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VALIDATION OF CONCEPT OF OPTIMAL MASS IN CHILDREN AND ADULTS — THE SEVENTH-GENERATION SOLUTION OF CHILDHOOD OBESITY

Syed Arif Kamal1, Nida Jamil2 and Shakeel Ahmed Ansari3

The NGDS Pilot Project and Jinnah University for Women, Karachi, Pakistan
2 e-mail: profdrakamal@gmail.com

ABSTRACT

Childhood obesity is a result of difference between intake and expenditure of energy, disturbing initial steady state and forming a new steady state at a higher level, resulting in increased body-fat storage. To avoid obesity, child needs to balance tissue synthesis, responsible for picking-up height, with fat storage, responsible for putting-on weight (mass). During 2002-2012, child growth and obesity were modeled, introducing the terms, estimated-adult BMI, pseudo-gain of height/mass and energy-channelization (co-existence of wasting and tallness/stunting and obesity). During 2013-2017, our group put forward first- to sixth-generation solutions of childhood obesity, which included new a definition of childhood obesity. This paper unveils seventh-generation solution, placing height-percentile-based-optimal mass and BMI-based-optimal mass on equal footing by defining modified status (pertaining-to-mass) in terms of that optimal mass, which is closer to net mass. Similarly, current-age-mid-parental height and current-age-army-cutoff height are treated on equal footing by defining modified status (pertaining-to-height) in terms of that current-age height, which is closer to recorded height. This leads to a modification of definitions of ‘instantaneous obesity/wasting’ and ‘true obesity/wasting’. Polar-coordinate representation of nutritional-status classification is expanded to 10 categories, viz. energy-channelization III (puberty-induced energy-channelization), obesity dominated over-nutrition, tallness dominated over-nutrition, tallness dominated energy-channelization I, wasting dominated energy-channelization I, stunting dominated energy-channelization II, obesity dominated energy-channelization II, stunting dominated under-nutrition, wasting dominated under-nutrition, acute malnutrition. This paper gives the method of constructing Growth-and-Obesity Vector-Roadmap 2.1, which includes ‘away-from-normality index’ and ‘polar angle’ in addition to build assigned from scaled percentiles, modified as well as descriptive statuses (pertaining-to-height) and (pertaining-to-mass). Vector-Roadmap 2.1 proposes 6 month-wise height-management-target values as well as mass-management-target ranges; these ranges should render the task of optimal-mass management easier. The authors have expanded lifestyle adjustment, diet and exercise plans to achieve the recommended targets. Vector-Roadmap 2.1 is generated from height and mass measurements obtained to least counts of 0.005 cm and 0.005 kg, respectively. Computations are performed using Extended CDC Growth Charts and Tables containing height and mass entries for percentiles in the range 0.01 to 99.99. Rigorous mathematical arguments are employed to prove true obesity implies instantaneous obesity and instantaneous wasting implies true wasting, with illustrative examples for each one.

Keywords: Height-percentile-based-optimal mass, BMI-based-optimal mass, instantaneous obesity, instantaneous wasting, true obesity, true wasting, expanded nutritional status

LIST OF ABBREVIATIONS

AC: Army-Cutoff (in the context of height)
AM: Acute Malnutrition
BMI: Body-Mass Index
CA: Current-Age (in the context of height)
CDC: Centers for Disease Control and Prevention
EC I-III: Energy-Channelization I-III
ECOG: European Childhood Obesity Group
IU: International Unit (dosage of vitamin D)
MP: Mid-Parental (in the context of height)
NGDS: National Growth and Developmental Standards for the Pakistani Children
ON: Over-Nutrition
P: Percentile
SGPP: Sibling Growth Pilot Project — a subproject of the NGDS Pilot Project
UN: Under-Nutrition
UC: Ultraviolet (in the context of sunlight radiation)
WHO: World Health Organization

1) Main contribution of PhD dissertation of the second author, registered from Department of Mathematics, University of Karachi (specialization: Childhood Obesity) under supervision of the first author

2) Prof. Dr. Syed Arif Kamal, PhD (Mathematical Neuroscience); MA, Johns Hopkins, Baltimore, MD, United States; MS, Indiana, Bloomington, IN, United States; Ex-Member, AAHPERD (American Alliance for Health, Physical Education, Recreation and Dance) and Subject Committee, Physical Education, Health and Sport Sciences, NTS Pakistan; Ex-Acting Vice Chancellor and Ex-Chairman, Department of Health, Physical Education and Sports Sciences, University of Karachi • paper mail: Founding Project Director, the NGDS Pilot Project and Ex-Dean, Faculty of Science, University of Karachi, PO Box 8423, Karachi 75270, Sindh, Pakistan • homepage: https://www.ngds-ku.org/kamal • ORCID: 000-0002-1711-4827 • the NGDS Pilot Project URL: https://ngds-ku.org

3) MPhil (Mathematics — specialization: Childhood Obesity), University of Karachi; Assistant Professor, Department of Mathematics, Jinnah University for Women, Plot ST-1, 5-C, Nazimabad, Karachi 74600

4) PhD (Physics — specialization: Childhood Obesity); MPhil (Mathematics), University of Karachi; Associate Professor and Head, Department of Physics, Government Degree College for Boys and Girls, SRE Majeed, Stadium Road, Karachi 75350
INTRODUCTION

Childhood obesity, being the outcome of a complex web of biological, cultural, environmental and psychological influences, has become a universal problem. The severe complications, which occur due to childhood obesity, affect cardiovascular, gastrointestinal, musculoskeletal, neurologic, psychosocial, pulmonary and renal systems. One must be quick to realize that childhood is a key period of life for shaping of health habits. Hence, this is definitely the ideal period to detect childhood obesity so that appropriate planning is done to initiate efficient and effective intervention strategies.

In this paper, concept of optimal mass is validated to generate 7th-generation solution of childhood obesity. Height-percentile-based-optimal mass and BMI-based-optimal mass have been integrated and definition of status (pertaining-to-mass) is modified to treat both of the above optimal masses on equal footing. During this exercise, polar-coordinate representation has been worked out, which provides ‘away-from-normality index’ and ‘polar angle’. Nutritional-status has now been classified into 10 categories instead of 6 categories being used since 2015.

CHILDHOOD OBESITY: SOCIO-ECONOMIC DETERMINANTS AND TRENDS

Wickramasinghe (2018) proposed a conceptual framework at the individual level, at the family level, at the community level and at the policy-making level, to understand the environmental as well as the socio-cultural factors, which influence occurrence of obesity in youngsters. The child was portrayed at the center of a socio-ecological model with culture and society at the outermost periphery, followed by government/industry, community, school and peers as well as family and home. Holmgren et al. (2017) have investigated relationship of pubertal height gain and peak body-mass index in childhood. Saldaña-Tejeda (2018) discussed mother’s experiences of masculinity in the context of child obesity in Mexico.


CHILDHOOD OBESITY: DEFINITIONS

The key to childhood-obesity management is agreeing on a definition of obesity. Obesity occurs, when there is discrepancy between energy input and output. The original steady state vanishes and a new one appears at a higher level. The consequence is increased body-fat storage (Wabitsch, 2000). Poskitt (1995), on behalf of the European Childhood Obesity Group (ECOG), observed that researchers were worried about a lack of definition of childhood obesity. She introduced relative BMI as the index of a 50th centile youngster. BMI (computed using the expression \( \mu / h^2 \) — \( \mu \) representing mass in kg and \( h \) height in m) was renamed as body-mass index from the Quetelet index 46 years ago (Keys et al., 1972). In a follow-up work, Poskitt (2000) stated that there is a considerable imprecision in defining obesity. However, there seems to be a general acceptance of the concept of relative BMI. In a 2001 paper, she was of the opinion that BMI does not offer the ‘best’ definition, although it may be regarded as the most ‘useful’ and ‘practical’ one for clinical, epidemiological and population-research purposes (Poskitt, 2001). Kolotourou et al. (2013) asked the question if BMI alone was a suitable indicator to decide about interventions for childhood obesity, concluding that setting a BMI-reduction cutoff might be misleading, other competing outcomes should be considered. Cole et al. (2000) gave a definition of childhood obesity based on pooled-international data. They connected childhood obesity to adult-obesity-cutoff point of BMI to be 30 kg/m². Flegal et al. (2010) classified BMI-for-age as ‘normal’, ‘intermediate’ and ‘high’. On behalf of ECOG, Rolland-Cacher (2011), gave 4 ranges for main cutoffs of BMI distribution status from the age of 5 years: ‘thin’, ‘normal’, ‘overweight’ (not obese) and ‘obese’. Skinner and Skelton (2014) defined overweight and obesity in children on the
Valuation of concept of optimal mass


The first author streamlined various definitions of childhood obesity and put forward ‘logical definition’ (Kamal, 2016b). Last year, a ‘mathematical definition’ was given (Kamal, 2017b). The mathematical definition was validated using anthropometric data collected during 1998-2013 (Kamal et al., 2017a).

Childhood obesity: models

Whitaker et al. (1997) presented a statistical model to predict obesity in adolescence from parental and childhood obesity. Golan and Weizman (2001) proposed a family-centered model for childhood-obesity management. Parents are convinced to adopt a healthy lifestyle to bring about the change through role modeling (Natale et al., 2014) and not losing mass. This becomes possible only when there is a will to bring about the change (Meldrum et al., 2017). Kumar and Kelly (2018) reviewed childhood obesity from epidemiological and etiological perspectives as well as the associated comorbidities. They discussed various methods of clinical assessment and treatment.

