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Evolution of growth charts in India

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Abstract

Growth charts are graphical representations of centile or standard deviation curves prepared from population-based studies. Growth charts are derived from large numbers of children either cross-sectionally or longitudinally. The variation in anthropometric measures amongst individuals of different ethnicities requires specific charts also for Indian children and need to be updated to reflect secular trends. Growth charts in India have come a long way from the development of first ones in the mid-1940s by National Institute of Nutrition (NIN) to Paediatrician Friendly IAP growth charts with mid-parental height and BMI tool. Indian BMI charts recommend overweight and obesity cut-offs for children to the adult equivalents of 23 and 27kg/m^2 to prevent the under-diagnosis of obesity. Indian growth charts have been published for upper:lower segment ratios, Turner syndrome, waist circumference, height velocity and sitting height.

Take-home message for students Growth charts are the most valuable tool to monitor growth and detect growth disorders at an early state. It is important that health care workers use and interpret growth charts. The lack of national growth references in many low-and-middle-income- countries poses significant challenges to their national health care systems.

Introduction

Anthropometry refers to the measurement of the human body. It characterizes physical properties of the human body including body length and weight, various circumferences, skinfold thickness, skeletal measures, proportions, etc. (Özkoçak, 2019). Measurements of patterns of growth lead to the construction of Growth charts which are graphical representations of growth, providing centile or standard deviation curves based on population studies. Growth charts are derived from large numbers of children either cross-sectionally or longitudinally. The variation in anthropometric measures amongst individuals of different ethnicities requires specific growth charts also for Indian children. Growth references describe how children do grow; growth standards describe how children should grow (de Onis et al., 2004). References need to be regularly updated to reflect trends in height, weight and other anthropometric variables. When these anthropometric measures are collected from a large number of children in a cross-sectional or longitudinal manner, a set pattern of growth is recognized that led to the development of growth charts.

Growth and growth charts

Growth means net increase in size or mass of tissues. Skeletal growth lasts till the child matures into an adult. Various factors like the genetic potential, sex, hormones, nutrition, infections, socio-economic-political-emotional factors (SEPE) (Bogin, 2021) as well as cultural factors and their interplay play a significant role in determining growth of an individual (Agarwal et al., 2015). Despite the fact that the growth pattern of every individual is unique, a certain order in direction (cephalocaudal and distal to proximal) and the timing in the acceleration of growth velocity (early postnatal, puberty) is noted. The study of growth in children is of prime importance as it can be a most reliable parameter of health and disease in a child. If the anthropometric measurements of a child are recorded over a period of time and marked on a growth chart, deviations from normal pattern for that age can be interpreted. Just like under-five mortality is related to the health status of a nation, the growth chart of a child mirrors health and disease and hence has also been referred as a **Road to Health** (Cole, 2012). Growth charts serve as the standard accepted way to monitor growth, to diagnose disease and monitor improvement.

Method to prepare growth charts

Growth charts are graphical representations of growth providing centile or standard deviation curves based on population studies. Growth charts are derived from large numbers of children either cross-sectionally or longitudinally. Modern sophisticated statistical methods are used to generate growth charts. Smoothening of centile curves is performed using various methods e.g., cubic spline method (Nummi and Mesue, 2013), lambda-mu-sigma (LMS) method (Cole, 2012), quantile regression (Wei et al., 2006), or by synthetic growth charts (Hermanussen et al., 2016) etc. to mention a few. The steps in brief to prepare a growth chart are:

