INT. J. BIOL. BIOTECH. 14 (4): 485-502, 2017

INTEGRATION OF *BMI*-BASED-OPTIMAL MASS AND HEIGHT-PERCENTILE-BASED-OPTIMAL MASS TO PROPOSE THE SIXTH-GENERATION SOLUTION OF CHILDHOOD OBESITY

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ABSTRACT

Childhood obesity is a manifestation of discrepancy between energy intake and expenditure, which disturbs the original steady state causing to form a fresh steady state at an elevated level, with the consequence of increased body-fat storage. Balance must be established between tissue synthesis, resulting in gain of height, and fat storage, resulting in gain in mass, in order to avert childhood obesity. Many definitions of childhood obesity are available. During the last 5 *years*, our group put forward the First- to the Fifth-Generation Solutions of Childhood Obesity. The last one consisted of a mathematical definition of childhood obesity, related to the logical definition. This paper proposes a range for 6 monthly mass-management targets instead of single values, by fitting two parabolic curves, both originating at the age of the most-rent checkup. One of these curves meets tangentially, at the age of 10 *years*, the straight line, which represents reference percentile at the age of the most-recent checkup, whereas the other curve meets the straight line, which represents percentile of *BMI*-based-optimal mass at the age of the most-rent checkup. The range is obtained by 6 line segments drawn parallel to vertical (percentile) axis drawn at the date of check up for the next 6 successive months. The range of mass-management goals may render the task of optimal-mass management easier instead of a single value.

Keywords: Growth-and-Obesity Vector-Roadmap 2.0, definitions of childhood obesity, height and mass management, instantaneous obesity, true obesity, instantaneous wasting, true wasting

LIST OF ABBREVIATIONS

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

AC: **A**rmy-**C**utoff
AM: **A**cute **M**alnutrition
***BMI*:** **B**ody-**M**ass **I**ndex
CDC: **C**enters for **D**isease **C**ontrol and **P**revention, Atlanta, GA, United States http://www.cdc.gov
ECOG: **E**uropean **C**hildhood **O**besity **G**roup
EC I: **E**nergy-**C**hannelization **I**
EC II: **E**nergy-**C**hannelization **II**
EC III: **E**nergy-**C**hannelization **III**
MP: **M**id-**P**arental
NGDS: **N**ational **G**rowth and **D**evelopmental **S**tandards for the Pakistani Children http://ngds-ku.org
ON: **O**ver-**N**utrition
P: **P**ercentile
SGPP: **S**ibling **G**rowth **P**ilot **P**roject
UN: **U**nder-**N**utrition

INTRODUCTION

Childhood obesity is the outcome of a complex web of biological, cultural, environmental and psychological influences. It has become a universal problem, associated with severe physical, psychological and social consequences. The complications associated with childhood obesity include cardiovascular, gastrointestinal, musculoskeletal, neurologic, psychosocial, pulmonary and renal problems. Childhood, being a key period of life for formation of health habits, is the ideal period to diagnose the condition at an early stage to plan and to implement efficient and effective intervention strategies.

In this work, 6 monthly targets for mass management of children are simplified by suggesting a range instead of a single value. In this process, a unified picture of the two optimal masses, one of them height-percentile-based optimal mass and the other *BMI*-based-optimal mass, is obtained.

DEFINITIONS OF CHILDHOOD OBESITY

Obesity is a manifestation of discrepancy between intake and output of energy. The original steady state disappears and a new one forms at a higher level. The net result is increased body-fat storage (Wabitsch, 2000). One must be aware of the fact that energy expenditure varies between school-going months and holiday months (Zinkel *et al.*, 2013). Poskitt (1995), representing European Childhood Obesity Group (ECOG), stated that researchers were bothered by absence of a proper definition of childhood obesity. She defines relative *BM*I (body-mass index) as *BMI* of a 50$^{\text{th}}$ *centile* youngster. *BMI* was renamed from Quetelet index in 1972 (Keys *et al.*, 1972). The expression μ / h^2 (μ repre-

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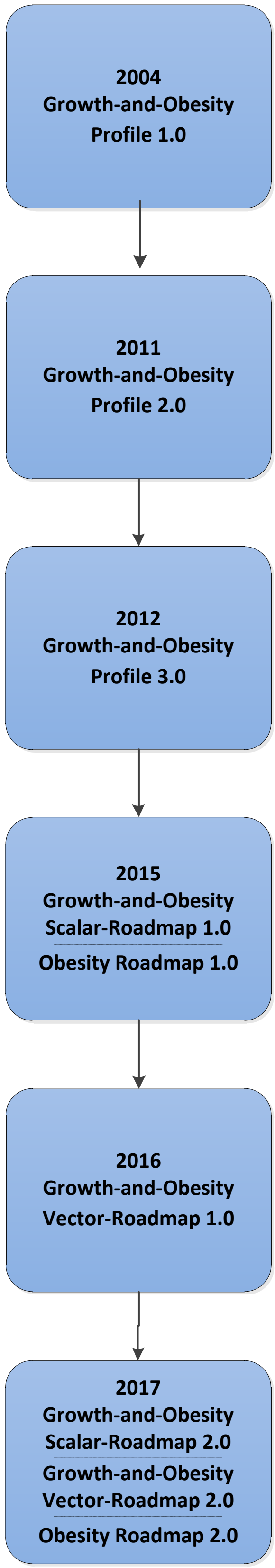

Fig. 1. Timeline of modeling of childhood-obesity problem — compare with Fig. 1 of Kamal *et al.* (2017*c*)

sents mass in *kg* and *h* height in *m*) is used to compute this index. In a follow-up work, Poskitt (2000) noted that there was a general acceptance of the concept of relative *BMI* despite considerable imprecision in defining obesity. In a 2001 paper, she opined that *BMI* can not be regarded as offering the 'best' definition, although it might be thought of as the most 'useful' and 'practical' one for clinical, epidemiological and population-research purposes (Poskitt, 2001). More recently, Kolotourou *et al.* (2013) raised the question if *BMI* alone was a sufficient outcome to evaluate interventions for childhood obesity. The authors conclude from their study that setting a z*BMI* reduction cutoff to evaluate how effective are interventions of childhood obesity may be erroneous, since other outcomes may be contributing to the effectiveness. Cole *et al.* (2000) put forward a definition of childhood obesity on the basis of pooled-international data. He related childhood obesity to adult-obesity-cutoff point of *BMI* to be 30 kg/m^2. Flegal *et al.* (2010) categorized *BMI*-for-age into three ranges**:** 'normal', 'intermediate' and 'high'. Rolland-Cachera (2011), on behalf of ECOG, described main cutoffs of *BMI* distribution status from the age of 5 *years*, giving four ranges**:** 'thin', 'normal', 'overweight' (not obese) and 'obese'. Zhao and Grant (2011) consider obesity a result of interactions between environmental and genetic factors. Skinner and Skelton (2014) defined overweight and obesity in children based on *BMI* percentiles (overweight greater than 85th percentile; obesity greater than 95th percentile). This year, Flegal and Ioannidis (2017) published an evaluation of the Global *BMI* Mortality Collaboration.

The author streamlined various definitions of childhood obesity and proposed 'logical definition' last year (Kamal, 2016). On the first day of this year, a 'mathematical definition' was put forward (Kamal, 2017). This definition was validated using anthropometric data collected during 1998-2013 (Kamal *et al.*, 2017*a*).

MODELING OF CHILDHOOD-OBESITY PROBLEM

Whitaker *et al.* (1997) put forward a model based on statistics to predict obesity in young adulthood from childhood and parental obesity. Golan and Weizman (2001) proposed a model for the management of childhood obesity using a family-based approach. Change is brought upon through parents by convincing them to adopt a healthy lifestyle and not shedding off weight.

Figure 1 gives timeline of modeling of childhood-obesity problem by our group. The challenges in constructing a mathematical model of childhood obesity are the realities that child, under normal conditions, who is gaining height with the passage of time as well as putting on (shedding off) weight. A losing of height may be because of severe scoliosis, which is progressing rapidly. If an obese child is required to lose weight, based on the current obesity status, without proper calculation of height to be gained within the next few months, the incumbent would become wasted (lesser weight-for-height). Our group attempted to take this into consideration, 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, provide growth and obesity statuses of child after at least a couple of checkups and include growth (height) velocity as well as rate of weight (mass) loss/gain over this period (Kamal *et al.*, 2004).

'Growth-and-Obesity Profiles 2.0', also known as KJK (Kamal-Jamil-Khan) model, comprise of 'Obesity Profiles' of parents as well as 'Growth-and-Obesity Profile 2.0' of each sibling based on a single check up (Kamal *et al.,* 2011). They give a snapshot in terms of height and mass management.

