INT. J. BIOL. BIOTECH. 18 (1): 123-145, 2021

GROWTH-AND-OBESITY ROADMAPS 4.0 OF THE PAKISTANI CHILDREN — THE NINTH-GENERATION SOLUTION OF CHILDHOOD OBESITY

Syed Arif Kamal[∃], Mohummed Khalid Rajput[$], Ashfaq Ali Naz[@] and Nida Jamil[§]

[∃]*The NGDS Pilot Project and ISST, University of Karachi, Karachi, Pakistan*; *e-mail*: profdrakamal@gmail.com

ABSTRACT

This paper proposes method of construction of Growth-and-Obesity Roadmaps 4.0 of families, with adult parents (father over-21; mother over-19) and their young children. Obesity Roadmap 2.5 is, still, applicable for parents. Scalar Roadmaps 4.0 are applicable to youngsters 9.5-*year* old or above but below 20 *years*. Vector Roadmaps 4.0 are applicable for children, who are below 9.5 *years*. The major change in Growth-and-Obesity Roadmaps 4.0 is the choice of reference height. Reference-height percentile is now taken as the maximum of CDC percentile of measured height, percentile of mid-parental height, percentile of (gender and country specific) army cutoff height and percentile of median of community-based height standard (CDC percentile valued at 40^{P} as suggested in 2015). Refined statuses (pertaining-to-height) and (pertaining-to-mass) now replace modified statuses (pertaining-to-height) and (pertaining-to-mass), with corresponding depictive statuses in place of descriptive statuses. Complex status (pertaining-to-height-and-mass) is constructed by combining real part, refined status (pertaining-to-mass), divided by 100; imaginary part, refined status (pertaining-to-height,) divided by 100 and multiplied by iota. Another innovation in this work is the introduction of instantaneous tallness and true tallness as well as instantaneous stunting and true stunting. Instantaneous tallness (stunting) exists when refined status (pertaining-to-height) is positive (negative). True tallness (stunting) is present when the difference of reference percentile and CDC percentile-of-height vanishes (is positive). Combined with definitions of instantaneous obesity (wasting) and true obesity (wasting), replacing refined status (pertaining-to-mass) in place of modified status (pertaining-to-mass), the categories of nutritional status are enhanced to 23 from 19. The new categories introduced are true over-nutrition, true under-nutrition and true energy-channelization I-II.

Keywords: Specific *BMI*, instantaneous obesity/wasting, true obesity/wasting, instantaneous tallness/stunting, true tallness/stunting, true over-/under-nutrition, true energy-channelization I-II

LIST OF ABBREVIATIONS

AC: **A**rmy-**C**utoff (in the context of height)
AM: **A**cute **M**alnutrition
BIA: **B**ioelectrical-**I**mpedance **A**nalysis
***BMI*:** **B**ody-**M**ass **I**ndex
CA: **C**urrent-**A**ge (in the context of height)
CDC: **C**enters for **D**isease **C**ontrol and Prevention
DXA: **D**ual-Energy-**X**-ray **A**bsorptiometry
EC I-III: **E**nergy-**C**hannelization **I-III**
ECOG: **E**uropean **C**hildhood **O**besity **G**roup
Fr: **F**ractional (in the context of statuses, pertaining-to height, pertaining-to-mass and combined)
MOD: **M**odified (in the context of statuses, pertaining-to-height and pertaining-to-mass)
MP: **M**id-**P**arental (in the context of height)
NGDS: **N**ational **G**rowth and **D**evelopmental **S**tandards for the Pakistani Children
O-EC II: **O**besity dominated **E**nergy-**C**hannelization II
O-ON: **O**besity dominated **O**ver-**N**utrition
ON: **O**ver-**N**utrition
P: **P**ercentile (expressed as superscript)
S-EC II: **S**tunting dominated **E**nergy-**C**hannelization II
SGPP: **S**ibling **G**rowth **P**ilot **P**roject — a subproject Of the NGDS Pilot Project
S-UN: **S**tunting dominated **U**nder-**N**utrition
T-EC I: **T**allness dominated **E**nergy-**C**hannelization I
T-ON: **T**allness dominated **O**ver-**N**utrition
Tr-EC I-II: **Tr**ue **E**nergy-**C**hannelization **I-II**
Tr-ON: **Tr**ue **O**ver-**N**utrition
Tr-UN: **Tr**ue **U**nder-**N**utrition
UN: **U**nder-**N**utrition
W-EC I: **W**asting dominated **E**nergy-**C**hannelization **I**
W-UN: **W**asting dominated **U**nder-**N**utrition

Citation: Kamal, S. A., M. K. Rajput, A. A. Naz and N. Jamil (2021). Growth-and-Obesity Scalar- and Vector-Roadmaps 4.0 of the Pakistani children — the ninth-generation solution of childhood obesity. *International Journal of Biology and Biotechnology* (*Karachi*), 18 (1)**:** 123-146.

