TWO-PARAMETER (HEIGHT AND MASS) PROBLEM SOLVED BY FITTING PARABOLIC CURVE TO CONSTRUCT GROWTH-AND-OBESITY VECTOR-ROADMAP 3.0 — THE EIGHTH-GENERATION SOLUTION OF CHILDHOOD OBESITY[£]

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ABSTRACT

This work presents the method of computing Growth-and-Obesity Vector-Roadmaps of sons and daughters, whose parents are still gaining height (under-19 mother and under-21 father). In order to compute target (adult-mid-parental) heights of such youngsters, one needs to replace heights of biological father and biological mother by their respective estimated-adult values. Simulated data of a still-growing couple and their twin children are used to demonstrate the procedure, termed as Growth-and-Obesity Vector-Roadmap 3.0, in which 6 monthly recommendations to pick up height and put on mass are given. A mass range is provided in place of a single value, so that it would be easier to achieve targets. Ranges are evaluated based on last-checkup values of reference percentile and reference-*BMI*-based-optimal-mass percentile. Reference-*BMI*-based-optimal-mass percentile has, also, been used to generate Growth-and-Obesity Scalar-Roadmap 2.5 and Growth-and-Obesity Vector-Roadmap 2.5 for individuals, whose parents have already reached their adult height. In this paper, 3 new indictors of obesity are proposed, viz. reference-*BMI*-based-optimal mass, specific *BMI* and estimated-adult-specific *BMI*. Two new parameters, height-gain-target-achievement index and mass-management-target-achievement index have been introduced, which measure compliance with the computed targets. Further, nutritional-status categories have been extended to 19 from the previously proposed 10 categories. In addition, different categories of ages are linked to maturity levels as well as build. Sociological implications of underage marriages are, briefly described.

Keywords: Specific *BMI*, instantaneous obesity, instantaneous wasting, true obesity, true wasting, extended nutritional status, underage marriage

LIST OF ABBREVIATIONS

AC: **A**rmy-**C**utoff (in the context of height)
AM: **A**cute **M**alnutrition
***BMI*:** **B**ody-**M**ass **I**ndex
CA: **C**urrent-**A**ge (in the context of height)
CDC: **C**enters for **D**isease **C**ontrol and Prevention
EC I-III: **E**nergy-**C**hannelization **I-III**
ECOG: **E**uropean **C**hildhood **O**besity **G**roup
Fr: **Fr**actional (in the context of statuses, pertaining-to height, pertaining-to-mass and combined)
MOD: **M**odified (in the context of statuses, pertaining-to-height, pertaining-to-mass and combined)
MP: **M**id-**P**arental (in the context of height)
NGDS: **N**ational **G**rowth and **D**evelopmental **S**tandards for the Pakistani Children
O-EC II: **O**besity dominated **E**nergy-**C**hannelization **II**
O-ON: **O**besity dominated **O**ver-**N**utrition
ON: **O**ver-**N**utrition
P: **P**ercentile
S-EC II: **S**tunting dominated **E**nergy-**C**hannelization **II**
SGPP: **S**ibling **G**rowth **P**ilot **P**roject — a subproject of the NGDS Pilot Project
S-UN: **S**tunting dominated **U**nder-**N**utrition
T-EC I: **T**allness dominated **E**nergy-**C**hannelization **I**
T-ON: **T**allness dominated **O**ver-**N**utrition
UN: **U**nder-**N**utrition
W-EC I: **W**asting dominated **E**nergy-**C**hannelization **I**
WHO: **W**orld **H**ealth **O**rganization
W-UN: **W**asting dominated **U**nder-**N**utrition

Units: *cm*: centimeter(s) • *ft*: foot (feet) • *in*: inch(es) • *kg*: kilogram(s) • *lb*: pound(s) • *m*: meter(s) • *oz*: ounce(s)

Conversion Factors: 1 *ft* = 12 *in* • 1 *in* = 2.54 *cm* • 1 *kg* = 2.205 *lb* • 1 *lb* = 16 *oz* • 1 *m* = 10^2 *cm*

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INTRODUCTION

Childhood obesity is a global epidemic and a prime risk factor for health complications. It is now established that childhood obesity is continued into adolescence as well as adulthood, resulting in elevated risk for premature morbidity and mortality. The increasing prevalence of childhood obesity in developing countries, in particular, Pakistan, highlights the need to model childhood-obesity problem using mathematical tools.

This paper puts forward the eighth-generation solution of childhood obesity applicable for children of parents, who have not, still, achieved their final height, *i. e.*, mother has not reached her 19th birthday and father not 21st birthday. The trick is to replace heights of father and mother with their respective estimated-adult values to determine target height. The problem of modeling childhood obesity is different from adult obesity in the sense that with the passage of time a child is gaining height as well as managing weight. If an intervention is suggested based on the current value of height and weight without taking into account of the height gained within the next 6 *months*, the youngster may become wasted at the end of half-a-year by losing too much weight. To figure out proper monthly recommendations for height gain and mass management of children under 9.5 *years*, parabolic curves were fitted to percentiles of height and mass, which generate the monthly targets for height and mass range. In the model proposed in this paper, *BMI*-based-optimal-mass percentile (*BMI* stands for Body-Mass Index) has been replaced by reference-*BMI*-based-optimal-mass percentile (*BMI*-based-optimal mass computed by using reference height in place of measured height). This work introduces 3 new obesity indicators, namely, reference-*BMI*-based-optimal mass, specific *BMI* and estimated-adult-specific *BMI*, in addition to existing indicators**:** *BMI*, renamed from 'Quetelet Index' by Ancel Keys in 1972, relative *BMI*, proposed by Poskitt in 1995 as well as 9 other indictors introduced by our group — height-percentile-based-optimal mass, *BMI*-based-optimal mass, *BMI* ratio, estimated-adult *BMI* as well as 5 statuses (pertaining-to-mass). Nutritional status has been extended into 19 categories (over-nutrition, under-nutrition, acute malnutrition, energy-channelization I-III, obesity dominated over-nutrition, obesity dominated energy-channelization II, tallness dominated over-nutrition, tallness dominated energy-channelization I, wasting dominated energy-chnnelization I, wasting dominated under-nutrition, stunting dominated under-nutrition, stunting dominated energy-channelization II, tallness, stunting, obesity, wasting, normality) in place of 10 categories proposed in 2018. Height-gain-target-achievement index and mass-management-target-achievement index are defined, which measure compliance with the computed targets Appendix A gives links of Additional Resources made available as Additional Files 1-8.

CHILDHOOD OBESITY: SOCIO-ECONOMIC DETERMINANTS AND GLOBAL TRENDS

Wickramasinghe (2018) proposed a conceptual framework at different levels to learn the socio-cultural and environmental factors influencing obesity prevalence in younger population. Akram *et al.* (2018) studies the impacts of behavioral, environmental and social factors on obesity. In a cross-sectional study, dos Santos *et al.* (2019) investigated the relationship between behaviors (eating patterns and physical activity) as well as socioeconomic and build factors that affect obesity in children. Saelens *et al.* (2018) looked into two-year changes in child weight status, diet and activity by neighborhood nutrition and physical activity environment. Holmgren *et al.* (2017) have studied relationship of pubertal height gain and peak body-mass index in childhood. Kato *et al.* (2018) have looked earlier *BMI* rebound and lower pre-*BMI* rebound as obesity risk among Japanese preschool children. Jaarsveld and Gulliford (2015) have explored childhood-obesity trends in UK. Kelly *et al.* (2019) gave findings from Bradford cohort study, which studied association between *BMI*, use of primary health care and morbidity in early childhood. Ogden *et al.* (2014; 2016) have investigated childhood, adolescent and adult obesity in United States during 3 periods from 1998 to 2014. Skinner and Skelton (2014) scrutinized prevalence and trends in obesity and severe obesity among youngsters in the United States during 1999-2012. Hardy *et al.* (2017) examined 30-year trends (1985-2015) in overweight, obesity and waist-to-height ratio by socioeconomic status in Australian children. Spinelli *et al.* (2019) discussed prevalence of severe obesity among primary school children in 21 European countries.

There has been an increasing awareness of risk factors for overweight and obesity in children in the developing countries (Hossain *et al.*, 2019; Rao *et al.*, 2017). Şerban *et al.* (2018) described web of causation between dietary patterns and childhood obesity. Şendur *et al.* (2018) investigated effective sociodemographic and clinical factors in weight loss in childhood obesity. Düzgun-Öncel and Karaoğlan (2019) examined the determinants of childhood obesity in Turkey using the 2013 round of Demographic Health Survey (DHS) data set.

DEFINITIONS OF CHILDHOOD OBESITY

While working for European Childhood Obesity Group (ECOG), Poskitt (1995) defined relative *BMI* as the index of a 50th centile of a child. Poskitt (2000) observed that there is a lot of imprecision in defining obesity. However, she was of the opinion that there appeared to be a general acceptance of the concept of relative *BMI*. In a 2001 paper, she stated that *BMI* did not propose the 'best' definition, although it might be considered as the most

Table 1. Indicators of obesity[ν]

Nomenclature	*Represented by*	*Mathematical*	*First Mention*
Body-Mass Index[ω]	*BMI*	μ/h^2	Keys *et al.* (1972)
Relative *BMI*	BMI_{relative}	50^{P} of *BMI* table[§]	Poskitt (1995)
Height-Percentile-based-Optimal Mass[∈]	μ_{opt}	$P_{\text{opt}} = P_{\text{CDC}}(h)$	Kamal *et al.* (2004; 2011)
Status (pertaining-to-mass)[τ]	$STATUS\,(\mu)$	$100\lvert\Delta\mu\rvert/\mu_{\text{opt}}$	Kamal *et al.* (2011)
Estimated-Adult *BMI*[ω]	$BMI_{\text{est-adult}}$	$\mu_{\text{est-adult}}/h^2_{\text{est-adult}}$	Kamal and Jamil (2012)
BMI Ratio	BMI_{ratio}	$BMI/\text{unit}\,BMI^{\eta}$	Kamal and Jamil (2014)
Algebraic Status (pertaining-to-mass)[φ]	$STATUS_{\pm}(\mu)$	$100\Delta\mu/\mu_{\text{opt}}$	Kamal *et al.* (2015)
Qualitative Status (pertaining-to-mass)	$STATUS_{\text{qual.}}(\mu)$	Explained in footnote[ψ]	Kamal *et al.* (2015)
BMI-based-Optimal Mass[ω, Ч]	μ_{BMI}	$24h^2$	Kamal (2017*b*)
Modified Status (pertaining-to-mass)	$STATUS^{\text{MOD}}_{\pm}(\mu)$	Defined in Figure 9*b*	Kamal *et al.* (2018)
Descriptive Status (pertaining-to-mass)	$STATUS_{\text{desc.}}(\mu)$	Defined in Figure 9*b*	Kamal *et al.* (2018)
Reference-*BMI*-based-Optimal Mass	$\mu_{\text{ref-BMI}}$	$24h^{2\ \kappa}_{\text{ref}}$	This work
Specific *BMI*[σ]	BMI_{specific}	$BMI/24$	This work
Estimated-Adult-Specific *BMI*	$BMI_{\text{est-adult-specific}}$	$BMI_{\text{est-adult}}/24$	This work

ν ‘*BMI*’, ‘relative *BMI*’ and ‘estimated-adult *BMI*’ are reported in kg/m^2; ‘height-percentile-based-optimal mass’, ‘*BMI*-based-optimal mass’ and ‘reference-*BMI*-based-optimal mass’ in *kg*; ‘status (pertaining-to-mass)’, ‘algebraic status (pertaining-to-mass)’ and ‘modified status (pertaining-to-mass)’ as percentage (%); ‘*BMI* ratio’, ‘specific *BMI*’, ‘specific-estimated-adult *BMI*’, ‘qualitative status (pertaining-to-mass)’ and ‘descriptive status (pertaining-to-mass)’ are dimensionless

ω Height, *h*, in these formulae entered in *m* and net mass (mass with zero clothing on), μ, in *kg* — drawbacks of *BMI* discussed in Kamal *et al.* (2013*b*); parents attitudes toward support for *BMI* screening are described in Linchey *et al.* (2019)

§ The superscript P stands for percentile

∈ The term ‘optimal mass’ mentioned in Kamal *et al.* (2004); formal definition given in Kamal *et al.* (2011) — 3-*year* ago, renamed as ‘height-percentile-based-optimal mass’ to differentiate from ‘*BMI*-based-optimal mass’ (Kamal, 2017*b*)

τ $\Delta\mu = \mu - \mu_{\text{opt}}$; if $\mu > \mu_{\text{opt}}$ and $STATUS\,(\mu) > 1\%$ adjective obese is added; if $\mu < \mu_{\text{opt}}$ and $STATUS(\mu) > 1\%$ adjective wasted is added; $STATUS(\mu) \le 1\%$ is considered normal — this indicator replaced by ‘algebraic status (pertaining-to-mass)’ 5-*year* ago (Kamal *et al.*, 2015)

η Unit *BMI* is taken as 1 kg/m^2

φ Positive (Negative) sign indicating incumbent to be obese (wasted); $-1 \le STATUS_{\pm}(\mu) \le +1$ considered normal — this indicator replaced by ‘modified status (pertaining-to-mass)’ in 2018 (Kamal *et al.*, 2018)

ψ ‘4th-degree obese’ $STATUS_{\pm}(\mu) \ge +30\%$; ‘3rd-degree obese’ $+20\% \le STATUS_{\pm}(\mu) < +30\%$; ‘2nd-degree obese’ $+10\% \le STATUS_{\pm}(\mu) < +20\%$; ‘1st-degree obese’ $+1\% \le STATUS_{\pm}(\mu) < +10\%$; ‘normal’ $-1\% \le STATUS_{\pm}(\mu) < +1\%$; ‘1st-degree wasted’ $-10\% \le STATUS_{\pm}(\mu) < -1\%$; ‘2nd-degree wasted’ $-20\% \le STATUS_{\pm}(\mu) < -10\%$; ‘3rd-degree wasted’ $-30\% \le STATUS_{\pm}(\mu) < -20\%$; ‘4th-degree wasted’ $STATUS_{\pm}(\mu) < -30\%$ — this indicator replaced by ‘descriptive status (pertaining-to-mass)’ (Kamal *et al.*, 2018)

Ч The formula $24h^2$ is valid for adults; for children *BMI*-based-optimal mass is computed in 3 steps (Additional File 4)

κ The formula $24h^2_{\text{ref}}$ is valid for adults; for children, this is computed in 3 steps by substituting reference height in place of measured height

σ Dimensionless parameter; the word specific came to mind of the first author (SAK) from ‘specific gravity’

‘useful’ and ‘practical’ one for clinical, epidemiological and population-research purposes (Poskitt, 2001). The formula to compute *BMI* as well as other indicators of obesity introduced by our group are listed in Table 1.

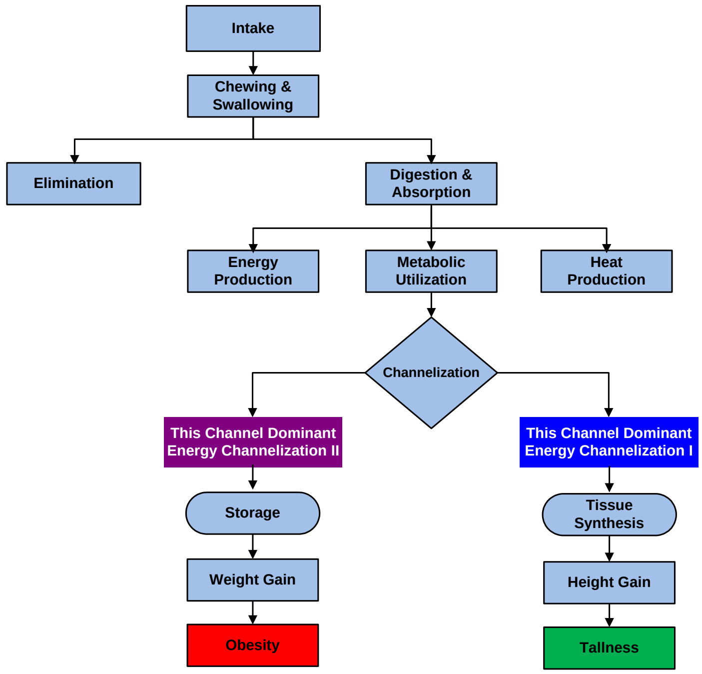


Fig. 1. Childhood obesity may be managed through a delicate balance between storage (weight gain resulting in 'obesity') and tissue synthesis (height gain resulting in 'tallness')

Kolotourou *et al.* (2013) opined that setting a *BMI*-reduction cutoff might be ambiguous. Cole *et al.* (2000) provided a definition by connecting childhood obesity to adult-obesity-cutoff point of *BMI* to be 30 kg/m^2. On behalf of ECOG, Rolland-Cachera (2011), divided the main cutoffs of *BMI* distribution status into 4 ranges starting from the age of 5 *years***:** 'thin', 'normal', 'overweight' (not obese) and 'obese'. Skinner and Skelton (2014) expressed childhood overweight and obesity in terms of *BMI* percentiles (>85^P overweight; >95^P obese). Flegal and Ioannidis (2017) published an evaluation of the Global *BMI* Mortality Collaboration.

The fundamental strategy to manage childhood obesity is to agree on its definition. Obesity manifests, when there is an imbalance between input and output of energy (Figure 1). The original steady state disappears and a new one is formed at a higher level. The result is increase in body-fat storage (Wabitsch, 2000).

Various definitions of childhood obesity were streamlined and 'logical definition' was proposed towards the end of 2016 (Kamal, 2016*b*). The following year, 'mathematical definition' was provided (Kamal, 2017*b*) and subsequently validated using anthropometric data collected during 1998-2013 (Kamal *et al.*, 2017*a*).

CHILDHOOD OBESITY: MODELS

A statistical model was presented to predict obesity in adolescence from parental and childhood obesity (Whitaker *et al.*, 1997). Kumar and Kelly (2018) discussed various methods of clinical assessment and treatment after reviewing obesity in children from epidemiological and etiological perspectives as well as the associated comorbidities.