'Growth-and-Obesity Profiles 3.0', also known as KJ (Kamal-Jamil) model, enhance the above model to include parents, who are still growing —fathers below 21 *years* and mothers below 19 *years* (Kamal and Jamil, 2012). In this model, target height of a child is determined by replacing heights of biological father and mother with their respective estimated-adult heights in the formulae.

The KJ-Regression model (Kamal and Jamil, 2014) extrapolates 'CDC Growth Charts and Tables' to include extreme percentiles by using sigmoid functions and linear interpolation.

Growth-and-Obesity Roadmaps

'Growth-and-Obesity Scalar-Roadmaps 1.0' (Kamal *et al.*, 2015) are generalized from 'Growth-and-Obesity Moving-Profiles' (Kamal *et al.*, 2014*b*), which contain month-wise recommendations to put on/shed off mass for parents (Obesity Roadmaps 1.0) as well as manage both mass and height for each of their children (Kamal, 2015*a*; *b*). These roadmaps, also, assign build (Kamal and Khan, 2015; Kamal *et al.*, 2017*b*) and classify nutritional status (Kamal, 2014; 2015*a*; Kamal *et al.*, 2014*b*; 2017*a*; *b*). Pseudo gain of height (mass) may be discovered by looking at these roadmaps (Kamal *et al.*, 2014*b*). Over a period of 2 to 3 consecutive checkups, the student shows slight height (mass) gain but a drop on CDC-percentile trajectory.

'Growth-and-Obesity Vector-Roadmaps 1.0' (Kamal *et al.*, 2016*a*) are identical to 'Growth-and-Obesity Scalar-Roadmaps 1.0' in the actual-checkup-age range. Main difference is in height- and mass-management targets. These targets are computed by fitting parabolic trajectories for CDC percentiles of height and mass, starting at age of the most-recent checkup, such that the reference trajectory becomes tangent to the desired course-of-action trajectory at the age of 10 *years*. In this way softer, easier-to-achieve targets are generated. This mechanism achieves 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' (Kamal *et al.*, 2013; 2014*a*; 2015) and 'Growth-and-Obesity Scalar-Roadmaps 1.1' (2017*b*; *c*) as well as 'Growth-and-Obesity Vector-Roadmaps 1.0' (Kamal *et al.*, 2016*a*; *b*) and 'Growth-and-Obesity Vector-Roadmaps 1.1' (2017*b*; *c*).

'Growth-and-Obesity Profiles 2.0' will, also, be used in constructing 'Growth-and-Obesity Scalar-Roadmaps 2.0' and 'Growth-and-Obesity Vector-Roadmaps 2.0' (described later in this work). For parents 'Obesity Roadmaps 1.0' are generalized to 'Obesity Roadmaps 2.0', also explained later in this paper. One must note that Scalar-Roadmap 1.1 and Vector-Roadmap 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).

SOLUTIONS OF CHILDHOOD-OBESITY PROBLEM

Obesity does not have any single most important intervention for its treatment (Rutter, 2012). However, family-based community interventions have been tried and their outcomes studied (Fagg *et al.*, 2014). Solutions of child-hood-obesity problem have been proposed by various groups. Poskitt (2005) is of the opinion that treatment focusing on decreasing energy intakes and increasing energy consumption seldom show effects that last for long term. Our group has suggested lifestyle adjustment combined with diet and exercise plans to achieve recommended goals (Kamal *et al.*, 2017*c*). Robinson and Sirard (2005) proposed the solution-oriented research paradigm for preventing childhood obesity, which encouraged research relevant to health of children and shortening discovery cycle so that benefits of research could trickle down to the younger population. Mazik *et al.* (2007) insisted on looking at the bigger picture of childhood obesity. Their suggestion was to understand the wider determinants of obesity, such as walking-biking-friendly neighborhood, social interactions, food marketing and prices. Wieting (2008) investigated cause and effect in childhood obesity to discover a solution. Finegood *et al.* (2010) discussed implications of the Foresight Obesity System Map, a map of all relevant factors and their interdependencies that determine

September 4, 2013	1st-Generation Solution of Childhood Obesity (Kamal *et al.*, 2013)
September 4, 2014	2nd-Generation Solution of Childhood Obesity (Kamal *et al.*, 2014*a*)
June 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)
October 1, 2017	6th-Generation Solution of Childhood Obesity (this work)

Fig. 2. Solutions of childhood-obesity problem proposed in SF-Growth-and-Imaging Laboratory, University of Karachi — picture of child's mass being recorded first appeared in Kamal *et al.* (2017*a*)

obesity condition for an individual or a group, to seek out a solution to childhood obesity.

During 2013-2017, 1st- to 5th-generation solutions of childhood obesity were proposed by our group using mathematical-statistical techniques. In this work, 6th generation solution is put forward (Figure 2). 1st- to 3rd-generation solutions are summarized in Kamal (2015*c*).

MONITORING CHILDHOOD OBESITY

The main anthropometric measures for monitoring of childhood obesity are height and mass (weight). Other measures, which focus on over-fat condition, are waist circumference and hip circumference. Kamal and Jamil (2014) described non-anthropometric and anthropometric measures of obesity. Below is a description of a field study and a laboratory study conducted by our group**:**

Field Study — the NGDS Pilot Project

The NGDS (National Growth and Developmental Standards for the Pakistani Children) Pilot Project was started in 1998 under the directives of Governor Sindh/Chancellor, University of Karachi, after going through 'Institutional Review Process'. This project was designed after taking into consideration the applicable ethical and human-right protocols (Kamal *et al.*, 2002). The project was conducted in 4 representative schools (one civilian and one each operated by the Pakistan Army, the Pakistan Navy and the Pakistan Air Force). An 'opt-in' policy was adopted. Only those students were checked whose parents signed the completed slip, which was part of 'Informed Consent Form' (http://www.ngds-ku.org/ngds_folder/Protocols/NGDS_Form.pdf). A dedicated room was provided by the school authorities, furnished according to examination needs. The room provided acoustic as well as visual privacy for these gender-segregated examinations.

SF-Growth-and-Imaging-Laboratory Study — Sibling Growth Pilot Project

A family-centered subproject, SGPP (Sibling Growth Pilot Project), monitors families who came to SF-Growth-and-Imaging Laboratory along with their 5-10-*year*-old children, for checkups. SF Laboratory is kept germ-free by disallowing outside shoes for children, their parents as well as laboratory staff. Entire floor is black tiled, which is mopped with dettol-mixed water before each session (generic name of dettol is chloroxylenol). For enrolment, the parents signed 'SGPP Participation Form' (http://www.ngds-ku.org/SGPP/SGPP_Form.pdf), which included address of website (http://ngds-ku.org) and contained detailed information and photographs of procedures.

The above-mentioned checkups are conducted giving due regard to participants' comfort, confidentiality, dignity, privacy and safety.

Appendix A lists web addresses of additional resources available for this work. Additional File 1 (http://www.ngds-ku.org/Papers/J49/Additional_File_1.pdf) explains compliance with ethical and human-right standards.

Anthropometric Techniques

Masses, μ, and heights, h, and were measured by anthropometrists, with documented reproducibility, as per laid-down protocols (Kamal *et al.*, 2013) given in the official manual of the NGDS Pilot Project (Kamal, 2006). Additional File 2 (http://www.ngds-ku.org/Papers/J49/Additional_File_2.pdf) gives the abbreviated version with step-by-step procedures explained through labeled photographs. Heights were recorded to least counts of 0.1 *cm* (1998-2011, setsquare set); 0.01 *cm* (2012-2015, Vernier scale — Kamal, 2010) and 0.005 *cm* (2016-present,