[∃]Meritorious Professor Dr. Syed Arif Kamal, PhD (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***:** 0000-0002-1711-4827 • *the NGDS Pilot Project URL***:** https://ngds-ku.org

[$]PhD (Physics); MPhil (Physics), University of Karachi; Retired Professor and Head, Department of Physics, Government College, Phuleli, Hyderabad 71000, Sindh

[@]PhD (Physics — Specialization**:** Childhood Obesity), University of Karachi; MPhil (Physics), University of the Punjab; Commander Pakistan Navy; Training Commander and Chief Education Officer, Pakistan Marine Academy, Ministry of Maritime Affairs, Government of Pakistan, Hawksbay Road, Mauripur, Karachi 75780

[§]PhD Candidate (Mathematics — Specialization**:** Childhood Obesity), 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

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

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

INTRODUCTION

Childhood obesity, being the outcome of a complex web of biological, cultural, environmental and psychological influences, has become a pandemic, which may have severe complications. Obesity has been indicated as one of the risk factors in acquiring COVID-19. It is now well known that childhood obesity forms the basis of adolescent obesity as well as adult obesity, which may result in elevating the risk for premature morbidity and mortality. The increasing prevalence of obesity in the Pakistani children warrants the necessity to propose mathematical-statistical solutions to childhood-obesity problem.

This paper puts forward the ninth-generation solution of childhood obesity by introducing Growth-and-Obesity Scalar- and Vector-Roadmaps 4.0. In this work, the authors introduce instantaneous tallness and true tallness as well as instantaneous stunting and true stunting. The categories of nutritional status are enhanced from 19 to 23. The new categories introduced are true over-nutrition, true under-nutrition and true energy-channelization I-II.

CHILDHOOD OBESITY IN PERSPECTIVE

Greydanus *et al.* (2018) discuss the concepts relating to obesity in youngsters and adolescents in the earlier part of 21^{st} century — history, definition, epidemiology, diagnostic perspectives, psychological considerations, musculo-skeletal as well as endocrine complications and principles of management. Akram et al. (2018) elaborate the impacts of various factors (behavioral, environmental and social) on obesity. Bramante *et al.* (2019) conducted a systematic review of natural experiments for childhood obesity prevention and control. Brock *et al.* (2019) discussed building and sustaining capacity to address childhood obesity in a 3-*year* mixed-methods case study of a community-academic advisory board. Hardy *et al.* (2017) study trends during 1985-2015 in overweight, obesity and waist-to-height ratio in terms of socioeconomic status in Australian children. There has been an increase in overweight and obesity risk-factor awareness in children belonging to the developing countries (Hossain *et al.*, 2019). Kumar and Kelly (2018) describe different methods of clinical assessment and treatment after reviewing obesity in children from epidemiological and etiological perspectives as well as the associated co-morbidities. Linchey *et al.* (2019) deal with the issues of parental underestimation of youngster's weight status and attitudes towards *BMI* screening. Ogden *et al.* (2016) investigate obesity (childhood, adolescent and adult) in United States during 3 periods from 1998 to 2014.

DEFINITIONS OF CHILDHOOD OBESITY

The key to management of obesity in children is accepting a universal definition of childhood obesity. Obesity manifests, when there is difference between input and output of energy. The original steady state disappears and a new one is formed at a higher level. The consequence is excess storage of body-fat. Poskitt (1995), on behalf of the European Childhood Obesity Group (ECOG), stated that researchers were worried about a lack of definition of childhood obesity. She put forward the concept of relative *BMI* as the index of 50^P of a youngster. *BMI*, the most common indicator used even these days, is computed from the mass, μ (in *kg*), and height, *h* (in *m*) of an individual (Keys *et al.*, 1972). Table 1 lists other indices used for describing obesity Cole *et al.* (2000) defined obesity in children on the basis of pooled-international data. They linked obesity in children to adult-obesity-cutoff point of *BMI* to be 30 kg/m^2. A detailed discussion of childhood-obesity definitions may be found elsewhere (Kamal, 2017*a*).

MONITORING OF CHILDHOOD OBESITY

Measures of anthropometry, generally used for childhood-obesity, are stature (standing height), weight (mass) as well as circumferences of waist and hip. Some of the anthropometric and non-anthropometric measures are listed in Kamal and Jamil (2014) — enhanced version is available in Figures 1*a*-*c*.

Our group conducted growth-and-obesity monitoring project in a local school (the NGDS Pilot Project) https://ngds-ku.org and in Growth-and-Imaging Laboratory (SGPP)**:**

https://www.ngds-ku.org/ngds_URL/subprojects.htm#SGPP**:**

Statures (heights) were obtained to least counts of 0.1 *cm* (1998-2011, setsquare set — Kamal *et al.*, 2004); 0.01 *cm* (2012-2015, Vernier scale — Kamal, 2010) and 0.005 *cm* (2016 to date, enhanced-Vernier scale — Kamal *et al.*,

