specific growth charts have synthetically been developed in various countries, e.g. for Romanian (Pascanu et al. 2016) and Indonesian children (Pulungan et al. 2018).

The effect of ethnicity on growth assessment

A study done in 2009 in India involving 2 to 5 year old children from affluent families showed mean SD scores for height, weight, and weight-for-height of -0.75 (SD 1.1), -0.59 (SD 1.1), and -0.26 (SD 1.18), respectively according to WHO 2006 standards (Khadilkar et al. 2010). Mean BMI for age SD score was –0.19 (SD 1.22). Indonesian children under 5 years have mean height SDS of boys of -2.03 and of girls of -2.03 when referred to WHO standards (Novina et al. 2020). This gives food for thought whether growth of even the most affluent children can be assessed by growth charts developed in other countries or ethnic groups. Doing so can lead to overreporting of undernutrition and underreporting of over-nutrition and in consequence to overtreatment of the undernourished, whereas the metabolic problems of the over-nourished get under-diagnosed followed by delayed management. Mismatched growth charts with cut-off values made for Western populations may well have contributed to the increase in non-communicable disease burden in South Asia.

Growth charts should assist parents and health care workers in guiding a child to achieve optimum growth. Appropriate growth references are needed as individual health management and public health decisions rely on them. Appropriate references reflect height, weight, and body composition of a healthy local population and cut-off values above and below the ‘healthy’ range that appropriately reflect the risks for impaired performance, disease, morbidity, and mortality. Anthropometry has its place as a valuable screening tool. But it is not a diagnostic tool for malnutrition. Anthropometry needs to be assessed in combination with many other factors. Anthropometric charts need to be based on the population distribution of the various parameters of interest. Single parameters do not always depict relevant information on morbidity and may lead to serious misclassification of risk factors for the single individual. This is especially true for children classified as undernourished though being active and healthy, and with good school performance (Hermanussen 2015; Scheffler et al. 2020).

Body composition as a proxy for nutritional status and health

Body composition is an important factor that is associated with morbidity (Wickramasinghe et al. 2017a). Commonly used parameters for addressing body composition are height, weight, weight-for-height (under 5 years of age), and BMI (over 5 years of age).

Body composition of South Asian populations differs from other ethnic groups of the world, independent of where they live. This is also true for migrants. The BMI for a given fat mass of South Asian children from Coventry, UK, is lower than the BMI of white children with the same body fat mass (Eyre et al. 2017). Sri Lankan children have a higher body fat content compared to their Western counterparts living in Australia for any given BMI SD score (Wickramasinghe 2011). Sri Lankan children living in their native country have significantly higher fat mass compared to Australian children of Sri Lankan (migrant) and European origin (Figure 1). Further studies showed that the differences in body composition between white Europeans and South Asian adults are apparent from early infancy (Deurenberg et al. 1998; Nightingale et al. 2011; Nightingale et al. 2013). The data suggest that not only genetics, but also the socio-economic state affect body composition and might explain the low efficacy of currently used anthropometric cut-off values for Sri Lankan children (Wickramasinghe et al. 2009). The differences in body composition showed that ethnicity specific body composition prediction equations are needed (Hussain et al. 2014; Nightingale et al. 2013; Wickramasinghe et al. 2005a). The UK CHASE study showed that UK South Asian children are more obese whereas African Caribbeans are less obese than white Europeans (Nightingale et al. 2011). The body fat content is not well represented by the BMI and stresses that BMI cut-off points need to be ethnicity specific (Eyre et al. 2017). The manifestation of obesity may be of genetic origin (Stanfield et al. 2012) or due to social-economic-political-emotional (SEPE) factors (Bogin et al. 2022; Wickramasinghe et al. 2009).

