ORIGINAL ARTICLE

Anthropometric Growth Reference for Indian Children and Adolescents

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ABSTRACT

Objective: We aimed to develop anthropometric growth references for Indian children and adolescents, based on available 'healthy' child data from multiple national surveys

Methodology: Data on 'healthy' children, defined by comparable WHO's Multicentre Growth Reference Study (MGRS) selection criteria, were extracted from four Indian surveys over the last 2 decades, *viz*, NFHS-3, 4, and 5 and Comprehensive National Nutrition Survey (CNNS). Reference distributions of height-for-age for children up to 19 years, weight-for-age for children up to 9y, weight-for-height for children less than 5 years and BMI for age for children between 5-19 y were estimated by GAMLSS with Box-Cox Power Exponential (BCPE) family. The national prevalence of growth faltering was also estimated by the NFHS-5 and CNNS data.

Results: The distributions of the new proposed Indian growth references are consistently lower than the WHO global standard, except in the first 6 months of age. Based on these references, growth faltering in Indian children and adolescents reduced > 50% in comparison with the WHO standard.

Conclusion: The study findings revealed that the WHO one-standard-fits-all approach may lead to inflated estimates of under nutrition in India and could be a driver of misdirected policy and public health expenditure in the Indian context. However, these findings need validation through prospective and focussed studies for more robust evidence base.

Keywords: *Anthropometry, Body Mass Index (BMI)-for-age, Growth reference, Stature-for-age, Weight-for-age, Weight-for-height*

Published online: March 19, 2024; **PII**:S097475591600615

INTRODUCTION

The prevalence of undernutrition among under-five Indian children, as measured through the WHO Child Growth Standards, remains high in the latest National Family Health Survey (NFHS-5, 2019-21) with 35.5% of children being stunted, 32.1% underweight and 19.2% wasted [1]. Another national survey, the Comprehensive National Nutrition Survey (CNNS 2016–18) also reported a prevalence of 35% stunting, 33% underweight and 17% wasting in a similar population [2]. These reports present a negligible decline from the 38.4% stunting, 35.7% underweight and 21% wasting reported in NFHS-4 (2014-15) [3], NFHS-3 (2004-05) [4]. This static level of growth faltering questions the impact of existing national programs aimed to prevent under nutrition in young children [5]. However, the apparent lack of adequate response could also be due to the use of the one-size-fits-all WHO Child Growth Standards to diagnose growth faltering in the Indian context.

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Received: Jul 20, 2023; Initial review: Aug 28, 2023;
Accepted: Mar 01, 2024

The WHO Growth Standards for under 5-year-old children were presented in the Multicentre Growth Reference Study (MGRS), 2006, which described these as how children should grow when their needs are met [6]. Longitudinal and cross-sectional data from six countries (Brazil, Ghana, India, Oman, Norway and USA), from participants who had no economic, environmental or biological risk factors for growth, who were singleton, delivered at term gestation, with no significant morbidity, and with non-smoking mothers who agreed to follow infant feeding recommendations. Affluent neighbour-hoods were purposively selected for Ghana and India. Growth references for school going children and adolescents (5-19 years) were developed by the WHO using the same data (derived from US children and adolescents) that was used for the construction of the original National Center for Health Statistics (NCHS) charts [6]. This involved the pooling of three data sets; Health Examination Survey (HES) Cycle II and Cycle III, and Health and Nutrition Examination Survey (HANES) Cycle I [7]. No information was given regarding their feeding.

In the Indian context, there has been recent advocacy for the use of local growth standards. The national representativeness of the small homogenous affluent neighbourhoods in South Delhi in the Indian site in the WHO study (0-5 years) has been questioned. Further justification stems from the analyses of national survey datasets, utilizing inclusion criteria similar to MGRS by WHO, which demonstrate a significant deviation of mean z-scores by WHO standards from zero for all the three indices: Height-for-age *z*-score (HAZ), weight-for-age *z*-score (WAZ) and weight-for-height *z*-score (WHZ) in under-five children (-0.52 to -0.79) in a subset of healthy Indian children [8]. In effect, using the WHO standard instead of these contextual references almost doubled the estimated growth failure in India [8]. From a clinical perspective, the use of WHO growth standards has also been shown to result in disease misclassification, including pathological short stature [9,10], macrocephaly and microcephaly [11], screening of fetal growth restriction for predicting future morbidity [12] and diagnosing cardiometabolic risk factors [13,14]. The WHO growth references for 5-19 years were developed from a potentially obesogenic environment (USA). Thus, there is a need for nationally representative standard for 5-19 years, preferably as a single (continuous), representative and contemporary Indian growth standard spanning from birth to 19 years for use in clinical practice [15].

We therefore aimed to develop anthropometric growth references for Indian children from birth to 19 years of age using predefined criteria to select participants at low risk of growth constraint from contemporary data of nationally representative surveys. These were compared against the global WHO anthropometric growth standards. In addition, based on the newly constructed growth references, we developed a simple software application to permit the immediate calculation of various indices of child growth from birth to 19 years. We prefer to use the term growth reference instead of standard, especially since these analyses emanate from retrospective datasets, and need further validation from robust, prospective studies.

METHODS

This study used multiple national cross sectional survey data sets, from each of which subsets of healthy children were extracted. Selection was based on uniform criteria for socio-demographic variables, so as to replicate those used in the WHO-MGRS survey to the extent feasible.

The Comprehensive National Nutritional Survey (CNNS, 2016-18) was the first ever nationally representative nutrition survey of Indian children and adolescents [2]. The CNNS survey reported data from preschool children (0-4-year-old), school-age children (5-9-year-old), and adolescents (10-19-year-old) in all the 30 geographical states of India by multistage sampling. Children and adolescents with physical deformity, cognitive disabilities, chronic illness, acute febrile or infectious illness, acute injury, ongoing fever, and pregnancy were excluded. Data of 31,058 children for under-5-year-old, 36,775 for 5-9-year-old and 34,154 for adolescents with valid anthropometric measurements were used for selection of healthy subset for analysis across the age groups.