Our group has been involved in childhood-obesity modeling since the start of the third millennium. Major challenges in such modeling are the realities that the child, under optimal conditions, is gaining height with the passage of time as well as putting on (shedding off) mass. Height gain in children could be understood on the basis of impulse-response model (Figure 2). In case a youngster is required to lose mass, based on 'instantaneous obesity', in the absence of rigorous calculation of height to be picked up within the next few months, the child could become wasted (lesser mass-for-height). Instantaneous obesity exists when modified status (pertaining-to-mass) is positive (Kamal *et al.*, 2018). Our group attempted to take into consideration height-gain trends by youngster in various phases

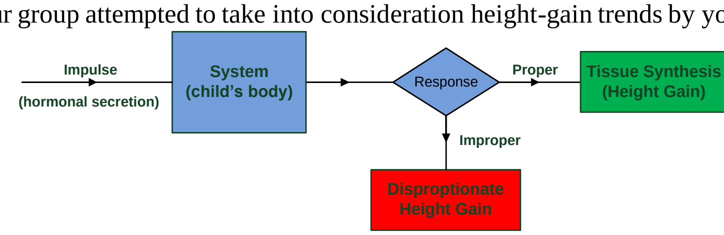


Fig. 2. Impulse-response model — height gain is a 'quasi-static', though 'irreversible' process, in the context of thermodynamics (Kamal and Jamil, 2012)

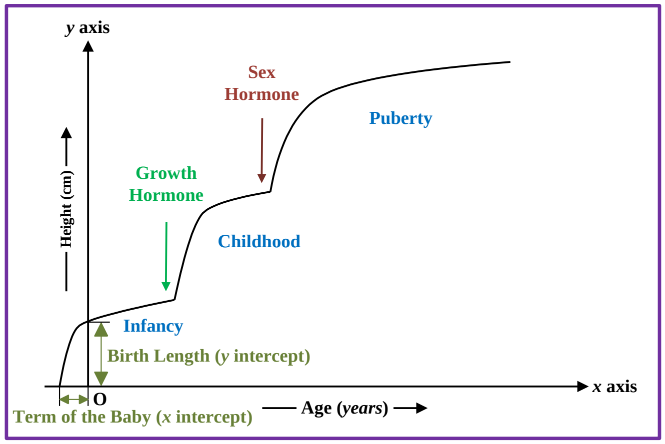


Fig. 3. Mathematical interpretation of ICP (Infancy-Childhood-Puberty) model (Karlberg, 1987) — transitions from infancy -to-childhood and childhood-to-puberty phases are continuous, but not smooth (height velocities undefined); height function single valued and bounded, *i. e.*, a well-behaved function (Kamal and Jamil, 2012)

of growth — infancy, childhood and puberty (Figure 3).

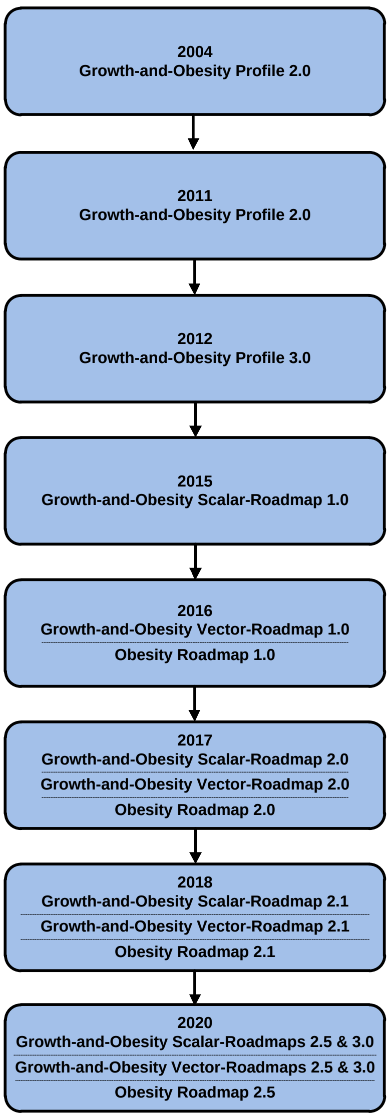


Fig. 4. Timeline of modeling of child growth and obesity

Figure 4 shows timeline of modeling of childhood-obesity problem by our group. Below is a brief description of childhood-obesity models developed by our group**:**

Growth-and-Obesity Profiles

'Growth-and-Obesity Profiles 1.0' determined growth and obesity statuses of youngster based on 2 checkups and computed height (growth) velocity as well as rate of weight (mass) loss/gain between these checkups (Kamal *et al.*, 2004). 'Growth-and-Obesity Profiles 2.0' included 'Obesity Profiles 2.0' of parents as well as growth and obesity statuses of sons and daughters based on a single check up (Jamil, 2009; Kamal *et al.*, 2011). 'Growth-and-Obesity Profiles 3.0' extended version 2.0 so that it, also, applies to still-growing parents (Jamil, 2014; Kamal and Jamil, 2012). This model determined target (adult-mid-parental) height of youngster by replacing heights of biological father and mother with their respective estimated-adult heights in the formulae. Percentile range in 'CDC Growth Charts and Tables' was extended (range 0.01 to 99.99) by employing the KJ-Regression model (Kamal and Jamil, 2014), so that extreme cases could be handled.

Growth-and-Obesity Roadmaps

Generalized from 'Growth-and-Obesity Moving-Profiles' (Kamal *et al.*, 2014*b*), 'Growth-and-Obesity Scalar-Roadmaps 1.0' (Ansari, 2015; Kamal *et al.*, 2015) generated 6 month-wise recommendations to shed off/put on mass (weight) for parents ('Obesity Roadmaps 1.0') as well as manage masses and heights for children through 6 monthly recommendations (Kamal, 2015*a*; *b*) and classify nutritional status (Kamal, 2014; Kamal *et al.*, 2014*b*). 'Growth-and-Obesity Vector-Roadmaps 1.0' were same as 'Growth-and-Obesity Scalar-Roadmaps 1.0' for actual checkups (Naz, 2017; Kamal *et al.*, 2016*a*). Main difference existed in assigning 6 monthly targets for mass and height management, determined by fitting parabolic trajectories for CDC height and mass percentiles. These softer targets were supposed to achieve corrections by the age of 10 *years*, instead of a short span of 6 *months*. 'Growth-and-Obesity Scalar-Roadmaps 1.1', 'Obesity Roadmaps 1.1' (Kamal *et al.*, 2017*b*; *c*) as well as 'Growth-and-Obesity Vector-Roadmaps 1.1' (2017*b*; *c*) were different from their respective versions 1.0 in the sense that CDC percentiles were replaced by scaled percentiles to compute build (Kamal and Khan, 2015; Kamal *et al.*, 2017*b*)

September 4, 2013	**1st-Generation Solution of Childhood Obesity (Kamal *et al.*, 2013*c*)**
September 4, 2014	**2nd-Generation Solution of Childhood Obesity (Kamal *et al.*, 2014*a*)**
July 1, 2015	**3rd-Generation Solution of Childhood Obesity (Kamal, 2015*b*)**
February 13, 2016	**4th-Generation Solution of Childhood Obesity (Kamal *et al.*, 2016*b*)**
January 1, 2017	**5th-Generation Solution of Childhood Obesity (Kamal, 2017*b*)**
October 1, 2017	**6th-Generation Solution of Childhood Obesity (Kamal, 2017*c*)**
October 1, 2018	**7th-Generation Solution of Childhood Obesity (Kamal *et al.*, 2018)**
January 1, 2020	**8th-Generation Solution of Childhood Obesity (this paper)**

Fig. 5. Solutions of childhood-obesity problem proposed by the NGDS Team — NGDS stands for 'National Growth and Developmental Standards for the Pakistani Children'

and severity of acute malnutrition, if present (Kamal, 2015*a*; Kamal *et al.*, 2017*b*). 'Growth-and-Obesity Vector-Roadmaps 2.0' provided ranges of 6 monthly mass-management targets instead of single values, which were more realistic to achieve. For parents, 'Obesity Roadmaps 1.0' were generalized to 'Obesity Roadmaps 2.0'.

Another group of researchers, Perry *et al.* (2018) have reported short-term and long-term behavior outcomes in a 6-*month* family-based weight management program.

SOLUTIONS OF CHILDHOOD OBESITY

Rutter (2012) is of the opinion that no single most important intervention exists for treatment of childhood obesity. Parkinson *et al.* (2017) described the food system compass to promote balanced eating, in order to control childhood obesity. Robinson and Sirard (2005) gave solution-oriented research paradigm for avoiding childhood obesity. Mazik *et al.* (2007) suggested looking at the wider determinants of obesity, such as walking-biking-friendly neighborhood, social interactions, food marketing and pricing in order to obtain a viable solution. Wieting (2008) dealt with cause and effect in childhood obesity to find out a solution.

The NGDS Team used mathematical-statistical techniques during 2013-2018 to propose the first- to the seventh-generation solutions of childhood obesity. The first- to the third-generation solutions were summarized in Kamal (2015*c*). In this paper, the eighth-generation solution is proposed (Figure 5).

One must realize that for a sustainable optimal-mass management, values as well as slopes must match for percentile curves of height and mass at the end of the childhood phase — dynamical-system approach (Kamal, 2015*b*). Alternatively, optimal-mass management could be visualized as optimal solution of diet, exercise and lifestyle adjustment — optimization approach (Kamal *et al.*, 2013*b*; 2014*b*). The goal is to counter the energy imbalance and form a new steady state at a lower level. Table 2 explains equilibrium, steady state and non-equilibrium in terms of probability of occupation, energy transfer and transfer function.

MONITORING OF CHILDHOOD OBESITY

Anthropometric measures, generally, used for childhood-obesity monitoring are stature (standing height), weight

Table 2. Equilibrium, steady state and non-equilibrium$^{\Omega}$

	Probability-of-Occupation Approach	*Energy-Transfer Approach*	*Transfer Function*
Equilibrium	Equal in different states, not varying with time	No net energy transfer	Zero
Steady state	Not equal in different states, not varying with time	Energy transfer at a constant rate	Non-zero constant
Non-equilibrium	Varying with time	Energy transfer at a variable rate	Function of state variables

$^{\Omega}$ Main ideas taken from Kamal (2011)

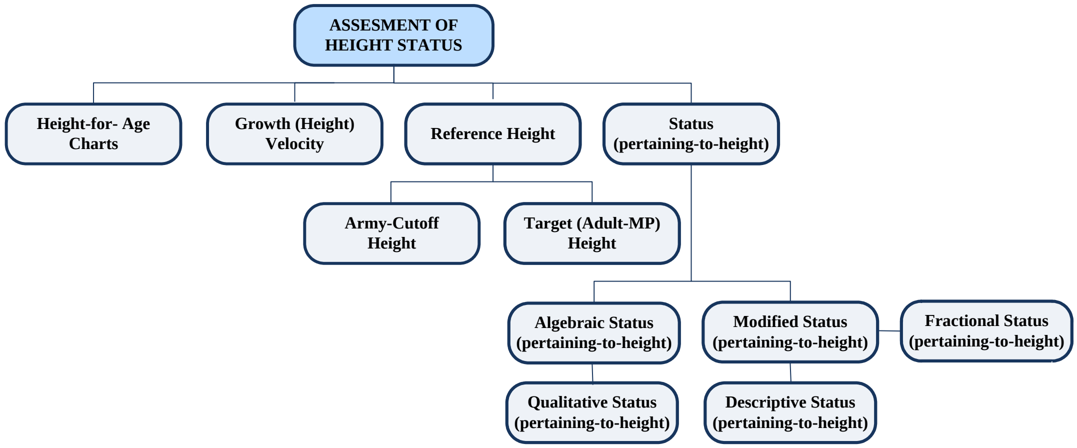


Fig. 6*a*. Classification of methods available for assessment of height status

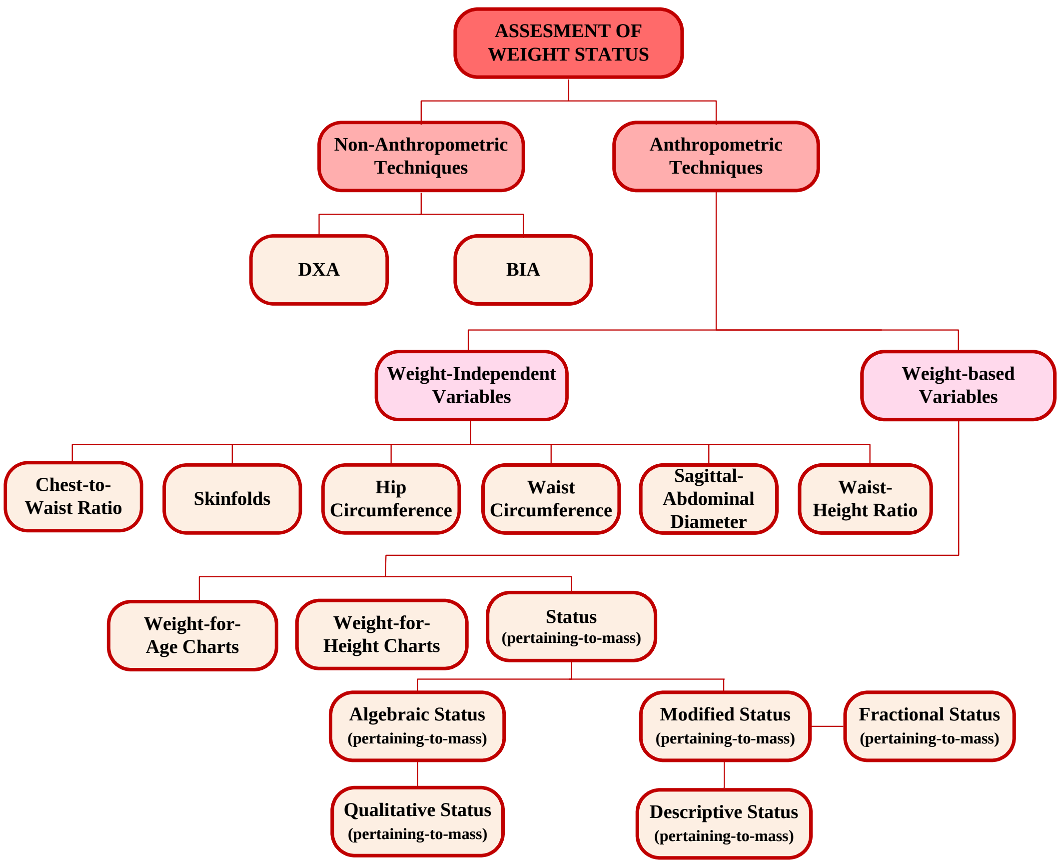


Fig. 6*b*. Classification of methods available for assessment of weight status

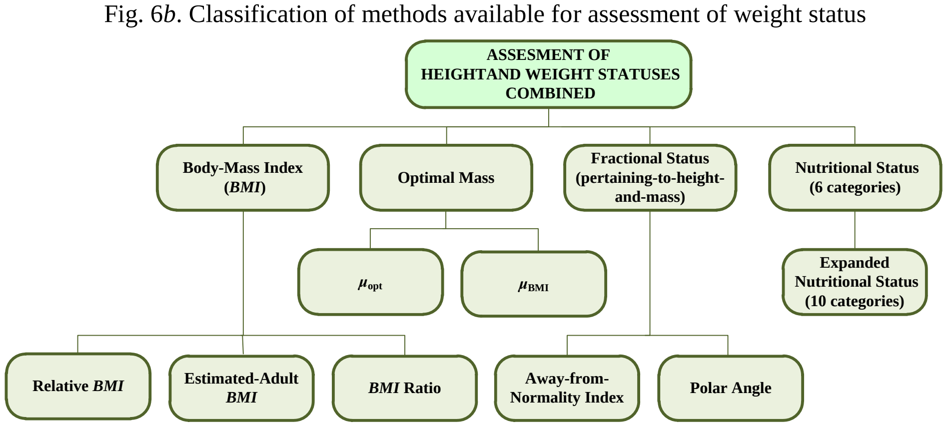


Fig. 6*c*. Classification of methods available for assessment of height and weight statuses combined

Fig. 7*a*-*d*. Measurements of heights and masses of twin siblings, brother Z. H. (*a*, *b*) and sister T. H. (*c*, *d*) — (*a*, *b*) first appeared in Kamal *et al.* (2015) and (*c*, *d*) in Kamal *et al.* (2017*a*); all of them published in the same journal

(mass), as well as chest, waist and hip circumferences. Figures 6*a*-*c* depict anthropometric and non-anthropmetric measures employed in monitoring childhood obesity. Brief descriptions of field and laboratory studies conducted by the NGDS Team are given below**:**

Field Study — the NGDS Pilot Project

Initiated 21-*year* ago, the NGDS Pilot Project was an observational study, based on convenience sampling. The study was designed in consultation with leading Pakistani and Swedish pediatricians taking into account the applicable ethical protocols (Appendix B). The participants comprised of boys and girls representing all provinces of Pakistan studying in three schools run by the Armed Forces of Pakistan (one each belonging to Pakistan Army, Navy and Air Force) as well as a civilian school during 1998-2013.

Laboratory Study — Sibling Growth Pilot Project

A family-centered subproject of the NGDS Pilot Project, Sibling Growth Pilot Project (SGPP) monitored health of enrolled families, who visited Growth-and-Imaging Laboratory for checkups along with their 5-10-*year*-old children during 2002-2019. Checkups were conducted giving due regard to parents' and their children's comfort, confidentiality, dignity, privacy and safety.

Protocols of the NGDS Pilot Project https://ngds-ku.org and Sibling Growth Pilot Project (SGPP) https://www.ngds-ku.org/ngds_URL/subprojects.htm#SGPP are described in detail in Additional File 1 of Kamal (2017*c*).