Current BMI cut-off values of 5- to 15-year old children have poor sensitivity for diagnosing obesity in Australian children of Sri Lankan (migrants) and European origin (Wickramasinghe et al. 2005b), as well as native Sri Lankan children (Wickramasinghe et al. 2008). Hattori chart-based analyses of the fat mass distribution of Sri Lankan children shows that the increase in fat mass is out of proportion to the increase in fat free mass (Wickramasinghe 2012). When Sri Lankan children grow, they increase the fat mass more than the fat free mass. Current BMI cut-off values under-estimate excess fat mass and under-diagnose obesity in Sri Lankan children. Western studies have shown that the non-communicable disease risk varies between a fat percentage of 20–25% in boys and 25–32% in girls (Dwyer and Blizzard 1996; Lohman 1989; Williams et al. 1992). For Sri Lankan children based on the risk of developing metabolic syndrome, percentage fat mass was defined to be 28.6% for boys and 33.8% for girls (Wickramasinghe et al. 2017a). Recent considerations on statistical artefacts when assessing BMI z-scores in short and tall child populations of various age emphasize that the prevalence of thinness, overweight and obesity depends on height and age and is particularly affected in the short populations (Hermanussen et al. 2022). Particularly abdominal fat is an influential risk factor for obesity related metabolic derangements. Waist circumference appears to be a suitable measure to identify abdominal obesity and is used by the International Diabetes Federation as an absolute criterion in the diagnosis of the metabolic syndrome at all ages (Alberti et al. 2006; Zimmet et al. 2007). Age, sex and ethnic specific cut-off values for waist circumference are provided by IDF in the diagnosis of metabolic syndrome (International Diabetes Federation 2007). Standardized waist to hip circumferences and waist circumference to height ratios were also explored. The waist to hip circumference ratio did not show good associations with metabolic derangements in Sri Lankan children (Silva et al. 2006), whereas the waist circumference to height ratio showed good correlations (Wickramasinghe et al.