The National Family Health Surveys (NFHS) [1,3,4] are large-scale, multi-round surveys conducted in a randomly selected representative sample of households across India. Multistage random sampling, with a consistent sampling strategy is used. The survey provides state and national information for India. Data on under-5 children from NFHS-5 (2019-21), NFHS-4 (2015-16) and NFHS-3 (2005-06) were accessed [1,3,4]. The NFHS-5, NFHS-4 and NFHS-3 collected anthropometric measurements and sociodemographic information from 2,32,920, 2,59,627 and 1,24,385 children of age below 5years, respectively, from across India.

The 'healthy child' selection criteria for children aged 1-4 years replicated to the extent feasible, those used by the 2006 WHO MGRS for Indian site [16]. Accordingly, a healthy child should *a*) live in an urban locality; *b*) belong to the highest two quintiles of socio-economic status (SES) as defined by respective surveys; *c*) have a non-smoking mother with education that was graduate or above; *d*) be exclusively breastfed for the first 4 months; *e*) be partially breastfed for 12 months; and *f*) be without infection, including any fever and diarrhea, in the two weeks prior to the survey. When applied to all under-5 children in the four selected national surveys, 13,204 under-5 children were selected in the analytical sample; 1,821 from NFHS-3, 4,531 from NFHS-4, 4,918 from NFHS-5 and 1,934 from CNNS (**Fig. 1**).

Healthy 5- to 19-year-old children and adolescents were selected from CNNS, based on the criteria that the child should: *a*) live in an urban locality; *b*) belong to richer and richest SES as defined by CNNS; *c*) be non-anemic; *d*) not use tobacco; *e*) have serum albumin concentration $^{24}_{12}$ 3.5 g/dL; hemoglobin A1c (HbA1c) concentration $^{c}_{\lambda}$ 6% and serum C-Reactive Protein level $^{c}_{\lambda}$ 5 mg/dL. Thus, 6,659 healthy children were extracted of which 3,583 were between 5-9 years while 3,077 were between 10-19 years.

Statistical methods: Prior to analysis, children in the lower and upper 5% (below 5th and above 95th percentile) of the respective *z*-scores were excluded to avoid excess variability due to unobserved factors. Homogeneity in the

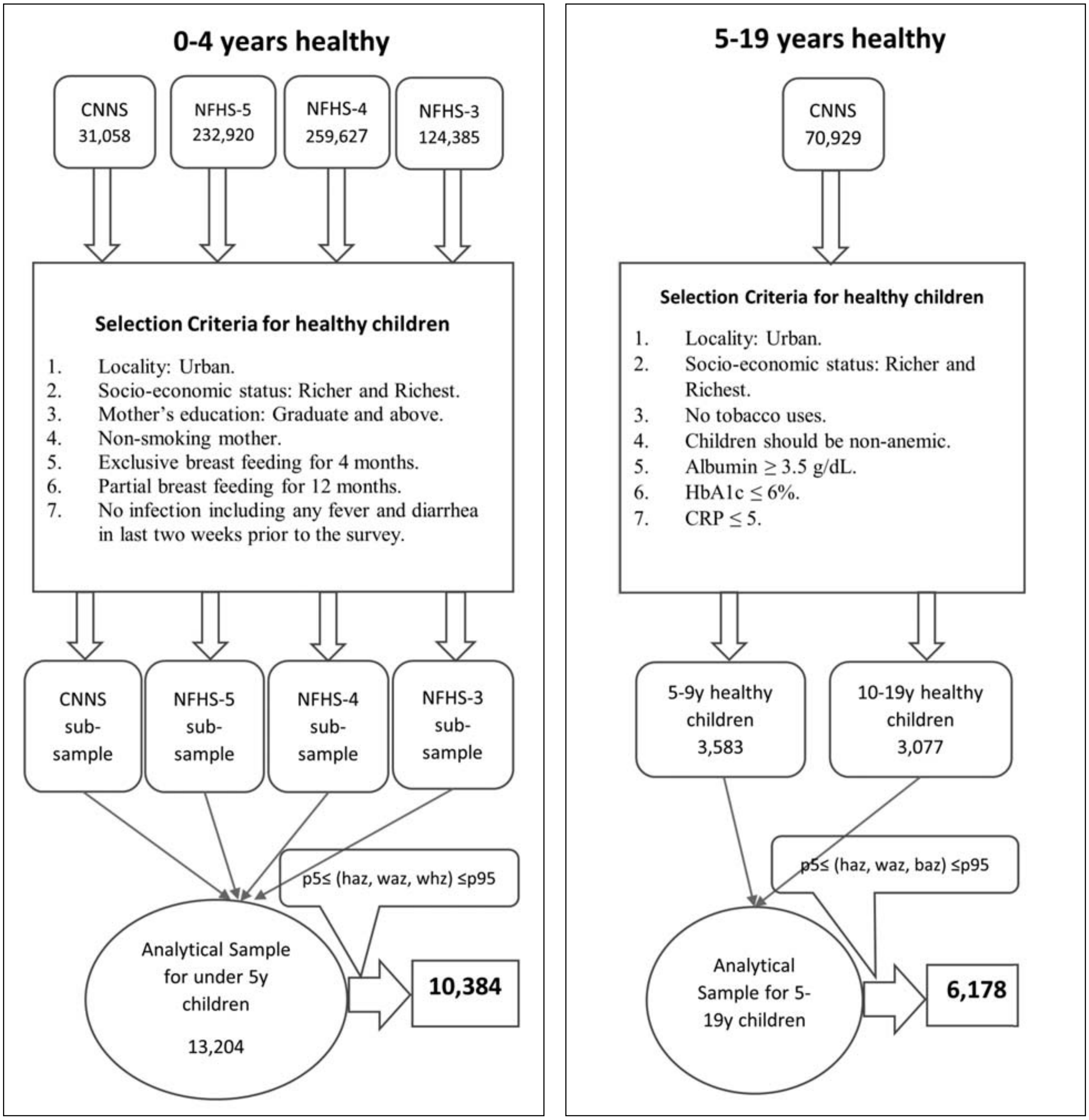

Fig. 1 Steps involved in the selection of the analytical sample (p5 5th percentile, p95 95th percentile)