Anthropometric Techniques — Least Counts: 0.005 cm (for Height) and 0.005 kg (for Mass)

The most important aspect of childhood-obesity research is getting accurate and precise (Kamal, 2009) height and weight measurements (Gobte and Meyer, 2018). Heights, *h*, and masses, μ, were obtained by trained and reproducible anthropometrists according to laid-down procedures (Kamal *et al.*, 2013*d*). The procedures were spelled out in the official manual (Kamal, 2016*a*) and elaborated step-by-step using labeled photographs in Additional File 1, further reinforced by video series (Kamal, 2017*a*). Standing heights were recorded to least counts of 0.1 *cm* (1998-2011, setsquare set — Kamal and Firdous, 2002*a*; *b*); 0.01 *cm* (2012-2015, Vernier scale — Kamal, 2010) and 0.005 *cm* (2016 to date, enhanced-Vernier scale — Kamal *et al.*, 2016*b*); weights (masses) measured to least counts of 0.5 *kg* (1998-2011, bathroom scale— Kamal and Firdous, 2002*a*; *b*); 0.01 *kg* (2012-2015, modified-beam scale — Kamal, 2010) and 0.005 *kg* (2016-present, enhanced-beam scale — Kamal *et al.*, 2016*b*), all measurements taken before 12 o'clock, with the boys and girls bareheaded, barefooted and completely undressed except short underpants (Figures 7*a*-*d*). First protocol of each daily session was calibration of instruments used in anthropometry, recording of zero errors and subtraction from the measured values. Disrobing to briefs/panties allowed the measurer to make sure that each boy and girl maintained upright posture (knees and elbows not flexed, toes and heels not lifted, Frankfort plane parallel to ground), air fully breathed in (stomach in, chest out), stand-at-ease posture and feet apart (for mass measurement)/attention posture and feet together (for height measurement).

HEALTH CONCERNS OF STILL-GROWING PARENTS AND THEIR CHILDREN

Still-growing parents are categorized as those, who have 'chronological ages' under 19 *years* (mother) and 21

Table 3*a*. Different categories of ages$^{\zeta}$

Chronological
Developmental
Skeletal
Phenotypic (Biological)

Table 3*b*. Different categories of maturity levels$^{\otimes, \varnothing}$

Physical
Mental
Social
Spiritual

$^{\zeta}$ 'Chronological age' is the age, which is the difference between the date (on which the age and date of birth — Kamal *et al.* (2011) provides a method to compute this age in *decimal years*; 'developmental age' is the age at which one's brain functions (instrumental in giving the person responsibilities and setting limits on behavior); 'skeletal age' is the age at which one's skeleton is formed (determined by studying X rays of bones); 'phenotypic age' is the age at which one's body functions

$^{\otimes}$ Maturity levels (Table 3*b*) may loosely be connected to the ages mentioned in Table 3*a* — physical maturity is related to chronological age, skeletal and phenotypic ages; mental, social and spiritual maturities are related to developmental age

$^{\varnothing}$ Maturity levels mentioned in Table 3*b* are taken from Andrews *et al.* (1963); these 4 interrelated levels of maturity have been discussed in detail in the varied roles as an individual, as a family member and as a community member elsewhere (Kamal and Jamil, 2012)

years (father). Chronological age is explained in Table 3*a*. Such couples may not have the necessary 'mental maturity' to groom the future torchbearers of nation. Different types of maturity levels are described in Table 3*b*. In addition to emotional imbalance, such marriages could, also, effect physical growth and both married boy and married girl might not be able to attain estimated-adult height. Further, young mothers run a very high risk of mortality during labor. The children of such parents are often undernourished and feeble-minded due to poor quality of health care available during infancy and early childhood. In many areas of the world, such marriages are very common (Kamal and Jamil, 2012). Table 4 summarizes the implications of underage, late, forced, love and arranged marriages.

GROWTH-AND-OBESITY SCALAR- AND VECTOR-ROADMAPS 2.5

These roadmaps are different from their respective 2.1 version only in the 6 monthly predictions of mass. Instead of *BMI*-based-optimal mass, reference *BMI*-based-optimal mass is employed to compute the ranges of mass management. *BMI*-based-optimal mass, μ_{BMI}, for a child is computed on the basis of estimated-adult height, whereas reference-*BMI*-based-optimal mass, $\mu_{\text{ref-BMI}}$, is evaluated by substituting estimated-adult-reference height, with the corresponding percentile represented by $P_{\text{ref-BMI}}$. Mathematical tools used in constructing Growth-and-Obesity Roadmaps 2.5 are listed in Additional File 2. Color-coding used in constructing these roadmaps is included in Additional File 3. Detailed methods for generating these roadmaps are described in Additional File 4.

A modification as well as an extension in the nutritional-status categories is proposed., Over-nutrition, under-nutrition, energy-channelization I and energy-channelization II are re-introduced as cases corresponding to polar angles, $45^{o}\left(\frac{\pi}{4}\right)$, $135^{o}\left(\frac{3\pi}{4}\right)$, $225^{o}\left(\frac{5\pi}{4}\right)$ and $315^{o}\left(\frac{7\pi}{4}\right)$, respectively, as well as obesity, tallness, wasting and

Table 4. Types of marriages

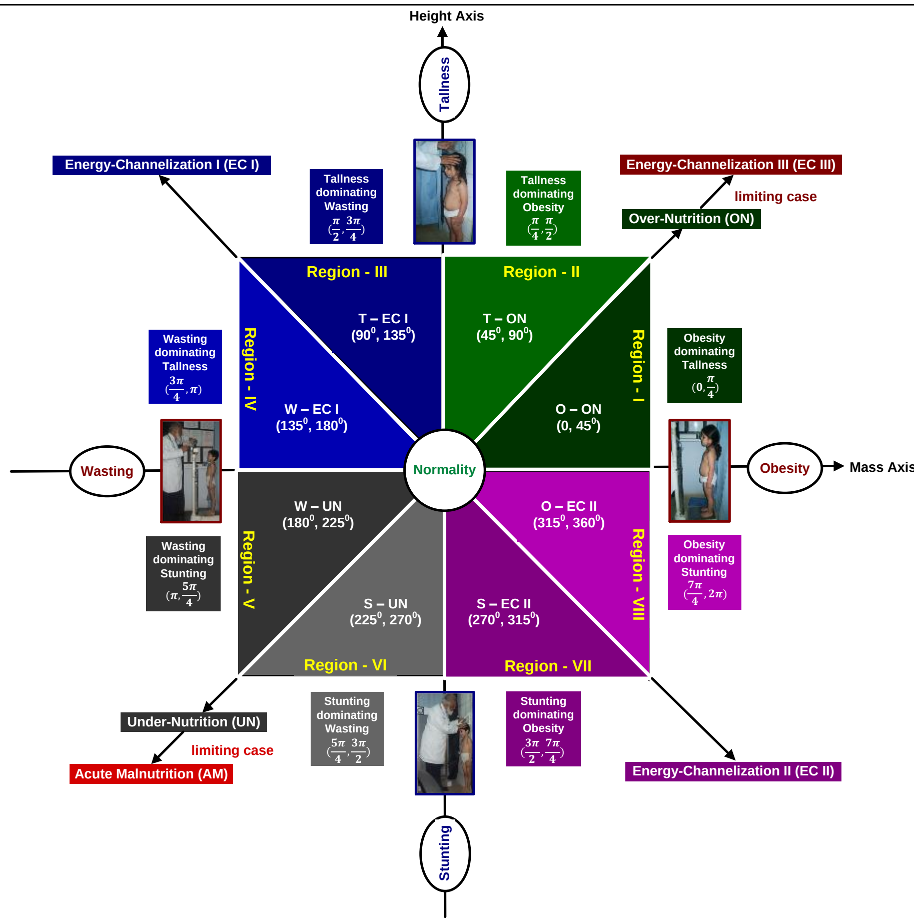
Type	*Implications*$^{\nabla}$
Underage$^{\partial}$	Emotional imbalance, retardation of mental capabilities, effect on physical growth
Late$^{\upsilon}$	Comes with maturity and responsibility; but may be associated with subsiding of vitalities
Forced	Pushed into relationship without consent, has similar consequences and repercussions as underage marriage
Love	May appear charming, but most of the time results in broken marriages or life-partner abuse/murder
Arranged	Looks like an optimal solution, avoiding both extremes, as long as stakeholders$^{\phi}$ are taken into confidence

$^{\nabla}$ These implications are summarized from Kamal and Jamil (2012)

$^{\partial}$ Also called 'very-young marriage'. This is the marriage, when the boy or the girl has not, even, entered secondary school — family entropy may be very high in this situation (Bates *et al.*, 2019)

$^{\upsilon}$ 'Late marriage' is the marriage, when all education is finished and the couple is in the middle of professional career

$^{\phi}$ Potential husband and wife — marrying a girl without taking her consent is strictly prohibited in *Islam*



Regular Categories (4) — the polar angle, θ, is expressed in degrees (radians)**)**

ON: **O**ver-**N**utrition; $\theta = 45^{\circ}\left(\frac{\pi}{4}\right)$

UN: **U**nder-**N**utrition; $\theta = 225^{\circ}\left(\frac{5\pi}{4}\right)$

EC I: **E**nergy-**C**hannelization **I**; $\theta = 135^{\circ}\left(\frac{3\pi}{4}\right)$

EC II: **E**nergy-**C**hannelization **II**; $\theta = 315^{\circ}\left(\frac{7\pi}{4}\right)$

Limiting Cases (2)

EC III: **E**nergy-**C**hannelization **III**, also called Puberty-Induced Energy-Channelization, characterized by sum of scaled percentiles exceeding 150 for a child, who has, already, entered puberty; limiting case of **ON**

AM: **A**cute **M**alnutrition, characterized by sum of scaled percentiles less than 6; limiting case of **UN**

Extended Categories (8)

O-ON: Obesity dominated **O**ver-**N**utrition
T-ON: Tallness dominated **O**ver-**N**utrition
T-EC I: Tallness dominated **E**nergy-**C**hannelization **I**
W-EC I: Wasting dominated **E**nergy-**C**hannelization **I**
W-UN: Wasting dominated **U**nder-**N**utrition
S-UN: Stunting dominated **U**nder-**N**utrition
S-EC II: Stunting dominated **E**nergy-**C**hannelization **II**
O-EC II: Obesity dominated **E**nergy-**C**hannelization **II**

Special Categories (5)

Obesity: $\theta = 0$

Wasting: $\theta = 180^{\circ}(\pi)$

Tallness: $\theta = 90^{\circ}\left(\frac{\pi}{2}\right)$

Stunting: $\theta = 270^{\circ}\left(\frac{3\pi}{2}\right)$

Normality: θ indeterminate[II]

[II] Proof of $\frac{0}{0}$ being 'indeterminate' is included in Additional File 2

Fig. 8. Extended nutritional statuses classification into 19 categories based on polar-coördinate interpretation; the word 'extended' used in place of 'expanded', which had 10 categories (Kamal *et al.*, 2018) — open intervals specify polar-angle range in degrees (inside the right-angled triangles) and in radians (inside the rectangles)

Table 5. Nutritional-status categories — timeline of evolution

Year	*Categories*	*Listing*	*First Mention*
Before 2014	3	ON, UN, AM[Я]	------
2014	6	ON, UN, AM, EC I-III[Л]	Kamal (2014); Kamal *et al.* (2014*b*)
2018	10	O-ON, EC III, T-ON, T-EC I, W-EC-I, W-UN, AM, S-UN, S-EC II, O-EC II[Ю]	Kamal *et al.* (2018)
2020	19	Obesity, O-ON, ON, EC III, T-ON, Tallness, T-EC I, EC I, W-EC I, Wasting, W-UN, UN, AM, S-UN, Stunting, S-EC II, EC II, O-EC II and Normality[Ж]	This work

[Я] Acute malnutrition (AM) is characterized by the condition that sum of scaled percentiles of height and mass is less than 6 — scaled percentiles introduced in Kamal *et al.* (2017*b*); over-nutrition (ON) occurs when tallness is combined with obesity and under-nutrition (UN) when stunting is combined with wasting

[Л] Energy-channelization is abbreviated as EC — EC I is present when tallness exists along with wasting, EC II when obesity exists along with stunting (Kamal *et al.*, 2014*b*); EC III was introduced in Kamal (2014), detailed explanation given in footnote[⊂] (Table 8) as well as in Kamal (2015*a*)

[Ю] Obesity dominated over-nutrition (O-ON) occurs when obesity prevails tallness [absolute value of modified status (pertaining-to-mass) exceeds absolute value of modified status (pertaining-to-height), both statuses positive]; tallness dominated over-nutrition (T-ON) occurs when tallness prevails obesity [absolute value of modified status (pertaining-to-height) exceeds absolute value of modified status (pertaining-to-mass), both statuses positive]; tallness dominated energy-channelization I (T-EC I) occurs when tallness prevails wasting [absolute value of modified status (pertaining-to-height) exceeds absolute value of modified status (pertaining-to-mass), first status positive, second negative]; wasting dominated energy-channelization I (W-EC I) occurs when wasting prevails tallness [absolute value of modified status (pertaining-to-mass) exceeds absolute value of modified status (pertaining-to-height), first status negative, second positive]; wasting dominated under-nutrition (W-UN) occurs when wasting prevails stunting [absolute value of modified status (pertaining-to-mass) exceeds absolute value of modified status (pertaining-to-height), both statuses negative]; stunting dominated under-nutrition (S-UN) occurs when stunting prevails wasting [absolute value of modified status (pertaining-to-height) exceeds absolute value of modified status (pertaining-to-mass), both statuses negative]; obesity dominated energy-channelization II (O-EC II) occurs when obesity prevails stunting [absolute value of modified status (pertaining-to-mass) exceeds absolute value of modified status (pertaining-to-height), first status positive, second negative]

[Ж] Obesity (Wasting) is the nutritional status assigned, when modified status (pertaining-to-mass) is positive (negative) and modified status (pertaining-to-height) vanishes; tallness (stunting) refers to the situation in which modified status (pertaining-to-height) is positive (negative) and modified status (pertaining-to-mass) vanishes; normality occurs when both modified statuses vanish

stunting corresponding to polar angles, 0, $90^{\mathrm{o}}\left(\dfrac{\pi}{2}\right)$, $180^{\mathrm{o}}(\pi)$ and $270^{\mathrm{o}}\left(\dfrac{3\pi}{2}\right)$, respectively. Polar angle for normality is indeterminate (Figure 8). This makes a total of 19 categories as compared to the 10 proposed in 2018 (Table 5). Build is determined based on scaled percentiles of height and mass, $P_{\text{scaled}}(h)$ and $P_{\text{scaled}}(\mu)$, and, subsequently, related to 'phenotypic age' and 'developmental age' (Table 6).

Table 6. Build and brain-body dominance[ℑ]

Build	*Recipe for Assignment*	*Brain-Body Dominance*	*Suitable for*
Small	$P_{\text{scaled}}(h)+P_{\text{scaled}}(\mu)<50$	Brain	Planning and development tasks, intellectual work
Medium	$50\le P_{\text{scaled}}(h)+P_{\text{scaled}}(\mu)<150$	Equal contribution of body and brain functions	May adapt to body- or brain-dominating tasks
Big	$150\le P_{\text{scaled}}(h)+P_{\text{scaled}}(\mu)$	Body	Tasks involving speed and strength

[ℑ] For a person of *small* build, the hypothesis is that 'developmental age' is greater than 'phenotypic age', whereas for a person of *big* build, 'phenotypic age' is supposed to be greater than 'developmental age' (Table 3*a*) — build was introduced in Kamal and Khan (2015) and defined in terms of scaled percentiles in Kamal *et al.* (2017*b*); build should be the main factor in forming sport teams (Kamal and Khan, 2015) and classroom sections (Kamal, 2015*c*; Kamal and Khan, 2018)

$$h_{\text{min}} = min\,(h_{\text{CA-AC}}, h_{\text{CA-MP}})$$
$$h_{\text{max}} = max\,(h_{\text{CA-AC}}, h_{\text{CA-MP}})$$

If $h < h_{\text{min}}$

$$STATUS_{\pm}^{\text{MOD}}(h) = 100\frac{h - h_{\text{min}}}{h_{\text{min}}}\% < 0$$

Else if $h_{\text{min}} \le h \le h_{\text{max}}$

$$STATUS_{\pm}^{\text{MOD}}(h) = 0$$

Else $h > h_{\text{max}}$

$$STATUS_{\pm}^{\text{MOD}}(h) = 100\frac{h - h_{\text{max}}}{h_{\text{max}}}\% > 0$$

$$STATUS_{\text{Fr}}(h) = \frac{STATUS_{\pm}^{\text{MOD}}(h)}{100}$$

4th-Degree Tall	$STATUS_{\pm}^{\text{MOD}}(h) \ge +30\%$
3rd-Degree Tall	$+20\% \le STATUS_{\pm}^{\text{MOD}}(h) < +30\%$
2nd-Degree Tall	$+10\% \le STATUS_{\pm}^{\text{MOD}}(h) < +20\%$
1st-Degree Tall	$0\% < STATUS_{\pm}^{\text{MOD}}(h) < +10\%$
Normal	$STATUS_{\pm}^{\text{MOD}}(h) = 0$
1st-Degree Stunted	$-10\% \le STATUS_{\pm}^{\text{MOD}}(h) < 0$
2nd-Degree Stunted	$-20\% \le STATUS_{\pm}^{\text{MOD}}(h) < -10\%$
3rd-Degree Stunted	$-30\% \le STATUS_{\pm}^{\text{MOD}}(h) < -20\%$
4th-Degree Stunted	$STATUS_{\pm}^{\text{MOD}}(h) < -30\%$

Fig. 9*a*. Formulae for modified and fractional statuses (pertaining-to-height) and color codes used to represent descriptive status (pertaining-to-height) — $h_{\text{CA-AC}}$ and $h_{\text{CA-MP}}$ explained in Table 7*a*

Figures 9*a*, *b* list formulae for computing modified and fractional statuses (pertaining-to-height) and (pertaining-to-mass) as well as color codes for descriptive statuses, which have been introduced and explained in detail earlier (Kamal *et al.*, 2018). In case, either or both of the parents' heights are not available, restricted Growth-and-Obesity Vector-Roadmap 2.5 is constructed. Target height, current-age-mid-parental height, modified statuses (pertaining-to-height), away-from-normality index and polar angle cannot be computed; descriptive status (pertaining-to-height) and extended nutritional status cannot be determined. When heights of parents are not available, reference percentile is taken as the maximum of height percentile and percentile of army-cutoff height — 2.72^{P} for boys (2.718014592103645… to be exact); 19.36^{P} for girls (19.35609323536863… to be exact). Sample Growth-and-

$$\mu_{\text{min}} = min\,(\mu_{\text{BMI}}^{\text{corrected}}, \mu_{\text{opt}}^{\text{corrected}})$$
$$\mu_{\text{max}} = max\,(\mu_{\text{BMI}}^{\text{corrected}}, \mu_{\text{opt}}^{\text{corrected}})$$