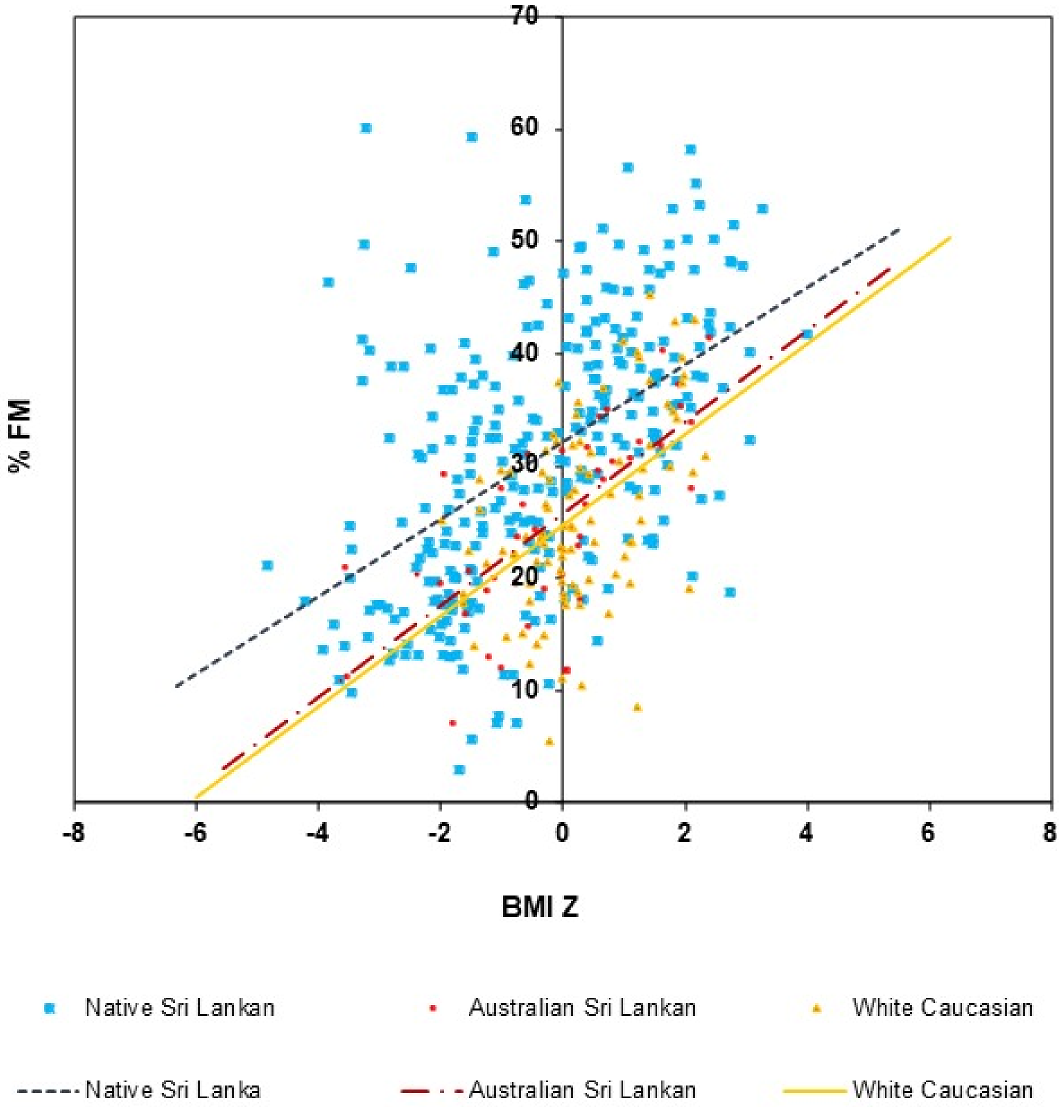

Figure 1 Effect of ethnicity and socioeconomic status on body fat mass of Australian and Sri Lankan children

2017b). Cut-off values of 0.5 and 0.45 appear to detect the metabolic syndrome, respectively at least two metabolic derangements, with high sensitivity and specificity (Wickramasinghe et al. 2017b). Therefore, BMI and the waist circumference to height ratio can be used as an appropriate screening tool in public health settings, although assessments of body composition would further improve the evaluation of the nutritional status.

The assessment of growth in Sri Lankan children

Growth monitoring has been an integral part of maternal and child health programs of Sri Lanka. Up to 5 years of age, growth parameters are usually monitored either at Medical Officer of Health (MOH) clinics or at mobile weighing posts. The practice is to measure weight every month till the completion of 2 years and at three-monthly intervals thereafter until 5 years of age. During the first year of life, it is recommended to measure length at 4 and 9 months – that is the time of the routine immunization – and at half annual intervals thereafter. Usually, growth during the first year of life is regularly monitored parallel with visiting the primary health care facility for routine child vaccination. Mobile weighing posts in the community have additionally increased the compliance for growth monitoring, with trained volunteers assisting the public health midwives and inviting parents to bring their children on a routine schedule. Weight-for-length/height is plotted at six-monthly intervals. Attention should be paid to centile crossings of weight-for-length/height, not to overlook under- and overweight/obesity. Growth monitoring in Sri Lanka identified many children with growth faltering at an early age, particularly infants between 4 and 6 months, and allowed for complimentary feeding already before 6 months of age. Growth monitoring makes even parents aware of growth deviations and let them seek medical advice. Yet, it should be stressed that currently recommended cut-off levels of less than -2SD for height-, weight- and BMI-for-age are statistical definitions and may not be mistaken as relevant indicators of malnutrition in the child population of Sri Lanka. The distributions of height, weight and BMI of healthy Sri Lankan children show a shift to the left when compared with WHO standards. Wickramasinghe and Samaranayake (2016) showed in 5- to 15-year-old healthy children that these parameters ranged between -3SD and +1SD. Thus, applying WHO standards often leads to false estimates when defining stunting, thinness, and obesity in these children and highlights the necessity for local growth references.

We advise to measure weight of school children at least once in 3 months and height at least once in 6 months. Formal programs occur at school medical inspections at grades 1 (5 years of age), 4 (8 years of age) and 7 (11 years of age). The primary and secondary school curriculum enforces growth monitoring. Children above the age of 10 years (secondary school) are empowered to monitor height, weight, and BMI and to have these data plotted and interpreted on relevant growth charts. Secondary school children are also empowered to correctly measure their waist circumference as an indicator of abdominal obesity. This has eliminated the need for calculating the BMI. A waist circumference-to-height ratio of <0.5 is considered normal.

Local standards are necessary

The Indian Academy of Paediatrics updated its national growth charts in 2021 based on new representative growth data from the whole of India (Khadikar et al. 2021). Growth of Asian children differs from that of children of European origin (El-Mouzan et al. 2007; Khadikar et al. 2021; Novina et al. 2020; Zong and Li 2013). Also Sri Lankan children need to have their own growth charts or at least validate the new Indian growth charts for the assessing growth in 5–18-year old children from Sri Lanka.