mean and variance of under-five growth metrics has been demonstrated across all the four surveys using the same extracted healthy subset [8] hence, these data were combined. A similar strategy was used for older children. If significant differences from 0 for these growth standards were found, growth reference were derived from the analytical sample described above, using the standard generalized additive model for location, scale and shape (GAMLSS) [17]. This method was used by WHO to develop their growth standards.

For 0 to 4-year-old children, the analytical sample data were used to derive the required parameters for the HAZ, WAZ and WHZ using GAMLSS with Box-Cox Power Exponential (BCPE) family. The GAMLSS technique can model the temporal growth with highly asymmetric data and can define age-specific distribution by location, scale, and shape (skewness and kurtosis) parameters without assuming any parametric probability distribution.

A penalized cubic smoothing function was used which estimated degrees of freedom by a least generalized cross validation score. Therefore, no degrees of freedom were required to be specified. Further, as a penalized spline was used, power transformation of age was not considered, because the number of knots and position are learned by the data in penalized splines. Observing that the kurtosis parameter (τ) of BCPE family was close to 2, we restricted (τ) = 2 for three references. Similarly, the skewness parameter or Box-Cox power parameter (ν) for HAZ reference was fixed at 1 but allowed to vary over age for WAZ and WHZ parameters. The goodness of fit of the model was examined by Q-Q normal plot of the z-scores that plotted sample quantiles against theoretical quantiles of normal distribution. To assess the fitting within subintervals of age ranges, a worm plot of *z*-scores was used. If most of the dots fell on the diagonal line (45^o angle) for Q-Q normal plot or in between the two dotted lines for each subgroup in worm plot, it was considered to be a good fit. With final models, BCPE parameters (μ, σ, ν, τ = 2) of HAZ, WAZ and WHZ references were estimated for each month of age until 5 years, separately. Further, age-specific HAZ, WAZ and WHZ were computed and compared within subsets of analytical sample by upper one and upper two deciles of Wealth Index with entire analytical sample as part of sensitivity analysis for choice of upper four deciles of Wealth Index as the cut-off.

The prevalence of stunting, underweight and wasting or thinness across age and sex groups of Indian children and adolescents was estimated in the NFHS-5 (for under-5) and the CNNS (for 5- to 19-year-old children) using the derived references. The values so obtained were compared with corresponding prevalence data obtained using the WHO Child Growth Standards. Non-overlapping 95% confidence intervals of the estimate of prevalence between the study references and the WHO standards was considered as statistically significant difference. Further, the occurrence of double burden of malnutrition (DBM), as the prevalence of a significant proportion of overweight or obese (WHZ > 2.0 or BAZ > 2.0) along with underweight (WHZ < -2.0 or BAZ < -2.0) children was also examined with the use of both standards. The statistical software R version 4.2.1 (R Core Team, 2022, Vienna, Austria) was used for data analysis. The accepted false positive error for all statistical tests was set at 5%.

RESULTS

For 0-4-year-old children: After excluding data corresponding to the upper and lower 5% of HAZ, WAZ and WHZ, 10,384 (CNNS: 1,585; NFHS-3: 1,561; NFHS-4: 3,622; NFHS-5: 3,616) valid data for under-five children (5377 boys, 5007 girls) were obtained. All growth metrics indicated substantial deviation from the standard normal distribution are shown in **Table I**. Age and sex of children in the analytical sample are reported in **Web Fig 1**. Location (M), scale (S) and shape (L) parameters for new reference HAZ (0 to 59 months), reference WAZ (0 to 59 months) and reference WHZ (50 to 120 cm), estimated by GAMLSS are reported in **Web Tables I-III**, respectively. Reference centile curves for HAZ, WAZ and WHZ for boys and girls are shown in **Fig. 2**. The overall fitting of the model to the data was found to be satisfactory. The 2.5th, 50th and 95.5th centile curves were estimated and compared between presently derived Indian reference and WHO Child Growth Standards in **Fig. 3**.

For 5-19-year-old children: After excluding data using the process described *vide supra*, data of 6,178 children were available from CNNS; 3,299 (1745 boys, 1554 girls) were in the 5 to 9 years age group while 2,879 (1458 boys, 1421 girls) were in the 10 to 19 years age group. Age (months) specific frequency distribution is reported in **Web Fig 1** and growth metrics indicating a substantial deviation from the standard normal distribution are shown in **Table I**.

Data estimated by GAMLSS are reported in **Web Tables I, II** and **IV**. The reference centile curves for HAZ, WAZ and BAZ are reported in **Fig. 4**. The goodness fit measure indicated satisfactory fit of the model to the data. Like in the under-five-year-old children, the centiles of the presently derived Indian references for children aged 5 to 19 years were also consistently lower than the existing WHO references for each respective metric (**Fig. 3**).