If $\mu < \mu_{\text{min}}$

$$STATUS_{\pm}^{\text{MOD}}(\mu) = 100\frac{\mu - \mu_{\text{min}}}{\mu_{\text{min}}}\% < 0$$

Else if $\mu_{\text{min}} \le \mu \le \mu_{\text{max}}$

$$STATUS_{\pm}^{\text{MOD}}(\mu) = 0$$

Else $\mu > \mu_{\text{max}}$

$$STATUS_{\pm}^{\text{MOD}}(\mu) = 100\frac{\mu - \mu_{\text{max}}}{\mu_{\text{max}}}\% > 0$$

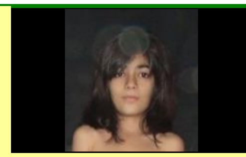
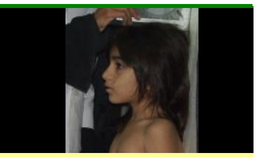
$$STATUS_{\text{Fr}}(\mu) = \frac{STATUS_{\pm}^{\text{MOD}}(\mu)}{100}$$

4th-Degree Obese	$STATUS_{\pm}^{\text{MOD}}(\mu) \ge +30\%$
3rd-Degree Obese	$+20\% \le STATUS_{\pm}^{\text{MOD}}(\mu) < +30\%$
2nd-Degree Obese	$+10\% \le STATUS_{\pm}^{\text{MOD}}(\mu) < +20\%$
1st-Degree Obese	$0\% < STATUS_{\pm}^{\text{MOD}}(\mu) < +10\%$
Normal	$STATUS_{\pm}^{\text{MOD}}(\mu) = 0$
1st-Degree Wasted	$-10\% \le STATUS_{\pm}^{\text{MOD}}(\mu) < 0$
2nd-Degree Wasted	$-20\% \le STATUS_{\pm}^{\text{MOD}}(\mu) < -10\%$
3rd-Degree Wasted	$-30\% \le STATUS_{\pm}^{\text{MOD}}(\mu) < -20\%$
4th-Degree Wasted	$STATUS_{\pm}^{\text{MOD}}(\mu) < -30\%$

Fig. 9*b*. Formulae for modified and fractional statuses (pertaining-to-mass) and color codes used to represent descriptive status (pertaining-to-mass) — $\mu_{\text{BMI}}^{\text{corrected}}$ and $\mu_{\text{opt}}^{\text{corrected}}$ explained in Table 13*a*

Table 7*a*. Growth-and-Obesity Vector-Roadmap 2.5 of Z. I. R. (SGPP-KHI-20100908-01/04)

Gender: Female ♀ • *Date of Birth* (*year-month-day*): 2004-03-29 • *Adult-Army-Cutoff Height*: 157.48 *cm* (19.36^{P})
Father's Height: ♂ 164.02 *cm* • *Mother's Height*: ♀ 151.12 *cm* • *Target* (*Adult-Mid-Parental*) *Height*: 151.07 *cm* (2.98^{P})

Checkup	1st	2nd
Photograph		
Scanned Signatures	ZIR	ZIR
Class	II	II
Date of Checkup (*year-month-day*)	2011-10-09	2012-01-08
Age (*year-month-day*)	07-06-10	07-09-09
Age (*decimal year*), *A*	7.53	7.78
Dress Code	$0/0.5^{\chi}$	0/0.5
Behavior Code	0^{χ}	0
Height, *h* (*cm*) ⇐	**115.81**	**117.13**
Height (*ft-in*)	3 *ft* 9.59 *in*	3 *ft* 10.11 *in*
CDC Percentile-of-Height, $P_{\text{CDC}}(h, A)$ ⇔	**4.97^{P}**	**4.96^{P}**
Scaled Percentile-of-Height, $P_{\text{Scaled}}(h, A)$	6.94^{P}	6.93^{P}
Current-Age-Army-Cutoff Height, $h_{\text{CA-AC}}$ (*cm*) ⇐	119.80	121.19
$\Delta\, h_{\text{AC}}\,(cm) = h - h_{\text{CA-AC}}$	–3.99	–4.06
Current-Age-Mid-Parental Height, $h_{\text{CA-MP}}$ (*cm*) ⇐	114.60	115.91
$\Delta\, h_{\text{MP}}\,(cm) = h - h_{\text{CA-MP}}$	+1.21	+1.22
Estimated-Adult Height (*cm*)	152.63	152.62
Estimated-Adult Height (*ft–in*)	**5 *ft* 0.089 *in***	**5 *ft* 0.087 *in***
Modified Status (pertaining-to-height), $STATUS_{\pm}^{\text{MOD}}(h)$	0	0
Descriptive Status (pertaining-to-height)	Normal	Normal
Net Mass, μ (*kg*) ⇒	20.90	21.56
Net Weight (*lb-oz*)	47 *lb* 1.36 *oz*	47 *lb* 8.64 *oz*
CDC Percentile-of-Net-Mass, $P_{\text{CDC}}(\mu, A)$ ⇔	17.20^{P}	17.89^{P}
Scaled Percentile-of-Net-Mass, $P_{\text{Scaled}}(\mu, A)$	23.13^{P}	24.01^{P}
Percentile-of-*BMI*-based-Optimal-Mass, $P_{\text{BMI}}(A)$ ⇔	39.94^{P}	39.91^{P}
BMI-based-Optimal-Mass, μ_{BMI} (*kg*) ⇒	23.26	23.95
$\Delta\, \mu_{\text{BMI}}\,(kg) = \mu - \mu_{\text{BMI}}$	–2.36	–2.39
Height-Percentile-based-Optimal Mass, μ_{opt} (*kg*) ⇒	19.13	19.62
$\Delta\, \mu_{\text{opt}}\,(kg) = \mu - \mu_{\text{opt}}$	+1.77	+1.94
Estimated-Adult Mass (*kg*)	50.35	50.54
Estimated-Adult Weight (*lb–oz*)	111 *lb* 0.30 *oz*	111 *lb* 6.99 *oz*
Modified Status (pertaining-to-mass), $STATUS_{\pm}^{\text{MOD}}(\mu)$	0	0
Descriptive Status (pertaining-to-mass)	Normal	Normal
Away-from-Normality Index, *r*	0	0
Polar Angle, θ (*degree*)	Indeterminate	Indeterminate
Extended Nutritional Status	Normality	Normality
Estimated-Adult *BMI* (kg/m^2)	21.61	21.70
Estimated-Adult-Specific *BMI*	0.901	0.904
Build	Small	Small

$^{\chi}$ 'Dress Code' 0/0.5 implies that Z. I. R. was measured wearing panties only (boys in briefs only — Table 10*a*), barefoot, all clothing above the waist removed; 'Behavior Code' 0 means child was relaxed and coöperative (Kamal, 2016*a*; Kamal *et al.*, 2002)

Table 7*b*. Month-wise targets of height and mass (weight) range, determined using Growth-and-Obesity Vector-Roadmap 2.5 of Z. I. R. based on her last checkup

Date of Last (*Second*) *Checkup*: January 8, 2012 • *Decimal Age*, $A_0 = 7.7786885246$ *years*

$P_{CDC}(h, A_0) = 4.96075732220966^P$ • $P_{CDC}(\mu, A_0) = 17.8923302986379^P$

$P_{ref}(A_0) = 19.3560932353686^P$ • $P_{ref\text{-}BMI}(A_0) = 54.26058262296929^P$

Target Date^λ	*Height Target*		*Range of Mass* (*Weight*) *Targets*	
	cm	*ft-in*	*kg*	*lb-oz*
January 8, 2012	**117.13**	**3 *ft* 10.11 *in***	**21.56**	**47 *lb* 8.64 *oz***
February 8, 2012	118.01	3 *ft* 10.46 *in*	21.77-22.10	48 *lb* 0.06 *oz* - 48 *lb* 11.60 *oz*
March 8, 2012	118.82	3 *ft* 10.78 *in*	21.97-22.60	48 *lb* 6.99 *oz* - 49 *lb* 13.25 *oz*
April 8, 2012	119.65	3 *ft* 11.11 *in*	22.18-23.12	48 *lb* 14.57 *oz* - 50 *lb* 15.73 *oz*
May 8, 2012	120.43	3 *ft* 11.41 *in*	22.40-23.59	49 *lb* 6.23 *oz* - 52 *lb* 0.41 *oz*
June 8, 2012	121.22	3 *ft* 11.72 *in*	22.62-24.08	49 *lb* 14.15 *oz* - 53 *lb* 1.56 *oz*
July, 2012	121.86	3 *ft* 11.98 *in*	22.84-24.35	50 *lb* 5.80 *oz* - 54 *lb* 12.04 *oz*

λ Dark green row represents values at the last checkup, which are taken as reference to generate 6 monthly recommendations

Obesity Vector-Roadmap 2.5 of Z. I. R. is given in Tables 7*a*, *b*.

Z. I. R. was referred to the first author for complaint of short stature. Her 2 older siblings received growth-hormone treatment, with adverse effects. The above analysis showed that her height was in the normal range and did not need medical intervention. She could pickup height using natural remedies, *i. e.*, lifestyle adjustment as well as diet and exercise plans given in Additional File 5. This is the power of Growth-and-Obesity Vector-Roadmap 2.5, which spared her from over-treatment (Kamal *et al.*, 2013*a*).

Table 7*a* exhibits **pseudo gain of height** (Kamal *et al.*, 2014*b*) between 1st and 2nd checkups (height pick-up from **115.81 *cm*** to **117.13 *cm***, CDC height percentile dropping from $\mathbf{4.97^P}$ to $\mathbf{4.96^P}$). Rate of change of fractional statuses, $\frac{d(STATUS_{Fr}(h))}{d(STATUS_{Fr}(\mu))}$, between the first and the second checkups comes out to be indeterminate. Navigational and guidance trajectories of percentiles of height and mass of Z. I. R. are shown in Additional File 6, with explanation of color-coding. Compare Tables 7*a*, *b* with Table 3*d* of Kamal *et al.* (2016*a*) and Tables A3*a*, *b* of Kamal (2017*b*).

GROWTH-AND-OBESITY SCALAR- AND VECTOR-ROADMAPS 3.0

Table 8 lists roadmap applicability in various phases of growth. Growth-and-Obesity Scalar-Roadmap 3.0 is utilized for still-growing parents, whereas Growth-and-Obesity Vector-Roadmap 3.0 is meant for young children of

Table 8. Roadmap applicability in various age ranges$^{\supset}$

Age Range$^{\subset}$	*Roadmap*	*Stage of Puberty*	*Tanner Score*
$A < 9.5$ *years*	Vector-Roadmap 3.0$^{\supseteq}$	Prepubertal	1
9.5 *years* $\le A < 12.0$ *years*	Scalar-Roadmap 3.0$^{\supseteq}$	Peripubertal	2
12.0 *years* $\le A < 13.5$ *years*	Scalar-Roadmap 3.0	Pubertal	3
13.5 *years* $\le A < 20.0$ *years*	Scalar-Roadmap 3.0	Adolescent	4
$A \ge 20.0$ *years*	Obesity Roadmap 2.5	Adult	5

$^{\supset}$ Age range for roadmap applicability first mentioned in Kamal *et al.* (2018); stages of puberty and their relationship to Tanner scores as well as mathematical definitions of early, delayed, excessively-early, excessively delayed and precarious puberty first pointed out in Kamal *et al.* (2017*b*) — Susman *et al.* (2019) emphasize the need for interdisciplinary work for research on puberty

$^{\subset}$ In 'the earlier-childhood period' ($A < 9.5$ *years*), the youngster is generally *prepubertal* (child not yet entered puberty); in 'the later-childhood period' (9.5 *years* $\le A < 12.0$ *years*), the individual is generally *peripubertal* (about to enter puberty, characterized by leveling off of height trajectory); in 'the transition period' (12.0 *years* $\le A < 13.5$ *years*), the incumbent is generally *pubertal* (in the process of entering puberty, characterized by energy-channelization III), followed by 'the adolescence period' (13.5 *years* $\le A < 20.0$ *years*) and 'the adulthood period' ($A \ge 20.0$ *years*)

$^{\supseteq}$ Growth-and-Obesity Vector-Roadmap 3.0 and Growth-and-Obesity Scalar-Roadmap 3.0, respectively

Height-Gain-Target-Achievement Index

Targeted height at the end of 6 *months*: $h^{\text{Targeted}}(A_0 + 6\,months)$

Measured height at the end of 6 *months*: $h\,(A_0 + 6\,months)$

If $h\,(A_0 + 6\,months) = h^{\text{Targeted}}(A_0 + 6\,months)$,

$h_C = 100\%$

Target critically achieved

Height attained exactly equal to the assigned target

Else if $h\,(A_0 + 6\,months) > h^{\text{Targeted}}(A_0 + 6\,months)$,

$h_C = 100\% \uparrow$

Target overachieved

Height attained exceeding the assigned target

Else

$$h_C = 100\left(1 - \frac{h^{\text{Targeted}}(A_0 + 6\,months) - h\,(A_0 + 6\,months)}{h^{\text{Targeted}}(A_0 + 6\,months)}\right)\%$$

Target underachieved

Height attained not reaching up to the assigned target

Mass-Management-Target-Achievement Index

Minimum of targeted mass at the end of 6 *months*: $\mu_{\min}^{\text{Targeted}}(A_0 + 6\,months)$

Maximum of targeted mass at the end of 6 *months*: $\mu_{\max}^{\text{Targeted}}(A_0 + 6\,months)$

Measured mass at the end of 6 *months*: $\mu(A_0 + 6\,months)$

If $\mu_{\min}^{\text{Targeted}}(A_0 + 6\,months) \le \mu\,(A_0 + 6\,months) \le \mu_{\max}^{\text{Targeted}}(A_0 + 6\,months)$,

$\mu_C = 100\%$

Target critically achieved

Mass within the normal range

Else if $\mu\,(A_0 + 6\,months) < \mu_{\min}^{\text{Targeted}}(A_0 + 6\,months)$,

$$\mu_C = 100\left(1 - \frac{\mu_{\min}^{\text{Targeted}}(A_0 + 6\,months) - \mu\,(A_0 + 6\,months)}{\mu_{\min}^{\text{Targeted}}(A_0 + 6\,months)}\right)\% \downarrow$$

Target underachieved

Lesser mass outside the normal range

Else $\mu\,(A_0 + 6\,months) > \mu_{\max}^{\text{Targeted}}(A_0 + 6\,months)$,

$$\mu_C = 100\left(1 - \frac{\mu\,(A_0 + 6\,months) - \mu_{\max}^{\text{Targeted}}(A_0 + 6\,months)}{\mu_{\max}^{\text{Targeted}}(A_0 + 6\,months)}\right)\% \uparrow$$

Target underachieved

Excess mass outside the normal range

Fig. 10. Achieving height-gain and mass-management targets (h_C, μ_C) at the end of 6 *months*, expressed as percentage — pictures of height and mass measurement first appeared in Kamal and Jamil (2014), published in the same journal

Table 9. Heights used in constructing Growth-and-Obesity Scalar- and Vector-Roadmaps 2.5 and 3.0

Nomenclature	*Depends on Child's Height (patient based)*	*Depends on Parents' Heights (family based)*	*National Standards (country based)*	*Corresponding Percentile*
Measured Height$^{\wp}$	Yes	No	No	$P_{CDC}(h)$
Current-Age-Mid-Parental Height$^{\aleph}$	No	Yes	No	P_{MP}
Current-Age-Army-Cutoff Height$^{\Re}$	No	No	Yes	P_{AC}
Reference Height	Maximum of the above 3 heights			P_{ref}

$^{\wp}$ 'Estimated-Adult Height' is extrapolated from 'Measured Height', *h*, by going through constant-percentile route

$^{\aleph}$ 'Current-Age-Mid-Parental Height', $h_{CA\text{-}MP}$, is back extrapolated from 'Adult-Mid-Parental (Target) Height' by going through constant-percentile route (Tanner *et al.*, 1970); 'Target Height' to generate children's Vector-Roadmap 3.0 has to be calculated afresh at each checkup from 'Estimated-Adult Heights' of still-growing parents

$^{\Re}$ 'Current-Age-Army-Cutoff Height', $h_{CA\text{-}AC}$, is back extrapolated from 'Adult-Army-Cutoff Height' by going through constant-percentile route; 'Adult-Army-Cutoff Height' for induction into the Armed Forces of Pakistan has been set at 5 *ft* 4 *in* for males and 5 *ft* 2 *in* for females; for still-growing youth (as the case of parents of H. Family, whose Scalar-Roadmaps are given in Tables 10*a*, *b*; 11*a*, *b*), it was suggested that percentiles (2.72^P for males and 19.36^P for females) should be used instead of the adult cutoff values (Kamal *et al.*, 2017*c*)

such parents. For adult parents Obesity Roadmap 2.5 is applicable, which is different from version 2.1, as it has specific *BMI* added to the profiles. One may appreciate that specific *BMI* expresses the ratio of *BMI* with the reference *BMI* (24 kg/m^2). A value greater than one should indicate overweight condition in adults, whereas a value lesser than one should express underweight condition (Table 1).

The reference height used to construct Growth-and-Obesity Scalar- and Vector-Roadmaps 2.5 and 3.0 is the maximum of measured height, current-age-mid-parental height and current-age-army-cutoff height (Table 9). When parental heights (maternal and paternal grandparents of children) of still-growing parents are unavailable, restricted Growth-and-Obesity Vector-Roadmap 3.0 can only be generated. Consequently, target height, current-age-mid-parental height, modified status (pertaining-to-height), away-from-normality index and polar angle cannot be computed. Further, descriptive status (pertaining-to-height) and extended nutritional status cannot be determined for still-growing parents.

It would be of interest to determine quantitatively if the guidelines for change in lifestyle as well as diet and exercise plans (if each of these 3 components have been implemented properly by the family) have been effective. For this purpose, height-gain-target-achievement index and mass-management-target-achievement index have been defined (Figure 10).