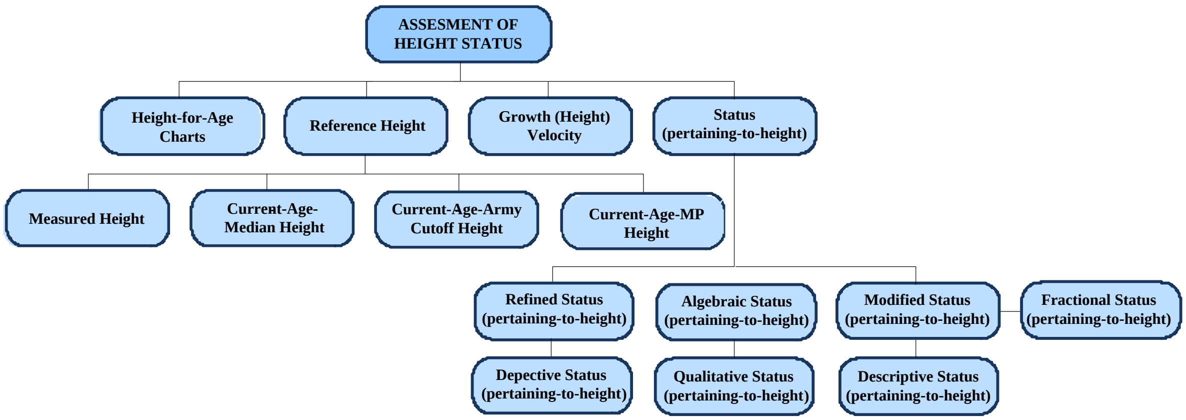


Fig. 1*a*. Assessment of height status

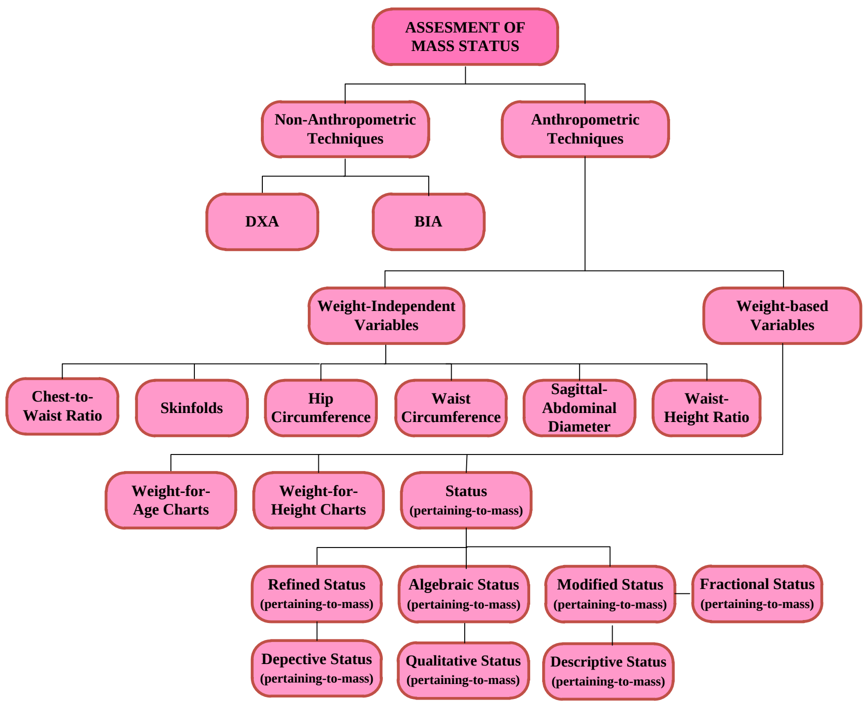


Fig. 1*b*. Assessment of weight status

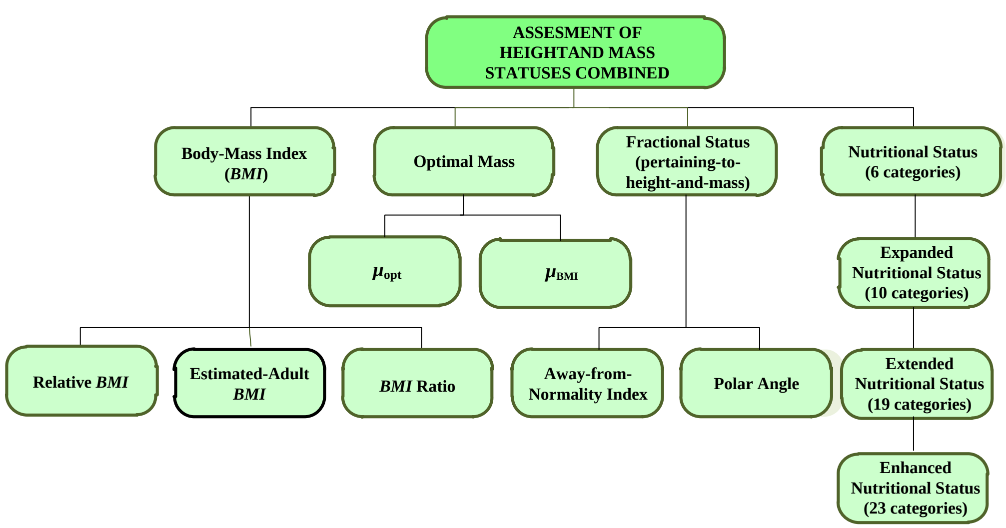


Fig. 1*c*. Assessment of height and weight statuses combined

Table 1. Obesity-status indicators

Nomenclature	*Represented by*	*Mathematical*	*First Mention*
Body-Mass Index	BMI	μ/h^2	Keys *et al.* (1972)
Relative *BMI*	$BMI_{relative}$	50^P of *BMI* table	Poskitt (1995)
Height-Percentile-based-Optimal Mass	μ_{opt}	$P_{opt} = P_{CDC}(h)$	Kamal *et al*. (2004)[л]
Status (pertaining-to-mass)	$STATUS(\mu)$	$100\|\Delta\mu\|/\mu_{opt}$	Kamal *et al.* (2011)
Estimated-Adult *BMI*	$BMI_{est-adult}$	$\mu_{est-adult}/h^2_{est-adult}$	Freedman *et al.* (2001)[ρ]
BMI Ratio	BMI_{ratio}	BMI/unit BMI	Kamal and Jamil (2014)
Algebraic Status (pertaining-to-mass)	$STATUS_{\pm}(\mu)$	$100\,\Delta\mu/\mu_{opt}$	Kamal *et al.* (2015)
Qualitative Status (pertaining-to-mass)	$STATUS_{qual.}(\mu)$	Figure 2 in 2015 reference	Kamal *et al.* (2015)
BMI-based-Optimal Mass'	μ_{BMI}	$24h^2$	Kamal (2017*a*)
Modified Status (pertaining-to-mass)	$STATUS_{\pm}^{MOD}(\mu)$	Table 2 in 2018 reference	Kamal *et al.* (2018)
Descriptive Status (pertaining-to-mass)	$STATUS_{descr.}(\mu)$	Figure 8*b* in 2018 reference	Kamal *et al.* (2018)
Fractional Status (pertaining-to-mass)	$STATUS_{Fr}(\mu)$	$STATUS_{\pm}^{MOD}(\mu)/100$	Kamal *et al.* (2018)
Reference-*BMI*-based-Optimal Mass	$\mu_{ref\text{-}BMI}$	$24h^2_{ref}$	Kamal *et al.* (2020)
Specific *BMI*	$BMI_{specific}$	$BMI/24$	Kamal *et al.* (2020)
Estimated-Adult-Specific *BMI*	$BMI_{est\text{-}adult\text{-}specific}$	$BMI_{est-adult}/24$	Kamal *et al.* (2020)
Refined Status (pertaining-to-mass)	$STATUS_{\pm}^{REF}(\mu)$	Figure 5*b*	This work
Depictive Status (pertaining-to-mass)	$STATUS_{depic.}(\mu)$	Figure 5*b*	This work
Complex Status (pertaining-to-mass)[£]	$STATUS_{Re}(z)$	Figure 5*b*	This work

[л] First mention; concept elaborated and complete definition given in Kamal *et al.* (2011)
[ρ] First mention; concept elaborated and complete definition given in Kamal and Jamil (2012)
[£] Real part of Complex Status (pertaining-to-height-and-mass), $STATUS_{Complex}(z)$