Figure 1 illustrates timeline of modeling of childhood-obesity problem by our group. The major challenge in constructing such a mathematical model is the reality that the youngsters, under optimal conditions, who is picking up height with the passage of time as well as putting on (shedding off) mass. If an obese child is required to reduce mass, based on status of current obesity, in the absence of rigorous calculation of height to be gained within the next few months, the youngster could become wasted (lesser mass-for-height). Hence, it becomes very important to account for the trend of height gain by youngster in various phases of growth — infancy, childhood and puberty (Figure 2). Our group attempted to take this into consideration,

Fig. 1. Timeline of modeling of child growth and obesity

Fig. 2. ICP model: mathematical interpretation (Karlberg, 1987) — children suffering from severe disease (e.g., diarrhea) during the weaning period may continue on the infancy curve a little longer, before picking up the childhood curve and, hence, end up stunted (the red path)
when constructing models of childhood obesity. The childhood-obesity models developed by our group are listed below:

**Growth-and-Obesity Profiles**

‘Growth-and-Obesity Profiles 1.0’, also known as KFA (Kamal-Firdous-Alam) model, compute growth and obesity statuses of child after at least 2 checkups and provide growth (height) velocity as well as rate of mass (weight) gain/loss between these checkups (Kamal et al., 2004).

‘Growth-and-Obesity Profiles 2.0’, also known as KJK (Kamal-Jamil-Khan) model, provide ‘Obesity Profiles 2.0’ of parents (also, all adults aged 20 years or more) as well as growth and obesity statuses of each child based on only one single checkup, growth velocity and rate of mass gain not possible to compute (Jamil, 2009; Kamal et al., 2011).

‘Growth-and-Obesity Profiles 3.0’, also known as KJ (Kamal-Jamil) model, extend version 2.0 to account for still-growing parents — mothers below 19 years and fathers below 21 years (Jamil, 2014; Kamal and Jamil, 2012). This model determines target height of a child by replacing heights of biological mother and father with their respective estimated-adult heights in the formulae.

‘CDC Growth Charts and Tables’ are extrapolated to include extreme percentiles (range 0.01 to 99.99) in the KJ-Regression model (Kamal and Jamil, 2014).

**Growth-and-Obesity Roadmaps**

‘Growth-and-Obesity Scalar-Roadmaps 1.0’ (Ansari, 2015; Kamal et al., 2015) are generalization ‘Growth-and-Obesity Moving-Profiles’ (Kamal et al., 2014b), which include 6 month-wise recommendations to gain/lose mass for parents (‘Obesity Roadmaps 1.0’) as well as manage heights and masses for sons and daughters through 6 monthly recommendations (Kamal, 2015a; b), assign build (Kamal and Khan, 2015; Kamal et al., 2017b) and classify nutritional status (Kamal, 2014; 2015a; Kamal et al., 2014b; 2017a; b). Scalar-Roadmaps 1.0 alert pediatrician to pseudo-gain of mass (height), whenever present (Kamal et al., 2014b) — mass (height) gain with a drop on CDC-percentile trajectory. Examples are available in Additional File of Kamal (2014).

‘Growth-and-Obesity Vector-Roadmaps 1.0’ (Naz, 2017; Kamal et al., 2016a) are identical to ‘Growth-and-Obesity Scalar-Roadmaps 1.0’ in the range of actual checkups. Prime difference is in assigning 6 monthly targets for height and mass management, computed by fitting parabolic trajectories for CDC height and mass percentiles. These softer targets propose to achieve corrections by the end-of-childhood phase, instead of a short span of 6 months.

‘Growth-and-Obesity Profiles 1.0’ (Kamal et al., 2004) are only of academic value, ‘Growth-and-Obesity Profiles 2.0’ (Kamal et al., 2011) are used to generate ‘Growth-and-Obesity Scalar-Roadmaps 1.0’, ‘Obesity Roadmaps 1.0’ (Kamal et al., 2013d; 2014a; 2015), ‘Growth-and-Obesity Scalar-Roadmaps 1.1’, ‘Obesity Roadmaps 1.1’ (Kamal et al., 2017b; c) as well as ‘Growth-and-Obesity Vector-Roadmaps 1.0’ (Kamal et al., 2016a; b) and ‘Growth-and-Obesity Vector-Roadmaps 1.1’ (2017b; c). Roadmaps 1.1 are different from their respective versions 1.0, mainly, in the introduction of scaled percentiles to compute build and severity of acute malnutrition (if present).

‘Growth-and-Obesity Profiles 2.0’ are used in constructing ‘Growth-and-Obesity Scalar-Roadmaps 2.0’ and ‘Growth-and-Obesity Vector-Roadmaps 2.0’. For parents ‘Obesity Roadmaps 1.0’ are generalized to ‘Obesity Roadmaps 2.0’. These roadmaps provide ranges of 6 monthly mass-management targets instead of single values, which are more realistic to achieve.

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

**CHILDHOOD OBESITY: SOLUTIONS**

No single most intervention approach is available for treatment of childhood obesity (Rutter, 2012). However, family-based community interventions have been attempted (Fagg et al., 2014; Perry et al., 2018). Mother’s perception of her child’s obesity problem (Berggren et al., 2018) and community beliefs (Covic et al., 2007) do matter 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 reflections on its history, definition, epidemiology, diagnostic perspectives, psychological considerations, muculoskeletal as well as endocrine complications and principles of management. Zylke and Buchner (2018) have discussed prevention strategies to overcome childhood obesity. Parkinson et al. (2017) have introduced the food-system compass to encourage balanced eating, which may result in controlling childhood obesity.

Various groups have proposed solutions of childhood-obesity problem. Poskitt (2005) opines that treatment focusing on increasing consumption of energy and decreasing intake of energy seldom show long-lasting effects. Robinson and Sirard (2005) put forward solution-oriented research paradigm for avoiding childhood obesity, which
encouraged child-health-related research. Mazik et al. (2007) suggested understanding the bigger picture of childhood obesity by looking at the wider determinants of obesity, such as walking-biking-friendly neighborhood, social interactions, food marketing and pricing. Wieting (2008) studied cause and effect in childhood obesity to uncover a solution. Finegood et al. (2010) looked into implications of the Foresight Obesity System Map.

Mathematical-statistical techniques were used by the NGDS Team — NGDS stands for ‘National Growth and Developmental Standards for the Pakistani Children’ https://ngds-ku.org — during 2013-2017 to propose 1st- to 6th-generation solutions of childhood obesity. 1st- to 3rd-generation solutions were summarized in Kamal (2015c). In this paper, 7th generation solution is put forward (Figure 3).

CHILDHOOD OBESITY: MONITORING

Anthropometric measures commonly employed for monitoring of childhood obesity are standing height (stature), mass (weight), waist circumference and hip circumference. Some of the anthropometric and non-anthropometric measures are described in Kamal and Jamil (2014) — expanded version is available in Figures 4a-c. Field and laboratory studies conducted by the NGDS Team are described below:

Field Study — the NGDS Pilot Project

The NGDS Pilot Project was initiated in 1998 under the directives of Governor Sindh, after following ‘Institutional Review Process’— project designed after considering applicable ethical and human-right protocols (Kamal et al., 2002), described in detail in Additional File 1 of Kamal (2017c).
ASSESMENT OF HEIGHT STATUS

- Height-for-Age Charts
- Height Velocity
- Army-Cutoff Height
- Target Height
- Reference Height
- STATUS

Fig. 4b. Classification of methods available for assessment of height status

ASSESMENT OF HEIGHT AND MASS STATUSES COMBINED

- Estimated-Adult BMI
- Body-Mass Index (BMI)
- Build
- Nutritional Status

Fig. 4c. Classification of methods available for assessment of height and mass statuses combined

Four representative schools (1 civilian and 3 operated by the Armed Forces of Pakistan: Pakistan Army; Pakistan Navy; Pakistan Air Force) were chosen for conduct of the NGDS Pilot Project, participation was based on ‘opt-in’ policy; only those pupils were measured whose parents signed the consent slip, part of ‘Informed Consent Form’ https://www.ngds-ku.org/ngds_folder/Protocols/NGDS_Form.pdf — A dedicated room, furnished according to examination needs, having acoustic as well as visual privacy for gender-segregated unclothed checkups, was provided by each school authority.

Laboratory Study — Sibling Growth Pilot Project

SGPP (Sibling Growth Pilot Project) https://www.ngds-ku.org/ngds_URL/subprojects.htm#SGPP was a family-centered subproject, which monitored health of enrolled families, who visited Growth-and-Imaging Laboratory for checkups along with their 5-10-year-old sons and daughters. The lab was maintained germ-free by forbidding outside shoes/flip-flops for youngsters, their parents as well as staff of laboratory. Floor was black tiled and mopped with dettol-mixed water prior to each session (generic name of dettol is chloroxylenol). For enrolment, the parents signed ‘SGPP Participation Form’, which included complete information and illustrations of procedures https://www.ngds-ku.org/SGPP/SGPP_Form.pdf

Checkups were conducted giving due regard to parents’ and children’s’ comfort, confidentiality, dignity, privacy and safety.

Techniques of Height and Mass Measurement — Least Counts: 0.005 cm and 0.005 kg

The key to childhood-obesity research is obtaining accurate height and weight measurements (Gobte and Meyer, 2018). Heights, \( h \), and masses, \( \mu \), were measured by reproducible anthropometrists (Figures 5a, b), according to laid-down protocols (Kamal et al., 2013c) given in the official manual (Kamal, 2016a). Additional File 2 of Kamal (2017c) gives the abbreviated version with step-by-step procedures explained through labeled photographs. A series of 5 educational videos have been prepared to further reinforce methods of taking anthropometric measurements (Kamal, 2017a). Heights were measured to least counts of 0.1 cm (1998-2011, setsquare set — Kamal and Firdous, 2002a; b); 0.01 cm (2012-2015, Vernier scale — Kamal, 2010) and 0.005 cm (2016 to date, enhanced-Vernier scale

Fig. 5a, b. Measurements of (a) height and (b) mass of a girl; the second author assisted in anthropometry of this child — photographs first appeared in Kamal et al. (2014b), published in the same journal
GROWTH-AND-OBESITY VECTOR-ROADMAP 2.1

For the purpose of the following discussion, age range, A, for different phases of growth are: the earlier-childhood period (generally prepubertal: child not yet entering puberty) — A < 9.5 years; the later-childhood period (generally peripubertal: youngsters about to enter puberty, characterized by leveling off of height trajectory) — 9.5 years ≤ A < 12 years; the transition period (generally pubertal: incumbent in the process of entering puberty, characterized by energy-channelization III, puberty-induced energy-channelization; height gain almost ceases, mass and fat gains, in particular below the waist) — 12 years ≤ A < 13.5 years; the adolescence period — 13.5 years ≤ A < 20 years; the adulthood period — A ≥ 20 years (Kamal et al., 2017b). Energy-channelization III was introduced in Kamal (2014) and explained in Kamal et al. (2016c).