References

Alberti, K. G./Zimmet, P./Shaw, J. (2006). Metabolic syndrome-a new world-wide definition. A Consensus Statement from the International Diabetes Federation. Diabetic Medicine 23 (5), 469–480. https://doi.org/10.1111/j.1464-5491.2006.01858.x.

Babson, S. G./Benda, G. I. (1976). Growth graphs for the clinical assessment of infants of varying gestational age. The Journal of Pediatrics 89 (5), 814–820. https://doi.org/10.1016/s0022-3476(76)80815-3.

Barker, D. J./Gluckman, P. D./Godfrey, K. M./Harding, J. E./Owens, J. A./Robinson, J. S. (1993). Fetal nutrition and cardiovascular disease in adult life. Lancet 341 (8850), 938–941. https://doi.org/10.1016/0140-6736(93)91224-a.

Barker, D. J./Osmond, C. (1986). Infant mortality, childhood nutrition, and ischaemic heart disease in England and Wales. Lancet 1 (8489), 1077–1081. https://doi.org/10.1016/s0140-6736(86)91340-1.

Barker, D. J./Winter, P. D./Osmond, C./Margetts, B./Simmonds, S. J. (1989). Weight in infancy and death from ischaemic heart disease. Lancet 2 (8663), 577–580. https://doi.org/10.1016/s0140-6736(89)90710-1.

Bhutta, Z. A./Berkley, J. A./Bandsma, R. H. J./Kerac, M./Trehan, I./Briend, A. (2017). Severe childhood malnutrition. Nature Reviews Disease Primers 3, 17067. https://doi.org/10.1038/nrdp.2017.67.

Bogin, B. (2020). Patterns of Human Growth. Cambridge University Press.

Bogin, B. (2021). Social-Economic-Political-Emotional (SEPE) factors regulate human growth. Human Biology and Public Health 1, 20. https://doi.org/10.52905/hbph.v1.10.

Bogin, B./Hermanussen, M./Scheffler, C. (2022). Bergmann's rule is a "just-so" story of human body size. Journal of Physiological Anthropology 41 (1), 15. https://doi.org/10.1186/s40101-022-00287-z.

Borghi, E./Onis, M. de/Garza, C./Broeck, J. van den/Frongillo, E. A./Grummer-Strawn, L./Buuren, S. van/Pan, H./Molinari, L./Martorell, R./Onyango, A. W./Martines, J. C./Group, W. H. O. Multicentre Growth Reference Study (2006). Construction of the World Health Organization child growth standards: selection of methods for attained growth curves. Statistics in Medicine 25 (2), 247–265. https://doi.org/10.1002/sim.2227.

Bowditch, H. P. (1891). The growth of children studied by Galton's method of percentile grades. Boston.

Cole, T. J. (1997). Growth monitoring with the British 1990 growth reference. Archives of Disease in Childhood 76 (1), 47–49. https://doi.org/10.1136/adc.76.1.47.

Cole, T. J./Bellizzi, M. C./Flegal, K. M./Dietz, W. H. (2000). Establishing a standard definition for child overweight and obesity worldwide: international survey. The BMJ 320 (7244), 1240–1243. https://doi.org/10.1136/bmj.320.7244.1240.

Cole, T. J./Flegal, K. M./Nicholls, D./Jackson, A. A. (2007). Body mass index cut offs to define thinness in children and adolescents: international survey. The BMJ 335 (7612), 194. https://doi.org/10.1136/bmj.39238.399444.55.

Department of Census and Statistics, Ministry of National Policies and Economic Affairs (2017). Sri Lanka demographic and health survey 2016.

Deurenberg, P./Yap, M./van Staveren, W. A. (1998). Body mass index and percent body fat: a meta analysis among different ethnic groups. International Journal of Obesity and Related Metabolic Disorders 22 (12), 1164–1171. https://doi.org/10.1038/sj.ijo.0800741.

Dwyer, T./Blizzard, C. L. (1996). Defining obesity in children by biological endpoint rather than population distribution. International Journal of Obesity and Related Metabolic Disorders 20 (5), 472–480. Available online at https://www.ncbi.nlm.nih.gov/pubmed/8696427.