2016). Masses (weights) were recorded to least counts of 0.5 *kg* (1998-2011, bathroom scale — Kamal *et al.*, 2004); 0.01 *kg* (2012-2015, modified-beam scale — Kamal, 2010) and 0.005 *kg* (2016-present, enhanced-beam scale — Kamal *et al.*, 2016) before midday (Figures 2*a-d*), with the youngsters barefoot and completely disrobed except

Fig. 2*a-d*. Measurements of heights (*a*, *b*) and masses (*c*, *d*) of children — (*a*, *c*) first appeared in Kamal *et al.* (2017*a*); published in the same journal

short underpants strictly following the laid-down procedures — Additional File 2 of Kamal (2017*b*).

PREVENTION AND MANAGEMENT OF CHILDHOOD OBESITY

During this decade there has been increased awareness for prevention of obesity in children. Merrotsy *et al.* (2018) have prepared review of literature of the most effective settings and components of programs of prevention of childhood obesity. This task can been accomplished when there becomes a will to bring about the change (Meldrum *et al.*, 2017). Kumanyika (2018) performed healthy communities study and has talked about prevention of obesity in US children. Palmer *et al.* (2018) explained online child's health assessment tool for programming of prevention of obesity. Ickovics *et al.* (2019) discussed the results of implementing school-based policies to prevent obesity in a cluster randomized trial.

SOLUTIONS OF CHILDHOOD-OBESITY PROBLEM

Figure 3 gives timeline of child growth and obesity modeling by our group. The NGDS Team used mathematical-statistical techniques to propose solutions of childhood obesity (1st- to 8th-generation) during the last seven years (2013-2020), which are described here briefly**:**

The First-Generation Solution

*Need***:** Growth-and-Obesity Profiles of children and their parents were generated from the measured masses and heights (Kamal *et al.*, 2011). While discussing these profiles, it became evident that the parents, whose children were severely wasted or stunted, already know that their offspring had a problem. The most important concern for them was not the identification of the problem, but the solution to remedy the existing problem in terms of guidance as to how much weight should be put-on/shed-off during the next 6 *months*. Further, they were interested to know how tall their son or daughter should be at the end of 6 *months*.