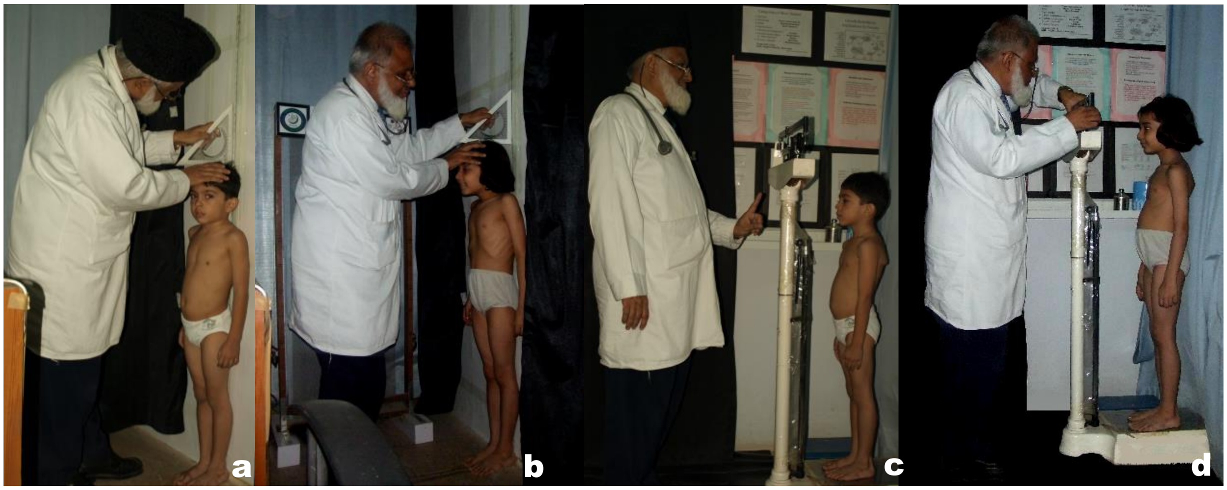

Fig. 3*a-d*. Height and mass measurements performed in SF-Growth-and-Imaging Laboratory — (*a*, *c*) first appeared in Kamal *et al.* (2017*a*) and (*b*, *d*) in Kamal and Jamil (2014), both sets printed in the same journal

enhanced-Vernier scale — Kamal *et al.*, 2016*b*). Masses were recorded to least counts of 0.5 *kg* (1998-2011, bathroom scale); 0.01 *kg* (2012-2015, modified-beam scale — Kamal, 2010) and 0.005 *kg* (2016-present, enhanced-beam scale — Kamal *et al.*, 2016*b*) before midday, with the youngsters completely undressed except short underpants (Figure 3). At the start of each daily session, calibration of the measuring instruments was done. Zero errors was subtracted from the measured values. Complete undressing ensured that the measurers were able to maintain upright posture (non flexing of knees and elbows and knees, non lifting of toes/heels not lifted, Frankfort horizontal/auriculo-orbital plane parallel to ground, feet apart for recording of mass/feet together for recording of height) and complete breathing in (to help in assuming erect posture).

GROWTH-AND-OBESITY VECTOR-ROADMAP 2.0

Need for Version 2.0

Growth-and-Obesity Vector-Roadmap 1.0 was proposed to set softer targets for height and mass management as the targets proposed in Scalar-Roadmap 1.0 were considered to too demanding as they tried to achieve the entire correction within the next 6 *months*. In Growth-and-Obesity Vector-Roadmap 2.0, a range is proposed instead of a single value for mass management. Further, this formulation resolves the conflict as to which mass, height-percentile-based-optimal mass or *BMI*-based-optimal mass, should be considered.

Method for Generating Growth-and-Obesity Vector-Roadmap 2.0

*Applicability***:** Growth-and-Obesity Vector-Roadmap 2.0 is applicable to children, who have both parents older than or of the age of 20 *years*.

*Dress Code***:** Observations, measurements, examinations and were influenced by the type and the quantity of garments a youngster or an adult has on at that time. Dress code was recorded with the findings (quantitative or descriptive) as a fraction, numerator (denominator) describing amount of apparel superior (inferior) to transverse plane containing the naval. A dress code 0/0.5 (optimal value for children) meant that the youngster was measured totally stripped wearing only briefs or panties.

*Behavior Code***:** Behavior code was ‘0’, when the incumbent was coöperative and relaxed, ideal for obtaining measurements. However, the measurements could, also, be performed when behavior code was ‘1’, meaning the child was shy and timid, however, still, coöperative. The measurements taken, when behavior code was ‘2’ were not reliable and must be obtained again. This behavior code represented a nagging and a resistant child.

Behavior and dress codes code are described in Kamal (2006) and Kamal *et al.* (2002). As masses of all youngsters are recorded completely undressed except short underpants, their ‘net masses’ are assumed to be equal to ‘gross masses’ (clothing correction very small to be neglected).

*Extended CDC Growth Charts and Tables***:** These charts and tables consist of masses and heights of females and males corresponding to 0.01^{th}, 0.1^{th}, 1^{st}, 99^{th}, 99.9^{th} and 99.99^{th} percentiles (called CDC percentiles to differen-

Table 1. Scaling of percentiles to be used for the Pakistani population[¥]

CDC Percentile	→	*Scaled Percentile*
0	→	0
40	→	50
100	→	100

[¥]Adapted from Table 7 of Kamal *et al.* (2017*b*).

tiate them from the percentiles scaled for the Pakistani population), in addition to values available in CDC Growth Charts and Tables (Kamal and Jamil, 2014).

*Scaled Growth Charts and Tables***:** Height and mass percentiles, suitable for the Pakistani population (called scaled percentiles), were generated from CDC percentiles by fitting a parabolic curve to each percentile, satisfying the conditions given in Table 1 (Kamal *et al.*, 2017*b*)**:**

(1*a*, *b*) $$P_{\text{Scaled}}(h) = \frac{17P_{\text{CDC}}(h)}{12} - \frac{{P_{\text{CDC}}}^2(h)}{240};\ P_{\text{Scaled}}(\mu) = \frac{17P_{\text{CDC}}(\mu)}{12} - \frac{{P_{\text{CDC}}}^2(\mu)}{240}$$

Children's Growth-and-Obesity Profiles 2.0**:** CDC percentiles of AC (army-cutoff) height, P_{AC} (Kamal *et al.*, 2017*c*), cutoff heights for induction into the Armed Forces of Pakistan, as well as MP (mid-parental), P_{MP} (Tanner *et al.*, 1970), were evaluated using age-20-height values read from Extended CDC Growth Tables using the technique of 'linear interpolation'. For the Pakistani males, P_{AC} comes out to 2.718014592103645…, corresponding to cutoff height 162.56 *cm* (5 *ft* 4 *in*), whereas for the Pakistani females the value is 19.35609323536863…, corresponding to cutoff height 157.48 *cm* (5 *ft* 2 *in*). P_{MP} was the CDC percentile corresponding to gender-specific-adult-mid-parental (target) height (in *cm*) given by $h_{\text{MP}} = \frac{h_{\text{M}} + h_{\text{F}}}{2} \pm 6.5\,cm$, where h_{M} and h_{F} were heights of mother and father measured in *cm*; + sign taken for boys' target height; – sign for girl's target height. Child's CDC percentiles of height, $P_{\text{CDC}}(h, A)$, and mass, $P_{\text{CDC}}(\mu, A)$, were determined by the technique of 'box interpolation' (Kamal *et al.*, 2011). 'Linear interpolation' was used to evaluate estimated-adult height (mass), $h_{\text{est-adult}}$ ($\mu_{\text{est-adult}}$), using the computed CDC percentiles of height (mass) as well as age-20 values. These values were put in the expression, $\frac{\mu_{\text{est-adult}}}{h^2_{\text{est-adult}}}$, to compute estimated-adult *BMI* (one must not forget to convert estimated-adult height in *m* to substitute in this formula).

'Height-Percentile-based-Optimal Mass', μ_{opt}, was defined as the mass corresponding to CDC percentile of height — name mentioned in 2004; formal definition given in 2011 (Kamal *et al.*, 2004; 2011). Constant-age route was utilized to evaluate height-percentile-based-optimal mass, μ_{opt}, and, subsequently, construct obesity profile.

'*BMI*-based-Optimal Mass', μ_{BMI}, for a growing child was evaluated in the following steps. In the first step, 'Estimated-Adult-*BMI*-based-Optimal Mass' was determined using the expression $\mu_{\text{BMI-est-adult}} = 24h^2_{\text{est-adult}}$, where estimated-adult height was in *m*. In the second step, 'CDC Percentile for *BMI*-based-Optimal Mass', $P_{\text{CDC}}(\mu_{\text{BMI}}, A)$, was computed by applying linear interpolation to estimated-adult-*BMI*-based-optimal mass. In the third and the final step, box interpolation (Kamal *et al.*, 2011) was employed to compute '*BMI*-based-Optimal Mass' at the given age.