El-Mouzan, M. I./Al-Herbish, A. S./Al-Salloum, A. A./Qurachi, M. M./Al-Omar, A. A. (2007). Growth charts for Saudi children and adolescents. Saudi Medical Journal 28 (10), 1555–1568. Available online at https://www.ncbi.nlm.nih.gov/pubmed/17914520.

Eyre, E. L. J./Duncan, M. J./Nevill, A. (2017). South Asian children have increased body fat in comparison to white children at the same body mass index. Children 4 (11). https://doi.org/10.3390/children4110102.

Fenton, T. R. (2003). A new growth chart for preterm babies: Babson and Benda's chart updated with recent data and a new format. BMC Pediatrics 3, 13. https://doi.org/10.1186/1471-2431-3-13.

Gairdner, D., Pearson, J. (1985). Revised Gairdner-Pearson growth charts. Archives of Disease in Childhood 60, 1202–1206.

Hamill, P. V./Drizd, T. A./Johnson, C. L./Reed, R. B./Roche, A. F. (1977). NCHS growth curves for children birth-18 years. United States. Vital and Health Statistics Series 11 (165), i-iv, 1–74. Available online at https://www.ncbi.nlm.nih.gov/pubmed/611680.

Hamill, P. V./Drizd, T. A./Johnson, C. L./Reed, R. B./Roche, A. F./Moore, W. M. (1979). Physical growth: National Center for Health Statistics percentiles. The American Journal of Clinical Nutrition 32 (3), 607–629. https://doi.org/10.1093/ajcn/32.3.607.

Hegsted, D. M./Darby, W. J./Filer, L. J., Jr./Shank, R. E. (1974). Comparison of body weights and lengths or heights of groups of children. Nutrition Reviews 32 (9), 284–288. https://doi.org/10.1111/j.1753-4887.1974.tb00977.x.

Hermanussen, M. (2015). Absolute or relative measures of height and weight? An editorial. European Journal of Clinical Nutrition 69 (6), 647–648. https://doi.org/10.1038/ejcn.2015.70.

Hermanussen, M. (2022). Pregnant women need local references for gestational weight gain – an editorial. European Journal of Clinical Nutrition 76 (6), 781–782. https://doi.org/10.1038/s41430-022-01113-6.

Hermanussen, M./Novine, M./Scheffler, C./Groth, D. (2022). The arithmetic dilemma when defiining thinness, overweight and obesity in stunted populations. Human Biology and Public Health 1. https://doi.org/10.52905/hbph2022.1.21.

Hermanussen, M./Wit, J. M. (2017). How much nutrition for how much growth? Hormone Research in Paediatrics 88 (1), 38–45. https://doi.org/10.1159/000454832.

Hussain, Z./Jafar, T./Zaman, M. U./Parveen, R./Saeed, F. (2014). Correlations of skin fold thickness and validation of prediction equations using DEXA as the gold standard for estimation of body fat composition in Pakistani children. BMJ Open 4 (4), e004194. https://doi.org/10.1136/bmjopen-2013-004194.

International Diabetes Federation (2007). The IDF consensus definition of the metablic syndrome in children and adolescents. Brussels, IDF Communication.

Jelliffe, D. B. (1966). The assessment of the nutritional status of the community (with special reference to field surveys in developing regions of the world). Monograph series. World Health Organization 53, 3–271. Available online at https://www.ncbi.nlm.nih.gov/pubmed/4960818.

Khadikar, V./Khadilkar, A. V./Lohiya, N. N./Karguppikar, M. B. (2021). Extended growth charts for Indian children. Journal of Pediatric Endocrinology and Metabolism 34 (3), 357–362. https://doi.org/10.1515/jpem-2020-0573.

Khadilkar, V. V./Khadilkar, A. V./Chiplonkar, S. A. (2010). Growth performance of affluent Indian preschool children: a comparison with the new WHO growth standard. Indian Pediatrics 47 (10), 869–872. https://doi.org/10.1007/s13312-010-0147-6.

Khadilkar, V./Khadilkar, A. (2011). Growth charts: A diagnostic tool. Indian Journal of Endocrinology and Metabolism 15 Suppl 3, S166-71. https://doi.org/10.4103/2230-8210.84854.