Block diagram of SOFTGROWTH 2.5 and 3.0 is given in Figure 11. Detailed methods for generating these Roadmaps 3.0 are described in Additional File 7.

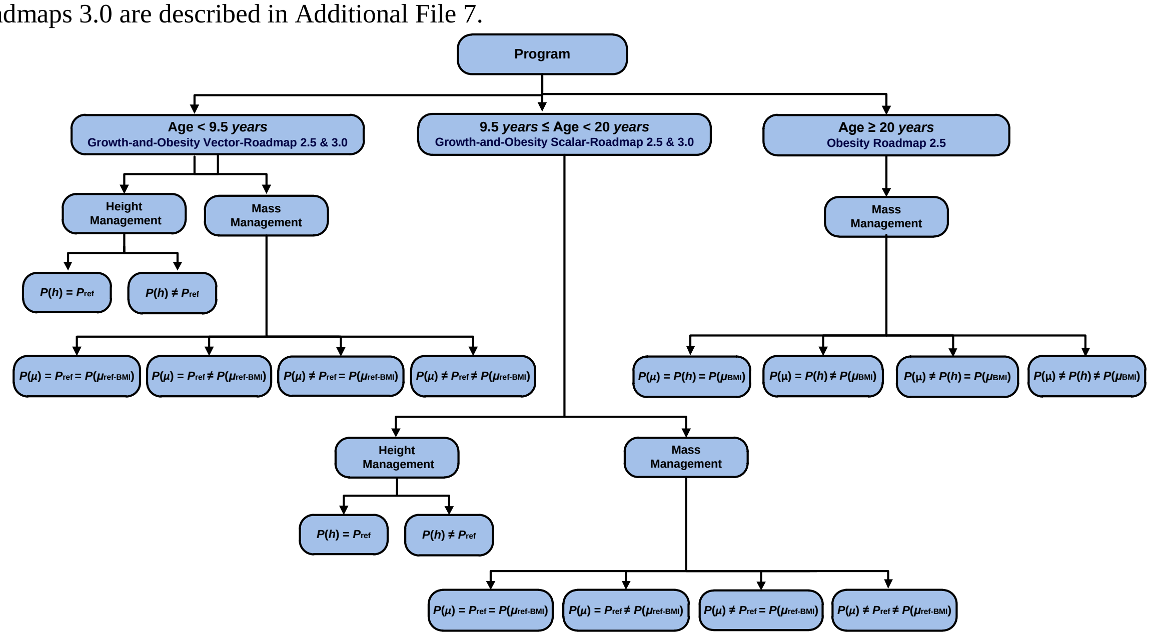


Fig. 11. Block diagram of SOFTGROWTH 2.5 and 3.0; flowcharts included in Additional File 8

Table 10*a*. Growth-and-Obesity Vector-Roadmap 3.0 of Z. H. (SGPP-KHI-20080104-01/simulated)

Gender: Male • *Date of Birth* (*year-month-day*): 2005-11-15 • *Adult-Army-Cutoff Height*: 162.56 *m* (2.72^{P})

Checkup	*1st*	*2nd*
Photograph		
Scanned Signatures	*ZH*	*ZH*
Class	ECE-I	ECE-I
Date of Checkup (*year-month-day*)	2008-08-10	2009-02-05
Age (*year-month-day*)	02-08-25	03-02-20
Age (*decimal year*), *A*	2.74	3.22
Dress Code	0/0.5	0/0.5
Behavior Code	0	0
Height, *h* (*cm*) ⇐	**96.00**	**98.10**
Height (*ft-in*)	3 *ft* 1.80 *in*	3 *ft* 2.62 *in*
CDC Percentile-of-Height, $P_{\text{CDC}}(h, A)$ ⇔	**78.47^{P}**	**63.55^{P}**
Scaled Percentile-of-Height, $P_{\text{Scaled}}(h, A)$	85.51^{P}	73.20^{P}
Current-Age-Army-Cutoff Height, $h_{\text{CA-AC}}$ (*cm*) ⇐	85.62	89.14
$\Delta\, h_{\text{AC}}\,(cm) = h - h_{\text{CA-AC}}$	+10.38	+8.96
Target (Adult-Mid-Parental) Height (*cm*)	170.10	170.71
Percentile-of-Mid-Parental-Height, $P_{\text{MP}}(A)$ ⇔	18.74^{P}	20.83^{P}
Current-Age-Mid-Parental Height, $h_{\text{CA-MP}}$ (*cm*) ⇐	89.41	93.39
$\Delta\, h_{\text{MP}}\,(cm) = h - h_{\text{CA-MP}}$	+6.59	+4.71
Estimated-Adult Height (*cm*)	182.54	179.35
Estimated-Adult Height (*ft–in*)	**5 *ft* 11.87 *in***	**5 *ft* 10.61 *in***
Modified Status (pertaining-to-height), $STATUS_{\pm}^{\text{MOD}}(h)$	+7.36%	+5.04%
Descriptive Status (pertaining-to-height)	**1st-Degree Tall**	**1st-Degree Tall**
Net Mass, μ (*kg*) ⇒	**12.00**	**12.70**
Net Weight (*lb-oz*)	26 *lb* 7.36 *oz*	28 *lb* 0.06 *oz*
CDC Percentile-of-Net-Mass, $P_{\text{CDC}}(\mu, A)$ ⇔	**8.74^{P}**	**8.55^{P}**
Scaled Percentile-of-Net-Mass, $P_{\text{Scaled}}(\mu, A)$	12.06^{P}	11.80^{P}
Percentile-of-*BMI*-based-Optimal-Mass, $P_{\text{BMI}}(A)$ ⇔	76.23^{P}	69.22^{P}
BMI-based-Optimal-Mass, μ_{BMI} (*kg*) ⇒	15.07	15.66
$\Delta\, \mu_{\text{BMI}}\,(kg) = \mu - \mu_{\text{BMI}}$	–3.07	–2.96
Height-Percentile-based-Optimal Mass, $\mu_{\text{opt}}(kg)$ ⇒	15.24	15.39
$\Delta\, \mu_{\text{opt}}\,(kg) = \mu - \mu_{\text{opt}}$	–3.24	–2.69
Estimated-Adult Mass (*kg*)	57.72	57.61
Estimated-Adult Weight (*lb–oz*)	127 *lb* 4.24 *oz*	127 *lb* 0.55 *oz*
Modified Status (pertaining-to-mass), $STATUS_{\pm}^{\text{MOD}}(\mu)$	–20.38%	–17.49%
Descriptive Status (pertaining-to-mass)	**3rd-Degree Wasted**	**2nd-Degree Wasted**
Away-from-Normality Index, *r*	0.2167	0.1820
Polar Angle, θ (*degree*)	160.13^{o}	163.91^{o}
Extended Nutritional Status	**W-EC I**	**W-EC I**
Estimated-Adult *BMI* (*kg/m*^{2})	17.32	17.91
Estimated-Adult-Specific *BMI*	0.722	0.746
Build	**Medium**	**Medium**

Table 10*b*. Month-wise targets of height and mass (weight) range, determined using Growth-and-Obesity Vector-Roadmap 3.0 of Z. H. based on his last checkup

Date of Last (*Second*) *Checkup*: February 5, 2009 • *Decimal Age*, $A_0 = 3.2246575342$ *years*

$P_{CDC}(h, A_0) = 63.5528026394^P$ • $P_{CDC}(\mu, A_0) = 8.5473186744186^P$

$P_{ref}(A_0) = 63.55280263943413^P$ • $P_{ref\text{-}BMI}(A_0) = 69.2173963274093^P$

Target Date	*Height Target*		*Range of Mass* (*Weight*) *Targets*	
	cm	*ft-in*	*kg*	*lb-oz*
February 5, 2009	**98.10**	**3 *ft* 2.62 *in***	**12.70**	**28 *lb* 0.06 *oz***
March 5, 2009	98.68	3 *ft* 2.85 *in*	13.02-13.03	28 *lb* 11.24 *oz* - 28 *lb* 11.78 *oz*
April 5, 2009	99.33	3 *ft* 3.10 *in*	13.22-13.25	29 *lb* 12.56 *oz* - 29 *lb* 13.38 *oz*
May 5, 2009	99.95	3 *ft* 3.35 *in*	13.42-13.45	29 *lb* 19.66 *oz* - 29 *lb* 10.77 *oz*
June 5, 2009	100.57	3 *ft* 3.60 *in*	13.64-13.67	30 *lb* 1.22 *oz* - 30 *lb* 2.62 *oz*
July 5, 2009	101.16	3 *ft* 3.83 *in*	13.85-13.90	30 *lb* 18.68 *oz* - 30 *lb* 10.37 *oz*
August 5, 2009	101.77	3 *ft* 4.07 *in*	14.07-14.13	31 *lb* 0.43 *oz* - 31 *lb* 12.43 *oz*

Sample Growth-and-Obesity Vector-Roadmaps 3.0 of twin children as well as parents of H. Family are presented in Tables 10*a*-c (boy, Z. H.), Tables 11*a*-*c* (girl, T. H.), Tables 12*a*-*c* (father) and Tables 13*a*-*c* (mother). Table 10*a* exhibits **pseudo gain of height** as well as **pseudo gain of mass** between 1st and 2nd simulated checkups (height pick-up from **96.00 *cm*** to **98.10 *cm***, CDC height percentile dropping from **78.47**$^{\mathbf{P}}$ to **63.55**$^{\mathbf{P}}$; mass put-on from **12.00 *kg*** to **12.70 *kg***, CDC mass percentile dropping from **8.74**$^{\mathbf{P}}$ to **8.55**$^{\mathbf{P}}$). Rate of change of fractional statuses, $\frac{d(STATUS_{Fr}(h))}{d(STATUS_{Fr}(\mu))}$, between the first and the second checkups comes out to be –0.8026. Navigational and

Table 10*c*. Height-gain-target-achievement index, h_C, and mass-management-target-achievement index, μ_C, of Z. H. at the end of 6-*month* period

End of 6th *month*Ξ	*Measured Height*		*Measured Mass* (*Weight*)	
	cm	*ft-in*	*kg*	*lb-oz*
August 5, 2009	**101.77**	**3 *ft* 4.07 *in***	**14.10**	**31 *lb* 1.45 *oz***
August 5, 2009	101.77	3 *ft* 4.07 *in*	14.07-14.13	31 *lb* 0.43 *oz* - 31 *lb* 12.43 *oz*
Target-Achievement Index	100%		100%	
Qualitative	h_C critically achieved϶		μ_C critically achieved (mass within the normal range)	

Ξ First row with dark blue background gives assumed values of measured height and mass in the simulated case; following row displays targets computed based on Growth-and-Obesity Vector-Roadmap 3.0

϶ Height attained exactly equal to the assigned target

guidance trajectories of percentiles of height and mass of Z. H. are shown in Figure 12.

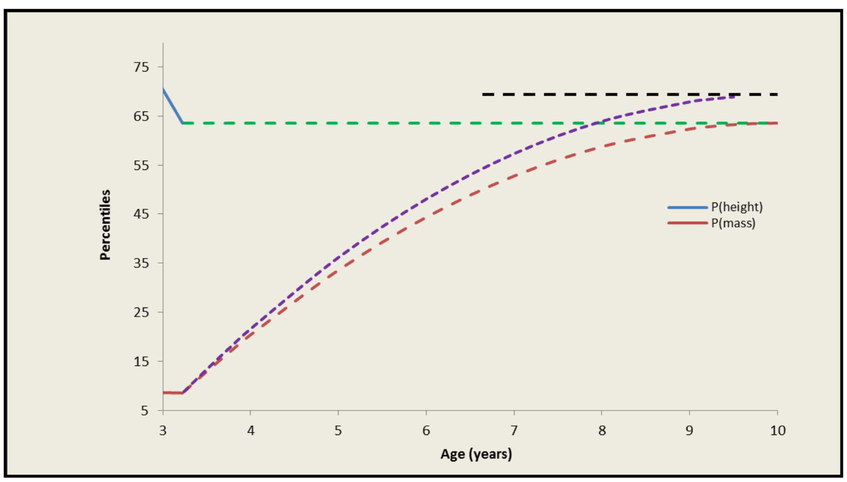


Fig. 12. Percentiles of height and mass of Z. H. — actual and targeted values

Table 11*a*. Growth-and-Obesity Vector-Roadmap 3.0 of T. H. (SGPP-KHI-20080104-01/simulated)

Gender: Female ♀ • *Date of Birth* (*year-month-day*): 2005-11-15 • *Adult-Army-Cutoff Height*: 157.48 *cm* (19.36^{P})

Checkup	*1st*	*2nd*
Photograph		
Scanned Signatures	*TH*	*TH*
Class	ECE-I	ECE-I
Date of Checkup (*year-month-day*)	2008-08-10	2009-02-05
Age (*year-month-day*)	02-08-25	03-02-20
Age (*decimal year*), *A*	2.74	3.22
Dress Code	0/0.5	0/0.5 $^{\phi}$
Behavior Code $^{\phi}$	0	0 $^{\phi}$
Height, h (*cm*) ⇐	**94.10**	**95.20**
Height (*ft-in*)	3 *ft* 1.05 *in*	3 *ft* 1.48 *in*
CDC Percentile-of-Height, $P_{\text{CDC}}(h, A)$ ⇔	**71.97^{P}**	**47.50^{P}**
Scaled Percentile-of-Height, $P_{\text{Scaled}}(h, A)$	80.38^{P}	57.89^{P}
Current-Age-Army-Cutoff Height, $h_{\text{CA-AC}}$ (*cm*) ⇐	89.51	91.87
$\Delta h_{\text{AC}}(cm) = h - h_{\text{CA-AC}}$	+4.59	+3.33
Target (Adult-Mid-Parental) Height (*cm*)	157.10	157.71
Percentile-of-Mid-Parental-Height, $P_{\text{MP}}(A)$ ⇔	17.90^{P}	20.21^{P}
Current-Age-Mid-Parental Height, $h_{\text{CA-MP}}$ (*cm*) ⇐	89.29	92.00
$\Delta h_{\text{MP}}(cm) = h - h_{\text{CA-MP}}$	+4.81	+3.20
Estimated-Adult Height (*cm*)	167.17	160.93
Estimated-Adult Height (*ft–in*)	**5 *ft* 5.82 *in***	**5 *ft* 3.36 *in***
Modified Status (pertaining-to-height), $STATUS_{\pm}^{\text{MOD}}(h)$	+5.13%	+3.47%
Descriptive Status (pertaining-to-height)	**1st-Degree Tall**	**1st-Degree Tall**
Net Mass, μ (*kg*) ⇒	**15.10**	**15.80**
Net Weight (*lb-oz*)	33 *lb* 4.73 *oz*	34 *lb* 13.42 *oz*
CDC Percentile-of-Net-Mass, $P_{\text{CDC}}(\mu, A)$ ⇔	**82.28^{P}**	**77.50^{P}**
Scaled Percentile-of-Net-Mass, $P_{\text{Scaled}}(\mu, A)$	88.35^{P}	84.77^{P}
Percentile-of-*BMI*-based-Optimal-Mass, $P_{\text{BMI}}(A)$ ⇔	76.92^{P}	62.90^{P}
BMI-based-Optimal-Mass, μ_{BMI} (*kg*) ⇒	14.67	14.95
$\Delta \mu_{\text{BMI}}(kg) = \mu - \mu_{\text{BMI}}$	+0.43	+0.85
Height-Percentile-based-Optimal Mass, $\mu_{\text{opt}}(kg)$ ⇒	14.39	13.69
$\Delta \mu_{\text{opt}}(kg) = \mu - \mu_{\text{opt}}$	+0.71	+2.11
Estimated-Adult Mass (*kg*)	70.46	67.44
Estimated-Adult Weight (*lb–oz*)	155 *lb* 5.81 *oz*	148 *lb* 11.23 *oz*
Modified Status (pertaining-to-mass), $STATUS_{\pm}^{\text{MOD}}(\mu)$	+2.90%	+5.70%
Descriptive Status (pertaining-to-mass)	**1st-Degree Obese**	**1st-Degree Obese**
Away-from-Normality Index, *r*	0.0589	0.0667
Polar Angle, θ (*degree*)	60.56^{o}	31.37^{o}
Extended Nutritional Status	**T-ON**	**O-ON**
Estimated-Adult *BMI* (*kg/m*^{2})	25.21	26.04
Estimated-Adult-Specific *BMI*	1.051	1.085
Build	**Medium**	**Medium**

Table 11*b*. Month-wise targets of height and mass (weight) range, determined using Growth-and-Obesity Vector-Roadmap 3.0 of T. H. based on her last checkup

Date of Last (*Second*) *Checkup*: February 5, 2009 • *Decimal Age*, $A_0 = 3.2246575343$ *years*

$P_{CDC}(h, A_0) = 47.4982793241^P$ • $P_{CDC}(\mu, A_0) = 77.5046227702382^P$

$P_{ref}(A_0) = 47.49827932404697^P$ • $P_{ref\text{-}BMI}(A_0) = 62.90241784775025^P$

Target Date	*Height Target*		*Range of Mass* (*Weight*) *Targets*	
	cm	*ft-in*	*kg*	*lb-oz*
February 5, 2009	**95.20**	**3 *ft* 1.48 *in***	**15.80**	**34 *lb* 13.42 *oz***
March 5, 2009	95.73	3 *ft* 1.69 *in*	15.84-15.91	34 *lb* 14.87 *oz* - 35 *lb* 1.28 *oz*
April 5, 2009	96.31	3 *ft* 1.92 *in*	15.96-16.07	35 *lb* 3.08 *oz* - 35 *lb* 6.81 *oz*
May 5, 2009	96.87	3 *ft* 2.14 *in*	16.09-16.22	35 *lb* 7.58 *oz* - 35 *lb* 12.13 *oz*
June 5, 2009	97.45	3 *ft* 2.37 *in*	16.24-16.38	35 *lb* 13.01 *oz* - 36 *lb* 1.84 *oz*
July 5, 2009	98.00	3 *ft* 2.58 *in*	16.39-16.54	36 *lb* 2.37 *oz* - 36 *lb* 7.46 *oz*
August 5, 2009	98.58	3 *ft* 2.81 *in*	16.55-16.70	36 *lb* 7.87 *oz* - 36 *lb* 13.23 *oz*

Table 11*a* exhibits **pseudo gain of height** as well as **pseudo gain of mass** between 1st and 2nd simulated checkups (height pick-up from **94.10 *cm*** to **95.20 *cm***, CDC height percentile dropping from **71.97^P** to **47.50^P**; mass put-on from **15.10 *kg*** to **15.80 *kg***, CDC mass percentile dropping from **82.28^P** to **77.50^P**). Rate of change of fractional statuses, $\frac{d(STATUS_{Fr}(h))}{d(STATUS_{Fr}(\mu))}$, between the first and the second checkups comes out to be –0.5927. Navigational and guidance trajectories of percentiles of height and mass of T. H. are shown in Figure 13. A summary of equations used to generate Vector-Roadmaps 3.0 is available in Figure 14.