*Main Features***:** The first-generation solution upgraded 'Growth-and-Obesity Moving-Profiles' to 'Growth-and-Obesity Roadmaps' (Kamal *et al.*, 2013), which were clusters of profiles along with predictions for the next 6 *months*. Linear interpolation was utilized to gender-specific mass and height tables (20-*year* values) to calculate CDC mass and height percentiles of parents. Net mass (mass without any clothing on) was compared with height-percentile-based optimal mass (from now onward written as 'optimal mass'). Target-height percentiles were computed employing procedures similar to those for obtaining CDC percentiles of parental heights. Target height (Tanner *et al.*, 1970) is, actually, 'adult-mid-parental height', calculated (in *cm*) using the formula $h_{\mathrm{MP}} = \frac{h_{\mathrm{F}} + h_{\mathrm{M}}}{2} \pm 6.5$ (h_{F} and h_{M} are heights of biological father and mother, respectively, in *cm*). Child's CDC mass (height) percentile was evaluated by first calculating mass (height) at the given age using box-interpolation technique (Kamal *et al.*, 2011). Constant-age route was used to evaluate optimal mass and, then, determine obesity profile. Mid-parental height at current age was evaluated by a similar procedure. If a child's measured height was more than the current-age-mid-parental height, the former was taken as reference and optimal mass, 6 *months*

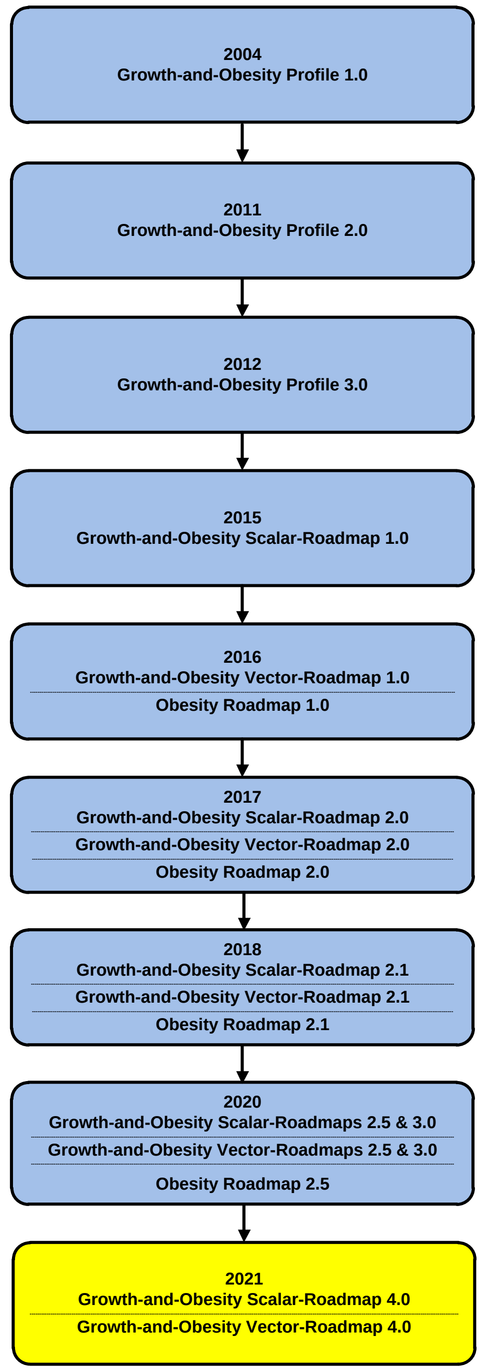


Fig. 3. Child growth and obesity modeling timeline

down the road, was computed based on the estimated value of height after 6 *months*. On the other hand, if the measured height was less than the current-age-mid-parental height, the later was taken as reference and optimal mass after 6 *months* was calculated based on the estimated value of mid-parental height. In the first case, estimated height (after 6 *months*, based on CDC percentile of current height) and the measured height was taken as a guideline to gain height, within the next 6 *months*; while in the second case, difference of estimated-mid-parental height (after 6 *months*) and the measured height (current value) used as guideline. In both of the above cases, difference of optimal mass (after 6 *months*) and the measured mass (current value) was taken as a target to gain (lose) mass within the next 6 *months*, if the difference was positive (negative). In case of weight-loss recommendation, it was recommended not to lose more than 1 *pound* per week. Losing weight rapidly could deteriorate health of a child. This model provided 6-*month* targets for gaining height and maintaining optimal weight using the technique of box interpolation.

*Drawbacks***:** This model provided guidelines to achieve height and mass targets at the end of 6 *months*. However, it was difficult to achieve the given targets since monthly breakdown of targets was not provided.