Kuczmarski, R. J./Ogden, C. L./Grummer-Strawn, L. M./Flegal, K. M./Guo, S. S./Wei, R./Mei, Z./Curtin, L. R./Roche, A. F./Johnson, C. L. (2000). CDC growth charts: United States. Advance data from vital and health statistics (314), 1–27. Available online at https://www.ncbi.nlm.nih.gov/pubmed/11183293.

Lara-Pompa, N. E./Hill, S./Williams, J./Macdonald, S./Fawbert, K./Valente, J./Kennedy, K./Shaw, V./Wells, J. C./Fewtrell, M. (2020). Use of standardized body composition measurements and malnutrition screening tools to detect malnutrition risk and predict clinical outcomes in children with chronic conditions. The American Journal of Clinical Nutrition 112 (6), 1456–1467. https://doi.org/10.1093/ajcn/nqaa142.

Lohman, T. G. (1989). The prevalence of obesity in children in the United States. Chmapaign, IL, Human Kinetics, Monogram.

Meredith, H. V. (1949). A physical growth record for use in elementary and high schools. American Journal of Public Health and the Nation's Health 39 (7), 878–885. https://doi.org/10.2105/ajph.39.7.878.

Mumm, R./Czernitzki, A. F./Bents, D./Musalek, M. (2017). Socioeconomic situation and growth in infants and juveniles. Anthropologischer Anzeiger 74 (2), 101–107. https://doi.org/10.1127/anthranz/2017/0706.

Nightingale, C. M./Rudnicka, A. R./Owen, C. G./Cook, D. G./Whincup, P. H. (2011). Patterns of body size and adiposity among UK children of South Asian, black African-Caribbean and white European origin: Child Heart And health Study in England (CHASE Study). International Journal of Epidemiology 40 (1), 33–44. https://doi.org/10.1093/ije/dyq180.

Nightingale, C. M./Rudnicka, A. R./Owen, C. G./Donin, A. S./Newton, S. L./Furness, C. A./Howard, E. L./Gillings, R. D./Wells, J. C./Cook, D. G./Whincup, P. H. (2013). Are ethnic and gender specific equations needed to derive fat free mass from bioelectrical impedance in children of South asian, black african-Caribbean and white European origin? Results of the assessment of body composition in children study. PLoS One 8 (10), e76426. https://doi.org/10.1371/journal.pone.0076426.

Novina, N./Hermanussen, M./Scheffler, C./Pulungan, A. B./Ismiarto, Y. D./Andriyana, Y./Biben, V./Setiabudiawan, B. (2020). Indonesian National Growth Reference Charts Better Reflect Height and Weight of Children in West Java, Indonesia, than WHO Child Growth Standards. Journal of Clinical Research in Pediatric Endocrinology 12 (4), 410–419. https://doi.org/10.4274/jcrpe.galenos.2020.2020.0044.

Onis, M. de/Onyango, A. W./Borghi, E./Siyam, A./Nishida, C./Siekmann, J. (2007). Development of a WHO growth reference for school-aged children and adolescents. Bulletin of the World Health Organization 85 (9), 660–667. https://doi.org/10.2471/blt.07.043497.

Pascanu, I./Pop, R./Barbu, C. G./Dumitrescu, C. P./Gherlan, I./Marginean, O./Preda, C./Procopiuc, C./Vulpoi, C./Hermanussen, M. (2016). Development of synthetic growth charts for Romanian population. Acta Endocrinologica 12 (3), 309–318. https://doi.org/10.4183/aeb.2016.309.

Pulungan, A. B./Julia, M./Batubara, J. R. L./Hermanussen, M. (2018). Indonesian national synthetic growth charts. Acta Scientific Paediatrics 1 (1), 15. Available online at https://www.actascientific.com/ASPE/pdf/ASPE-01-0006.pdf (accessed 2/3/2023).