The prevalence of stunting (15% vs 35%), underweight (17% vs 32%) and wasting (11% vs 19%) among children aged under-five were significantly reduced when the references for growth were applied to the NFHS-5 data, in comparison to the WHO Growth

Table I Distribution of z-scores for Different Anthropometric Growth Metrics Derived Against WHO Global Standards for Indian Children and Adolescents

	Estimated z-score	
Variable	*Mean (95% CI)*	*SD (95% CI)*
0-4 y children		
HAZ	-0.69 (-0.71, -0.66)	1.16 (1.14,1.17)
WAZ	-0.75 (-0.76, -0.73)	0.93 (0.91, 0.94)
WHZ	-0.53 (-0.55, -0.51)	1.07 (1.06, 1.08)
5-19 y children		
HAZ	-0.78 (-0.8, -0.76)	1.01 (1, 1.03)
WAZ	-0.8 (-0.83, -0.77)	1.14 (1.12, 1.16)
BAZ	-0.71 (-0.74, -0.69)	1.19 (1.17, 1.22)

HAZ Height-for-age z-score, WAZ Weight-for-age z-score, WHZ Weight-for-height z-score

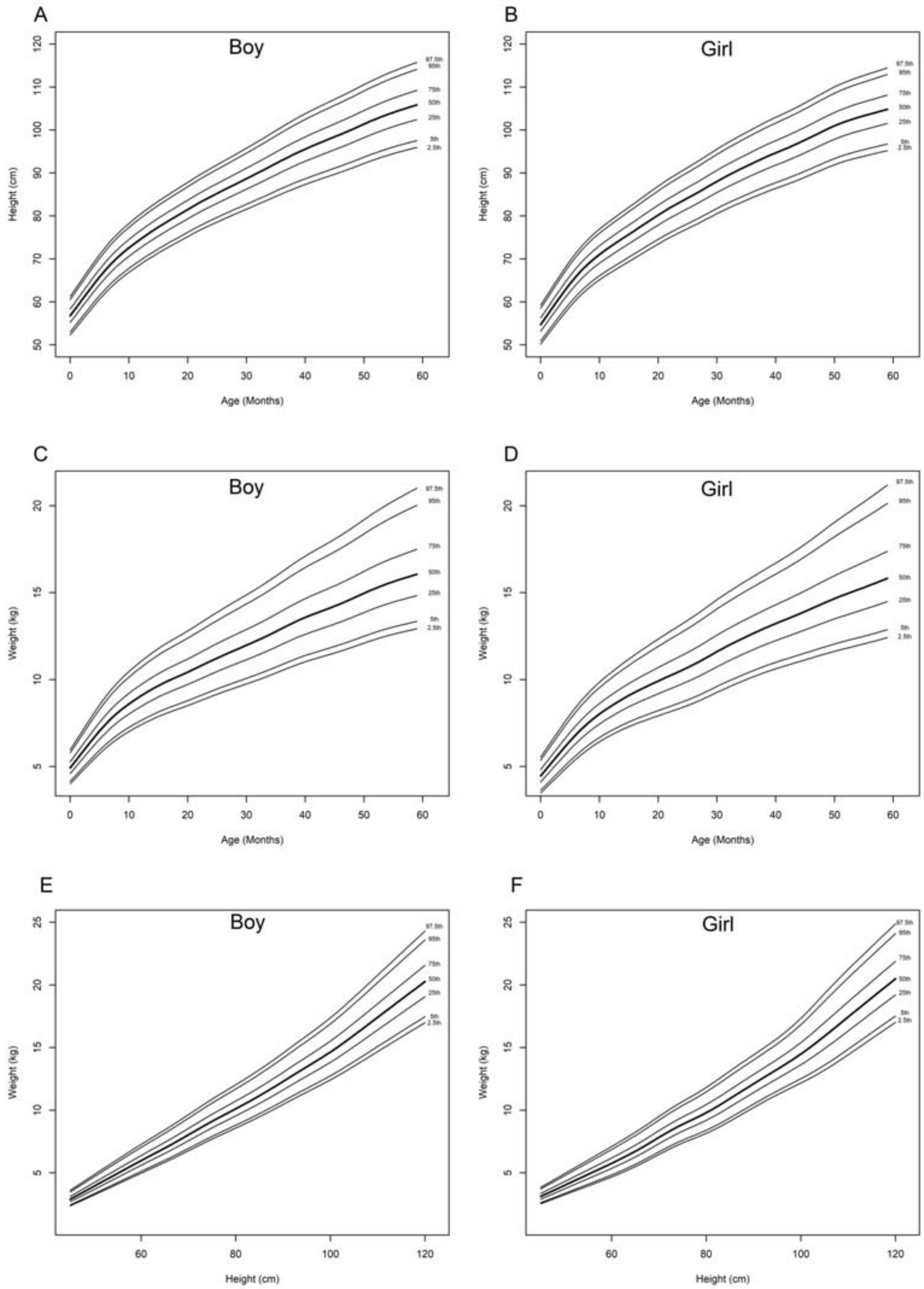

Fig. 2 Centiles of reference growth of height-for-age, weight-for-age, and weight-for-height in Indian children aged 0-4y

Standards. The prevalence of stunting in the CNNS data for children aged 5 to 19 years (6% vs 21%), 10- to 14-year-olds (7% vs 25%) and 15- to 19-year-olds (5% vs 29%) was also significantly reduced when India-specific height standard was compared to the WHO height standards. A similar pattern was observed for thinness based on BMI standards (**Table II**).