The Second-Generation Solution

*Need***:** There was a need to enhance the first-generation solution of childhood obesity to include month-wise recommendations of height and mass management. Further, the height taken as reference should, not only, depend on the current-age-mid-parental height, but also, on other factors.

*Main Features***:** Proposed 6-*year* ago (Kamal *et al.*, 2014*a*), a complete version was published as a journal paper in the subsequent year (Kamal *et al.*, 2015). To compute parents' obesity profiles, gender-specific heights and masses read from extended tables, available in Additional File 3 of Kamal and Jamil (2014), containing heights and masses corresponding to percentiles having values 0.01^P, 0.1^P, 1^P, 99^P, 99.9^P and 99.99^P, were used to interpolate, linearly, percentiles of heights and masses of father and mother using age-20 values. Either parent was suggested to gain mass corresponding to the difference obtained by subtracting net mass from optimal mass, if the value of later exceeded the former. In case, value of optimal mass was lesser than net mass, father was advised to reduce mass corresponding to that difference, if the value did not exceed 10 *kg*, otherwise he should lose 10 *kg* within the next 6 *months*. For mothers (currently married or recently divorced/widowed), the recommended suggestion to reduce mass was computed by adding 5 *kg* to net mass, to account for possible pregnancy and the resulting fetal mass. For males and females up to the age of 30 *years*, optimal mass was taken as the mass corresponding to extended percentile-of-height. Above that age, *BMI* (body-mass index) was taken as reference and optimal mass was computed by multiplying square of height with the ideal *BMI* value (24 kg/m^2). This mass is being referred to as *BMI*-based-optimal mass since 2017. To determine whether the child was tall or stunted, the incumbent's height was compared with gender-specific-mid-parental height at the current age. To generate 'Growth-and-Obesity Enhanced-Roadmaps' of sons or daughters, more than one profile was listed (each profile representing a checkup), and recommendations were included to gain height and acquire or lose mass (weight), to be generated from the most-recent profile. 3 height values were compared — measured height, current-age-mid-parental height and current-age-army-cutoff height. Maximum value of set of the above 3 values was taken as reference and optimal mass, after 6 *months*, was computed based on the estimated-reference height (6 *month* ahead in time scale). Difference of measured mass (current value) and optimal mass (after 6 *months*) might be taken as guideline to set targets to lose (gain) mass within the next 6 *months*, if the value was positive (negative). Month-wise recommendations to pick up height or gain (lose) mass were prepared, taking care of the principle that a child should not be required to lose more than 10 *kg* within the next 6 *months*, in order to avoid any adverse health effects due to a rapid loss of mass.

*Drawbacks***:** Although this model provided month-wise recommendations to gain height and put-on/shed-off mass, it was still difficult for ordinary parents to add these quantities to the height and mass recorded at the most-recent checkup in order to monitor their children's health.

The Third-Generation Solution

*Need***:** There was a need to generate pinpointed targets, which could guide the family to achieve 6 milestones of height and mass after the completion of each month following the checkup. In addition, current status (pertaining-to-mass) could be misleading to decide whether a child should gain or lose mass, as a child declared obese based on such criterion might still require to put-on mass based on height targets proposed.

*Main Features***:** The third-generation solution was proposed 5-*year* ago (Kamal, 2015). This solution gave an objective criterion for losing or gaining weight (mass) in slightly obese children at the same time giving month-wise recommendations to pick-up height and gain/lose weight (mass). With enhanced consciousness of obesity of children among various factions of society, there were efforts to shed-off weight based on the current obesity profile of a youngster. However, this approach did not incorporate the fact that a youngster, by the very nature of age group under study, was picking-up height at the same time trying to manage weight through a combination of lifestyle adjustment, diet and exercise plans — optimization approach. A youngster instantaneously approached the value of optimal mass when trajectory of extended percentile-of-mass crossed trajectory of extended percentile-of-height. However, for the purpose of maintaining optimal mass, not only, the values, but also, the slopes of trajectories of extended percentiles-of-height and -mass must be matched — dynamical-system approach (Kamal, 2015).

*Drawbacks***:** The height- and the mass-management targets proposed in the third-generation solution suggested achieving all the corrections within a short span of 6 *months*, which might be difficult to achieve as well as harmful for the growing body of a child.

The Fourth-Generation Solution

*Need***:** The scalar-roadmap model, proposed as part of the first- to the third-generation solutions of childhood obesity (Kamal, 2015; Kamal *et al.*, 2013; 2014*a*; 2015), suggested that height and mass targets be achieved within the next half-a-year. These targets were computed by fitting a linear model to recommended net height and mass gain within the next 6 *months*. ICP (Infancy-Childhood-Puberty) model suggests that a child does not gain height linearly during the childhood phase (Karlberg, 1987). There are attempts at modeling of growth of a person from fetal stage to adolescent stage (Nierop *et al.*, 2016). These were studied before devising a desired course-of-action.