Version 2.1 — the Need

Growth-and-Obesity Vector-Roadmap 1.0 (Kamal et al., 2016a; b) was supposed to assign softer targets for mass and height management as the targets proposed in Scalar-Roadmap 1.0 (Kamal et al., 2015) were thought to be too demanding as they tried to achieve the entire correction within a short span of 6 months. Growth-and-Obesity Vector-Roadmap 2.0 (Kamal, 2017b) proposed a range instead of a single value for mass management. However, this formulation was biased towards height-percentile-based-optimal mass, as status (pertaining-to-mass) was computed using this optimal mass. In order to have an unbiased interpretation of both height-percentile-based- and BMI-based-optimal masses (defined in the section on ‘Growth-and-Obesity Profiles 2.1’ appearing below), we are modifying the definition of status (pertaining-to- mass).

Version 2.1 — Method of Constructing

Condition of Applicability: Growth-and-Obesity Vector-Roadmap 2.1 applies to youngsters, who have both parents in the adulthood period.

Behavior Code: Behavior code has 3 possible values: 0 (coöperative and relaxed — ideal for measurements); 1 (shy and timid, but cooperative — measurements permissible); 2 (nagging and resistant — measurements not reliable)

Dress Code: Dress code was recorded with the findings (quantitative or descriptive) as a fraction, numerator (denominator) describing amount of clothing superior (inferior) to transverse plane containing the naval. A value 0/0.5 (recommended for measurements of youngsters) meant that the child was measured barefoot and completely undressed except under-shorts. Behavior and dress codes code are described in Kamal (2016a) and Kamal et al. (2002).
CDC Growth Charts and Tables (extended version): These charts and tables list masses and heights of females and males in the extended range of CDC percentiles, 0.01-99.99 (Kamal and Jamil, 2014).

Scaled Growth Charts and Tables (for the Pakistani population): Height and mass scaled percentiles, to be used for the Pakistani population, were obtained from CDC percentiles by fitting a parabolic curve to each percentile such that 40th CDC percentile corresponds to 50th scaled percentile (Kamal et al., 2017b).

\[ P_{\text{Scaled}}(h) = \frac{17P_{\text{CDC}}(h)}{12} - \frac{P_{\text{CDC}}^2(h)}{240}; \quad P_{\text{Scaled}}(\mu) = \frac{17P_{\text{CDC}}(\mu)}{12} - \frac{P_{\text{CDC}}^2(\mu)}{240} \]

Growth-and-Obesity Profiles 2.1 (for the periods of childhood, transition and adolescence): CDC percentiles of cutoff heights for induction into the Armed Forces of Pakistan, \( P_{\text{AC}} \) (Kamal et al., 2017c), as well as target height, also called ‘mid-parental percentile’, \( P_{\text{MP}} \) (Tanner et al., 1970), were evaluated using age-20-height values obtained from Extended CDC Growth Tables using the technique of ‘linear interpolation’. For the Pakistani boys, adult-army-cutoff height, \( h_{\text{AC}} \), is 62.56 cm (5 ft 4 in), \( P_{\text{AC}} \) comes out to 2.718014592103645... for girls \( h_{\text{AC}} \) is 157.48 cm (5 ft 2 in), the corresponding percentile is 19.35609323536863... \( P_{\text{MP}} \) is the CDC percentile corresponding to gender-specific-adult-mid-parental (target) height (in cm) given by \( h_{\text{MP}} = \frac{h_{F} + h_{M}}{2} \pm 6.5 \text{ cm} \), where \( h_{F} \) and \( h_{M} \) were heights of father and mother measured in cm; positive sign taken for male child’s target height; negative sign for female child’s target height. ‘Box interpolation’ (Kamal et al., 2011) was employed to determine child’s CDC percentiles of height, \( P_{\text{CDC}}(h, A) \), and mass, \( P_{\text{CDC}}(\mu, A) \). ‘Linear interpolation’ was utilized to compute estimated-adult height (mass), \( h_{\text{est}}-\text{adult} \) (\( \mu_{\text{est}}-\text{adult} \)), using these percentiles and age-20 values as well as evaluate estimated-adult BMI (Kamal and Jamil, 2012), \( \mu = \frac{h_{\text{est}}-\text{adult} \times \text{mass}}{h_{\text{est}}-\text{adult}} \), (mass in kg; height in m). Constant-age route was utilized to evaluate ‘height-percentile-based-optimal mass’, \( \mu_{\text{opt}} \) mass corresponding to CDC percentile of height (Kamal et al., 2004; 2011).

‘BMI-based-optimal mass’, \( \mu_{\text{BMI}} \), for a youngster was computed in 3 steps: (i) ‘Estimated-adult-BMI-based-optimal mass’ was evaluated using the expression \( \mu_{\text{BMI}}-\text{est-adult} = 24h_{\text{est}}-\text{adult} \times \text{estimated-adult height in m} \), (ii) ‘Percentile of BMI-based-optimal mass’, \( P_{\text{BMI}}(A) \), was evaluated using linear interpolation to estimated-adult-BMI-based-optimal mass, \( \mu_{\text{BMI}}-\text{est-adults} \) (iii) box interpolation (Kamal et al., 2011) was used to evaluate ‘BMI-based-optimal mass’ at the given age. Similar procedure was employed to estimate current-age-mid-parental height, \( h_{\text{CA-AC}} \), and current-age-army-cutoff height, \( h_{\text{CA-AC}} \).

Algebraic status (pertaining-to-height), \( STATUS_{\pm}(h) \), and algebraic status (pertaining-to-mass), \( STATUS_{\pm}(\mu) \), employed in Growth-and Obesity Vector-Roadmap 2.0 are, now, replaced by modified status (pertaining-to-height), \( STATUS_{\pm}^{\text{MOD}}(h) \), and modified status (pertaining-to-mass), \( STATUS_{\pm}^{\text{MOD}}(\mu) \), respectively.

In \( STATUS_{\pm}^{\text{MOD}}(h) \) range of normality is extended, stunting and tallness are redefined based on closeness of measured height to \( h_{\text{CA-AC}} \) and \( h_{\text{CA-AC}} \) (Table 1). Figure 7a represents concept of stunting and tallness in the form of number line. Descriptive status (pertaining-to-height) now replaces qualitative status (pertaining-to-height) and assigned as per recipe given in Figure 7b. Fractional status (pertaining-to-height), \( STATUS_{\text{Fr}}(h) \), is obtained as

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

Table 1. Mathematical expressions of modified status (pertaining-to-height)²

<table>
<thead>
<tr>
<th>Mathematical Condition</th>
<th>Mathematical Expression of ( STATUS_{\pm}^{\text{MOD}}(h) )</th>
<th>Qualitative Description</th>
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<tr>
<td>( h &lt; h_{\text{min}} )</td>
<td>( 100 \times \frac{h_{\text{min}}}{h_{\text{min}}} ) % &lt; 0</td>
<td>Stunted</td>
</tr>
<tr>
<td>( h_{\text{min}} \leq h \leq h_{\text{max}} )</td>
<td>0</td>
<td>Normal</td>
</tr>
<tr>
<td>( h &gt; h_{\text{max}} )</td>
<td>( 100 \times \frac{h_{\text{max}}}{h_{\text{max}}} ) % &gt; 0</td>
<td>Tall</td>
</tr>
</tbody>
</table>

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

²: \( h_{\text{min}} = \text{min}(h_{\text{CA-AC}}, h_{\text{CA-AC}}), h_{\text{max}} = \text{max}(h_{\text{CA-AC}}, h_{\text{CA-AC}}) \)
In $STATUS_{±}^{MOD}(μ)$, range of normality is extended, wasting and obesity are redefined based on closeness of net mass (mass obtained without any clothing worn; for children weighed in short underpants, stripped-to-waist, measured mass is very close to net mass and no clothing correction is applied) to $μ_{BMI}^{corrected}$ and $μ_{opt}^{corrected}$—corrected masses are obtained by adding 5 kg to computed optimal masses of females, who are about to be married/married/recently divorced/recently widowed to accommodate for possible pregnancy and the associated fetal mass (Table 2). Figure 8a represents concept of wasting and obesity in the form of number line. Descriptive status (pertaining-to-mass) now replaces qualitative status (pertaining-to-mass) and assigned as per recipe given in Figure 8b. Fractional status (pertaining-to-mass), $STATUS_{Fr}(μ)$, is obtained as

$ STATUS_{Fr}(μ) = \frac{STATUS_{±}^{MOD}(μ)}{100} $  

(2b)

<table>
<thead>
<tr>
<th>Degree</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>4th</td>
<td>$STATUS_{±}^{MOD}(h) ≥ +30%$</td>
</tr>
<tr>
<td>3rd</td>
<td>$+20% ≤ STATUS_{±}^{MOD}(h) &lt; +30%$</td>
</tr>
<tr>
<td>2nd</td>
<td>$+10% ≤ STATUS_{±}^{MOD}(h) &lt; +20%$</td>
</tr>
<tr>
<td>1st</td>
<td>$0% &lt; STATUS_{±}^{MOD}(h) &lt; +10%$</td>
</tr>
<tr>
<td>Normal</td>
<td>$STATUS_{±}^{MOD}(h) = 0$</td>
</tr>
<tr>
<td>1st</td>
<td>$−10% ≤ STATUS_{±}^{MOD}(h) &lt; 0$</td>
</tr>
<tr>
<td>2nd</td>
<td>$−20% ≤ STATUS_{±}^{MOD}(h) &lt; −10%$</td>
</tr>
<tr>
<td>3rd</td>
<td>$−30% ≤ STATUS_{±}^{MOD}(h) &lt; −20%$</td>
</tr>
<tr>
<td>4th</td>
<td>$STATUS_{±}^{MOD}(h) &lt; −30%$</td>
</tr>
</tbody>
</table>