1. Select a representative sample of the population for which growth chart is being prepared.

2. Anthropometry methods: Select the parameters for which growth charts are being prepared. Usually height, weight and head circumference (only for children less than 5 years) are measured. Select a standardized method of recording anthropometric measures. For example, the WHO MGRS (Multicenter Growth Reference Study) (WHO, n.d.) used UNICEF Electronic Scale 890 calibrated to 0.1 kg to measure weight, and Harpenden Infantometer and Stadiometer to measure height (WHO, 2006).
3. Sample Description: Describe the sample which has been used to generate the growth chart and specify its characteristics and exclusions.
4. Data Cleaning and Exclusion: In depth data cleaning is performed using validation reports and descriptive statistics. Again, using the example of WHO MGRS, it excluded observations falling beyond +3 SD and below -3 SD (de Onis et al., 2004).
5. Statistical Method to Construct the Growth Curve: Johnson's SU (Johnson, 1949), Box-Cox-Power-Exponential (Box and Cox, 1964) and modulus-exponential-normal are methods available to test the distribution (Royston and Wright, 1998). Smoothing techniques available include cubic spline and fractional polynomials (Borghi et al., 2006). Amongst the two, cubic spline is proven to be the more efficient smoothing technique. A spline can be described as a piece-wise polynomial where coefficients of each polynomial are fixed between joints. The coefficients that are chosen match the function and its first and second derivative at each joint. Instead of requiring a spline to coincide with function at specified points, it may be chosen to pass closer to allow certain degree of smoothening.

Centile spacing

To interpret the distribution of anthropometry on the chart, a median along with a set of centiles mirroring each other on both sides like 3^{rd}- 97^{th}, 10^{th}- 90^{th} and 25^{th}- 75^{th} are provided. Standard deviations can be used in place of centiles with zero as mean and -1 & +1SD, -2 & +2SD and -3 & +3SD as used by WHO MGRS 2006 standards. A correlation between two formats can be obtained by spacing two centiles lines $2/3^{rd}$ SD apart, as suggested by Cole in 1994 (Cole, 1994). The WHO recommends the use of Generalized Additive Models for Location, Scale and Shape (GAMLSS) for constructing centile lines. It is based on the LMS method used by Cole and Green in 1992 (Cole and Green, 1992) in which an assumption was made that measures at each age can be converted to normal distribution using Box-Cox power λ, coefficient of variation σ and median μ. They change smoothly with age and show the variation in underlying distribution. The curves are named as L=age-changing skewness, M=median, S=change in fractional standard deviations with age.

Growth reference and growth standard

Growth Reference: Growth references describe how children do grow (de Onis et al., 2004). A growth reference is descriptive. It is a summary of anthropometric measures which is presented as frequency distribution at variable ages and usually includes mean values, medians, standard deviations and centiles. Growth references are representative of a particular geographic location at a specific time and allow studying secular trends of height, weight and other parameters. Growth references need to be updated regularly.

Growth Standard: Growth standards describe how children should grow (de Onis et al., 2004). A growth standard is prescriptive and prepared from a healthy population under optimum conditions. It is an aspirational model for many populations living in relative poverty. An example of growth standards are the WHO MGRS 2006 charts.

Caution needs to be exercised when using WHO growth standards and references for Indian children. A growing body of evidence suggests that WHO MGRS standards may not be applicable all the countries in the world. They over-diagnose stunting and wasting in apparently healthy, but short stature populations and may lead to over-referral.

Distance and velocity charts

A growth chart is a graphic design where reference is visually displayed for clinical use. It consists of series of centile lines.

Distance Chart: Distance charts are usually obtained from cross-sectional data. The anthropometric measures of a person when plotted on a distance chart can be described in terms of centiles. For example, a 7-year-old Indian boy weighing 20 kg falls between 25^{th}-50^{th} centile on an Indian reference for that particular age and sex (Indian Academy of Pediatrics Growth Charts Committee et al., 2015). It indicates the **Distance** travelled by him along the growth road till that age. Plotting many measures of the same child over a period of time visualizes the growth curve of this child. Growth parallel to the centile lines indicates average growth velocity. Crossing centiles up or downward indicates faster or slower than average growth velocity. As distance charts do not quantify growth velocity because centile crossing is uncalibrated, velocity charts have been introduced

Velocity Chart: Velocity charts are usually obtained from longitudinal data and depict centiles for annual height, weight, or BMI increments. The term **growth tempo** refers to the pace of maturation (the biological age) in relation to chronological time. Children with an accelerated tempo mature earlier than average, children with a delayed tempo mature later than average (Hermanussen and Scheffler, 2022).