*Main Features***:** 'Growth-and-Obesity Vector-Roadmaps' were same as 'Growth-and-Obesity Scalar-Roadmaps' in the range of age for which actual checkups were conducted. The main difference was in recommended goals of height and weight management. These goals were obtained through a parabolic curve fitted to height and mass percentile trajectories beginning at age of the most-recent checkup and ending at the reference age, taken as 10 *years*. The curve was constructed in such a manner that desired trajectory became tangent to the reference trajectory at the age of 10 *years*. The reference trajectory was a line parallel to x axis (age axis) representing reference percentile (maximum of extended percentiles-of-height measured at the most-recent checkup, mid-parental-height and army-cutoff height). This trajectory originated at the age of the most-recent checkup. This formulation provided softer targets, which were less difficult to attain. Hence, the complete correction was achieved when childhood phase ended (Kamal *et al.*, 2016).

Drawbacks: Although this model suggested softer targets of height and mass management, it was not possible to manage childhood obesity unless a universally-agreed definition of childhood obesity was available, which served as guideline whether a child had to shed-off or put-on mass within the next 6 *months*.

The Fifth-Generation Solution

*Need***:** One needed to streamline various existing definitions of childhood obesity in order to formulate a working definition of childhood obesity, which could be used to propose an efficient and an effective criterion for reducing mass in children, who were determined to be obese.

*Main Features***:** This formulation proposed logical and mathematical definitions of childhood obesity (Kamal, 2017*a*). This model, also, proposed a method to compute *BMI*-based-optimal mass for adults and children based on the reference value 24 kg/m^2 (Kamal, 2017*a*).

*Drawbacks***:** Although the model had been successful in providing a working definition of childhood obesity, it still recommended a single value of mass target for each of the next 6 *months*, which at times became difficult to achieve.

The Sixth-Generation Solution

*Need***:** There was a need for proposing a range of mass-management targets, so that it could be easier for the youngster and parents to comply with the recommendations. Such a trend, already, existed in reports of laboratory testing, where a range of normal values was printed instead of a single number.

*Main Features***:** The sixth-generation solution gave a range for 6 month-wise targets of management of mass in place of single values. This was accomplished using statistical technique of curve fitting. 2 parabolic curves were fitted. Both curves started at the age, when the most-rent checkup was performed. One of these curves was tangent, at the age of 10 *years,* to the straight line representing reference percentile computed, when the most-recent checkup was conducted. The other curve met the straight line, at the age of 10 *years*, representing percentile of *BMI*-based-optimal mass, when the most-rent checkup took place. The range was determined by drawing 6 line segments parallel to vertical (percentile) axis sketched at the date of checkup for the next 6 successive months (Kamal, 2017*b*).

*Drawbacks***:** Although this model was proposing mass targets based on both height-percentile-based-optimal mass and *BMI*-based-optimal mass, algebraic status (pertaining-to-mass) was still calculated by taking height-percentile-based-optimal mass as reference. There was a need to reconsider this approach and redefine algebraic status (pertaining-to-mass) in terms of both optimal masses and similar exercise to be done for algebraic status (pertaining-to-height).

The Seventh-Generation Solution

*Need***:** Growth-and-Obesity Vector-Roadmap 1.0 (Kamal *et al.*, 2016) 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 try to achieve the entire correction within a short span of 6 *months*. Growth-and-Obesity Vector-Roadmap 2.0 (Kamal, 2017*b*) proposed a range instead of a single value for mass management. However, this formulation was biased towards height-percentile-based-optimal mass, as algebraic 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, the definition of algebraic status (pertaining-to-mass) was needed to be modified.

*Main Features***:** Growth-and-Obesity Vector-Roadmap 2.1 used modified statuses (pertaining-to-height) and (pertaining-to-mass) instead of the corresponding algebraic statuses as well as descriptive statuses (pertaining-to-height) and (pertaining-to-mass) instead of the corresponding qualitative statuses. Two heights were considered in the modified status (pertaining-to-height) viz. current-age-army-cutoff height and current-age-mid-parental height, instead of a single height used in the algebraic status. Similarly, two masses were taken into account in the modified status (pertaining-to-mass) viz. height-percentile-based-optimal mass and *BMI*-based-optimal mass, instead of a single height used in the algebraic status. Nutritional-status categories have been expanded to 10 from the previously used 6 categories. Factional statuses (pertaining-to-height) and (pertaining-to-mass) were obtained through the mechanism of dividing the respective modified statuses by 100. Fractional status (pertaining-to-height-and-mass) was obtained by creating a complex number from fractional status (pertaining-to-mass) and fractional status (pertaining-to-height) — the former acting as real part and the later as imaginary part. Magnitude of this complex number represented 'away-from-normality index' (Kamal *et al.*, 2018).

Drawbacks: The seventh-generation solution considered *BMI*-based-optimal mass for determining 6-*month* mass targets, whereas reference height was used to generate 6-*month* height targets. This brought up the question why reference-*BMI* (*BMI* generated from estimated-adult-reference height, not the estimated-adult height) not used to compute these targets. Further, this solution was not capable of generating roadmaps for children of still-growing parents (mother under the age of 19 *years* and father under the age of 21 *years*).