Fig. 7b. Color codes used to represent descriptive status (pertaining-to-height)
Table 2. Mathematical expressions of modified status (pertaining to mass)  

<table>
<thead>
<tr>
<th>Mathematical Condition</th>
<th>Mathematical Expression of $STATUS_{\text{MOD}}^{\pm}(\mu)$</th>
<th>Qualitative Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu &lt; \mu_{\text{min}}$</td>
<td>$100 \frac{\mu - \mu_{\text{min}}}{\mu_{\text{min}}} % &lt; 0$</td>
<td>Wasted</td>
</tr>
<tr>
<td>$\mu_{\text{min}} \leq \mu \leq \mu_{\text{max}}$</td>
<td>$0$</td>
<td>Normal</td>
</tr>
<tr>
<td>$\mu &gt; \mu_{\text{max}}$</td>
<td>$100 \frac{\mu - \mu_{\text{max}}}{\mu_{\text{max}}} % &gt; 0$</td>
<td>Obese</td>
</tr>
</tbody>
</table>

$\mu_{\text{min}} = \min(\mu_{\text{BMIcorrected}}, \mu_{\text{optcorrected}})$, $\mu_{\text{max}} = \max(\mu_{\text{BMIcorrected}}, \mu_{\text{optcorrected}})$

Fig. 8a. Number-line representation of BMI-based-optimal mass and height-percentile-based-optimal mass

<table>
<thead>
<tr>
<th>Degree Obese</th>
<th>STATUS$_{\text{MOD}}^{\pm}(\mu)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>4th</td>
<td>$\geq +30%$</td>
</tr>
<tr>
<td>3rd</td>
<td>$+20% \leq \leq +30%$</td>
</tr>
<tr>
<td>2nd</td>
<td>$+10% \leq \leq +20%$</td>
</tr>
<tr>
<td>1st</td>
<td>$0% &lt; \leq +10%$</td>
</tr>
<tr>
<td>Normal</td>
<td>$= 0$</td>
</tr>
<tr>
<td>1st</td>
<td>$-10% \leq \leq 0$</td>
</tr>
<tr>
<td>2nd</td>
<td>$-20% \leq \leq -10%$</td>
</tr>
<tr>
<td>3rd</td>
<td>$-30% \leq \leq -20%$</td>
</tr>
<tr>
<td>4th</td>
<td>$&lt; -30%$</td>
</tr>
</tbody>
</table>

Fig. 8b. Color codes used to represent descriptive status (pertaining to mass)
Fractional status (pertaining-to-height-and-mass), $STATUS_Fr(h)$, may be represented as a complex number. We include below a little mathematics of complex-number representation as this paper is intended for audiences in biological sciences, who do not have a solid background in mathematics. A complex number, $\xi$, having a real part, $x$, and an imaginary part, $y$, may be expressed in terms of $r$ and $\theta$ ($i = \sqrt{-1}$)

$$\xi = x + iy = r(\cos \theta + i \sin \theta) \Rightarrow r = \sqrt{x^2 + y^2}, \theta = \tan^{-1} \frac{y}{x}$$

$r$ in our case is termed as ‘away-from-normality index’. Equation (3), therefore, becomes (Figure 9)

$$STATUS_Fr(h) = STATUS_Fr(\mu) + i STATUS_Fr(h) \Rightarrow r = \sqrt{STATUS_Fr(\mu) + STATUS_Fr(h)}, \theta = \tan^{-1} \frac{STATUS_Fr(h)}{STATUS_Fr(\mu)}$$

Figure 10 illustrates expanded classification of nutritional statuses. Polar-angle range both in degrees and in radians

![Figure 9. Polar-coördinate interpretation of fractional statuses (pertaining-to-height) and (pertaining-to-mass)](image)

![Figure 10. Expanded classification of nutritional statuses based on polar-coördinate interpretation — limiting cases illustrated: color-coding of Growth-and-Obesity Scalar- and Vector-Roadmaps 2.1, which includes color-coding of expanded classification of nutritional status, is available in Additional File](image)

https://www.ngds-ku.org/Papers/J52/Additional_File.pdf
A is estimated based on \( \pi \leq A \leq \pi \) is computed. \( d \), whose boundaries are given by the domain for navigational \( \mu \) and touching,

\[ \text{BMI} = A = \mu \]

one requires two or more checkup profiles to construct these roadmaps. Reference-height percentile, \( P_{\text{ref}}(A) = \max(P_{\text{CDC}}(h,A),P_{\text{AC}},P_{\text{MP}}) \), is computed. \( \mu_{\text{opt}} \) is estimated based on reference height at \( A_0 \) (age at the most recent checkup) and \( \mu_{\text{BMI}} \) from CDC percentile of BMI-based-optimal mass at \( A_0 \), both of them evaluated after a lapse of 6-month period. 6 monthly recommendations to pick up height and put on/shed off mass (range given instead of a single value) are generated from the last profile.

**Growth-and-Obesity Scalar-Roadmaps 2.1 (for the periods of later childhood, transition and adolescence):** Valid in the age (\( A \)) range, 9.5 years \( \leq A < 20 \) years, one requires two or more checkup profiles to construct these roadmaps. Reference-height percentile, \( P_{\text{ref}}(A) = \max(P_{\text{CDC}}(h,A),P_{\text{AC}},P_{\text{MP}}) \), is computed. \( \mu_{\text{opt}} \) is estimated based on reference height at \( A_0 \) (age at the most recent checkup) and \( \mu_{\text{BMI}} \) from CDC percentile of BMI-based-optimal mass at \( A_0 \), both of them evaluated after a lapse of 6-month period. 6 monthly recommendations to pick up height and put on/shed off mass (range given instead of a single value) are generated from the last profile.

**Growth-and-Obesity Vector-Roadmaps 2.1 (for the period of early childhood):** Useful to study growth and obesity statuses of children till the age of 9.5 years, these roadmaps use the concepts of navigation, guidance and control. The navigational trajectories for height and mass percentiles are obtained by fitting freehand curves to the respective CDC height-and mass-percentile values, \( P = P_{\text{CDC}}(h,A) \) and \( P = P_{\text{CDC}}(\mu,A) \), the domain for navigational trajectory being \( A_{\text{Enrolm ent}} \leq A \leq A_0 \) (\( A_{\text{Enrolm ent}} \) is age at enrolment/first checkup; control action needs to be initiated at \( A_0 \)). The navigational trajectories are common for both Scalar- and Vector-Roadmaps 2.1. The domain for guidance trajectories (both height and mass management) is the closed interval \( A_0 \leq A \leq 10 \) years — control action ends at the age of 10 years in the context of Vector-Roadmap 2.1.

The guidance trajectory for height management takes the form, \( P = P_{\text{ref}}(A) \), where \( P_{\text{ref}}(A) = P_{\text{ref}}(A_0) \). A parabolic curve, \( P = P_{\text{CDC}}(h,A) \), is fitted to generate trajectory of the desired course-of-action for height management, passing through \( (A_0,P_{\text{CDC}}(h,A_0)) \) and touching, smoothly, the guidance trajectory, \( P = P_{\text{ref}}(A) \), at the vertex \( (10,P_{\text{ref}}(A_0)) \), in such a way that the guidance trajectory is tangent to parabola at this location. The guidance trajectories for mass management form the band, whose boundaries are given by \( P = P_{\text{ref}}(A) \), where \( P_{\text{ref}}(A) = P_{\text{ref}}(A_0) \) and \( P = P_{\text{BMI}}(A) \), where \( P_{\text{BMI}}(A) = P_{\text{BMI}}(A_0) \). Six (6) monthly targets for mass and height management are generated by erecting lines parallel to the vertical (percentile) axis.

Sample Vector-Roadmap 2.1 of M. E. is given in Tables 4a, b, which include modified statuses, descriptive statuses, away-from-normality index, \( r \), polar angle, \( \theta \), expanded nutritional status and 6 monthly recommendations for mass and height management. Time evolution of CDC percentiles of height and mass for M. E.’s 2 checkups is

<table>
<thead>
<tr>
<th>Region</th>
<th>Nutritional Status</th>
<th>Description</th>
<th>Polar-Angle Range (radian)</th>
<th>Polar-Angle Range (degree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Obesity dominated</td>
<td>Obesity dominating</td>
<td>( 0 \leq \theta &lt; \frac{\pi}{4} )</td>
<td>([0,45^\circ])</td>
</tr>
<tr>
<td>II</td>
<td>Tallness dominated</td>
<td>Tallness dominating</td>
<td>( \frac{\pi}{4} \leq \theta &lt; \frac{\pi}{2} )</td>
<td>([45^\circ},90^\circ])</td>
</tr>
<tr>
<td>III</td>
<td>Tallness dominated</td>
<td>Tallness dominating</td>
<td>( \frac{\pi}{2} \leq \theta &lt; \frac{3\pi}{4} )</td>
<td>([90^\circ},135^\circ])</td>
</tr>
<tr>
<td>IV</td>
<td>Wasting dominated</td>
<td>Wasting dominating</td>
<td>( \frac{3\pi}{4} \leq \theta &lt; \pi )</td>
<td>([135^\circ},180^\circ])</td>
</tr>
<tr>
<td>V</td>
<td>Wasting dominated</td>
<td>Wasting dominating</td>
<td>( \pi \leq \theta &lt; \frac{5\pi}{4} )</td>
<td>([180^\circ},225^\circ])</td>
</tr>
<tr>
<td>VI</td>
<td>Stunting dominated</td>
<td>Stunting dominating</td>
<td>( \frac{5\pi}{4} \leq \theta &lt; \frac{3\pi}{2} )</td>
<td>([225^\circ},270^\circ])</td>
</tr>
<tr>
<td>VII</td>
<td>Stunting dominated</td>
<td>Stunting dominating</td>
<td>( \frac{3\pi}{2} \leq \theta &lt; \frac{7\pi}{4} )</td>
<td>([270^\circ},315^\circ])</td>
</tr>
<tr>
<td>VIII</td>
<td>Obesity dominated</td>
<td>Obesity dominating</td>
<td>( \frac{7\pi}{4} \leq \theta &lt; 2\pi )</td>
<td>([315^\circ},360^\circ])</td>
</tr>
</tbody>
</table>
Gender: Female  
Date of Birth (year-month-day): 2002-09-23  
Adult-Army-Cutoff Height: 157.48 cm (19.36\textsuperscript{P})  
Father’s Height: 167.80 cm  
Mother’s Height: 171.00 cm  
Target Height: 162.90 cm (47.49\textsuperscript{P})