The prevalence of overweight, as measured by WHZ > 2 for under-five-year-old children and BMI-for-age Z scores (BAZ) > 2 for children and adolescents aged above 5 years, using the present Indian reference, were comparable with the prevalence of overweight derived using the WHO standard (4.4% vs 3.4% for age <5y; 2.8% vs 2.1% for 5-19y; 1.6% vs 1.3% for 10-14y and 0.8% vs

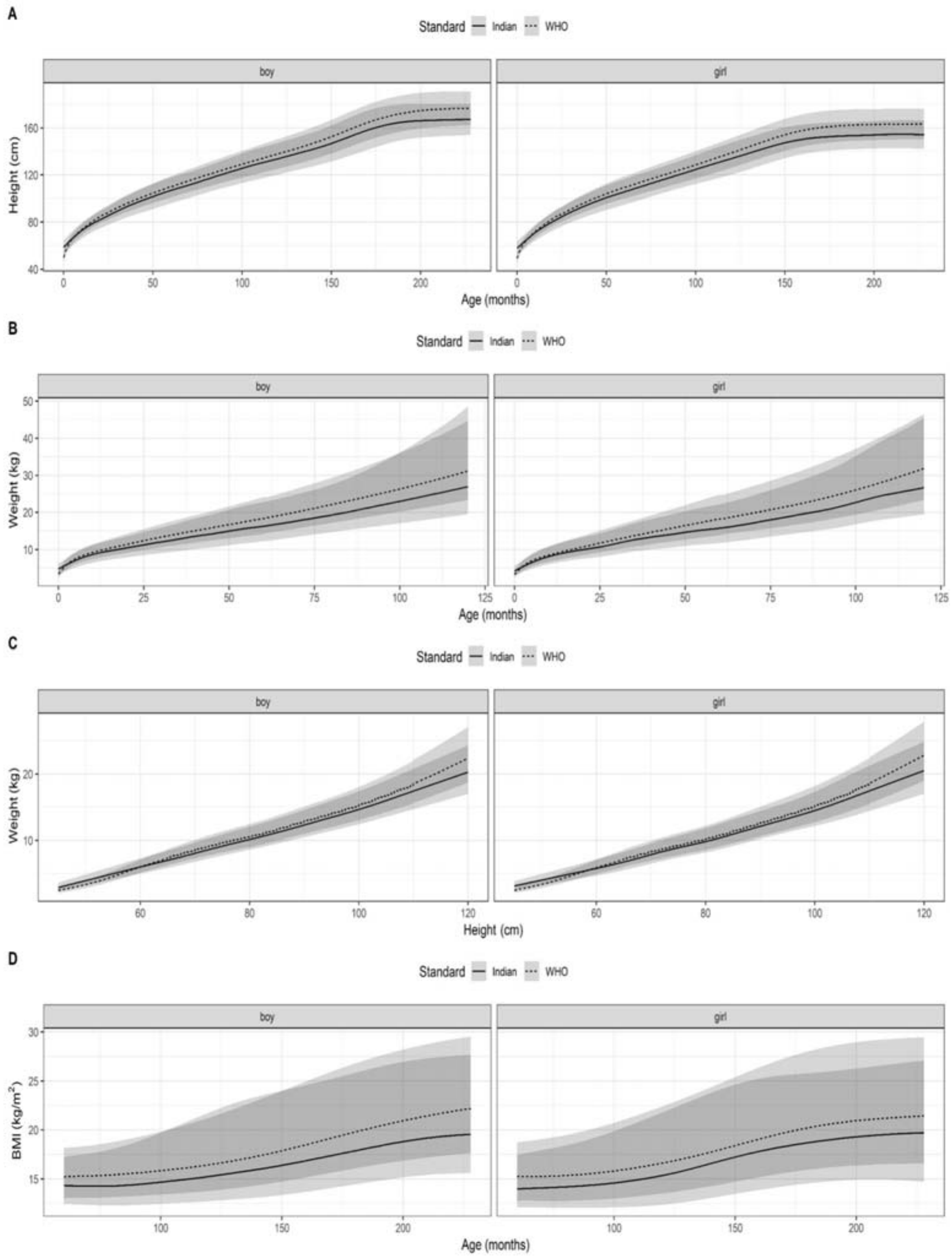

Fig. 3 Comparison of the present Indian growth reference against WHO growth standards and references (median with band of 2.5th and 97.5th percentiles). A Height-for-age; B Weight-for-age; C Weight-for-height; D BMI-for-age

0.1% for 15-19y respectively, **Table III**). However, the risk of being overweight (as measured by WHZ >1 for under-five children or BAZ >1 children and adolescents aged >5y) was higher using the present Indian reference in comparison with the WHO standard (13.8% vs 9.0% for < 5 year; 12% vs 6.3% for 5 to 19 year; 12.7% vs 7.5% for 10 to 15 year and 11.9% vs 4.3% respectively) as seen in **Table II**.

A user friendly web application (*https://datatools.sjri.res.in/ZSC/*) was developed on Python and Streamlit to calculate z-score and risk of growth faltering [8].

DISCUSSION

This paper has constructed contextual, nationally representative, and contemporary growth curves which are continuous; unlike the WHO standard, with a discontinuity