History of growth charts in India

1. PC Mahalanobis made pioneering studies in anthropometry in India. He is considered the father of modern statistics in India and he also founded the Indian Statistical Institute (ISI). His birthday (29 June) is celebrated as National Statistics Day in India. He obtained seminal insights in diversity, structure and affinity of ethnic populations of India and initiated genetic studies in ISI.

2. Professor David Morley established the concept of **Road to Health**. His work was later adopted by the WHO and UNICEF. He gave utmost importance to growth monitoring for early detection of malnutrition in developing countries and is considered innovator of **Parent Held Growth Chart**. His notable works include Paediatric Priorities in Developing World, Monitoring Child Growth for appropriate Healthcare in Developing Countries and inclusion of growth monitoring in UNICEF GOBI measures to improve child health.

3. The Indian Council for Medical Research (ICMR) carried out a nationwide cross section study in 1956 and 1965 to make Indian reference charts. They were made on children belonging to lower socio-economic class.

4. Growth reference curves based on upper socioeconomic representing all zones of India were developed by Agarwal in 1989 and published in 1992 and 1994. These were adopted by Indian Academy of Paediatrics in 2007 (Agarwal et al., 1992).
5. WHO MGRS growth standards for children less than 5-year age in 2006 (WHO, 2006).
6. Indian girls and boys height, weight and BMI for 2–18 years by Khadilkar et al. in 2009 (Khadilkar et al., 2009).
7. Indian Academy of Paediatrics growth chart for 5–18-years in 2015
(Indian Academy of Pediatrics Growth Charts Committee et al., 2015).

Current scenario

The Indian Academy of Paediatrics (IAP) produced and recommends the use of simplified WHO MGRS 2006 growth standards for children of age 0–5 years and the use of IAP growth charts for 5–18 years for the purpose of growth monitoring in Indian children. The WHO growth charts for 0–5-years provide centiles and z-scores for height, weight, head circumference, and weight-for-height/length. These charts are available on (WHO, 2009).

The IAP growth charts (Indian Academy of Pediatrics Growth Charts Committee et al., 2015) provide reference values for height, weight, and BMI. It is important to note that to ensure the user friendliness of these charts, the concept of decimal age has been removed and each month has been represented in the grid. Thus, the x-axis has labels viz. 5, 5.6, 6, 6.6 and so on. The BMI charts have orange line and red line to denote overweight and obesity respectively at 23kg/m^2 and 27kg/m^2 adult equivalent instead of conventional 85th and 95th centile to prevent the under-diagnosis of obesity in Indian children (Khadilkar et al., 2012). The charts are available for use on the IAP website at (Indian Academy of Pediatrics, 2020).

Paediatrician friendly IAP growth charts for 0–18 years (Parekh and Khadilkar, 2020) are combined WHO-IAP weight and height charts to allow paediatricians and endocrinologists to monitor growth from birth to 18 years. It helps us to compare the height of a child with mid parental height (MPH) even for children less than 5-year age which was not the case on split charts. The advantage of this chart is that it provides a BMI tool and MPH tool without requiring calculation, for easy interpretation in a busy clinic. The BMI tool will classify a child as underweight, normal, overweight and obese just by using height on x-axis and weight on y-axis. The MPH tool gives the MPH centile for sex by joining father's height on the left to mother's height on the right.

Khadilkar et al. published Extended Growth Charts for Indian Children to be used by endocrinologists with additional centile/z-score lines to specify indication specific cut-offs in height. The extended growth chart has three additional centile lines at -2.25SD (1.25 centile), -2.5SD (0.6 centile) and -3SD (0.1 centile) to keep in mind idiopathic short stature (ISS), small for gestational age (SGA) and the detailed evaluation of the growth hormone insulin-like-growth-factor-1 axis (GH-IGF-1 axis) (Khadikar et al., 2021).

Height velocity charts for Indian boys and girls provide longitudinal references for height velocity of Indian children who differ from European children due to genetic and environmental factors. Children with growth velocity less than 25th centile should be assessed as they might suggest an underlying disease (V. Khadilkar et al., 2019).