### Table 4a. Growth-and-Obesity Vector-Roadmap 2.1 of M. E. (SGPP-KHI-20100421-03/01)

<table>
<thead>
<tr>
<th>Checkup</th>
<th>1\textsuperscript{st}</th>
<th>2\textsuperscript{nd}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photograph</td>
<td><img src="image" alt="Photograph" /></td>
<td><img src="image" alt="Photograph" /></td>
</tr>
<tr>
<td>Scanned Signatures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class</td>
<td>IV</td>
<td>IV</td>
</tr>
<tr>
<td>Date of Checkup (year-month-day)</td>
<td>2011-05-22</td>
<td>2011-11-13</td>
</tr>
<tr>
<td>Age (year-month-day)</td>
<td>08-07-29</td>
<td>09-01-20</td>
</tr>
<tr>
<td>Age (decimal year), A</td>
<td>8.66</td>
<td>9.14</td>
</tr>
<tr>
<td>Dress Code</td>
<td>0/0.5\textsuperscript{a}</td>
<td>0/0.5</td>
</tr>
<tr>
<td>Behavior Code</td>
<td>0\textsuperscript{b}</td>
<td>0</td>
</tr>
<tr>
<td>Height, h (cm)</td>
<td>(129.50\textsuperscript{£} )</td>
<td>(131.00\textsuperscript{£} )</td>
</tr>
<tr>
<td>Height (ft-in)</td>
<td>(4 ft 2.98 in)</td>
<td>(4 ft 3.57 in)</td>
</tr>
<tr>
<td>CDC Percentile-of-Height, (P_{\text{CDC}}(h,A))</td>
<td>(39.73\textsuperscript{P} )</td>
<td>(34.33\textsuperscript{P} )</td>
</tr>
<tr>
<td>Scaled Percentile-of-Height, (P_{\text{Scaled}}(h,A))</td>
<td>(49.70\textsuperscript{P} )</td>
<td>(43.72\textsuperscript{P} )</td>
</tr>
<tr>
<td>Current-Age-Army-Cutoff Height, (h_{\text{CA-AC}}(cm))</td>
<td>125.78</td>
<td>128.06</td>
</tr>
<tr>
<td>Current-Age-Mid-Parental Height, (h_{\text{CA-MP}}(cm))</td>
<td>130.76</td>
<td>133.20</td>
</tr>
<tr>
<td>(\Delta h_{\text{CA-AC}}(cm) = h - h_{\text{CA-AC}})</td>
<td>+3.72</td>
<td>+2.94</td>
</tr>
<tr>
<td>(\Delta h_{\text{CA-MP}}(cm) = h - h_{\text{CA-MP}})</td>
<td>–1.26</td>
<td>–2.20</td>
</tr>
<tr>
<td>Reference Height (cm)</td>
<td>130.76</td>
<td>133.20</td>
</tr>
<tr>
<td>Percentile-of-Reference-Height, (P_{\text{ref}}(A))</td>
<td>(47.49\textsuperscript{P} )</td>
<td>(47.49\textsuperscript{P} )</td>
</tr>
<tr>
<td>Estimated-Adult Height (cm)</td>
<td>161.54</td>
<td>160.60</td>
</tr>
</tbody>
</table>

### Estimated-Adult Height (ft-in)

| Estimated-Adult Height (ft-in) | \(5 ft 3.60 \text{ in}\) | \(5 ft 3.23 \text{ in}\) |

### Modified Status (pertaining-to-height), \(\text{STATUS}_{\text{MOD}}(h)\)

| Modified Status | \(0\) | \(0\) |

### Descriptive Status (pertaining-to-height)

<table>
<thead>
<tr>
<th>Normal</th>
<th>Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Mass, (\mu (kg))</td>
<td>31.90</td>
</tr>
<tr>
<td>Net Weight (lb-oz)</td>
<td>(70 \text{ lb 5.43 oz})</td>
</tr>
<tr>
<td>CDC Percentile-of-Net-Mass, (P_{\text{CDC}}(\mu,A))</td>
<td>(75.79\textsuperscript{P} )</td>
</tr>
<tr>
<td>Scaled Percentile-of-Net-Mass, (P_{\text{Scaled}}(\mu,A))</td>
<td>(83.43\textsuperscript{P} )</td>
</tr>
<tr>
<td>Percentile-of-BMI-based-Optimal-Mass, (P_{\text{BMI}}(A))</td>
<td>(64.44\textsuperscript{P} )</td>
</tr>
<tr>
<td>(\text{BMI-based-Optimal Mass, } \mu_{\text{BMI}}(kg))</td>
<td>30.03</td>
</tr>
<tr>
<td>Height-Percentile-based-Optimal Mass, (\mu_{\text{opt}}(kg))</td>
<td>26.57</td>
</tr>
<tr>
<td>Estimated-Adult Mass (kg)</td>
<td>66.35</td>
</tr>
<tr>
<td>Estimated-Adult Weight (lb-oz)</td>
<td>(146 \text{ lb 4.86 oz})</td>
</tr>
</tbody>
</table>

### Modified Status (pertaining-to-mass), \(\text{STATUS}_{\text{MOD}}(\mu)\)

| \(\text{h} \) | +6.21% | +0.73% |

### Descriptive Status (pertaining-to-mass)

<table>
<thead>
<tr>
<th>1\textsuperscript{st}-Degree Obese</th>
<th>1\textsuperscript{st}-Degree Obese</th>
</tr>
</thead>
<tbody>
<tr>
<td>Away-from-Normality Index, (r)</td>
<td>0.0621</td>
</tr>
<tr>
<td>Polar Angle, (\theta) (degree)</td>
<td>0</td>
</tr>
</tbody>
</table>

### Expanded Nutritional Status

<table>
<thead>
<tr>
<th>Obesity</th>
<th>Obesity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated-Adult BMI (kg/m(^2))</td>
<td>(25.43)</td>
</tr>
<tr>
<td>(P_{\text{Scaled}}(h,A) + P_{\text{Scaled}}(\mu,A))</td>
<td>133.14</td>
</tr>
</tbody>
</table>

### Build

| Medium | Medium |

\(\textsuperscript{P}\) The superscript \(P\) stands for percentile.

\(\textsuperscript{a}\) Dress Code 0/0.5 implies that the child was relaxed and cooperative (Kamal, 2016a; Kamal et al., 2002)

\(\textsuperscript{b}\) Pseudo-gain of ‘height’ (Kamal et al., 2014b) exhibited between 1\textsuperscript{st} and 2\textsuperscript{nd} checkups — height pick-up from 129.50 cm to 131.00 cm, CDC percentile dropping from 39.72\textsuperscript{P} to 34.33\textsuperscript{P}.

\(\textsuperscript{c}\) The superscript \(\mu\) stands for \(\mu\)-value.

\(\textsuperscript{d}\) The superscript \(\mu\) stands for \(\mu\)-value.

\(\textsuperscript{e}\) The superscript \(\mu\) stands for \(\mu\)-value.
Table 4b. Month-wise mass and weight target ranges as well as height targets for M. E. based on her last checkup — targets determined using Growth-and-Obesity Vector-Roadmap 2.1

*Date of Last (Second) Checkup: November 13, 2011 • Decimal Age, \( A_0 = 9.139726027 \) years

\[ P_{ref} = 47.49439769505168 \] • \( P_{CDC}(\mu, A_0) = 63.4213131272754 \) • \( P_{CDCH}(h, A_0) = 34.33112094538 \)

<table>
<thead>
<tr>
<th>Target Date (^b)</th>
<th>Mass and Weight Target Ranges</th>
<th>Height Target</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg</td>
<td>lb-oz</td>
</tr>
<tr>
<td>November 13, 2011</td>
<td>31.79</td>
<td>70 lb 1.55 oz</td>
</tr>
<tr>
<td>December 13, 2011</td>
<td>31.64-32.04</td>
<td>69 lb 12.26 oz - 70 lb 10.48 oz</td>
</tr>
<tr>
<td>January 13, 2012</td>
<td>31.52-32.37</td>
<td>69 lb 8.03 oz - 71 lb 5.97 oz</td>
</tr>
<tr>
<td>February 13, 2012</td>
<td>31.44-32.70</td>
<td>69 lb 5.20 oz - 72 lb 1.52 oz</td>
</tr>
<tr>
<td>March 13, 2012</td>
<td>31.40-33.01</td>
<td>69 lb 3.79 oz - 72 lb 12.42 oz</td>
</tr>
<tr>
<td>April 13, 2012</td>
<td>31.42-33.35</td>
<td>69 lb 4.50 oz - 73 lb 8.69 oz</td>
</tr>
<tr>
<td>May 13, 2012</td>
<td>31.49-33.70</td>
<td>69 lb 6.97 oz - 74 lb 4.94 oz</td>
</tr>
</tbody>
</table>

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

illustrated in Figure 11.