A procedure similar to evaluating height-percentile-based-optimal mass was utilized to determine current-age-mid-parental height, $h_{\text{CA-MP}}$. Algebraic status (pertaining-to-mass), $STATUS_{\pm}(\mu)$, as well as algebraic status (pertaining-to-height), $STATUS_{\pm}(h)$, was evaluated and quantitative statuses (pertaining-to-height) and (pertaining-to-mass) were assigned. Once these statuses were available, they were used to determine nutritional status — AM**:** acute malnutrition $P_{\text{Scaled}}(h) + P_{\text{Scaled}}(\mu) < 6$ (Kamal *et al.*, 2017*a*; *b*); UN**:** under-nutrition (stunting + wasting) $STATUS_{\pm}(h) < 0$, $STATUS_{\pm}(\mu) < 0$; ON**:** over-nutrition (tallness + obesity) $STATUS_{\pm}(h) > 0$, $STATUS_{\pm}(\mu) > 0$; EC I**:** energy-channelization I (tallness + wasting) $STATUS_{\pm}(h) > 0$, $STATUS_{\pm}(\mu) < 0$ (Kamal *et al.*, 2014*b*); EC II**:** energy-channelization II (stunting + obesity) $STATUS_{\pm}(h) < 0$, $STATUS_{\pm}(\mu) > 0$ (Kamal *et al.*, 2014*b*); EC III**:** energy-channelization III, also termed as puberty-induced energy-channelization (Kamal, 2014) and built assigned —

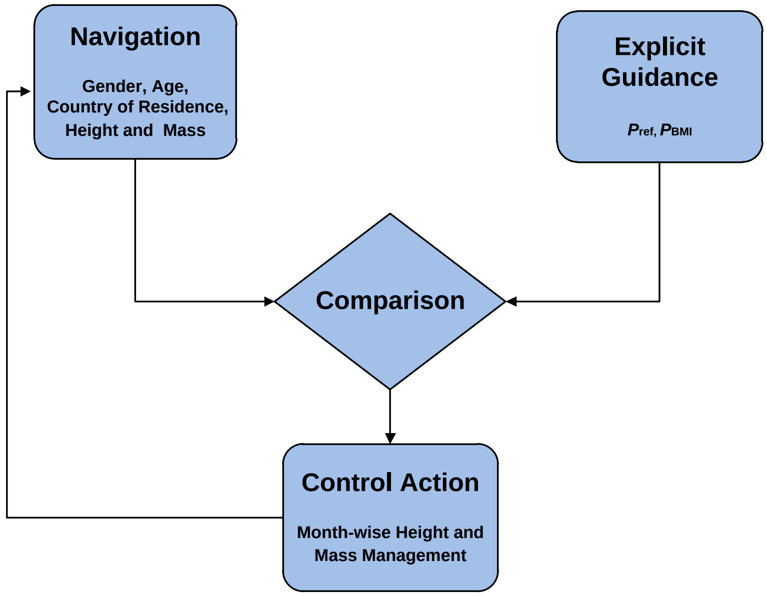

Fig. 4. Navigation, guidance and control loop applied to the problem of childhood obesity — compare with Fig. 5 of Kamal *et al.* (2017*a*), in which explicit guidance was based, solely, on reference percentile

small $0 \le P_{\text{Scaled}}(h) + P_{\text{Scaled}}(\mu) < 50$; medium $50 \le P_{\text{Scaled}}(h) + P_{\text{Scaled}}(\mu) < 150$; big $150 \le P_{\text{Scaled}}(h) + P_{\text{Scaled}}(\mu) < 200$ (Kamal and Khan, 2015; Kamal *et al.*, 2017*b*). For youngsters, exhibiting acute malnutrition $(P_{\text{Scaled}}(h) + P_{\text{Scaled}}(\mu) < 6)$, severity was evaluated using the equation (Kamal, 2015*a*; Kamal *et al.*, 2017*b*)

(2) $$\textit{Severity of Acute Malnutrition} = 100\left(1 - \frac{P_{\text{Scaled}}(h) + P_{\text{Scaled}}(\mu)}{6}\right)$$

Children's Growth-and-Obesity Scalar-Roadmaps 2.0**:** Growth-and-Obesity Scalar-Roadmaps of children are valid in the age (A) range, $9.5\,years \le A < 20\,years$. To construct these roadmaps, one requires two or more check-ups, a profile is generated from each checkup. Reference-height percentile, $P_{\text{ref}}(A)$, is computed by taking the maximum of three percentiles**:** CDC percentile of height, army-cutoff height and mid-parental height. Mathematically, $P_{\text{ref}}(A) = \max\left(P_{\text{CDC}}(h, A), P_{\text{AC}}, P_{\text{MP}}\right)$. Height-percentile-based-optimal mass, after 6 *months*, was evaluated based on reference height, estimated after a lapse of 6-*month* period. *BMI*-based-optimal mass, after 6 *months*, was determined from CDC percentile of *BMI*-based-optimal mass at the most-recent checkup, $P_{\text{CDC}}(\mu_{\text{BMI}}, A_0)$, where A_0 is the age at the most-recent checkup. Recommendations to gain height and put on or shed off mass (weight) were prepared from the most-recent profile. Difference of heights, most-recent measured value and reference value, extrapolated after 6 *months*, was taken to be as guideline to determine short-term goals to gain height within the next half-a-*year*. Differences of masses, most-recent measured value and height-percentile-based-optimal mass, extra-polated after 6 *months*, as well as most-recent measured value and *BMI*-based-optimal mass, extrapolated after 6 *months*, were considered as guidelines to set range of short-term goals for mass management within the next half-a-*year*. Monthly recommendations to pick up height or put on (shed off) mass (weight) were compiled, keeping in light the principle that a youngster should not be asked to reduce in excess of 10 *kg* within the next half-a-*year*, the main reason is to prevent the child from having any bad health effects from losing mass rapidly. 6 recommendations (on checkup date of each successive month) to reach certain values of height and a range of values of mass (based on height-percentile-based-optimal mass and *BMI*-based-optimal mass) were prepared employing linear interpolation taking the most-recent checkup and 6-*month*-down-the-road prediction as 2 fixed points.

Children's Growth-and-Obesity Vector-Roadmaps 2.0**:** Vector-Roadmaps 2.0 are useful to study growth and obesity statuses of youngsters till the age of 9.5 *years*. These roadmaps employ the concepts of navigation, guidance and control (Figure 4). The navigational trajectories for height and mass percentiles are determined 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 $A_{\text{Enrolment}} \leq A \leq A_0$ ($A_{\text{Enrolment}}$ is child's age at enrolment/first checkup; control action needs to be initiated at the age of the most-recent checkup, A_0). The navigational trajectories (common for both Scalar- and Vector-Roadmaps) are displayed as solid curves in blue (representing height) and maroon (representing mass) — please refer to the sample Vector-Roadmap given the following section. The domain for guidance trajectories (both height and mass management) is the closed interval $A_0 \leq A \leq 10$ *years* (10 *years* is the age, when control action is ended in the context of vector-Roadmap).

The guidance trajectory for height management takes the form, $P = P_{\text{ref}}(A)$, where $P_{\text{ref}}(A) = P_{\text{ref}}(A_0)$, shown as green-dashed line in Figure 6. A parabolic curve, $P = P_{\text{CDC}}(h, A)$, is fitted to generate trajectory the of 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 equations of this trajectory are

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

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

The guidance trajectories for mass management form the band, whose boundaries are given by $P = P_{\text{ref}}(A)$, where $P_{\text{ref}}(A) = P_{\text{ref}}(A_0)$, shown as green-dashed line in Figure 6, and $P = P_{\text{CDC}}(\mu_{\text{BMI}}, A)$, where $P_{\text{CDC}}(\mu_{\text{BMI}}, A) = P_{\text{CDC}}(\mu_{\text{BMI}}, A_0)$, shown as black-dashed line in Figure 6. For mass-management range, two parabolic curves are fitted, both of them initiating at $(A_0, P_{\text{CDC}}(\mu, A_0))$, one of them touching, smoothly, the guidance trajectory, $P = P_{\text{ref}}(A)$, at the vertex $(10, P_{\text{ref}}(A_0))$, whereas the other touching the trajectory representing CDC percentile of *BMI*-based-optimal mass at the most recent checkup, $P = P_{\text{CDC}}(\mu_{\text{BMI}}, A)$, at the vertex $(10, P_{\text{CDC}}(\mu_{\text{BMI}}, A_0))$, equations describing these trajectories are

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

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

(4*c*) $$P_{\text{BMI}}(\mu, A) = P_{\text{CDC}}(\mu_{\text{BMI}}, A_0);\ \text{if}\ P_{\text{CDC}}(\mu, A_0) = P_{\text{CDC}}(\mu_{\text{BMI}}, A_0)$$

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

The height and the mass-range recommendations are generated by erecting lines parallel to the vertical (percentile) axis. Month-wise targets to gain height- and gain/lose mass are prepared by noting down values, where these desired course-of-action trajectories, blue-dashed curve (representing height trajectory, approaching the value of reference percentile at the age of most-recent checkup, A_0) as well as maroon-dashed curve (representing mass trajectory, approaching the value of reference percentile at the age of most-recent checkup, A_0) and violet-dashed curve (representing mass trajectory, approaching the value of CDC percentile of *BMI*-based-optimal-mass at the age of most-recent checkup, A_0) curves, blue, maroon mass trajectory) intersect with lines parallel to the vertical axis. These lines cross the horizontal (age) axis at the ages for which targets are proposed.