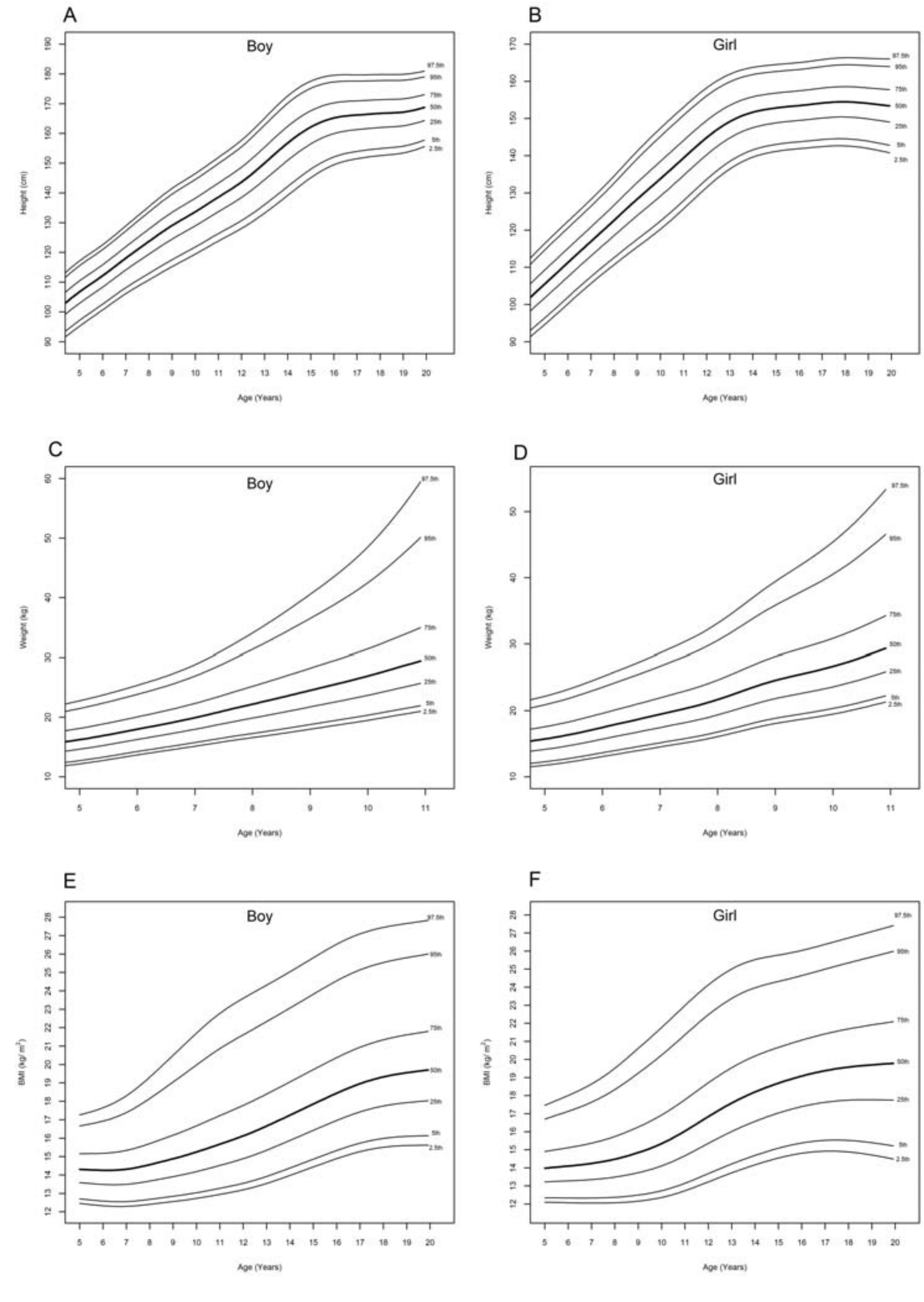

Fig. 4 Centiles of standard growth of height-for-age, weight-for-age, and BMI-for-age for Indian children aged 5-19 years

at 2 years and a different population after 5 years. The ideal approach to constructing growth references locally would be through a prospective, adequately powered and specifically focused study. Till such standards become available, we provide a reasonable alternative to fulfil the need for children aged 0-19 years. Following earlier reports [11] we reassessed the appropriateness of WHO Growth Standards using data on healthy children in India, and proceeded to develop India-specific anthropometric growth references across ages and for both genders of children and adolescents. This was possible because a healthy representative sample of under-5 year-old children could be selected from four different national surveys over the last 15 or so years, and similarly, a healthy sample of 5- to 19-year-old children could be selected from the CNNS, using similar criteria for health as used in the WHO MGRS study [16] as used by WHO [7] along with additional biomedical parameters (**Fig. 1**) making the analytical data more robust. The present references were also developed by the same conventional GAMLSS [17] technique as was used by WHO [16].

The present references were consistently lower than the WHO growth standards (Fig.3). Thus, with these references, the estimates of growth faltering in Indian children and adolescents were reduced by ~40-80% across different metrices in comparison to those derived from WHO growth standards (**Table II**).

A caveat is that the present derived reference should only be applied for children aged 4 months and above, since in the healthy subsample of children had a limited representation of children upto 3 months of age. Therefore, the WHO Growth Standards should be recommended for infants upto 3 months of age.

A high prevalence of undernutrition is usually reported in low- and middle- income countries surveys when WHO Growth Standards are used [18]. However, several studies have critically examined the validity of the WHO Growth Standards for different populations, and a systematic review of the comparison of the use of regional growth references against the WHO Growth Standards has recommended the adoption of regional standards for growth [19]. While a method of creating synthetic growth reference charts by incorporating information from existing reference growth studies has also been suggested [20], there are no studies, to our knowledge, that have critically examined the appropriateness of the WHO standard, or the generation of contextual standards by using local healthy child populations defined by the stringent inclusion criteria that were used by WHO to develop the global standards.