Obesity Profiles 2.1 (for the period of adulthood): CDC percentiles of heights and masses of parents/non-parents computed using linear interpolation from lesser and greater age-20 values read from extended-gender-specific tables. Modified and descriptive statuses (pertaining-to-mass) were evaluated on the basis of height-percentile-based as well as BMI-based optimal masses, scaled percentiles determined and build assigned.

Obesity Roadmaps 2.1 (for the period of adulthood): Instead of a single value of optimal mass, a range is available for the parents/non-parents to maintain their masses in such a way that after 6 months their masses should lie between \( \min(\mu_{opt}(A_0 + 6\text{months}), \mu_{BMI}(A_0 + 6\text{months})) \) and \( \max(\mu_{opt}(A_0 + 6\text{months}), \mu_{BMI}(A_0 + 6\text{months})) = \mu_{opt}(A_0 + 6\text{months}) \) and \( \mu_{BMI}(A_0 + 6\text{months}) \) are computed based on height measured at the last checkup. Individual is advised to maintain mass (weight) in the light of the above range, taking care of the principle that the incumbent should not be required to lose more than 10 kg within 6-month period, in order to avoid any adverse effects from a rapid loss of mass.

Version 2.1—Software Development

Software was developed to generate Growth-and-Obesity Vector-Roadmap 2.1. This software was named SOFTGROWTH 2.1. The software was developed in Microsoft Visual Studio (Visual Basic Dot Net 2008), which is an enhancement of SOFTGROWTH 2, whose features are reported earlier (Kamal et al., 2017a). Version 2.1 is different from version 2 in the age ranges. Age-range interval, \( A \geq 30 \) years, \( 20 \) years \( \leq A < 30 \) years, has been merged as \( A \geq 20 \) years (adulthood range). Both height-percentile-based and BMI-based optimal masses are now calculated and a range of mass values assigned for mass-management targets. For ages below 20 years, height management, also, plays a role and height-management targets are, also, given. Modified, descriptive as well as fractional statuses (pertaining-to-height) and (pertaining-to-mass) were computed and build assigned. Block diagram of SOFT-
Fig. 12a. Block diagram of SOFTGROWTH 2.1

GROWTH 2.1 is given in Figure 12a. Screen shots of month-wise targets of parents of M. E. are displayed in Figures 12b, c.

MATHEMATICS OF OBESITY AND WASTING BASED ON VERSION 2.1

The terms ‘instantaneous obesity’ and ‘instantaneous wasting’ were introduced (Kamal et al., 2017c) and later defined mathematically (Kamal, 2017c) to differentiate them from ‘true obesity’ and ‘true wasting’ (Kamal et al., 2017a).

Instantaneous Obesity

Instantaneous obesity exists, when modified status (pertaining-to-mass) is greater than zero. Definition of instan-

![Fig. 12b. SOFTGROWTH 2.1 screen shot of month-wise targets of mass (weight) range for father of M. E.](image-url)
taneous obesity is given in Table 5 and clinical example available in Table 6, demonstrated during all of the check-ups of Z. J. (SGPP-KHI-20060412-01/01), the case documented in Kamal (2017a).

Table 5. Logical and mathematical definitions of instantaneous obesity and true obesity

<table>
<thead>
<tr>
<th>Instantaneous Obesity</th>
<th>True Obesity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Logical Definition</strong></td>
<td><strong>Mathematical Definition</strong></td>
</tr>
<tr>
<td>$\mu - \mu_{\text{max}} &gt; 0$, $\mu_{\text{max}} = \max(\mu_{\text{opt}}, \mu_{\text{BMI}})$</td>
<td>$\mu_{\text{REC}}(A_0 + 6 \text{ months}) - \mu(A_0) &lt; 0$</td>
</tr>
<tr>
<td>$\text{STATUS}_{\text{MOD}}(\mu) &gt; 0$</td>
<td>$P_{\text{CDC}}(\mu, A_0) - \max(P_{\text{ref}}(A_0), P_{\text{BMI}}(A_0)) &gt; +15$</td>
</tr>
</tbody>
</table>

**True Obesity**

True obesity exists, when the youngster’s recommended upper value of mass (weight) range at the end of 6-month

Table 6. Z. J. demonstrates instantaneous obesity and true obesity during all of her checkups

<table>
<thead>
<tr>
<th>Existence of Instantaneous Obesity</th>
<th>Existence of True Obesity</th>
</tr>
</thead>
<tbody>
<tr>
<td>STATUS_{MOD}^{\beta}(\mu) &gt; 0</td>
<td>$\Delta \mu^K; P_{\text{CDC}}(\mu, A_0) - \max(P_{\text{ref}}(A_0), P_{\text{BMI}}(A_0))^T &gt; +15$</td>
</tr>
</tbody>
</table>

$^\beta$Instantaneous obesity exists when $\text{STATUS}_{\text{MOD}}(\mu) > 0$

$^\xi$Logical definition: $\Delta \mu = \mu_{\text{max}}(A_0 + 6 \text{ months}) - \mu(A_0) < 0$

$^\zeta$Mathematical definition: $P_{\text{CDC}}(\mu, A_0) - \max(P_{\text{ref}}(A_0), P_{\text{BMI}}(A_0)) > +15$

$^\gamma$Obtained from rounding off the number $100 \times 4250 - 37.0820027676469 = +14.6108538589614$

$^\delta$Obtained from rounding off the number $100 \times 4650 - 39.39435503681415 = +18.03721613552399$
Logical and mathematical definitions of instantaneous wasting and true wasting

<table>
<thead>
<tr>
<th>Instantaneous Wasting</th>
<th>True Wasting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Logical Definition</strong></td>
<td></td>
</tr>
<tr>
<td>$\mu - \mu_{\min} &lt; 0$, $\mu_{\min} = \min(\mu_{\text{opt}}, \mu_{\text{BMI}})$</td>
<td>$P_{\text{CDC}}(\mu, A_0) - P_{\text{REC}}(\mu, A_0 + 6 \text{ months}) &lt; 0$</td>
</tr>
<tr>
<td><strong>Mathematical Definition</strong></td>
<td></td>
</tr>
<tr>
<td>STATUS$^{\text{MOD}}_{&lt;0}(\mu)$</td>
<td>$P_{\text{CDC}}(\mu, A_0) - \min(P_{\text{ref}}(A_0), P_{\text{BMI}}(A_0)) &lt; 0$</td>
</tr>
</tbody>
</table>

period is lesser than net mass at the last checkup — logical definition. A mathematical definition has, also, been proposed, which classifies the child as truly obese, when the difference of the incumbent’s CDC mass percentile and maximum of the reference percentile at the last checkup and BMI-based-optimal mass, both of them computed at the most recent checkup, exceeds 15 (Table 5). Presented in Table 6 are examples of true obesity, demonstrated during all of the checkups of Z. J. Proof of true obesity implying instantaneous obesity based on modified status (pertaining-to-mass) is given in Appendix A.

**Instantaneous Wasting**

Instantaneous wasting exists, when modified status (pertaining-to-mass) is less than zero. Definition of instantaneous wasting is given in Table 7 and clinical example available in Table 8, demonstrated during all of the checkups of L. G. (SGPP-KHI-20131021-02/01), the case documented in Kamal et al. (2017b).

**True Wasting**

A child is termed as truly wasted if the incumbent is recommended to climb on the trajectory of CDC percentile-of-mass within the next 6 months to the minimum of the reference percentile at the last checkup and BMI-based-optimal mass, also, at the most recent checkup. A mathematical definition has, also, been proposed, which classifies the child as truly wasted, when the difference of the youngster’s CDC mass percentile at the most recent checkup and the minimum of the reference percentile at the last checkup and BMI-based-optimal mass, also, at the most recent checkup is negative (Table 7). Equivalence of logical and mathematical definitions of true wasting is proved in Appendix B. Further, it is shown that instantaneous wasting implies true wasting. However, the converse is not true. Presented in Table 8 are examples of true wasting, demonstrated during all of the checkups of L. G. Proof of instantaneous wasting implying true wasting based on modified status (pertaining-to-mass) is given in Appendix B.

It must be emphasized that not all the scenarios, which involve recommendation of mass gain by a child, corresponding to true wasting. All such possibilities are listed in Appendix C.

**LIFESTYLE ADJUSTMENT, DIET AND EXERCISE PLANS**

In order to achieve height- and mass-management targets proposed by Growth-and-Obesity Vector-Roadmap 2.1, lifestyle, diet and exercise plans have been prepared (Table 9), which are extended and refined from previous versions.