Parents' Obesity Profiles 2.0**:** Linear interpolation was employed to compute CDC percentiles of masses and heights of mother and father from lesser and greater age-20 values of masses and heights read from extended-gender-specific tables. Algebraic and qualitative statuses (pertaining-to-mass) were evaluated on the basis of height-percentile-based optimal mass taken as reference. In addition, scaled percentiles were determined and build assigned. These profiles are, *not only*, applicable to parents, *but also*, to unmarried individuals above the age of 20 *years*.

Parents' Obesity Roadmaps 2.0**:** Instead of a single value of optimal mass, a range is available for the parents to maintain their mass in such a way that after 6 *months* their masses should lie between $\min\left(\mu_{\text{opt}}(A_0 + 6\,months), \mu_{\text{BMI}}(A_0 + 6\,months)\right)$ and $\max\left(\mu_{\text{opt}}(A_0 + 6\,months), \mu_{\text{BMI}}(A_0 + 6\,months)\right)$. Mother

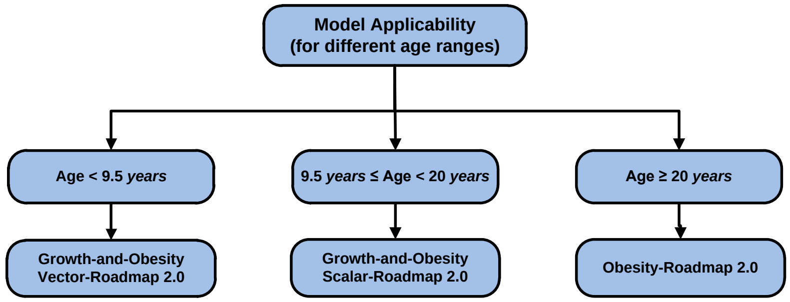

Fig. 5. Model applicability for different age ranges

(Father) was advised to maintain mass (weight) in the light of the above range, taking care of the principle 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. For expecting mothers, the recommendation to lose mass was computed by subtracting 5 *kg* from gross mass, to take care of possible pregnancy and the associated fetal mass. Monthly as well as date-wise recommendations to manage mass (weight) were generated following procedures given for children's roadmaps. The relations 1 *kg* = 2.205 *lb*; 1 *lb* = 16 *oz* were used to covert weight in *lb* and *oz*. These roadmaps are, *not only*, useful parents, *but also*, to persons, who are not yet married, but have crossed the age of 20 *years*.

Obesity Roadmap 1.0, described in Kamal *et al*. (2015), has 2 segments, $20\,years \leq A < 30\,years$ as well as $A \geq 30\,years$. Both of these segments are merged in Obesity Roadmap 2.0, as the roles of height-percentile-based-optimal mass and *BMI*-based-optimal mass are integrated.

For the age range $A < 9.5\,years$, Growth-and-Obesity Vector-Roadmap 2.0 is applicable**.** For the age range $9.5\,years \leq A < 20\,years$, Growth-and-Obesity Scalar-Roadmap 2.0 is applicable. For the age range $A \geq 20\,years$, Obesity Roadmap 2.0 is applicable (Figure 5)**.**

Sample Growth-and-Obesity Vector-Roadmap* 2.0: *Case Illustration

Figure 6 shows time evolution of CDC height and mass percentiles of M. E., female (SGPP-KHI-20100421-03/01) for her two checkups. Age range of the child is below 9.5 *years* for both of her checkups. Hence, the equations for height and mass CDC percentiles may be written as

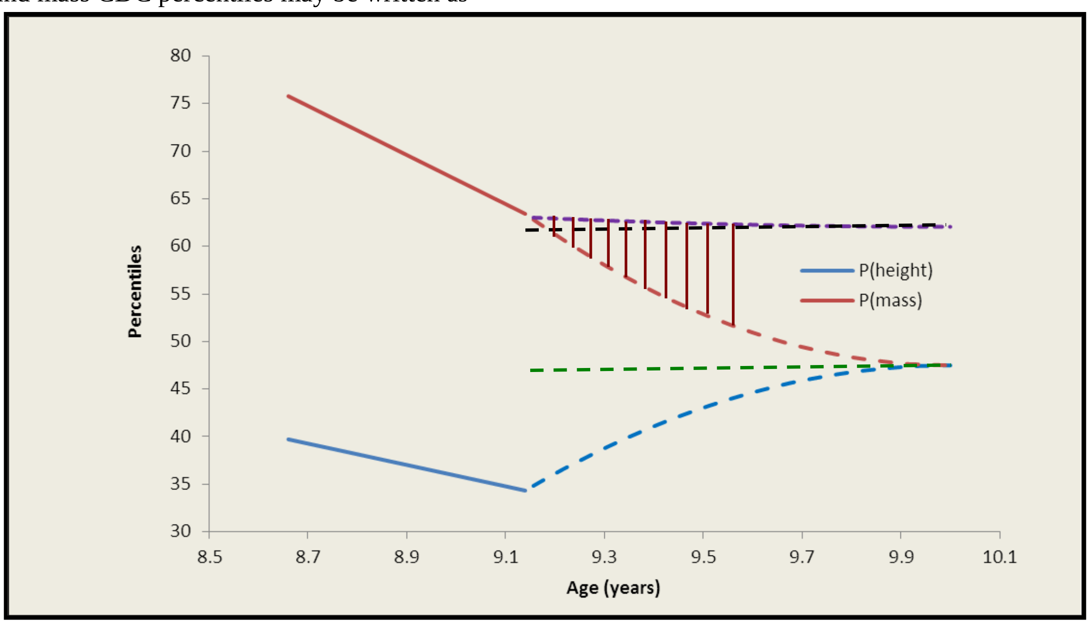

Fig. 6. Time evolution of CDC height and mass percentiles of M. E. for her two checkups in the age range 8.66-9.14 *years* (navigational trajectories**:** solid curves), including the desired course-of-action (guidance trajectories**:** green-dashed line for reference percentile; black-dashed line for *BMI*-based-optimal-mass percentile) and recommended intervention (control action**:** blue-dashed for height-percentile curve and maroon-shaded for mass-percentile curve) — compare with Fig. 3*f* of Kamal *et al.* (2016*a*), in which mass-control-action trajectory is single line

Table 2*a*. Growth-and-Obesity Vector-Roadmap 2.0 of M. E. (SGPP-KHI-20100421-03/01)

Gender: Female • *Date of Birth* (*year-month-day*): 2002-09-23 • *Army-Cutoff Height*: 157.48 *cm* (19.36^{P})[§]

Father's Height: 167.80 *cm* • *Mother's Height*: 171.00 *cm* • *Target Height*: 162.90 *cm* (47.49^{P})