Table 11*c*. Height-gain-target-achievement index, h_C, and mass-management-target-achievement index, μ_C, of T. H. at the end of 6-*month* period

End of 6th *month*	*Measured Height*		*Measured Mass* (*Weight*)	
	cm	*ft-in*	*kg*	*lb-oz*
August 5, 2009	**98.61**	**3 *ft* 2.82 *in***	**16.75**	**36 *lb* 14.94 *oz***
August 5, 2009	98.58	3 *ft* 2.81 *in*	16.55-16.70	36 *lb* 7.87 *oz* - 36 *lb* 13.23 *oz*
Target-Achievement Index	100% ↑		99.71% ↑	
Qualitative	h_C overachieved		μ_C underachieved (excess mass outside the normal range)	

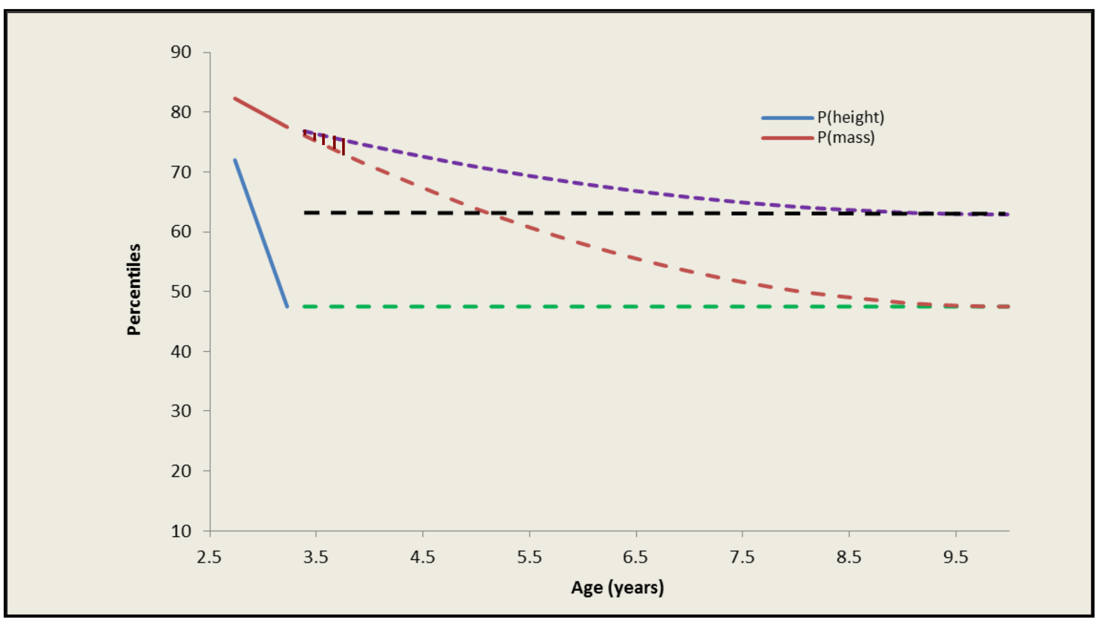


Fig. 13. Percentiles of height and mass of T. H. — actual and targeted values

Table 12*a*. Growth-and-Obesity Scalar-Roadmap 3.0 of father (SGPP-KHI-20080104-01/simulated)

Date of Birth (*year-month-day*)**:** 1990-07-04 • *Adult-Army-Cutoff Height***:** 162.56 *cm* (2.72^{P})

Checkup	*1st*	*2nd*
Date of Checkup (*year-month-day*)	2008-08-10	2009-02-05
Age (*year-month-day*)	18-01-06	18-07-01
Age (*decimal year*), *A*	18.10	18.59
Dress Code	2/2¶	2/2
Behavior Code	0	0
Height, *h* (*cm*)⇐	168.20	170.10
Height (*ft-in*)	5 *ft* 6.22 *in*	5 *ft* 6.97 *in*
CDC Percentile-of-Height, $P_{\text{CDC}}(h, A)$ ⇔	15.64^{P}	20.75^{P}
Scaled Percentile-of-Height, $P_{\text{Scaled}}(h, A)$	21.14^{P}	27.60^{P}
Current-Age-Army-Cutoff Height, $h_{\text{CA-AC}}$ (*cm*) ⇐	161.45	161.90
$\Delta h_{\text{AC}}(cm) = h - h_{\text{CA-AC}}$	+6.75	+8.20
Target (Adult-Mid-Parental) Height (*cm*)	167.43*	167.43
Percentile-of-Mid-Parental-Height, $P_{\text{MP}}(A)$ ⇔	9.76^{P}	9.76^{P}
Current-Age-Mid-Parental Height, $h_{\text{CA-MP}}$ (*cm*) ⇐	166.39	166.81
$\Delta h_{\text{MP}}(cm) = h - h_{\text{CA-MP}}$	+1.81	+3.29
Estimated-Adult Height (*cm*)	169.19	170.68
Estimated-Adult Height (*ft–in*)	**5 *ft* 6.61 *in***	**5 *ft* 7.20 *in***
Modified Status (pertaining-to-height), $STATUS_{\pm}^{\text{MOD}}(h)$	+1.09%	+1.97%
Descriptive Status (pertaining-to-height)	**1st-Degree Tall**	**1st-Degree Tall**
Net Mass, μ (*kg*) ⇒	57.60	59.40
Net Weight (*lb-oz*)	127 *lb* 0.13 *oz*	130 *lb* 15.63 *oz*
CDC Percentile-of-Net-Mass, $P_{\text{CDC}}(\mu, A)$ ⇔	15.23^{P}	18.00^{P}
Scaled Percentile-of-Net-Mass, $P_{\text{Scaled}}(\mu, A)$	20.61^{P}	29.16^{P}
Percentile-of-*BMI*-based-Optimal-Mass, $P_{\text{BMI}}(A)$ ⇔	43.19^{P}	47.56^{P}
BMI-based-Optimal-Mass, μ_{BMI} (*kg*) ⇒	65.61	67.73
$\Delta \mu_{\text{BMI}}(kg) = \mu - \mu_{\text{BMI}}$	–8.01	–8.33
Height-Percentile-based-Optimal Mass, $\mu_{\text{opt}}(kg)$ ⇒	57.73	60.31
$\Delta \mu_{\text{opt}}(kg) = \mu - \mu_{\text{opt}}$	–0.13	–0.91
Estimated-Adult Mass (*kg*)	60.23	61.99
Estimated-Adult Weight (*lb–oz*)	132 *lb* 13.00 *oz*	134 *lb* 15.90 *oz*
Modified Status (pertaining-to-mass), $STATUS_{\pm}^{\text{MOD}}(\mu)$	–0.23%	–1.50%
Descriptive Status (pertaining-to-mass)	**1st-Degree Wasted**	**1st-Degree Wasted**
Away-from-Normality Index, *r*	0.1086	0.0248
Polar Angle, θ (*degree*)	102.10^{o}	127.31^{o}
Extended Nutritional Status	**T-EC I**	**T-EC I**
Estimated-Adult *BMI* (*kg/m*^{2})	21.04	21.01
Estimated-Adult-Specific *BMI*	0.877	0.875
Build	**Small**	**Small**

¶ 'Dress Code' 2/2 implies that father was measured wearing T-shirt and trousers, barefoot

* Paternal grandmother of T. H. and Z. H. is above the age of 19 *years* (measured height = estimated-adult height = 150.27 *cm*); paternal grandfather is above the age of 21 *years* (measured height = estimated-adult height = 171.59 *cm*); target height computed using formula for boys, *F* and *M* are heights of father and mother measured in *cm* (Tanner *et al.*, 1970)**:** $\textit{Target Height of Boy}\ (cm) = \frac{F + M + 13}{2}$; $\textit{Target Height of Girl}\ (cm) = \frac{F + M - 13}{2}$

Table 12*b*. Month-wise targets of height and mass (weight) range, determined using Growth-and-Obesity Scalar-Roadmap 3.0 of father based on his last checkup

Date of Last (*Second*) *Checkup*: February 5, 2009 • *Decimal Age*, $A_0 = 18.59178082191781$ *years*

$P_{\text{CDC}}(h, A_0) = 20.7481334780^{\text{P}}$ • $P_{\text{CDC}}(\mu, A_0) = 18.0047025145^{\text{P}}$

$P_{\text{ref}}(A_0) = 20.748133478026^{\text{P}}$ • $P_{\text{ref-BMI}}(A_0) = 47.55814246138709^{\text{P}}$

Target Date	*Height Target*		*Range of Mass* (*Weight*) *Targets*	
	cm	*ft-in*	*kg*	*lb-oz*
February 5, 2009	**170.10**	**5 *ft* 6.97 *in***	**59.40**	**130 *lb* 15.63 *oz***
March 5, 2009	170.14	5 *ft* 6.98 *in*	59.66-60.82	131 *lb* 8.87 *oz* - 134 *lb* 1.88 *oz*
April 5, 2009	170.19	5 *ft* 7.00 *in*	59.95-62.40	132 *lb* 3.09 *oz* - 137 *lb* 9.51 *oz*
May 5, 2009	170.23	5 *ft* 7.02 *in*	60.23-63.93	132 *lb* 12.99 *oz* - 140 *lb* 15.34 *oz*
June 5, 2009	170.28	5 *ft* 7.04 *in*	60.52-65.50	133 *lb* 7.21 *oz* - 144 *lb* 6.98 *oz*
July 5, 2009	170.32	5 *ft* 7.06 *in*	60.80-67.03	134 *lb* 1.11 *oz* - 147 *lb* 12.81 *oz*
August 5, 2009	170.37	5 *ft* 7.08 *in*	61.09-68.61	134 *lb* 11.33 *oz* - 151 *lb* 4.44 *oz*

Rate of change of fractional statuses, $\frac{d(STATUS_{Fr}(h))}{d(STATUS_{Fr}(\mu))}$, between the first and the second checkups comes out to be –0.6980.

Table 12*c*. Height-gain-target-achievement index, h_{C}, and mass-management-target-achievement index, μ_{C}, of father at the end of 6-*month* period — indices, h_{C} and μ_{C}, defined in Figure 10

End of 6th *month*	*Measured Height*		*Measured Mass* (*Weight*)	
	cm	*ft-in*	*kg*	*lb-oz*
August 5, 2009	**170.45**	**5 *ft* 7.11 *in***	**61.05**	**134 *lb* 9.84 *oz***
August 5, 2009	170.37	5 *ft* 7.08 *in*	61.09-68.61	134 *lb* 11.33 *oz* - 151 *lb* 4.44 *oz*
Target-Achievement Index	100% ↑		99.93% ↓	
Qualitative	h_{C} overachieved[ς]		μ_{C} underachieved (lesser mass outside the normal range)	

[ς] Height attained exceeding the assigned target

HEIGHT GAIN

Percentile of height approaching asymptotically at the age of 10 *years* to last-checkup-reference percentile

$$P_{\text{CDC}}(h, A) = P_{\text{ref}}(A_0);\ \text{if}\ P_{\text{CDC}}(h, A_0) = P_{\text{ref}}(A_0)$$

$$P_{\text{CDC}}(h, A) = P_{\text{ref}}(A_0) - \left(P_{\text{ref}}(A_0) - P_{\text{CDC}}(h, A_0)\right)\left(\frac{A-10}{A_0-10}\right)^2, \text{otherwise}$$

MASS MANAGEMENT

Percentile of mass approaching asymptotically at the age of 10 *years* to last-checkup-reference percentile

$$P_{\text{CDC}}(\mu, A) = P_{\text{ref}}(A_0);\ \text{if}\ P_{\text{CDC}}(\mu, A_0) = P_{\text{ref}}(A_0)$$

$$P_{\text{CDC}}(\mu, A) = P_{\text{ref}}(A_0) - \left(P_{\text{ref}}(A_0) - P_{\text{CDC}}(\mu, A_0)\right)\left(\frac{A-10}{A_0-10}\right)^2, \text{otherwise}$$

Percentile of mass approaching asymptotically at the age of 10 *years* to percentile of last-checkup-reference-*BMI*-based-optimal mass

$$P_{\text{CDC}}(\mu, A) = P_{\text{ref-BMI}}(A_0);\ \text{if}\ P_{\text{CDC}}(\mu, A_0) = P_{\text{ref-BMI}}(A_0)$$

$$P_{\text{CDC}}(\mu, A) = P_{\text{ref-BMI}}(A_0) - \left(P_{\text{ref-BMI}}(A_0) - P_{\text{CDC}}(\mu, A_0)\right)\left(\frac{A-10}{A_0-10}\right)^2, \text{otherwise}$$

Fig. 14. Equations used to generate monthly predictions in the context of Growth-and-Obesity Vector-Roadmap 3.0

Table 13*a*. Growth-and-Obesity Scalar-Roadmap 3.0 of mother (SGPP-KHI-20080104-01/simulated)

Date of Birth (*year-month-day*)**:** 1992-12-30 • *Adult-Army-Cutoff Height***:** 157.48 *cm* (19.36^P)

Checkup	*1st*	*2nd*
Date of Checkup (*year-month-day*)	2008-08-10	2009-02-05
Age (*year-month-day*)	15-07-10	16-01-05
Age (*decimal year*), *A*	15.61	16.10
Dress Code	3/3®	3/3 ϕ
Behavior Code ϕ	0	0 ϕ
Height, *h* (*cm*) ⇐	157.00	157.00
Height (*ft-in*)	5 *ft* 1.81 *in*	5 *ft* 1.81 *in*
CDC Percentile-of-Height, $P_{\text{CDC}}(h, A)$ ⇔	21.31^P	20.30^P
Scaled Percentile-of-Height, $P_{\text{Scaled}}(h, A)$	28.30^P	27.04^P
Current-Age-Army-Cutoff Height, $h_{\text{CA-AC}}$ (*cm*) ⇐	156.49	156.75
$\Delta\, h_{\text{AC}}\,(cm) = h - h_{\text{CA-AC}}$	+11.71	+0.25
Target (Adult-Mid-Parental) Height (*cm*)	157.55¥	157.55
Percentile-of-Mid-Parental-Height, $P_{\text{MP}}(A)$ ⇔	19.62^P	19.62^P
Current-Age-Mid-Parental Height, $h_{\text{CA-MP}}$ (*cm*) ⇐	156.56	156.82
$\Delta\, h_{\text{MP}}\,(cm) = h - h_{\text{CA-MP}}$	+11.64	+0.18
Estimated-Adult Height (*cm*)	158.00	157.73
Estimated-Adult Height (*ft–in*)	**5 *ft* 2.20 *in***	**5 *ft* 2.10 *in***
Modified Status (pertaining-to-height), $STATUS_{\pm}^{\text{MOD}}(h)$	+6.92%	+0.11%
Descriptive Status (pertaining-to-height)	**1st-Degree Tall**	**1st-Degree Tall**
Net Mass, μ (*kg*) ⇒	**52.50**	**53.10**
Net Weight (*lb-oz*)	115 *lb* 12.20 *oz*	117 *lb* 1.37 *oz*
CDC Percentile-of-Net-Mass, $P_{\text{CDC}}(\mu, A)$ ⇔	**46.56^P**	**45.67^P**
Scaled Percentile-of-Net-Mass, $P_{\text{Scaled}}(\mu, A)$	56.93^P	56.01^P
Percentile-of-*BMI*-based-Optimal-Mass, $P_{\text{BMI}}(A)$ ⇔	55.54^P	54.88^P
Corrected-*BMI*-based-Optimal-Mass, $\mu_{\text{BMI}}^{\text{corrected}}$ $(kg)^{\subseteq}$ ⇒	60.43	60.43
$\Delta\, \mu_{\text{BMI}}\,(kg) = \mu - \mu_{\text{BMI}}^{\text{corrected}}$	–7.93	–7.33
Corrected-Height-Percentile-based-Optimal Mass, $\mu_{\text{opt}}^{\text{corrected}}$ $(kg)^{\subseteq}$ ⇒	51.92	52.53
$\Delta\, \mu_{\text{opt}}\,(kg) = \mu - \mu_{\text{opt}}^{\text{corrected}}$	+0.58	+0.57
Estimated-Adult Mass (*kg*)	57.50	57.23
Estimated-Adult Weight (*lb–oz*)	126 *lb* 10.10 *oz*	126 *lb* 2.91 *oz*
Modified Status (pertaining-to-mass), $STATUS_{\pm}^{\text{MOD}}(\mu)$	0	0
Descriptive Status (pertaining-to-mass)	**Normal**	**Normal**
Away-from-Normality Index, *r*	0.0692	0.0011
Polar Angle, θ (*degree*)	90.00^o	90.00^o
Extended Nutritional Status	**Tallness**	**Tallness**
Estimated-Adult *BMI* (*kg/m*^{2})	23.01	23.00
Estimated-Adult-Specific *BMI*	0.959	0.958
Build	**Medium**	**Medium**

® ‘Dress Code’ 3/3 implies that mother was measured wearing *abaya* (Kamal, 2016*a*) over regular clothes, barefoot
¥ Maternal grandmother of T. H. and Z. H. is above the age of 19 *years* (measured height = estimated-adult height = 157.49 *cm*); maternal grandfather is above the age of 21 *years* (measured height = estimated-adult height = 170.61 *cm*); target height computed using formula for girls — see footnote after Table 12*a*
⊆ 5 *kg* mass is added to mother’s *BMI*-based-optimal mass and height-percentile-based-optimal mass to account for possible pregnancy and the associated mass of fetus. No correction needed for father and children.