Scheffler, C./Hermanussen, M./Bogin, B./Liana, D. S./Taolin, F./Cempaka, Pmvp/Irawan, M./Ibbibah, L. F./Mappapa, N. K./Payong, M. K. E./Homalessy, A. V./Takalapeta, A./Apriyanti, S./Manoeroe, M. G./Dupe, F. R./Ratri, R. R. K./Touw, S. Y./K, P. V./Murtani, B. J./Nunuhitu, R./Puspitasari, R./Riandra, I. K./Liwan, A. S./Amandari, P./Permatasari, A. A. I./Julia, M./Batubara, J./Pulungan, A. (2020). Stunting is not a synonym of malnutrition. European Journal of Clinical Nutrition 74 (3), 377–386. https://doi.org/10.1038/s41430-019-0439-4.

Silva, K. S. de/Wickramasinghe, V. P./Gooneratne, I. N. (2006). Metabolic consequences of childhood obesity-a preliminary report. Ceylon Medical Journal 51 (3), 105–109. https://doi.org/10.4038/cmj.v51i3.1253.

Singhal, A./Cole, T. J./Fewtrell, M./Kennedy, K./Stephenson, T./Elias-Jones, A./Lucas, A. (2007). Promotion of faster weight gain in infants born small for gestational age: is there an adverse effect on later blood pressure? Circulation 115 (2), 213–220. https://doi.org/10.1161/CIRCULATIONAHA.106.617811.

Sontag, L. W. (1971). The history of longitudinal research: implications for the future. Child Development 42 (4), 987–1002. Available online at https://www.ncbi.nlm.nih.gov/pubmed/4945427.

Stanfield, K. M./Wells, J. C./Fewtrell, M. S./Frost, C./Leon, D. A. (2012). Differences in body composition between infants of South Asian and European ancestry: the London Mother and Baby Study. International Journal of Epidemiology 41 (5), 1409–1418. https://doi.org/10.1093/ije/dys139.

Stevenson, S. S./Stuart, H. C. (1950). Paranatal factors affecting adjustment in childhood. American Journal of Diseases of Children 79 (5), 931–934. Available online at https://www.ncbi.nlm.nih.gov/pubmed/15410693.

Sullivan, K./Trowbridge, F./Gorstein, J./Pradilla, A. (1991). Growth references. Lancet 337 (8754), 1420–1421. https://doi.org/10.1016/0140-6736(91)93113-n.

Tanner, J. M./Whitehouse, R. H./Takaishi, M. (1966). Standards from birth to maturity for height, weight, height velocity, and weight velocity: British children, 1965. I. Archives of Disease in Childhood 41 (219), 454–471. https://doi.org/10.1136/adc.41.219.454.

Thiruvengadam, R./Desiraju, B. K./Natchu, U. C. M./Wadhwa, N./Sachdeva, K./Misra, S./Parmar, N./Juyal, M./Mittal, P./Bharti, R./Tripathi, R./Ramji, S./Sachdev, H. S./Bhatnagar, S./GARBH–Ini study team (2022). Gestational weight gain trajectories in GARBH-Ini pregnancy cohort in North India and a comparative analysis with global references. European Journal of Clinical Nutrition 76 (6), 855–862. https://doi.org/10.1038/s41430-021-01040-y.

van Wieringen, J. C. (1972). Secular Changes of Growth. 1964–1966 height and weight surveys in the Netherlands.

Villar, J./Papageorghiou, A. T./Pang, R./Ohuma, E. O./Cheikh Ismail, L./Barros, F. C./Lambert, A./Carvalho, M./Jaffer, Y. A./Bertino, E./Gravett, M. G./Altman, D. G./Purwar, M./Frederick, I. O./Noble, J. A./Victora, C. G./Bhutta, Z. A./Kennedy, S. H./International, Fetal/Newborn Growth Consortium for the 21st, Century (2014). The likeness of fetal growth and newborn size across non-isolated populations in the INTERGROWTH-21st Project: the Fetal Growth Longitudinal Study and Newborn Cross-Sectional Study. Lancet Diabetes Endocrinol 2 (10), 781–792. https://doi.org/10.1016/S2213-8587(14)70121-4.

Waterlow, J. C./Buzina, R./Keller, W./Lane, J. M./Nichaman, M. Z./Tanner, J. M. (1977). The presentation and use of height and weight data for comparing the nutritional status of groups of children under the age of 10 years. Bulletin of the World Health Organization 55 (4), 489–498. Available online at https://www.ncbi.nlm.nih.gov/pubmed/304391.