Table 8. L. G. demonstrates instantaneous wasting and true wasting during all of her checkups

<table>
<thead>
<tr>
<th>Existence of Instantaneous Wasting</th>
<th>Existence of True Wasting</th>
</tr>
</thead>
<tbody>
<tr>
<td>STATUS$^{\text{MOD}}_{&lt;0}(\mu)$</td>
<td>$\Delta P^\delta; P_{\text{CDC}}(\mu, A_0) - \min(P_{\text{ref}}(A_0), P_{\text{BMI}}(A_0))^0$</td>
</tr>
<tr>
<td>$1^{\text{st}}$ Checkup</td>
<td>$-10.28% &lt; 0$</td>
</tr>
<tr>
<td>$2^{\text{nd}}$ Checkup</td>
<td>$-19.42% &lt; 0$</td>
</tr>
<tr>
<td>$3^{\text{rd}}$ Checkup</td>
<td>$-17.53% &lt; 0$</td>
</tr>
<tr>
<td>$4^{\text{th}}$ Checkup</td>
<td>$-19.44% &lt; 0$</td>
</tr>
</tbody>
</table>

$^a$Instantaneous wasting exists when STATUS$^{\text{MOD}}_{<0}(\mu) < 0$

$^d$Logical definition: $\Delta P = P_{\text{CDC}}(\mu, A_0) - P_{\text{REC}}(\mu, A_0 + 6 \text{ months}) < 0$

$^b$Mathematical definition: $P_{\text{CDC}}(\mu, A_0) - \min(P_{\text{ref}}(A_0), P_{\text{BMI}}(A_0))^0 < 0$

$^c$Obtained from rounding off the number $51.309704525242 - 74.37584574646 = -23.0663880049404$

$^d$Obtained from rounding off the number $65.2854556480498 - 91.82448368775 = -26.53902803970095$
Table 9. Lifestyle adjustment, diet and exercise plans\(^3\) for children to achieve month-wise targets

<table>
<thead>
<tr>
<th>Lifestyle Adjustment</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-3-hour family time on a daily basis, with cell phones and tablets kept away (conversation — parents should educate children about environmental-resource preservation; trees and forests, water reservoirs, clean-fresh air, plastic pollution; religious tolerance; ethnic diversity; empathy to feeling of others; joy of sharing); parents may stroll in the park/relax on benches, while children engage in free play; recommended daily dose of vitamin D (600 IU(^5)) through 10-15-minute guarded-graduated(^6) sun-exposure (early morning or late afternoon) with the child minimally dressed (head, arms, legs and spinal column exposed, last one from external auditory meatus to hip joint; facing away from sun and eyes protected through UV (ultraviolet)-cutoff glasses or indigenously-made spectacles(^7); hair spread out and opened up and bare (dried) feet (to prevent fungus infection); 2-3-hour play in fresh air to spread-out hair, striped-to-waist, wearing pure cotton socks and sneakers; hair and body massage with olive oil before bathing; 8-hour, night-time, sound sleep dressed in fire-resistant pajama-shorts only, stripped-to-waist(^8); 3-minute, slow-stoke back massage to improve quality and quantity of sleep — before retiring to bed (girls’) hair unbraided and opened up(^9), all hair accessories, jewelry, watch, belt removed; glass of milk consumed before bedtime; teeth brushed 5 times — upon rising, after breakfast, lunch and dinner each as well as before going to bed; additional brushing after consuming candies/chocolates/cookies/juices/milk; maximum 2-hour screen time (computer/video games/TV/DVD — computer monitor at eye level, neck and back straight as well as normal to thighs); 2-strap school bags worn on back with each strap on a shoulder (unnecessary books/copies/journals taken out); pure cotton undergarments and socks (disinfectant powder to be applied to dry body parts and wipe feet before putting on underwea/socks), pure leather mocation shoes with foot support — tight undergarments, clothes, shoes and slippers (flip-flops) should not be worn, slippers got wet during ablution should be replaced immediately with dry ones to be put on carefully dried and feet wiped between toes (same goes on with clothes drenched in rain, etc.); absolutely NO high heels for girls — cause toes to bend inward</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Diet Plans</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 relaxed (wait for food, not let the food wait for you; no eating/drinking while walking or standing; eat when very hungry, abstain when some appetite remains) and balanced meals, should include fresh fruits and green vegetables; 10-12 glasses of water daily; only one 250-ml bottle of carbonated drink in a month(^10) and exercise plans</td>
</tr>
<tr>
<td>To gain height, diet plan should include calcium-, protein- and fiber-rich diet (chicken, fish, fresh fruit and milk)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Exercise Plans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exercises for 5 minutes each after waking up, at the end of every hour and before going to bed — bending on sides, focusing eyes far away and moving eyeballs, moving fingers and wrists after computer work writing, stretching, touching toes without flexing knees, exercising neck muscles (left, right, up, down), light exercises during TV/DVD watching; guarded-graduated(^6) structured exercises, preceded by warm-up and followed by cool-down routines, preferably outdoors (weather permitting) in exercise-friendly clothing(^3) — form-fitting, made of absorbent material; table tennis; jogging; cycling</td>
</tr>
<tr>
<td>To pick up height, child should perform light-stretching exercises (bar hanging, mild-stretching, summersault, cartwheel)</td>
</tr>
</tbody>
</table>

\(^3\) Diet and exercise plans compiled from Kamal et al. (2013b, c)  
\(^4\) According to the Consensus Report of the Institute of Medicine (November 30, 2010) — 1 IU (International Unit, established by WHO in 1931) of vitamin D equivalent to 0.025 \(\mu\)g of cholecalciferol or ergocalciferol; remedial measures to overcome vitamin-D deficiency are given in Kamal et al. (2013a) as well as Kamal and Khan (2018)  
\(^5\) ‘Guarded’ implies overexposure surveillance, may cause skin burn, short-term consequence, and skin cancer, long-term consequence; ‘graduated’ means systematic increase in exposure for body conditioning (Kamal and Khan, 2015)  
\(^6\) Made from one layer of completely-exposed photographic film, ASA 100, having high sliver content, 2 layers needed to observe partial-solar eclipse (Kamal, 2018)  
\(^7\) Sleeping in day clothes or underwear to be discouraged; in gender-segregated sleeping quarters, boys of all ages and younger girls should be encouraged to sleep unclothed from the waist up, allowing the body to breathe and increasing tactile stimulation (Kamal and Khan, 2014)  
\(^8\) Allowing hair to breathe during night  
\(^9\) Carbonated drinks take away body’s capacity to absorb calcium and iron and hence should be avoided, not only, by children, but also, by persons of all ages, in particular, older individuals  
\(^10\) Guarded-graduated exercises should contribute towards health- as well as skill-related fitness (performance considerations). Such practices, also, avoid exercise-related injuries (safety considerations); ‘guarded’ related to the concept that different body ligaments are in stable equilibrium, locally, during different exercise phases and ‘graduated’ implies that sequential exercise phases are related by infinitesimal transformations (Kamal and Khan, 2013)
CONCLUSION AND FUTURE DIRECTIONS

Childhood obesity is a major issue globally, obesity being a complicated condition influenced by interactions between genetic and environmental factors. The true prevalence of childhood obesity becomes difficult to quantify in the absence of a universally accepted definition. Our research group has proposed mathematical and logical definitions of instantaneous obesity and true obesity. In this paper, mathematical-statistical solutions of childhood obesity, presented during 2013-2017, have been enhanced. Growth-and-Obesity Scalar- and Vector-Roadmaps have been simplified by modifying definitions of statuses (pertaining-to-height) and (pertaining-to-mass). Both of these statuses, expressed as fractional statuses, have been combined to write fractional status (pertaining-to-height-and-mass), which is a complex number. Magnitude of this complex number represents away-from-normality index.

Future work should focus on extending Growth-and-Obesity Vector-Roadmaps to include still-growing parents. Further, scaled percentile transformation equations should be formulated based on analysis of data of the Pakistani children. The long-term term goals should include enhancement of anthropometric instruments to measure heights and masses to least counts of 0.001 cm and 0.001 kg, respectively. In addition, Growth Charts and Tables for the Pakistani children should be constructed.

It is through improving health and emotional status of the Pakistani children that the dream of making this nation a regional power could be realized.

ACKNOWLEDGMENTS

The authors are indebted to Commander Dr. Ashfaq Ali Naz, PhD (Physics — Specialization: Childhood Obesity) of Pakistan Marine Academy, Ministry of Maritime Affairs, Karachi, for drawing diagrams using Visio. The first author is indebted to renowned pediatrician, Prof. Dr. Zulfiqar Ahmed Bhutta, PhD (Karolinska, Sweden), Husein Lalji Dewraj Professor of Paediatrics and Child Health at the Aga Khan University Medical College, Karachi as well as Professor at Center for Global Health and Center for Excellence in Women and Child Health, Hospital for Sick Kids, Toronto, Canada, for comments inserted in the caption of Figure 2.

APPENDIX A: PROOF OF TRUE OBESITY

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**Already 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/m² (adult *BMI*), *BMI* ranges (below 85%→ normal, 85% to 95%→ intermediate, equal to or above 95%→ high).

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**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
- 2013-2017 1st- to 6th-generation solutions of childhood obesity
- 2014 Energy-channelization I-III; pseudo-gain of mass/height; use of percentile trajectories of height/mass instead of *BMI* (growth height/velocity rate of mass gain/loss; CDC Growth Tables extended to include percentiles in the range 0.01* to 99.99* (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 *BMI*-based-optimal mass; mathematical definition of childhood obesity (instantaneous obesity vs. true obesity); mathematical definition of childhood wasting (instantaneous wasting vs. true wasting); validation of mathematical definition of childhood obesity based on anthropometric data collected during 1998-2013
- 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

---

**This work adds**

Integration of height-percentile-based-optimal mass with *BMI*-based-optimal mass to modify definitions of statuses (pertaining-to-height) and (pertaining-to-mass) — 7th-generation solution of childhood obesity (Growth-and-Obesity Vector-Roadmaps 2.1)

Polar-coordinate representation of nutritional-status classification

Extension of nutritional-status classification from 6 to 10 categories

---

**The next step**

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

Growth-and-Obesity Vector-Roadmaps 3.0 for children of still-growing parents
IMPLYING INSTANTANEOUS OBESITY BASED ON MODIFIED STATUS (PERTAINING-TO-MASS)

One needs to prove \( \mu_{\text{REC}}^{\text{max}}(A_0 + 6 \text{ months}) - \mu(A_0) < 0 \Rightarrow STATUS^{\text{MOD}}_\pm(\mu) > 0 \). 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 5).

\[
(A1) \quad \mu_{\text{REC}}^{\text{max}}(A_0 + 6 \text{ months}) - \mu(A_0) < 0 \Rightarrow \mu_{\text{REC}}^{\text{max}}(A_0 + 6 \text{ months})
\]

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., 2014b). On the other hand, when there is a loss of mass as a child gets older, this loss may be true (Kamal, 2014 — Additional File) or recommended (lower limit of recommended mass in Table 4b) — phenomenon of true obesity (Kamal, 2017b), it 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

\[
(A2) \quad P_{\text{CDC}}(\mu, A_0) > P_{\text{REC}}^{\text{max}}(\mu, A_0 + 6 \text{ months})
\]