Table 13*b*. Month-wise targets of height and mass (weight) range, determined using Growth-and-Obesity Scalar-Roadmap 3.0 of mother based on her last checkup

Date of Last (*Second*) *Checkup*: February 5, 2009 • *Decimal Age*, $A_0 = 16.101362377423466$ *years*

$P_{\text{CDC}}(h, A_0) = 20.3027442047^{\text{P}}$ • $P_{\text{CDC}}(\mu, A_0) = 45.6720128834^{\text{P}}$

$P_{\text{ref}}(A_0) = 20.30274420472^{\text{P}}$ • $P_{\text{ref-BMI}}(A_0) = 54.87774174538221^{\text{P}}$

Target Date	*Height Target*		*Range of Mass* (*Weight*) *Targets*	
	cm	*ft-in*	*kg*	*lb-oz*
February 5, 2009	**157.00**	**5 *ft* 1.81 *in***	**53.10**	**117 *lb* 1.37 *oz***
March 5, 2009	157.02	5 *ft* 1.82 *in*	55.26-55.68	121 *lb* 13.71 *oz* - 122 *lb* 12.39 *oz*
April 5, 2009	157.06	5 *ft* 1.84 *in*	57.66-58.54	127 *lb* 0.14 *oz* - 129 *lb* 1.17 *oz*
May 5, 2009	157.10	5 *ft* 1.85 *in*	59.98-61.30	132 *lb* 4.02 *oz* - 135 *lb* 2.69 *oz*
June 5, 2009	157.13	5 *ft* 1.86 *in*	62.37-64.16	137 *lb* 8.54 *oz* - 141 *lb* 7.47 *oz*
July 5, 2009	157.16	5 *ft* 1.87 *in*	64.69-66.92	142 *lb* 10.33 *oz* - 147 *lb* 8.99 *oz*
August 5, 2009	157.19	5 *ft* 1.89 *in*	67.09-69.78	147 *lb* 14.85 *oz* - 153 *lb* 13.77 *oz*

Table 13*a* exhibits **pseudo gain of mass** between 1st and 2nd simulated checkups (mass put-on from **52.50 *kg*** to **53.10 *kg***, CDC mass percentile dropping from **46.56P** to **45.67P**). Rate of change of fractional statuses, $\frac{d(STATUS_{Fr}(h))}{d(STATUS_{Fr}(\mu))}$, between the first and the second checkups comes out to be infinity.

Table 13*c*. Height-gain-target-achievement index, h_{C}, and mass-management-target-achievement index, μ_{C}, of mother at the end of 6-*month* period

End of 6th *month*	*Measured Height*		*Measured Mass* (*Weight*)	
	cm	*ft-in*	*kg*	*lb-oz*
August 5, 2009	**157.09**	**5 *ft* 1.85 *in***	**68.05**	**150 *lb* 0.80 *oz***
August 5, 2009	157.19	5 *ft* 1.89 *in*	67.09-69.78	147 *lb* 14.85 *oz* - 153 *lb* 13.77 *oz*
Target-Achievement Index	99.3%		100%	
Qualitative	h_{C} underachieved&		μ_{C} critically achieved (mass within the normal range)	

& Height attained not reaching up to the assigned target

The above Growth-and-Obesity Roadmaps 3.0 are extensions of Growth-and-Obesity Profiles 3.0 included in Kamal and Jamil (2012). One may expect that the parameters of the second checkup given in Tables 10*a*-13*a* should be identical to those given in Kamal and Jamil (2012) as Tables 1-3. However, this is not the case. There are 2 reasons for these apparent differences:

a) Extended growth charts and tables are used in current calculations (Kamal and Jamil, 2014).

b) Modified definitions of statuses (pertaining-to-height) and (pertaining-to-mass) are employed, which are included in Figures 9*a*, *b* (Kamal *et al.*, 2018).

MATHEMATICS OF OBESITY AND WASTING BASED ON VERSIONS 2.5 and 3.0

The terms 'instantaneous obesity' and 'instantaneous wasting' were introduced (Kamal *et al.*, 2017*c*) and later defined mathematically (Kamal, 2017*c*) to differentiate them from 'true obesity' and 'true wasting' (Kamal *et al.*, 2017*a*). These definitions are slightly modified based on versions 2.5 and 3.0, which are summarized in Table 14

Table 14. Logical and mathematical definitions of instantaneous obesity and true obesity[α]

	Instantaneous Obesity	*True Obesity*
Logical Definition	$\mu - \mu_{\max} > 0,\ \mu_{\max} = max(\mu_{\text{opt}}, \mu_{\text{BMI}})$	$\mu_{\max}^{\text{Targeted}}(A_0 + 6\ months) - \mu(A_0) < 0$
Mathematical Definition	$STATUS_{\pm}^{\text{MOD}}(\mu) > 0$	$P_{\text{CDC}}(\mu, A_0) - max(P_{\text{ref}}(A_0), P_{\text{ref-BMI}}(\mu, A_0)) > +15$

α Comparing with Table 5 of Kamal *et al.* (2018), one notes that in the mathematical definition of true obesity percentile of reference *BMI* has replaced percentile of *BMI* — because of this change desired maximum mass at the end of 6-*month* period is termed as 'Targeted' not 'REC' (recommended) (instantaneous and true obesity) and Table 15 (instantaneous and true wasting).

Z. J. demonstrates true and instantaneous obesity during all of her checkups. The demonstration in terms of numbers is identical to that presented in Table 6 of Kamal *et al.* (2018), as $P_{\text{ref-BMI}}(A)$ is same as $P_{\text{BMI}}(A)$ for all of her checkups. Growth-and-Obesity Scalar-Roadmap 2.5 of Z. J. is given in Additional File 9. Proof of true obesity implying instantaneous obesity, based on versions 2.5 and 3.0, is given in Appendix C.

L. G. demonstrates true and instantaneous wasting during all of her checkups. The demonstration in terms of numbers is identical to Table 8 of Kamal *et al.* (2018), as $P_{\text{ref-BMI}}(A)$ is same as $P_{\text{BMI}}(A)$ for all of her checkups. Growth-and-Obesity Vector-Roadmap 2.5 of L. G. is given in Additional File 9. Proof of instantaneous wasting implying true wasting, based on versions 2.5 and 3.0, is given in Appendix D.

It must be noted that not all the scenarios, which recommend gain of mass by a youngster, correspond to true wasting. All such possibilities are listed in Appendix E.

PREVENTION AND MANAGEMENT OF CHILDHOOD OBESITY

Awareness has been growing for childhood-obesity prevention. Merrotsy *et al.* (2018) have given a literature review of the most effective settings and components of obesity-prevention programs in children. Palmer *et al.* (2018) have described online child's health assessment tool for obesity-prevention programming. Kumanyika (2018) has discussed childhood-obesity prevention in US communities in the context of healthy communities study. Mother's perception of her child's obesity problem (Berggren *et al.*, 2018) is key factor in the outcome of any intervention program. Greydanus *et al.* (2018) elaborate concepts of obesity in children and adolescents in the earlier part of this century, including principles of management. One must have a positive attitude and should not lose hope in facing the colossal task of preventing obesity in children (Zylke and Buchner, 2018). Keya *et al.* (2019) discussed role of population-based preventive approaches to confront childhood obesity. Figueroa *et al.* (2019) conducted a study, which supported 3-factor model of obesity parenting with a single factor for physical activity, food and sleep parenting, which has been integrated into intervention.

Obesity prevention becomes possible when there is a will to bring about the change (Meldrum *et al.*, 2017). Poskitt (2005) has mentioned the role

Existing knowledge — aleady known on this topic

Childhood obesity a prime concern for global health, obesity is a complicated condition, which is influenced by interactions between environmental and genetic factors

The true prevalence of childhood obesity difficult to quantify as there is no universally accepted definition available at present

BMI still the most popular index for classifying fatness and thinness

Various definitions of obesity proposed include relative *BMI*, cutoff point as 30 *kg*/*m*² (adult *BMI*), *BMI* ranges (below 85ᴾ → normal, 85ᴾ to 95ᴾ → intermediate, equal to or above 95ᴾ → high)

Existing scenario — the NGDS Team (our group) contributions

2004 Height-percentile-based-optimal mass (name mention as 'optimal mass'; formal definition in 2011)

2011 Statuses (pertaining-to-height) and (pertaining-to-mass); only 'obese' and 'wasted' used with percentage indicating severity instead of overweight, fat, underweight, lean

2012 Estimated-adult *BMI*; model extended to still-growing parents

2013-2018 1st- to 7th-generation solutions of childhood obesity

2014 Energy-channelization I-III; pseudo-gain of mass/height; use of percentile trajectories of height/mass instead of growth (height) velocity/ rate of mass gain/loss; CDC Growth Tables extended to include percentiles in the range 0.01th to 99.99th (to handle extreme cases)

2015 Month-wise targets (next 6 *months*) to shed-off mass; mathematical definition of build; formula to compute severity of acute malnutrition

2016 Mass and height measurements to least counts of 0.005 *kg* and 0.005 *cm*, respectively, accompanied by manual, version 9.11

2017 Mathematical criteria to classify normal, early, delayed and precarious puberty through scaled percentiles; assignment of Tanner scores to prepubertal, peripubertal, pubertal, adolescent and adult stages

2018 Integration of height-percentile-based-optimal mass with *BMI*-based-optimal mass to modify definitions of statuses (pertaining-to-height) and (pertaining-to-mass) to construct Growth-and-Obesity Vector-Roadmaps 2.1; polar-coördinate representation of nutritional-status classification expanded to 10 categories

This work adds

Introduction of specific *BMI* (a dimensionless quantity) defined as *BMI* divided by 24 (reference *BMI*)

Growth-and-Obesity Scalar- and Vector-Roadmaps 2.5 and 3.0 as 8th-generation solution of childhood obesity

Height-Gain-Target-Achievement Index and Mass-Management-Target-Achievement Index defined and illustrated through examples

Proposed scenario — the next step

Four mathematical equations to convert CDC percentiles to scaled percentiles generated from indigenously-collected anthropometric data

Growth-and-Obesity Vector-Roadmap 4.0 incorporating community-based criterion for stunting (height below 50th percentile)

Table 15. Logical and mathematical definitions of instantaneous wasting and true wasting[β]

	Instantaneous Wasting	*True Wasting*
Logical Definition	$\mu - \mu_{\min} < 0, \mu_{\min} = min(\mu_{opt}, \mu_{BMI})$	$P_{CDC}(\mu, A_0) - P_{\min}^{Targeted}(\mu, A_0 + 6\ months) < 0$
Mathematical Definition	$STATUS_{\pm}^{MOD}(\mu) < 0$	$P_{CDC}(\mu, A_0) - min(P_{ref}(A_0), P_{ref\text{-}BMI}(\mu, A_0)) < 0$

[β] Compare with Table 7 of Kamal *et al.* (2018), one notes that in the mathematical definition of true obesity percentile of reference *BMI* has replaced percentile of *BMI* — because of this change desired minimum percentile at the end of 6-*month* period is termed as 'Targeted' not 'REC'

of diet, exercise and lifestyle adjustment in tracking childhood obesity. Our group's efforts consisted of generating monthly height-gain and mass-management targets. In order to achieve height- and mass-management targets proposed by Growth-and-Obesity Scalar-Roadmap 2.5, Growth-and-Obesity Vector-Roadmap 2.5 as well as Growth-and-Obesity Vector-Roadmap 3.0, lifestyle adjustment as well as diet and exercise plans for youngsters and their parents were been proposed in Additional File 5, which included limiting computer time to one hour per day and suggesting 8-*hour* night-time sleeping for children and 6-*hour* night-time sleeping parents (Klinic, 2019).

CONCLUSION

In this paper, mathematical-statistical solutions of childhood obesity, presented during 2013-2018, have been extended to propose the eighth-generation solution of childhood obesity, which models growth and obesity of sons and daughters of still-growing parents. Calculations have been performed using estimated-adult heights of father and mother and reference height has been employed in computation of *BMI*-based-optimal mass to improve 6 monthly recommendations of mass management in children as well as their parents. In addition, new indicators of obesity have been introduced; notable among them is specific *BMI*, which is a ratio of *BMI* with reference *BMI* (24 kg/m^2). 9 new nutritional-status categories have been added to the previously proposed 10 categories. Marriages of still-growing parents have been scrutinized from different perspectives. The dream of making Pakistan a regional power could be realized through enhancing health and well being of the future leaders of this nation.

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APPENDIX A: ADDITIONAL RESOURCES

Additional File 1 https://www.ngds-ku.org/Papers/J54/Additional_File_1.pdf outlines techniques of anthropometric measurements, explained through step-by-step procedures, illustrated through labeled photographs.

Additional File 2 https://www.ngds-ku.org/Papers/J54/Additional_File_2.pdf lists mathematical tools used in constructing Obesity Roadmap 2.5, Growth-and-Obesity Scalar-Roadmap 2.5 as well as Growth-and-Obesity Vector-Roadmaps 2.5 and 3.0.

Additional File 3 https://www.ngds-ku.org/Papers/J54/Additional_File_3.pdf explains color-coding used in Obesity Roadmap 2.5, Growth-and-Obesity Scalar-Roadmap 2.5 as well as Growth-and-Obesity Vector-Roadmaps 2.5 and 3.0.

Additional File 4 https://www.ngds-ku.org/Papers/J54/Additional_File_4.pdf gives method of constructing Obesity Roadmap 2.5, Growth-and-Obesity Scalar-Roadmap 2.5 as well as Growth-and-Obesity Vector-Roadmap 2.5.

Additional File 5 https://www.ngds-ku.org/Papers/J54/Additional_File_5.pdf contains lifestyle adjustment as well as diet and exercise plans for children and their parents (control-action plans).

Additional File 6 https://www.ngds-ku.org/Papers/J54/Additional_File_6.pdf shows navigational and guidance trajectories based on Growth-and-Obesity Vector-Roadmap 2.5 for Z. I. R. along with color-coding of these trajectories.

Additional File 7 https://www.ngds-ku.org/Papers/J54/Additional_File_7.pdf gives method of constructing Growth-and-Obesity Vector-Roadmap 3.0

Additional File 8 https://www.ngds-ku.org/Papers/J54/Additional_File_8.pdf includes flowcharts of SOFTGROWTH 2.5 and 3.0.

Additional File 9 https://www.ngds-ku.org/Papers/J54/Additional_File_9.pdf gives Growth-and-Obesity Scalar-Roadmap 2.5 of Z. J. as well as Growth-and-Obesity Vector-Roadmaps 2.5 of L. G., M. E. and Z. H. Z.

APPENDIX B: COMPLIANCE WITH ETHICAL STANDARDS

Conflict of Interest: The authors state that there are no financial/non-financial competing interests in the research presented in this paper.

Institutional Review: In 1998, the NGDS Pilot Project was started under of directives of Governor Sindh after going through all the formalities of the institutional review process. The project protocols were prepared after taking into consideration North American and European, ethical and human-right standards (Kamal *et al.*, 2002).

Informed Consent: For school studies, 'The Informed Consent Form' was employed based on opt-in policy:

https://www.ngds-ku.org/ngds_folder/Protocols/NGDS_form.pdf

For detailed checkups in Growth-and-Imaging Laboratory, 'The SGPP Participation Form' was used:

https://www.ngds-ku.org/SGPP/SGPP_form.pdf

Both forms required signatures of each parent as well as participating child(ren). At the beginning of examination, verbal permission was obtained from the examinee(s) and the attending parent(s).

Privacy, Confidentiality, Comfort and Safety: Both acoustic as well as visual privacy was ascertained in Growth-and-Imaging Laboratory. Initials of children included in this work and Additional File 7 do not correspond to first letters in their real names (as per confidentiality standards established by the NGDS Team). Same is true about case numbers as well as pictures of child appearing in the main document and the supplementary appendix. Comfort of patients was given due consideration. Although, both father and mother were encouraged to attend checkups to give history and share progress, same-gender parent was preferred to be present at the unclothed physical examination in the curtained-off area for utmost comfort of the youngster. Before checkups, school-checkup-room floor was mopped and sharp objects removed from floor. Chairs/benches were checked for sharp edges of wood/metal as well as both boundaries of the mounted engineering tape to safeguard abrasions and cuts of skin. In Growth-and-Imaging Laboratory, the entire floor was black-tiled, street shoes were not allowed for anyone, floor mopped with dettol (chloroxylenol)-mixed water. Thermometer bulbs, when not in use, remained dipped in dettol-mixed water. Hand washing/sanitization was compulsory at the start of each checkup. Health professionals and anthropometrists were required to remove hand-worn chains, rings and wristwatches to prevent injury to children.

Disclosure and Regret Model: This model is adapted from University of Michigan Health System's Disclosure, Apology and Offer Model (Simmons, 2016), in which any wrong entry in report is communicated immediately to the parents with regrets — mother, along with father, is invited to come and discuss the report with the principal investigator (the first author).

APPENDIX C: PROOF OF TRUE OBESITY IMPLYING INSTANTANEOUS OBESITY BASED ON MODIFIED STATUS (PERTAINING-TO-MASS)

One needs to prove $\mu_{\max}^{\text{Targeted}}(A_0 + 6\ months) - \mu(A_0) < 0 \Rightarrow STATUS_{\pm}^{\text{MOD}}(\mu) > 0$. In other words, if a child is recommended to lose mass within a time span of 6 *months* (condition of true obesity), such a child must exhibit instantaneous obesity (Table 14).

(C1) $$\mu_{\max}^{\text{Targeted}}(A_0 + 6\ months) - \mu(A_0) < 0 \Rightarrow \mu(A_0) > \mu_{\max}^{\text{Targeted}}(A_0 + 6\ months)$$

The function, $P = P_{\text{CDC}}(\mu, A_0)$, generating CDC percentiles-of-masses, $P_{\text{CDC}}(\mu, A_0)$, from values of masses, $\mu(A_0)$, is a monotonically increasing function of masses, provided the age, A_0, is kept constant, as noted by inspecting Additional File 3 of Kamal and Jamil (2014). The same holds for inverse function, $\mu = P_{\text{CDC}}^{-1}(\mu, A_0)$, generating masses, $\mu(A_0)$, from values of CDC percentiles-of-masses, $P_{\text{CDC}}(\mu, A_0)$. In layman's language, mass increases with the advancing percentile, for a given age, and vice versa.