Waist circumference reference curves for Indian boys and girls were published by

Khadilkar et al. in 2014 (Khadilkar et al., 2014) and give centiles for Indian children between age 2–18 years. These charts are useful to detect central adiposity as a risk factor for the Metabolic Syndrome (MS). The National Health and Nutrition Examination Survey (NHANES) proposed the 90th centile as a cut-off for MS risk, but sex and age-specific reference curves for Indian children rather suggest that the 70th centile may be used for screening for MS risk (Khadilkar et al., 2014).
Girls with Turner syndrome are known to have short stature. Turner syndrome specific growth charts (Khadilkar et al., 2020) help to detect other diseases such as celiac disease or hypothyroidism that may be prevalent in girls with Turner syndrome.
Besides these, Indian reference centile curves for wrist circumference for Indian children aged 3–18 years for screening the risk of hypertension (above 70th centile) (Khadilkar et al., 2018), sitting height centiles in 3–17-year-old Indian children (A. Khadilkar et al., 2019) and upper and lower body segment ratios from birth to 18 years (Kondpalle et al., 2019) in children from Western Maharashtra for population specific diagnosis of disproportionate short stature like Achondroplasia and Marfan Syndrome have been published, for use in the Indian population, as considerable differences compared to Caucasian children have been noted for each of these parameters.

The future of growth charts in India

Indian Anthropometric data vary significantly from the Western world due to difference in genetics and socioeconomic status. An averaged single standard cannot account for diversity between populations as reflected in a study on growth performance of affluent Indian preschool children (Khadilkar et al., 2009).
Over and above the variation in anthropometry amongst different geographical regions, there exists a significant difference in anthropometric measurements of a population indigenous to a geographic location over a period of time (secular trend). The prevalence of low birth weight i.e., birth weight <2500 grams has decreased from 26% in NFHS-1 (National Family Health Survey-1, 1992–93) to 18.2% in NFHS-4, 2015–16 (International Institute for Population Sciences, 2017). Height and weight of boys and girls at 18-year age in 1989 and 2015 are shown in table 1.

Table 1 Comparison of centiles for height and weight of boys and girls at 18-year of age published in 1989 and 2015 Indian growth charts (International Institute for Population Sciences, 2017)

Sex	centile	height 1989 (cm)	height 2015 (cm)	weight 1989 (kg)	weight 2015 (kg)
Boys	3	162.9	158	47.3	41
	50	170.8	173.6	58.6	61
	97	181.2	186	83.1	88
Girls	3	148.3	146.6	37.6	37.6
	50	156.8	157.8	48	52
	97	167.8	170.6	75.3	73.5

There is a trend towards increase in height from 1989 to 2015 in both sexes. The decrease of the 3rd centile may be explained by the lack of use of smoothing methods. The reason for upward trend may be the rapid social and economic transition in India, especially in urban areas. Thus, periodically updating growth references is necessary especially in a developing country like ours. Secular trends may occur over relatively short period of time. Large datasets are regularly required to monitor the secular trend. Collection of data for such studies is cumbersome and expensive. Since such data is difficult to obtain, 'synthesizing growth references' is a practical alternative (Hermanussen et al., 2016). The method allows for amalgamation of global patterns of human growth with specific local information. Synthetic growth charts are based on Likelihood principle and Principal Component Analysis and non-linear regression equations. Standard non-linear regression equations compute means for height, weight and BMI for all ages between 0–18 years using means at country specific data points preferably at birth, 6 years, pubertal age and 18 years.

Conclusion

Anthropometry and growth charts are the most valuable tools to monitor growth and detect growth disorders at an early state. Regular monitoring of growth gives reassurance to physicians and parents and reduces the cost of unnecessary investigations. It is a proven method to suspect and diagnose disease early before major damage is done and is useful to monitor response to treatment in a diseased child. It is important that health care workers use growth charts. Training of health care workers for use and interpretation of growth charts is necessary for the improvement of child and adolescent health. The lack of national growth references in many low- and middle-income countries poses a significant challenge to their national health care systems.

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