Now

\[
(A3) \quad P_{\text{REC}}^{\text{max}}(\mu, A_0 + 6 \text{ months}) > \max(P_{\text{ref}}(A_0), P_{\text{BMI}}(A_0))
\]

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

\[
(A4) \quad a < b, b < c \Rightarrow a < c; a < b, b \leq c \Rightarrow a < c; a < b, b < c \Rightarrow a < c; a \leq b, b < c \Rightarrow a < c
\]

Applying the above to (A2) and (A3), one concludes

\[
(A5) \quad P_{\text{CDC}}(\mu, A_0) > \max(P_{\text{ref}}(A_0), P_{\text{BMI}}(A_0))
\]

By definition

\[
(A6) \quad P_{\text{ref}}(A_0) \geq P_{\text{CDC}}(h, A_0) \Rightarrow \max(P_{\text{ref}}(A_0), P_{\text{BMI}}(A_0)) \geq \max(P_{\text{CDC}}(h, A_0), P_{\text{BMI}}(A_0))
\]

Applying transitive property (A4) to (A5) and (A6), one obtains

\[
(A7) \quad P_{\text{CDC}}(\mu, A_0) > \max(P_{\text{CDC}}(h, A_0), P_{\text{BMI}}(A_0))
\]

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 (A1), one infers

\[
(A8) \quad \mu(A_0) > \max(P_{\text{opt}}, \mu_{\text{BMI}})
\]

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

\[
(A9) \quad \mu > \mu_{\text{max}} \Rightarrow 100\frac{\mu_{\text{max}} - \mu_{\text{max}}}{\mu_{\text{max}}} > 0 \Rightarrow STATUS^{\text{MOD}}_\pm(\mu) > 0
\]

This completes the proof.

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

Consider the case of M. E., presented in Tables 4a, b. At the time of her 2nd checkup, conducted on November 13, 2011, she was 9 years 1 month 20 days old (decimal age, \( A_0 = 9.139726027 \) years). Her mass was recorded as 31.70 kg. She was advised to maintain a mass between 31.49 kg and 33.70 kg, at the end of 6-month period. She was 1st-degree obese, since \( STATUS^{\text{MOD}}_\pm(\mu) = 0.73\% \). However, \( \mu_{\text{REC}}^{\text{max}}(A_0 + 6 \text{ months}) = 33.70 \text{kg}, \mu(A_0) = 31.70 \text{kg} \). Therefore
\[
\mu_{\text{REC}}^\text{REC} (A_0 + 6\text{ months}) - \mu(A_0) = +2.00\text{ kg} \Rightarrow \mu_{\text{REC}}^\text{REC} (A_0 + 6\text{ months}) - \mu(A_0) \neq 0
\]

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

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

The lengthy proof given in Appendix B of Kamal (2017b) 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.,

\[
P_{\text{CDC}}(\mu, A_0) - P_{\text{CDC}}(\mu, A_0 + 6\text{ months}) < 0 \iff P_{\text{CDC}}(\mu, A_0) - \min(P_{\text{ref}}(A_0), P_{\text{BMI}}(A_0)) < 0
\]

The above statement is equivalent to

\[
(B1a)\quad P_{\text{CDC}}(\mu, A_0) - P_{\text{CDC}}(\mu, A_0 + 6\text{ months}) < 0 \Rightarrow P_{\text{CDC}}(\mu, A_0) - \min(P_{\text{ref}}(A_0), P_{\text{BMI}}(A_0)) < 0
\]

and

\[
(B1b)\quad P_{\text{CDC}}(\mu, A_0) - P_{\text{CDC}}(\mu, A_0 + 6\text{ months}) < 0 \iff P_{\text{CDC}}(\mu, A_0) - \min(P_{\text{ref}}(A_0), P_{\text{BMI}}(A_0)) < 0
\]

To prove (B1a), 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, \(P_{\text{BMI}}(A_0)\), starting at age of the last checkup, \(A_0\), and terminating at the reference age (10 years), 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 after (A1). The converse, (B1b), can be easily proved by the same line of argument.

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

\[
\text{STATUS}^\text{MOD}(\mu) < 0 \Rightarrow 100\frac{\mu - \mu_{\text{min}}}{\mu_{\text{min}}} < 0 \Rightarrow \mu < \mu_{\text{min}}, \quad \mu_{\text{min}} = \min(\mu_{\text{opt}}, \mu_{\text{BMI}})
\]

**Case 1:** \(\mu_{\text{opt}} < \mu_{\text{BMI}} \Rightarrow \mu_{\text{min}} = \mu_{\text{opt}} \Rightarrow \mu < \mu_{\text{opt}}\), from (B2). One writes, based on comments entered below (A1)

\[
(B3)\quad P_{\text{CDC}}(\mu, A_0) < P_{\text{CDC}}(h, A_0)\); noting that \(P_{\text{CDC}}(\mu_{\text{opt}}, A_0) = P_{\text{CDC}}(h, A_0)\)

Rewriting (A6) as \(P_{\text{CDC}}(h, A_0) \leq P_{\text{ref}}(A_0)\). Applying transitive property of equations cum inequalities (A4) to (B3) and (A6), rewritten above, one concludes

\[P_{\text{CDC}}(\mu, A_0) < P_{\text{ref}}(A_0)\]

Also, based on comment below (A1) and explanation given in (B3), the condition on masses

\[
(B4)\quad \mu_{\text{opt}} < \mu_{\text{BMI}} \Rightarrow P_{\text{CDC}}(h, A_0) < P_{\text{BMI}}(A_0)
\]

Again applying transitive property (A4) to (B3) and (B4), one concludes

\[
(B5)\quad P_{\text{CDC}}(\mu, A_0) < P_{\text{BMI}}(A_0) \Rightarrow P_{\text{CDC}}(\mu, A_0) < \min(P_{\text{ref}}(A_0), P_{\text{BMI}}(A_0))
\]

which is the mathematical definition of true wasting (Table 7). 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 (B2). Again employing observation below (A1) regarding functional dependence of CDC percentile-of-mass on child’s net mass, one writes

\[
(B6)\quad P_{\text{CDC}}(\mu, A_0) < P_{\text{BMI}}(A_0)
\]

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 observation below (A1) and comment appearing in (B3), \(P_{\text{CDC}}(\mu_{\text{opt}}, A_0) = P_{\text{CDC}}(h, A_0)\). Applying transitive property of equations cum inequalities (A4) to (B6) and the inequality written below (B6), one concludes that \(P_{\text{CDC}}(\mu, A_0) < P_{\text{CDC}}(h, A_0)\). Applying (A4) again to this inequality and (A6), rewritten as \(P_{\text{CDC}}(h, A_0) \leq P_{\text{ref}}(A_0)\), one finally obtains

\[P_{\text{CDC}}(\mu, A_0) < P_{\text{ref}}(A_0) \Rightarrow P_{\text{CDC}}(\mu, A_0) < \min(P_{\text{ref}}(A_0), P_{\text{BMI}}(A_0))\]
Now, \( A \leq \mu \) \( A \mu \) \( A \mu \) \( A \mu \) \( A \mu \)

one concludes

SGPP

\( A \mu \) \( A \mu \) \( A \mu \) \( A \mu \) \( A \mu \)

and

\( A \mu \) \( A \mu \) \( A \mu \) \( A \mu \) \( A \mu \)

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

\[ \mu_{\text{max}} (A_0 + 6 \text{ months}) - \mu (A_0) > 0 \]

\( \mu_{\text{opt}} = \mu_{\text{min}} = \mu_{\text{max}} = \mu_0 \).

Noting that \( \mu_{\text{max}} (A_0 + 6 \text{ months}) - \mu (A_0) > 0 \) \( \mu_{\text{max}} (A_0 + 6 \text{ months}) - \mu (A_0) > 0 \) \( \mu_{\text{max}} (A_0 + 6 \text{ months}) - \mu (A_0) > 0 \)

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

which translates to

(B7a, b)

\( \mu < \mu_{\text{BMI}}, \mu < \mu_{\text{opt}} \)

Based on comments written after (A1), the above conditions become conditions on respective percentiles. (B7a) may, then, be expressed as (B6), i.e.,

\[ P_{\text{CDC}} (\mu, A_0) < P_{\text{BMI}} (A_0) \]

and (B7b) as (B3). 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 (A6). Applying transitive property of equations cum inequalities (A4) to (A6) rewritten as \( P_{\text{CDC}} (h, A_0) \leq P_{\text{ref}} (A_0) \), one concludes

\[ P_{\text{CDC}} (\mu, A_0) < P_{\text{ref}} (A_0) \]

which translates to

\[ P_{\text{CDC}} (\mu, A_0) < \min (P_{\text{ref}} (A_0), P_{\text{BMI}} (A_0)) \]

This completes the proof.

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

Consider the case of Z. H. Z. (SGPP-KHI-20110412-0101; NGDS-BLA-2010-5484/Z), presented in Kamal (2017a). 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).

\( P_{\text{CDC}} (\mu, A_0) = 63.50^P, \min (P_{\text{ref}} (A_0), P_{\text{BMI}} (A_0)) = \min (76.12^P, 72.73^P) = 72.73^P \)

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

Therefore, one notes that true wasting is present.

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

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

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

Therefore, \( STATUS_{\text{MOD}} (\mu) \neq 0 \), in fact, \( STATUS_{\text{MOD}} (\mu) = 0 \), 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, 2017b).
APPENDIX C: THREE SCENARIOS, IN WHICH A CHILD IS RECOMMENDED TO GAIN MASS

Table 10 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 recommended mass at the end of 6-month period, the second one applicable, when CDC percentile of mass lies between minimum and maximum and the third one applicable, when CDC percentile of mass exceeds the minimum of CDC percentile of recommended mass at the end of 6-month period.

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Additional File 1 — Compliance with Ethical and Human-Right Standards: https://www.ngds-ku.org/Papers/J49/Additional_File_1.pdf


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