However, with the advancing age, this might not hold true as a slight gain in mass could be accompanied by a drop in percentile — phenomenon of pseudo-gain of mass (Kamal *et al.*, 2014*b*). On the other hand, when there is a loss of mass as a child gets older, this loss may be true or targeted (Table 14). A targeted loss indicates true obesity (Kamal, 2017*b*), which is, always, associated with a drop in percentile. This could, also, be observed by looking at Additional File 3 of Kamal and Jamil (2014). Hence

(C2) $$P_{\text{CDC}}(\mu, A_0) > P_{\max}^{\text{Targeted}}(\mu, A_0 + 6\ months)$$

Now

(C3) $$P_{\max}^{\text{Targeted}}(\mu, A_0 + 6\ months) > max\left(P_{\text{ref}}(A_0), P_{\text{ref-BMI}}(\mu, A_0)\right)$$

as the percentile must decrease to this value at the age of 10 *years*, in case of true obesity. In this proof and the following one, transitive property of equations cum inequalities shall be used many times, which is mathematically expressed as

(C4) $a < b,\, b < c \Rightarrow a < c;\; a < b,\, b \le c \Rightarrow a < c; a \le b,\, b < c \Rightarrow a < c;\; a \le b, b \le c \Rightarrow a \le c$

Applying the above to (C2) and (C3), one concludes

(C5) $P_{\text{CDC}}(\mu, A_0) > max\left(P_{\text{ref}}(A_0),\, P_{\text{ref-BMI}}(A_0)\right)$

By definition

(C6) $P_{\text{ref}}(A_0) \ge P_{\text{CDC}}(h, A_0) \Rightarrow max\left(P_{\text{ref}}(A_0),\, P_{\text{ref-BMI}}(A_0)\right) \ge max\left(P_{\text{CDC}}(h, A_0),\, P_{\text{ref-BMI}}(A_0)\right)$

Applying transitive property (C4) to (C5) and (C6), one obtains

(C7) $P_{\text{CDC}}(\mu, A_0) > max\left(P_{\text{CDC}}(h, A_0),\, P_{\text{ref-BMI}}(A_0)\right)$

One must realize that $P_{\text{ref-BMI}}(A_0)$ is computed by taking estimated-adult-reference height in place of estimated-adult height (for children and still-growing parents), which is used for computation of $P_{\text{BMI}}(A_0)$. Now

(C8) $P_{\text{ref}}(A_0) \ge P_{\text{CDC}}(h, A_0) \Rightarrow P_{\text{ref-BMI}}(A_0) \ge P_{\text{BMI}}(A_0)$

Combing this with (C7), one concludes that

(C9) $P_{\text{CDC}}(\mu, A_0) > max\left(P_{\text{CDC}}(h, A_0),\, P_{\text{BMI}}(A_0)\right)$

Noting that $P_{\text{CDC}}(\mu_{\text{opt}}, A_0) = P_{\text{CDC}}(h, A_0)$ and invoking the functional property of percentile of mass, mentioned below (C1), one infers

(C10) $\mu(A_0) > max(\mu_{\text{BMI}},\, \mu_{\text{opt}})$

Recognizing $\mu_{\max} = max(\mu_{\text{BMI}}, \mu_{\text{opt}})$

(C11) $\mu > \mu_{\max} \Rightarrow 100\dfrac{\mu - \mu_{\max}}{\mu_{\max}} > 0 \Rightarrow STATUS_{\pm}^{\text{MOD}}(\mu) > 0$

This completes the proof.

The converse is not true, *i. e.*, $STATUS_{\pm}^{\text{MOD}}(\mu) > 0 \not\Rightarrow \mu_{\max}^{\text{Targeted}}(A_0 + 6\; months) - \mu(A_0) < 0$, which is illustrated by the following counter example**:**

Consider the case of M. E. Her Growth-and-Obesity Vector-Roadmap 2.5 is given in Additional File 7. At the time of her 2nd checkup, conducted on November 13, 2011, she was 9 *year*s 1 *month* 20 *days* old (decimal age, $A_0 = 9.139726027$ *years*). Her mass was recorded as 31.70 *kg*. Her mass-management targets are now computed based on reference-*BMI* percentile. She was advised to maintain mass between 31.49 *kg* and 34.46 *kg*, at the end of 6-*month* period. The computations indicated that she was 1st-degree obese, since $STATUS_{\pm}^{\text{MOD}}(\mu) = +0.73\%$. However, $\mu_{\max}^{\text{Targeted}}(A_0 + 6\; months) = 34.46 kg,\, \mu(A_0) = 31.79\; kg,$ Therefore

$$\mu_{\max}^{\text{Targeted}}(A_0 + 6\; months) - \mu(A_0) = +2.67\; kg \Rightarrow \mu_{\max}^{\text{Targeted}}(A_0 + 6\; months) - \mu(A_0) \not< 0$$

This is a demonstration that M. E. is not demonstrating true obesity.

APPENDIX D: PROOF OF INSTANTANEOUS WASTING IMPLYING TRUE WASTING BASED ON MODIFIED STATUS (PERTAINING-TO-MASS)

The lengthy proof given in Appendix B of Kamal (2017*c*) takes a very simple form, when modified status (pertaining-to-mass) is used, *i. e.*, instantaneous wasting implies true wasting.

First of all, one proves that the logical and the mathematical definitions of true wasting are equivalent, *i. e.*,

$$P_{\text{CDC}}(\mu, A_0) - P_{\text{CDC}}^{\text{Targeted}}(\mu, A_0 + 6\; months) < 0 \Leftrightarrow P_{\text{CDC}}(\mu, A_0) - min\left(P_{\text{ref}}(A_0), P_{\text{ref-BMI}}(A_0)\right) < 0$$

The above statement is equivalent to

(D1*a*) $P_{\text{CDC}}(\mu, A_0) - P_{\text{CDC}}^{\text{Targeted}}(\mu, A_0 + 6\; months) < 0 \Rightarrow P_{\text{CDC}}(\mu, A_0) - min\left(P_{\text{ref}}(A_0),\, P_{\text{ref-BMI}}(A_0)\right) < 0$

and

(D1*b*) $$P_{\text{CDC}}(\mu, A_0) - P_{\text{CDC}}^{\text{Targeted}}(\mu, A_0 + 6\,months) < 0 \Leftarrow P_{\text{CDC}}(\mu, A_0) - min\left(P_{\text{ref}}(A_0), P_{\text{ref-BMI}}(A_0)\right) < 0$$

To prove (D1*a*), one notes that for true wasting the child is recommended to climb on the curve, representing CDC percentile-of-mass, to tangentially approach, at the end of intervention period (reference age taken as 10 *years*), the line segment representing minimum of reference percentile, $P_{\text{ref}}(A_0)$, and *BMI*-based-optimal-mass percentile computed from estimated-adult-reference height, $P_{\text{ref-BMI}}(A_0)$, in the process gaining mass. This is only possible, when the value of this minimum is greater than the value of mass percentile at age of the last checkup, $P_{\text{CDC}}(\mu, A_0)$, based on comments inserted after (C1). The converse, (D1*b*), can be easily proved by the same line of argument.

The proof of instantaneous wasting implying true wasting, using modified status (pertaining-to-mass), $STATUS_{\pm}^{\text{MOD}}(\mu)$, is now given using the mathematical definition of true wasting. Noting that instantaneous wasting is defined as**:**

(D2) $$STATUS_{\pm}^{\text{MOD}}(\mu) < 0 \Rightarrow 100\frac{\mu - \mu_{\text{min}}}{\mu_{\text{min}}} < 0 \Rightarrow \mu < \mu_{\text{min}},\ \mu_{\text{min}} = min(\mu_{\text{BMI}}, \mu_{\text{opt}})$$

Case 1**:** $\mu_{\text{opt}} < \mu_{\text{BMI}} \Rightarrow \mu_{\text{min}} = \mu_{\text{opt}} \Rightarrow \mu < \mu_{\text{opt}}$, from (D2). One writes for the corresponding percentiles, based on comments entered below (C1)

(D3) $$P_{\text{CDC}}(\mu, A_0) < P_{\text{CDC}}(h, A_0);\ \text{noting that } P_{\text{CDC}}(\mu_{\text{opt}}, A_0) = P_{\text{CDC}}(h, A_0)$$

Rewriting (C6) as $P_{\text{CDC}}(h, A_0) \le P_{\text{ref}}(A_0)$. Applying transitive property of equations cum inequalities (C4) to (D3) and (C6), rewritten above, one concludes

$$\boxed{P_{\text{CDC}}(\mu, A_0) < P_{\text{ref}}(A_0)}$$

The condition on masses in case 1 becomes the condition on the corresponding percentiles, based on comment written below (C1) and explanation given in (D3)

(D4) $$\mu_{\text{opt}} < \mu_{\text{BMI}} \Rightarrow P_{\text{CDC}}(h, A_0) < P_{\text{BMI}}(A_0)$$

Again applying transitive property (C4) to (D3) and (D4), one concludes $P_{\text{CDC}}(\mu, A_0) < P_{\text{BMI}}(A_0)$. Rewriting (C8) as $P_{\text{BMI}}(A_0) \le P_{\text{ref-BMI}}(A_0)$ and applying transitive property (C4) again, one gets

(D5) $$\boxed{P_{\text{CDC}}(\mu, A_0) < P_{\text{ref-BMI}}(A_0)} \Rightarrow \boxed{P_{\text{CDC}}(\mu, A_0) < min\left(P_{\text{ref}}(A_0), P_{\text{ref-BMI}}(A_0)\right)}$$

which is the mathematical definition of true wasting (Table 15). Hence, it is proved that in case 1, instantaneous wasting implies true wasting.

Case 2**:** $\mu_{\text{BMI}} < \mu_{\text{opt}} \Rightarrow \mu_{\text{min}} = \mu_{\text{BMI}} \Rightarrow \mu < \mu_{\text{BMI}}$, as concluded from (D2). Again employing observation below (C1) regarding functional dependence of CDC percentile-of-mass on child's net mass, one writes

(D6) $$P_{\text{CDC}}(\mu, A_0) < P_{\text{BMI}}(A_0)$$

Rewriting (C8) as $P_{\text{BMI}}(A_0) \le P_{\text{BMI-ref}}(A_0)$ and applying transitive property (C4), one concludes

(D7) $$\boxed{P_{\text{CDC}}(\mu, A_0) < P_{\text{ref-BMI}}(A_0)}$$

Further by the supposition in this case, $\mu_{\text{BMI}} < \mu_{\text{opt}} \Rightarrow P_{\text{BMI}}(A_0) < P_{\text{CDC}}(h, A_0)$, based on comment appearing in (D3), $P_{\text{CDC}}(\mu_{\text{opt}}, A_0) = P_{\text{CDC}}(h, A_0)$. Applying transitive property of equations cum inequalities (C4) to (D6) and the inequality written below (D7), one concludes that $P_{\text{CDC}}(\mu, A_0) < P_{\text{CDC}}(h, A_0)$. Applying (C4) again to this inequality and (C6), rewritten as $P_{\text{CDC}}(h, A_0) \le P_{\text{ref}}(A_0)$, one finally obtains

$$\boxed{P_{\text{CDC}}(\mu, A_0) < P_{\text{ref}}(A_0)} \Rightarrow \boxed{P_{\text{CDC}}(\mu, A_0) < min\left(P_{\text{ref}}(A_0), P_{\text{ref-BMI}}(A_0)\right)}$$

Case 3**:** $\mu_{\text{BMI}} = \mu_{\text{opt}} \Rightarrow \mu_{\text{min}} = \mu_{\text{max}} = \mu_{\Updownarrow}$. Now, $\mu_{\Updownarrow} = \mu_{\text{BMI}} = \mu_{\text{opt}} \Rightarrow P_{\text{BMI}}(\mu, A_0) = P_{\text{CDC}}(h, A_0)$, based on note in (D3) and comments after (C1). Since the child exhibits instantaneous wasting,

$$STATUS_{\pm}^{\text{MOD}}(\mu) < 0 \Rightarrow 100\frac{\mu - \mu_{\Updownarrow}}{\mu_{\Updownarrow}} < 0 \Rightarrow \mu < \mu_{\Updownarrow}$$

which translates to

(D8*a*, *b*) $$\mu < \mu_{\text{BMI}},\ \mu < \mu_{\text{opt}}$$

Based on comments written after (C1), the above conditions become conditions on respective percentiles. (D8*a*) may, then, be expressed as (D7), *i. e.*,

$$\boxed{P_{\text{CDC}}(\mu, A_0) < P_{\text{ref-BMI}}(A_0)}$$

and (D8*b*) as (D3). Further, by definition CDC percentile-of-height, $P_{\text{CDC}}(h, A_0)$, is lesser than or equal to reference percentile, $P_{\text{ref}}(A_0)$, as spelled out in (C6). Applying transitive property of equations cum inequalities (C4) to (C6) rewritten as $P_{\text{CDC}}(h, A_0) \le P_{\text{ref}}(A_0)$, one concludes

$$\boxed{P_{\text{CDC}}(\mu, A_0) < P_{\text{ref}}(A_0)}$$

which translates to

$$\boxed{P_{\text{CDC}}(\mu, A_0) < min\left(P_{\text{ref}}(A_0), P_{\text{ref-BMI}}(\mu, A_0)\right)}$$

This completes the proof.

The converse is not true, *i. e.*, $P_{\text{CDC}}(\mu, A_0) < min\left(P_{\text{ref}}(A_0), P_{\text{ref-BMI}}(\mu, A_0)\right) \not\Rightarrow STATUS_{\pm}^{\text{MOD}}(\mu) < 0$, which is illustrated by the following counter example**:**

Consider the case of Z. H. Z. (SGPP-KHI-20110412-01/01; NGDS-BLA-2010-5484/Z). Growth-and-Obesity Vector-Roadmap 2.5 of Z. H. Z. is given in Additional File 7. At the time of her 5th checkup, conducted on November 23, 2014, she was 9 *years* 5 *months* 7 *days* old (decimal age, $A_0 = 9.438356165$ *years*).

$$P_{\text{CDC}}(\mu, A_0) = 63.50^{\text{P}},\ min\left(P_{\text{ref}}(A_0), P_{\text{ref-BMI}}(\mu, A_0)\right) = min\left(76.12^{\text{P}}, 77.96^{\text{P}}\right) = 76.12^{\text{P}}$$

$$\Rightarrow P_{\text{CDC}}(\mu, A_0) < min\left(P_{\text{ref}}(A_0), P_{\text{ref-BMI}}(\mu, A_0)\right)$$

Therefore, one notes that true wasting is *present*.

$$\mu = 33.06\,kg,\ \mu_{\text{min}} = min(\mu_{\text{opt}}, \mu_{\text{BMI}}) = min(32.12\,kg, 34.71\,kg) = 32.12\,kg \Rightarrow \mu > \mu_{\text{min}}$$

Hence, one concludes that instantaneous wasting is *not present*. Noting that

$$\mu_{\text{max}} = max(\mu_{\text{opt}}, \mu_{\text{BMI}}) = max(32.12\,kg, 34.71\,kg) = 34.71\,kg \Rightarrow \mu < \mu_{\text{max}}$$

Therefore, $STATUS_{\pm}^{\text{MOD}}(\mu) \not< 0$, in fact, $STATUS_{\pm}^{\text{MOD}}(\mu) = 0$, descriptive status (pertaining-to-mass) being normal, instead of 1st-degree obese, which was previously determined by Growth-and-Obesity Vector-Roadmap 1.0 (Kamal, 2017*b*).

APPENDIX E: THREE SCENARIOS, IN WHICH A CHILD IS RECOMMENDED TO GAIN MASS

Table 16 lists 3 scenarios and the associated mathematical conditions, in which a child is recommended to gain mass. These are true wasting, optimal-mass management and pseudo-gain of mass — the first one applicable, when CDC percentile of mass at the last checkup is less than the minimum of CDC percentile of targeted masses at the end of 6-*month* period; the second one applicable, when CDC percentile of mass lies between minimum and maximum of CDC percentiles of targeted masses; the third one applicable, when CDC percentile of mass exceeds the maximum of CDC percentile of recommended masses at the end of 6-*month* period.

Table 16. Three scenarios, in which a child is recommended to gain mass$^{\Upsilon}$ within 6 *months*$^{\oplus}$

Difference of CDC Percentiles-of-Mass	*Mass Management*
$P_{\text{CDC}}(\mu, A_0) < P_{\text{min}}^{\text{Targeted}}(\mu, A_0 + 6\ months)$	True wasting
$P_{\text{min}}^{\text{Targeted}}(\mu, A_0 + 6\ months) \le P_{\text{CDC}}(\mu, A_0) \le P_{\text{max}}^{\text{Targeted}}(\mu, A_0 + 6\ months)$	Optimal-mass management
$P_{\text{CDC}}(\mu, A_0) > P_{\text{max}}^{\text{Targeted}}(\mu, A_0 + 6\ months)^{\forall}$	Pseudo-gain of mass

$^{\Upsilon}$ $\mu_{\text{max}}^{\text{Targeted}}(A_0 + 6\ months) - \mu(A_0) > 0$

$^{\oplus}$ Modified version of Table 10 of Kamal *et al.* (2018)

$^{\forall}$ Noting that $\mu_{\text{max}}^{\text{Targeted}}(A_0 + 6\ months) - \mu(A_0) > \mu_{\text{min}}^{\text{Targeted}}(A_0 + 6\ months) - \mu(A_0)$ and

$\mu_{\text{min}}^{\text{Targeted}}(A_0 + 6\ months) - \mu(A_0) > 0 \Rightarrow \mu_{\text{max}}^{\text{Targeted}}(A_0 + 6\ months) - \mu(A_0) > 0$

applying transitive property for inequalities. Combining this with $P_{\text{max}}^{\text{Targeted}}(\mu, A_0 + 6\ months) < P_{\text{CDC}}(\mu, A_0)$, this becomes definition of 'pseudo-gain of mass'

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