Wickramasinghe, V. P. (2011). Body composition of Sri Lankan children: Effects of ethnicity. Sri Lanka Journal of Child Health 40 (3), 89–104.

Wickramasinghe, V. P. (2012). Hattori chart based evaluation of body composition and its relation to body mass index in a group of Sri Lankan children. Indian Journal of Pediatrics 79 (5), 632–639. https://doi.org/10.1007/s12098-011-0615-6.

Wickramasinghe, V. P./Arambepola, C./Bandara, P./Abeysekera, M./Kuruppu, S./Dilshan, P./Dissanayake, B. S. (2013). Distribution of obesity-related metabolic markers among 5–15 year old children from an urban area of Sri Lanka. Annals of Human Biology 40 (2), 168–174. https://doi.org/10.3109/03014460.2012.753109.

Wickramasinghe, V. P./Arambepola, C./Bandara, P./Abeysekera, M./Kuruppu, S./Dilshan, P./Dissanayake, B. S. (2017a). Defining obesity using a biological end point in Sri Lankan children. Indian Journal of Pediatrics 84 (2), 117–123. https://doi.org/10.1007/s12098-016-2191-2.

Wickramasinghe, V. P./Arambepola, C./Bandara, P./Abeysekera, M./Kuruppu, S./Dilshan, P./Dissanayake, B. S. (2017b). Use of waist to height ratio in assessing metabolic derangements among normal and overweight/obese 5–15 year old individuals. Ceylon Journal of Medical Sciences 54 (1), 9. https://doi.org/10.4038/cjms.v54i1.4813.

Wickramasinghe, V. P./Cleghorn, G. J./Edmiston, K. A./Davies, P. S. (2005a). Impact of ethnicity upon body composition assessment in Sri Lankan Australian children. Journal of Paediatrics and Child Health 41 (3), 101–106. https://doi.org/10.1111/j.1440-1754.2005.00558.x.

Wickramasinghe, V. P./Cleghorn, G. J./Edmiston, K. A./Murphy, A. J./Abbott, R. A./Davies, P. S. (2005b). Validity of BMI as a measure of obesity in Australian white Caucasian and Australian Sri Lankan children. Annals of Human Biology 32 (1), 60–71. https://doi.org/10.1080/03014460400027805.

Wickramasinghe, V. P./Lamabadusuriya, S. P./Cleghorn, G. J./Davies, P. S. (2008). Assessment of body composition in Sri Lankan children: validation of a skin fold thickness equation. Ceylon Medical Journal 53 (3), 83–88. https://doi.org/10.4038/cmj.v53i3.247.

Wickramasinghe, V. P./Lamabadusuriya, S. P./Cleghorn, G. J./Davies, P. S. (2009). Validity of currently used cutoff values of body mass index as a measure of obesity in Sri Lankan children. Ceylon Medical Journal 54 (4), 114–119. https://doi.org/10.4038/cmj.v54i4.1451.

Wickramasinghe, V. P./Samaranayake, D. B. (2016). Growth charts: do they reflect healthy growth in Sri Lankan children? BMC Research Notes 9, 208. https://doi.org/10.1186/s13104-016-2016-4.

Williams, D. P./Going, S. B./Lohman, T. G./Harsha, D. W./Srinivasan, S. R./Webber, L. S./Berenson, G. S. (1992). Body fatness and risk for elevated blood pressure, total cholesterol, and serum lipoprotein ratios in children and adolescents. American Journal of Public Health 82 (3), 358–363. https://doi.org/10.2105/ajph.82.3.358.

Zimmet, P./Alberti, K. G./Kaufman, F./Tajima, N./Silink, M./Arslanian, S./Wong, G./Bennett, P./Shaw, J./Caprio, S./Group, I. D. F. Consensus (2007). The metabolic syndrome in children and adolescents – an IDF consensus report. Pediatric Diabetes 8 (5), 299–306. https://doi.org/10.1111/j.1399-5448.2007.00271.x.

Zong, X. N./Li, H. (2013). Construction of a new growth references for China based on urban Chinese children: comparison with the WHO growth standards. PLoS One 8 (3), e59569. https://doi.org/10.1371/journal.pone.0059569.