Checkup	*1st*	*2nd*
Photograph		
Scanned Signatures	*ME*	*ME*
Class	IV	IV
Date of Checkup (*year-month-day*)	2011-05-22	2011-11-13
Age (*year-month-day*)	08-07-29	09-01-20
Age (*decimal year*), *A*	8.66	9.14
Dress Code [φ]	0/0.5[φ]	0/0.5 [φ]
Behavior Code [φ]	0[φ]	0 [φ]
Height, *h* (*cm*)	129.50[£]	131.00[£]
Height (*ft-in*)	4 *ft* 2.98 *in*	4 *ft* 3.57 *in*
CDC Percentile-of-Height, $P_{\text{CDC}}(h, A)$	39.73[£]	34.33[£]
Scaled Percentile-of-Height, $P_{\text{Scaled}}(h, A)$	49.70	43.72
Estimated-Adult Height (*cm*)	161.54	160.60
Estimated-Adult Height (*ft–in*)	**5 *ft* 3.60 *in***	**5 *ft* 3.23 *in***
CA-MP (Current-Age-Mid-Parental) Height (*cm*)	130.76	133.20
Δ Height *w. r. t.* CA-MP Height (*cm*)	–1.26	–2.20
Algebraic Status (pertaining-to-height), $STATUS_{\pm}(h)$	–0.96%	+1.65%
Qualitative Status (pertaining-to-height)	Normal	1st-Deg Stunted
CA-AC (Current-Age-Army-Cutoff) Height (*cm*)	125.78	128.06
Δ Height *w. r. t.* CA-AC Height (*cm*)	+3.72	+2.94
Reference Height (*cm*)	130.76	133.20
Percentile-of-Reference-Height, $P_{\text{ref}}(A)$	47.49	47.49
Gross Mass (*kg*)	31.90	31.79
Clothing Correction (*kg*)	0	0
Net Mass, μ (*kg*)	31.90	31.79
Net Weight (*lb-oz*)	70 *lb* 5.43 *oz*	70 *lb* 1.55 *oz*
CDC Percentile-of-Net-Mass, $P_{\text{CDC}}(\mu, A)$	75.79	63.42
Scaled Percentile-of-Net-Mass, $P_{\text{Scaled}}(\mu, A)$	83.43	73.09
Estimated-Adult Mass (*kg*)	66.35	62.32
Estimated-Adult Weight (*lb–oz*)	146 *lb* 4.86 *oz*	137 *lb* 6.54 *oz*
Height-Percentile-based-Optimal Mass, μ_{opt} (*kg*)	26.57	27.45
Δ Mass-for-Height (*kg*)	+5.33	+4.34
Algebraic Status (pertaining-to-mass), $STATUS_{\pm}(\mu)$	+20.08%	+15.82%
Qualitative Status (pertaining-to-mass)	3rd-Deg Obese	2nd-Deg Obese
CDC Percentile-of-*BMI*-based-Optimal-Mass, $P_{\text{CDC}}(\mu_{\text{BMI}}, A)$	64.44	62.05
BMI-based-Optimal-Mass, μ_{BMI} (*kg*)	30.03	31.56
Estimated-Adult *BMI* (kg/m^2)	25.43	24.16
Nutritional Status	Energy-Ch. II	Energy-Ch. II
$P_{\text{Scaled}}(h, A) + P_{\text{Scaled}}(\mu, A)$	133.14	116.81
Build	Medium	Medium

[§]The superscript P stands for percentile.

[φ]'Dress Code' 0/0.5 implied that the child was measured wearing panties only, barefoot, all clothing above the waist removed; 'Behavior Code' 0 means the child was relaxed and cooperative (Kamal, 2006; Kamal *et al.*, 2002)

[£]Pseudo-gain of height (Kamal *et al.*, 2014*b*) exhibited between 1st and 2nd checkups (height pick up from 129.50 *cm* to 131.00 *cm*, percentile dropping from 39.72 to 34.74).

Table 2*b*. Month-wise targets determined using Growth-and-Obesity Vector-Roadmap 2.0 for M. E. based on her last checkup[Я]

Date of Last (*Second*) *Checkup* (*year-month-day*)**:** 2011-11-13 • *Decimal Age*, $A_0 = 9.139726027$ *years*

$P_{\text{ref}} = 47.49439769505168$ • $P(h, A_0) = 34.33112094538$ • $P(\mu, A_0) = 63.421313127254$

Target Date	*Height Target*		*Range of Mass (Weight) Target*	
	cm	*ft-in*	*kg*	*lb-oz*
December 13, 2011	131.80	4 *ft* 3.89 *in*	31.64-32.04	69 *lb* 12.26 *oz* - 70 *lb* 10.48 *oz*
January 13, 2012	132.59	4 *ft* 4.32 *in*	31.52-32.37	69 *lb* 8.03 *oz* - 71 *lb* 5.97 *oz*
February 13, 2012	133.33	4 *ft* 4.49 *in*	31.44-32.70	69 *lb* 5.20 *oz* - 72 *lb* 1.52 *oz*
March 13, 2012	134.00	4 *ft* 4.76 *in*	31.40-33.01	69 *lb* 3.79 *oz* - 72 *lb* 12.42 *oz*
April 13, 2012	134.66	4 *ft* 5.02 *in*	31.42-33.35	69 *lb* 4.50 *oz* - 73 *lb* 8.69 *oz*
May 13, 2012	135.29	4 *ft* 5.26 *in*	31.49-33.70	69 *lb* 6.97 *oz* - 74 *lb* 4.94 *oz*

[Я]Compare Tables 2*a*, *b* with Table A1*a*, *b* of Kamal (2017). Build in Table 2*a* is computed using scaled percentiles, whereas in Table A1*a* build was computed using CDC percentiles. Table 2*b* mainly differs from Table A1b in mass (weight) recommendations, which are now proposed in the form of a range instead of a single value.

(6*a*) $$P_{\text{CDC}}(h, A) = 47.4949769505 - 17.786497880\,(A-10)^2$$

(6*b*) $$P_{\text{CDC}}(\mu, A) = 47.4949769505 + 21.52078488591\,(A-10)^2$$

(6*c*) $$P_{\text{BMI}}(\mu, A) = 62.05447478910533 + 1.36683833814941\,(A-10)^2$$

Sample Vector-Roadmap 2.0 of M. E. is given in Tables 2*a*, *b*.

Table 3. Instantaneous obesity vs. true obesity and instantaneous wasting vs. true wasting (A_0 is the decimal age at the most-recent checkup)

Instantaneous Obesity	*True Obesity*[⊗]	*Instantaneous Wasting*	*True Wasting*[Ю]
$STATUS_{\pm}(\mu) > 0$	$\mu(A_0 + 6\,months) - \mu(A_0) < 0$	$STATUS_{\pm}(\mu) < 0$	$P_{\text{CDC}}(\mu, A_0 + 6\,months) - P_{\text{CDC}}(\mu, A_0) > 0$

[⊗]Whenever a boy or girl is recommended to lose mass within the next 6 *months*, the individual is, also, stepping down on the trajectory of CDC percentile-of-mass within the same period, *i. e.*

$$\mu(A_0 + 6months) - \mu(A_0) < 0 \Rightarrow P_{\text{CDC}}(\mu, A_0 + 6months) - P_{\text{CDC}}(\mu, A_0) < 0$$

A_0 is the age at the most-recent checkup.

[Ю]This is a modification of the definition of 'true wasting' proposed in Kamal *et al.* (2017*a*), in which a child was considered to be 'truly wasted' if the incumbent was recommended, *not only*, to gain mass, *but also*, climb on the trajectory of CDC percentile-of-mass within the next 6 *months*. Note that

$$P_{\text{CDC}}(\mu, A_0 + 6months) - P_{\text{CDC}}(\mu, A_0) > 0 \Rightarrow \mu(A_0 + 6months) - \mu(A_0) > 0$$

However, the reverse is not true, as shown in Table 4.

INSTANTANEOUS OBESITY, TRUE OBESITY, INSTANTANEOUS WASTING AND TRUE WASTING

The terms 'instantaneous obesity' and 'instantaneous wasting' (Table 3) were introduced to differentiate them from 'true obesity' and 'true wasting' (Kamal, 2016; 2017; Kamal *et al.*, 2017*a*; *c*).

Table 4. Three scenarios, when a child is recommended to gain mass within half-an-*year*, $\mu(A_0 + 6months) - \mu(A_0) > 0$

Difference of CDC Percentiles-of-Mass	*Mass Management*
$P_{\text{CDC}}(\mu, A_0 + 6\,months) - P_{\text{CDC}}(\mu, A_0) < 0$	Pseudo-gain of mass (Kamal *et al.*, 2014*b*)
$P_{\text{CDC}}(\mu, A_0 + 6\,months) - P_{\text{CDC}}(\mu, A_0) = 0$	Optimal-mass management[⊕] (Kamal, 2015*b*)
$P_{\text{CDC}}(\mu, A_0 + 6\,months) - P_{\text{CDC}}(\mu, A_0) > 0$	True Wasting (Kamal *et al.*, 2017*a*)

[⊕]Since age increases, child gains mass, but remains on the same percentile. Hence, this is the condition of optimal-mass management.

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

	True Obesity	*True Wasting*
Logical Definition	$\mu(A_0 + 6\ months) - \mu(A_0) < 0$ (Kamal, 2016)	$P_{\text{CDC}}(\mu, A_0 + 6\ months) - P_{\text{CDC}}(\mu, A_0) > 0$ (this work)
Mathematical Definition	$P_{\text{CDC}}(\mu, A_0) - P_{\text{ref}}(A_0) > +15$ (Kamal, 2017)	$P_{\text{CDC}}(\mu, A_0) - P_{\text{ref}}(A_0) < 0$ (this work)$^{\$}$

$^{\$}$Mathematical definition modified from the one proposed in Kamal *et al.* (2017*a*), according to which a child was classified as 'truly wasted' if $P_{\text{CDC}}(\mu, A_0) - P_{\text{ref}}(A_0) \leq 0$. In Appendix B, equivalence of mathematical and logical definitions is proven.

Instantaneous Obesity

Instantaneous obesity exists, when status (pertaining-to-mass) is greater than zero (Table 3). In other words, CDC percentile of mass exceeds CDC percentile of height at the time of checkup.