Given that the NFHS-5 has shown an increase in the prevalence of overweight children from 9.9% to 13.8% compared to NFHS-4, it seems likely that the supplementary programs are having some effect on the right-hand tail of this distribution already. Using the present overweight cut-offs, the prevalence of overweight is much more, and this points to a serious emerging problem of double burden of malnutrition (DBM) in Indian children, which may be the tip of the iceberg, as an analysis of metabolic indicators of obesity in the CNNS showed that over 50% of adolescent children, whether normal weight, underweight or stunted, had at least one biomarker (high blood glucose, triglycerides or high blood

Table II Comparison of the Prevalence (95% CI) of Growth Faltering and Overweight or Obese Derived by WHO Standard and Indian Reference for Indian Children and Adolescents (Under 5y: NFHS-5 and Above 5y: CNNS)

Standard	Prevalence (%) with 95% CI			
	< 5y	5-9y	10-14y	15-19y
Stunting				
WHO	35.5 (35.2, 35.9)	20.8 (20.1, 21.5)	24.9 (23.9, 26.0)	28.9 (27.7, 30.2)
India	15.5 (15.3, 15.8)	6.2 (5.8, 6.6)	7.4 (6.8, 7.9)	5.5 (5.1, 6)
Underweight				
WHO	32.1 (31.8, 32.5)	30.5 (29.5, 31.4)		
India	16.9 (16.6, 17.1)	5.4 (5, 5.7)		
Wasting				
WHO	19.2 (18.9, 19.6)			
India	10.9 (10.6, 11.2)			
Thinness				
WHO		19.3 (18.6, 20.0)	22.9 (22.0, 23.8)	17.0 (16.2, 17.7)
India		5.3 (4.9, 5.7)	5.7 (5.2, 6.1)	3.2 (2.8, 3.5)
Overweight (WHZ >1) or Overweight (BAZ >1)				
WHO	9.0 (8.8, 9.2)	6.3 (5.7, 6.8)	7.5 (6.8, 8.2)	4.3 (3.9, 4.7)
India	13.8 (13.5, 14.0)	12.0 (11.2, 12.9)	12.7 (11.7, 13.6)	11.9 (11.0, 12.9)
Overweight (WHZ >2) or Obese (BAZ >2)				
WHO	3.4 (3.3, 3.5)	2.1 (1.9, 2.4)	1.3 (1.1, 1.5)	0.05 (0.01, 0.09)
India	4.4 (4.2, 4.6)	2.8 (2.5, 3.1)	1.6 (1.4, 1.8)	0.79 (0.59, 0.98)

WHO World Health Organization, BAZ Body mass index-for-age z-score, WHZ Weight-for-height z-score

WHAT THIS STUDY ADDS?

- The distribution of growth metrics among ‘healthy’ children and adolescents of India deviate significantly from the WHO growth standards.
- New growth references for Indian children and adolescents, based on ‘healthy’ participants were developed, which are nationally representative and could be more suitable for routine clinical use and for informing policy.
- Estimates of the prevalence of growth faltering among Indian children and adolescents reduced by approximately half using these references in comparison to WHO growth standards.

pressure) of excess nutrition [21]. This is because Indians are likely to have a greater adiposity for a given BAZ or WHZ [22], but this surprising finding is somewhat vindicated in the increased prevalence of anthropometric overweight in different age groups (13.8%, 12.0%, 11.7% and 11.9% for < 5 y, 5-19 y, 10-14 y and 15-19 y respectively) when the present standard is applied to the NFHS-5 and the CNNS populations. Further, the underestimation of possible risk of overweight (WHZ > 1; 14% vs 9%) diverts policy action away from the emerging epidemic of overnutrition and DBM in this age group.

A strength of this study is the use of data extracted from four different national surveys over different times and that the age-specific mean HAZ, WAZ and WHZ of the extracted analytical sample are consistent across the upper four deciles and the uppermost decile (**Web Fig. 2**) for under-5-year-old children. The 5-19 year data from the CNNS is recent, nationally representative and employed predefined criteria, including biochemistry, to select participants for analysis. The extreme measurements at both ends were also removed before analysis to avoid undue variability by unknown and unobserved factors, which are expected to partially account for the measurement error. The limitations are lack of adequate data for 0-3 months age, ‘intersurveyor’ variability in measurements, which is mostly random in largescale surveys, and some dissimilarity in selection criteria from the WHO MGRS due to non-availability of relevant data.

It could be argued that that the ‘affluent neighbourhood’ in South Delhi that were sampled for the WHO MGRS represented the most privileged and were therefore best suited for selecting children free from environmental constraints for child growth. However, we believe that environmental growth constraints among the richer families selected by us are broadly comparable, given the additional socio-demographic selection criteria. Further, these children are more representative of the national population.

The evidence presented here and from the systematic review [19], argues that the one-growth standard-fits-all approach for deriving population estimates of anthropometric growth faltering could be misleading. However, these findings need validation through prospective and focussed studies for developing a more robust evidence base. In the interim, Indian stakeholders could consider using the present growth references for routine clinical use and for informing policy after factoring for the potential barriers and logistic challenges.

Ethics clearance: The Institution Ethics Review board of St. John’s Medical College provided waiver of review for this secondary data analysis. No. 164/2022, dated Aug 22, 2022.

Contributors: SG, TT, AVK: Conceptualised the study; RM, SG, AVK, TT: Wrote the first draft of the paper. HPS: Reviewed and edited the manuscript. RM, SG: Performed the statistical analysis. All authors have approved the final version of the manuscript. SG, TT: Had access to the data and have verified the data.

Funding: SG and TT received funding from Science and Engineering Research Board under POWER grant #SERB/F/3504/2022-2023. AVK, TT and HSS are recipients of the Wellcome Trust/Department of Biotechnology India Alliance Clinical/Public Health Research Centre Grant #IA/CRC/19/1/610006.

Competing interest: None stated.