True Obesity

True obesity exists, when the youngster is recommended to reduce mass (weight) at the end of 6-*month* period, from date of the most-recent checkup, according to Growth-and-Obesity Vector-Roadmap 1.0 — logical definition (Table 3). A mathematical definition has, also, been proposed, which classifies the child as truly obese, when the difference of the incumbent's CDC mass percentile at the most recent checkup and the reference percentile at the most-recent checkup exceeds 15 (Table 5).

obesity does not imply true obesity. Counter example may be seen by studying the case of Z..H..Z. (SGPP-KHI-20110412-01/01; NGDS-BLA-2010-5484/A) reported in Kamal (2015*b*; 2017). At her last checkup on November 23, 2014, she presented with status (pertaining-to-mass) as +2.94% (a manifestation of instantaneous obesity). She was recommended to gain $38.87 - 33.06 = 5.81\ kg$ mass at the end of 6-*month* period (Kamal, 2017).

Instantaneous Wasting

Instantaneous wasting exists, when status (pertaining-to-mass) is less than zero (Table 3). In other words, CDC percentile of mass is lesser than CDC percentile of height at the time of checkup.

True Wasting

A child is termed as 'truly wasted' if the youngster is recommended to climb on the trajectory of CDC percentile-of-mass within the next 6 *months* as per recommendations computed using Growth-and-Obesity Vector-Roadmap 1.0. A mathematical definition has, also, been proposed, which classifies the child as truly wasted, when the difference of the incumbent's CDC mass percentile at the most recent checkup and the reference percentile at the most-recent checkup is negative (Table 5).

Logical and mathematical definitions of true wasting are equivalent (Appendix B). Instantaneous wasting implies true wasting. Proof is given in Appendix B. Reverse is not true. Counter example exists as the case of Z. H. Z. (Kamal, 2017). At the end of 6-*month* period from the date of her last checkup, Z. H. Z. was advised to gain mass in such a way that her CDC percentile of mass climbs from 63.50 to 75.93 — logical definition of true wasting. Further, at her last checkup, the difference of CDC percentile of mass and reference percentile is negative ($63.50 - 76.12 = -2.62 < 0$) — mathematical definition of true wasting. However, non-negative status (pertaining-to-mass) indicates absence of instantaneous wasting.

Instantaneous and True Obesity in Illustrated Case

The case of M. E. exhibits instantaneous obesity as well as true obesity at each of her two checkups (Table 6). Status (pertaining-to-mass) for each checkup is available in Table 2*a*. Difference of mass at the end of 6-*month* period and the first checkup is evaluated in Appendix C, whereas this difference for the second checkup is obtained from Table 2*b*.

Table 6. Instantaneous obesity and true obesity exhibited in illustrated case

Checkup	*Instantaneous Obesity*	*True Obesity*: *Logical Definition*	*True Obesity*: *Mathematical Definition*
	$STATUS_{\pm}(\mu) > 0$	$\mu(A_0 + 6\ months) - \mu(A_0) < 0$	$P_{\text{CDC}}(\mu, A_0) - P_{\text{ref}}(A_0) > +15$
First	$+20.08\% > 0$	$-0.84\ kg < 0$	$+28.29 > +15$
Second	$+15.82\% > 0$	$-0.30\ kg < 0$	$+15.93 > +15$

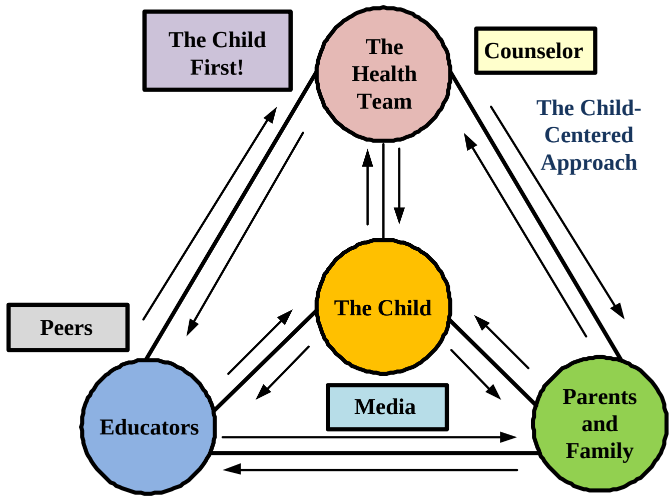

Fig. 7. The child-centered approach to accomplish height- and mass-management targets in children

Additional File 3 (http://www.ngds-ku.org/Papers/J49/Additional_File_3.pdf) and Additional File 4 (http://www.ngds-ku.org/Papers/J49/Additional_File_4.pdf) contain detailed and condensed reports, the former, also, contains 'Obesity Roadmaps 2.0' of M. E.'s parents. Step-by-step calculations of M. E.'s 'Growth-and-Obesity Vector-Roadmap 2.0' are presented in Additional File 5 (http://www.ngds-ku.org/Papers/J49/Additional_File_5.pdf). Additional File 6 (http://www.ngds-ku.org/Papers/J49/Additional_File_6.pdf) shows calculations of 'Obesity Roadmaps 2.0'. Additional File 7 (http://www.ngds-ku.org/Papers/J49/Additional_File_7.pdf) lists 'Growth-and-Obesity Scalar-Roadmap 2.0' for a child, Z. J. (SGPP-KHI-20060412-01/01), appearing for checkups in the age range $9.5\,years \le A < 20\,years$.

RECOMMENDATIONS

A child-centered approach is needed to motivate youngsters to maintain optimal weight-for-height, reinforced by encouragement from parents and family as well the educators based on the recommendations of the health team. The author fully endorses views of Mazik *et al.* (2007), who insisted on looking at the big picture of childhood obesity. Their suggestion is to understand the wider determinants of obesity, such as walking-biking-friendly neighborhood, social interactions, food marketing and prices. Community beliefs need to be changed (Covic *et al.*, 2007) and a conducive environment to be created with proper counseling, awareness created through media and support from peers to lead the child on the path of a healthy and a happy life (Figure 7).

FUTURE DIRECTIONS

Equations for converting CDC percentiles of height (mass) to respective scaled percentiles, suitable for studying the Pakistani population, need to be developed based on median of indigenous data instead of mapping 40^{th} CDC percentile to 50^{th} scaled percentile (median). 4 such equations, one each for height percentiles (males), mass percentiles (males), height percentiles (females) and mass percentiles (females), need to be obtained to analyze data of the Pakistani children. Once these equations are available, childhood obesity should be monitored nationwide using anthropometric data collected by trained local teams (Kamal *et al.*, 2017*c*), on the pattern of studies conducted abroad (Hardy *et al.*, 2017; Sjöberg and Hulthén, 2011)

It is desirable to validate mathematical definition of true wasting by analysis of anthropometric data collected indigenously.

Growth-and-Obesity Vector-Roadmaps 3.0, applicable for children of still-growing parents, should be constructed based on the logic put forward for generating Growth-and-Obesity Profiles 3.0 (Kamal and Jamil, 2012).

CONCLUSION

In this work method of constructing Growth-and-Obesity Vector-Roadmaps 2.0 is given. Height recommendations are same as in the previous version. However, instead of giving a single value for month-wise mass (weight) recommendation, a range is suggested based on height-percentile-based-optimal mass and *BMI*-based-optimal mass, with the hope that it would become easier for the parents and their children to maintain their masses (weights) within the suggested range.

APPENDIX A: ADDITIONAL RESOURCES

Additional File 1 (http://www.ngds-ku.org/Papers/J49/Additional_File_1.pdf): Compliance with ethical and human-right standards

Additional File 2 (http://www.ngds-ku.org/Papers/J49/Additional_File_2.pdf)**:** Height, Mass and MUAC Measurements (step-by-step protocols illustrated through labeled photographs)

Additional File 3 (http://www.ngds-ku.org/Papers/J49/Additional_File_3.pdf)**:** Detailed Report of M. E. (SGPP-KHI-20100421-03/01) — for SGPP checkups in SF-Growth-and-Imaging Laboratory

Additional File 4 (http://www.ngds-ku.org/Papers/J49/Additional_File_4.pdf): Condensed Report of M. E. — for NGDS checkups on school premises

Additional File 5 (http://www.ngds-ku.org/Papers/J49/Additional_File_5.pdf): Detailed Calculations of Growth-and-Obesity Vector-Roadmap 2.0 of M. E.

Additional File 6 (http://www.ngds-ku.org/Papers/J49/Additional_File_6.pdf): Detailed Calculations of Obesity Profiles 2.0 of Parents of M. E.