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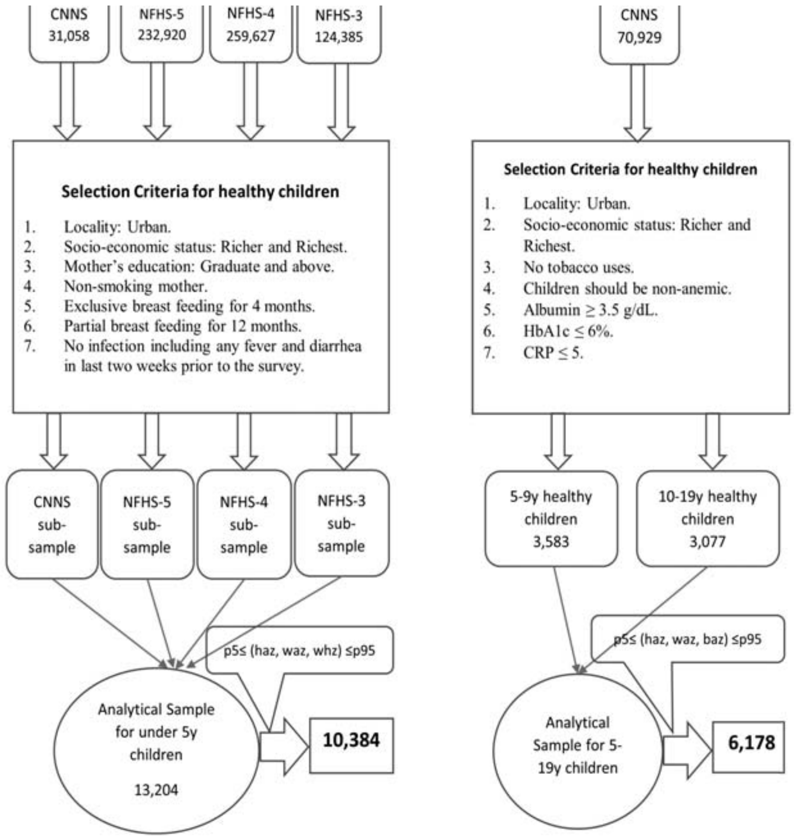
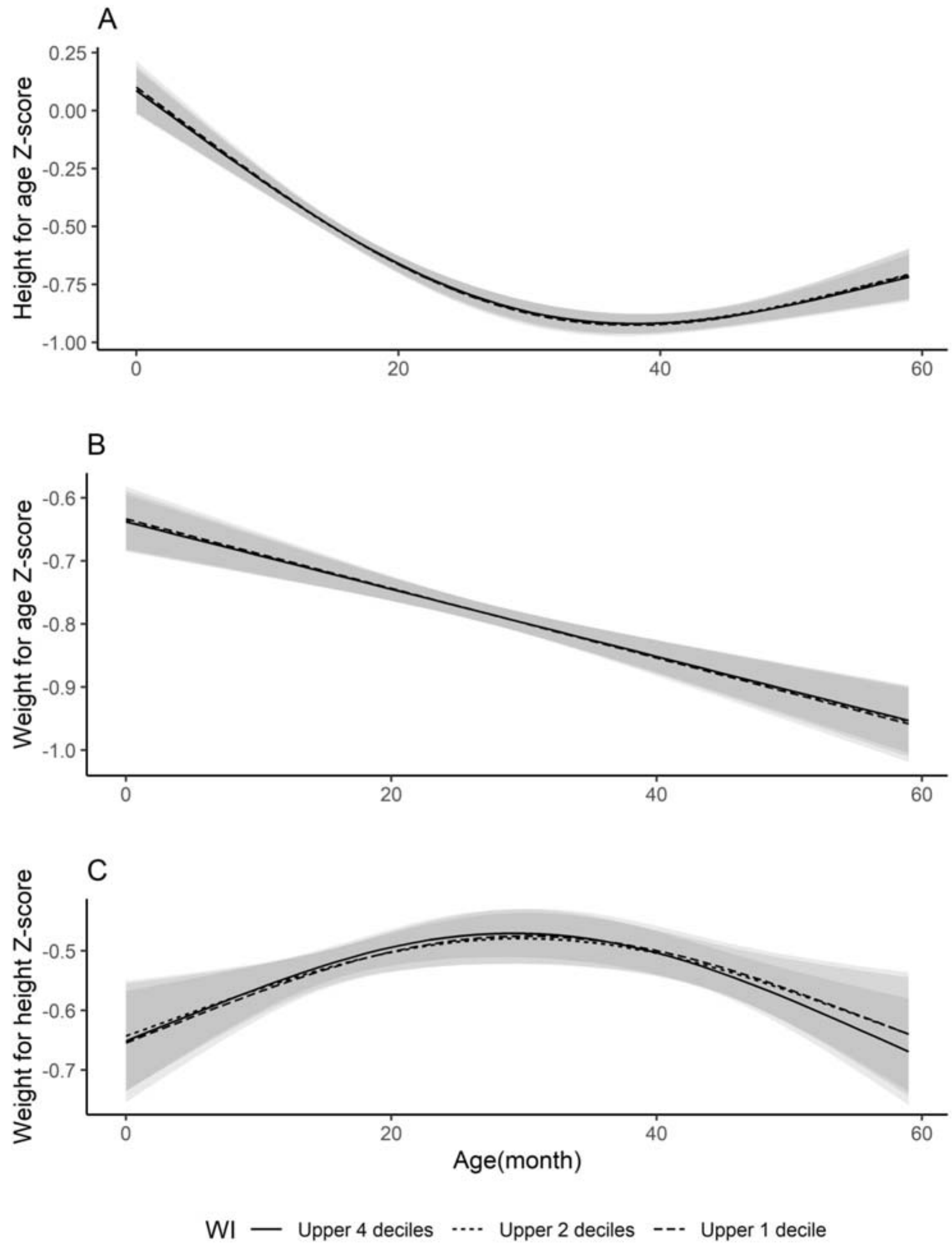


Web Fig. 1 The multiple bar diagrams depict age and sex wise available data



Web Fig. 2 Age-specific mean z-scores of HAZ, WAZ and WHZ of healthy under-five children across upper 4 deciles, upper 2 deciles and uppermost deciles of wealth