Additional File 7 (http://www.ngds-ku.org/Papers/J49/Additional_File_7.pdf): Growth-and-Obesity Scalar-Roadmap 2.0 of Z. J. (SGPP-KHI-20060412-01/01)

APPENDIX B: PROOF OF INSTANTANEOUS WASTING IMPLYING TRUE WASTING

Instantaneous wasting is defined as the condition in which status (pertaining-to-mass) is negative, *i..e.*, $STATUS_{\pm}(\mu) > 0.$ A proof is needed to show that instantaneous wasting implies true wasting, *i. e.*, a child is recommended to climb up on CDC percentile of mass, whenever the individual presents oneself with instantaneous wasting. Mathematically

(B1) $$STATUS_{\pm}(\mu) < 0 \Rightarrow P_{\text{CDC}}(\mu, A_0 + 6\ months) - P_{\text{CDC}}(\mu, A_0) > 0$$

To start, one notes that

(B2) $$STATUS_{\pm}(\mu) < 0 \Rightarrow P_{\text{CDC}}(\mu, A) < P_{\text{CDC}}(h, A)$$

Since $$P_{\text{CDC}}(h, A) \le P_{\text{ref}}(A) \Rightarrow P_{\text{CDC}}(\mu, A) < P_{\text{ref}}(A)$$

By applying the result $a < b$ and $b \le c \Rightarrow a < c.$ Hence

$$P_{\text{CDC}}(h, A) \le P_{\text{ref}}(A) \Rightarrow P_{\text{CDC}}(\mu, A) - P_{\text{ref}}(A) < 0$$

For $A = A_0,$ this becomes

(B3) $$P_{\text{CDC}}(\mu, A_0) - P_{\text{ref}}(A_0) < 0 \text{ (proposed mathematical definition of true wasting)}$$

The proof is given for 3 age ranges, viz. (*a*) $A < 9.5$ *years*, (*b*) $9.5\,years \le A < 20$ *years* and (*c*) $A \ge 20\,years$.

a) *Age Range* — $A < 9.5\,years$**:** In this age range, Equation (4*b*), is applicable in this case. To proceed, one needs to convert 6 *months* into *decimal years* (0.5 *year*), as ages are expressed in *years*.

$$\Delta P_{\text{CDC}} = P_{\text{CDC}}(\mu, A_0 + 6\ months) - P_{\text{CDC}}(\mu, A_0) = P_{\text{CDC}}(\mu, A_0 + 0.5\ year) - P_{\text{CDC}}(\mu, A_0)$$

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

$$= P_{\text{ref}}(A_0) - \left(P_{\text{ref}}(A_0) - P_{\text{CDC}}(\mu, A_0)\right)\left(\frac{A_0 + 0.5 - 10}{A_0 - 10}\right)^2 - P_{\text{CDC}}(\mu, A_0)$$

Rearranging and simplifying one gets

(B4) $$\Delta P_{\text{CDC}} = \left[P_{\text{ref}}(A_0) - P_{\text{CDC}}(\mu, A_0)\right]\left[1 - \left(\frac{A_0 + 0.5 - 10}{A_0 - 10}\right)^2\right]$$

Now $\left(\frac{A_0+0.5-10}{A_0-10}\right)^2<1,$ when $A_0<10\,years$, which makes $1-\left(\frac{A_0+0.5-10}{A_0-10}\right)^2>0$. Rewriting (B3) as

$$P_{\text{ref}}(A_0)-P_{\text{CDC}}(\mu,A_0)>0$$

one gets

$$\Delta P_{\text{CDC}}=P_{\text{CDC}}(\mu,A_0+6\;months)-P_{\text{CDC}}(\mu,A_0)>0$$

which completes the proof.

Corollary: Logical definition of 'true wasting' is equivalent to mathematical definition of 'true wasting' in this age range. This can be illustrated by examining (B4). Since, $1-\left(\frac{A_0+0.5-10}{A_0-10}\right)^2>0,$ one notes that

$$\Delta P_{\text{CDC}}>0\Leftrightarrow P_{\text{ref}}(A_0)-P_{\text{CDC}}(\mu,A_0)>0$$

which may be rewritten as

$$P_{\text{CDC}}(\mu,A_0+6\;months)-P_{\text{CDC}}(\mu,A_0)>0\Leftrightarrow P_{\text{CDC}}(\mu,A_0)-P_{\text{ref}}(A_0)<0$$

b) *Age Range* — $9.5\,years\le A<20$ *years*: At the end of 6 *months*, both CDC height and mass percentiles should match reference percentile at the age of the most-recent checkup

(B5) $$P_{\text{CDC}}(\mu,A_0+6\;months)=P_{\text{CDC}}(h,A_0+6\;months)=P_{\text{ref}}(A_0)$$

Therefore

(B6) $$\Delta P_{\text{CDC}}=P_{\text{CDC}}(\mu,A_0+6\;months)-P_{\text{CDC}}(\mu,A_0)=P_{\text{ref}}(A_0)-P_{\text{CDC}}(\mu,A_0)>0$$

by rearranging (B3). The above equation cum inequality, also, establishes equivalence of logical and mathematical definitions of true wasting.

Corollary: Logical definition of 'true wasting' is equivalent to mathematical definition of 'true wasting' in this age range, as evident from (B6).

c) *Age Range* — $A\ge 20$ *years*: In this age range height is not changing.

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

Hence, only mass management is needed, in such a way that at the end of 6-*month* period, percentile of mass matches with the percentile of height. Mathematically,

$$P_{\text{CDC}}(\mu,A_0+6\;months)=P_{\text{CDC}}(h,A_0+6\;months)\Rightarrow P_{\text{CDC}}(\mu,A_0+6\;months)=P_{\text{CDC}}(h,A_0)$$

Therefore

$$\Delta P_{\text{CDC}}=P_{\text{CDC}}(\mu,A_0+6\;months)-P_{\text{CDC}}(\mu,A_0)=P_{\text{CDC}}(h,A_0)-P_{\text{CDC}}(\mu,A_0)=P_{\text{ref}}(A_0)-P_{\text{CDC}}(\mu,A_0)>0$$

by virtue of (B2). Hence

(B7) $$P_{\text{CDC}}(\mu,A_0+6\;months)-P_{\text{CDC}}(\mu,A_0)=P_{\text{ref}}(A_0)-P_{\text{CDC}}(\mu,A_0)>0$$

which completes the proof.

Corollary: Logical definition of 'true wasting' is equivalent to mathematical definition of 'true wasting' in this age range, as evident from (B7).

APPENDIX C: DEMONSTRATION OF TRUE OBESITY AT THE TIME OF FIRST CHECKUP OF M. E.

Since $P_{\text{CDC}}(\mu,A_0)\ne P_{\text{ref}}(A_0)$, Equation (4*b*), is applicable. Substituting A_0 = 8.6602739726027397 *years*, P_{ref} = 47.4949769505, $P_{\text{CDC}}(\mu,A_0)=75.78724587042077$, one gets

(C1) $$P_{\text{CDC}}(\mu,A)=47.4949769505+15.76288793897834\,(A-10)^2$$

The value of CDC percentile of mass is evaluated using Equation (C1), when

$$A = A_0 + 6\ months$$
$= 2011.8931506849315068$ (November 22, 2011) – 2002.7287671232876712 (September 23, 2002)
$= 9.1643835616438356$ *years*

This value comes out to

(C2) $$P_{\text{CDC}}(\mu, A_0 + 6\ months) = 58.50148962097072$$

Mass corresponding to this percentile is computed using the technique of box interpolation as 31.05713887665487 *kg*. Hence

(C3) $$\mu(A_0 + 6\ months) - \mu(A_0) = 31.05713887665487 - 31.90 = -0.8428611233451318\ kg < 0$$

which demonstrates true obesity at the time of the first checkup.

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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/m^2 (adult *BMI*), *BMI* ranges (below $85^P \rightarrow$ normal, 85^P to $95^P \rightarrow$ intermediate, equal to or above $95^P \rightarrow$ high)

SF-Growth-and-Imaging Laboratory 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 5th-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 *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 propose smarter criteria for optimal-mass management — 6th-generation solution of childhood obesity (Vector-Roadmap 2.0)

Modification of logical and mathematical definitions of 'true wasting'

The next step

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

Validation of mathematical definition of childhood wasting based on anthropometric data collected during 1998-2016 by the NGDS Team

Growth-and-Obesity Vector-Roadmaps 3.0 for children of still-growing parents

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*(Accepted for Publication***:** *June 2017)*

Web address of this document (*on author's homepage*)**:** http://www.ngds-ku.org/Papers/J49.pdf
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