The Eighth-Generation Solution

*Need***:** In version 2.1 the control action for picking up height was based on reference percentile, which was maximum of percentile of height, percentile of army-cutoff height and percentile of mid-parental height. However, control action for mass management was based on reference percentile and percentile of *BMI*-based-optimal mass. Using estimated-adult height to compute *BMI*-based-optimal-mass percentile was not appropriate, as the other percentile was reference percentile. Further, there was a need to generalize the model for children of still growing parents.

*Main Features***:** In version 2.5 estimated-adult-reference height was used to compute percentile of reference-*BMI*-based-optimal mass, which served as a better limiting case for mass management. In place of *BMI*-based-optimal mass, reference-*BMI*-based-optimal mass was used to compute the ranges of mass management. A new parameter, specific *BMI* was introduced and categories of nutritional status extended from 10 to 19 (Kamal *et al.*, 2020).

Drawbacks: Reference height used in the first- to the eighth-generation solutions of childhood obesity depends on the measured height of the child, current-age-army-cutoff height and current-age-mid-parental height. There is a need to include median of height based on community standards (see 9th-generation solution below — Figure 4).

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*)**
July 1, 2015	**3rd-Generation Solution of Childhood Obesity (Kamal, 2015)**
February 13, 2016	**4th-Generation Solution of Childhood Obesity (Kamal *et al.*, 2016)**
January 1, 2017	**5th-Generation Solution of Childhood Obesity (Kamal, 2017*a*)**
October 1, 2017	**6th-Generation Solution of Childhood Obesity (Kamal, 2017*b*)**
October 1, 2018	**7th-Generation Solution of Childhood Obesity (Kamal *et al.*, 2018)**
January 1, 2020	**8th-Generation Solution of Childhood Obesity (Kamal *et al.*, 2020)**
January 1, 2021	**9th-Generation Solution of Childhood Obesity (this paper)**

Fig. 4. Solutions of childhood-obesity problem proposed by the NGDS Team

Table 2. Heights used in generating Growth-and-Obesity Scalar- and Vector-Roadmaps 4.0

Heights	*Depends on Child's Height (patient based)*	*Depends on Parents' Heights (family based)*	*Depends on Community Sampling (community based)*	*National Standards (country based)*	*Corresponding Percentile*
h^{α}	Yes	No	No	No	$P_{CDC}(h)$
$h^{\beta}_{CA\text{-}AC}$	No	No	No	Yes	P_{AC}
$h^{\gamma}_{CA\text{-}MP}$	No	Yes	No	No	P_{MP}
$h^{\delta}_{CA\text{-}median}$	No	No	Yes	No	P_{median}
h_{ref}	Maximum of the above 4 heights				P_{ref}

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

$^{\beta}$ 'Current-Age-Army-Cutoff Height', $h_{CA\text{-}AC}$, is back extrapolated from 'Adult-Army-Cutoff Height' by going through constant-percentile route; 'Adult-Army-Cutoff Height' for induction into the Armed Forces of Pakistan has been set at 5 *ft* 4 *in* for males and 5 *ft* 2 *in* for females (Kamal *et al.*, 2017*c*)

$^{\gamma}$ 'Current-Age-Mid-Parental Height', $h_{CA\text{-}MP}$, is back extrapolated from 'Adult-Mid-Parental (Target) Height' by going through constant-percentile route (Tanner *et al.*, 1970)

$^{\delta}$ 'Current-Age-Median Height', $h_{CA\text{-}median}$, is the height corresponding to CDC percentile 40^P,which is mapped to scaled percentile 50^P, currently, used to generate roadmaps of the Pakistani population (Kamal *et al.*, 2015) — our group is in the process of generating better estimates on the basis of sampled data of the Pakistani children

NEED FOR THE NINTH-GENERATION SOLUTION

Reference height employed in existing solutions of childhood obesity is taken as the maximum of the measured height of youngster, current-age-army-cutoff height and current-age-mid-parental height. It does not take into account that CDC percentiles are not applicable for the Pakistani population and need to be scaled to be applied to the local community. Based on the suggestion given in Kamal *et al.* (2015), CDC percentile 40^P is scaled for the local population as 50^P (Kamal *et al.*, 2017*b*). This should be considered as median of height based on community standards and be included in computation of reference percentile.

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

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

If $h < h_{min}$

$$STATUS^{REF}_{\pm}(h) = 100\frac{h - h_{min}}{h_{min}}\% < 0$$

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

$$STATUS^{REF}_{\pm}(h) = 0$$

Else $h > h_{max}$

$$STATUS^{REF}_{\pm}(h) = 100\frac{h - h_{max}}{h_{max}}\% > 0$$

$$STATUS_{Im}(z) = \frac{STATUS^{REF}_{\pm}(h)}{100}$$

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

Fig. 5*a*. Formulae for refined and complex (imaginary part) statuses (pertaining-to-height) and color codes used to represent depictive status (pertaining-to-height)

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

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

If $\mu < \mu_{min}$

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

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

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

Else $\mu > \mu'_{max}$

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

$$STATUS_{Re}(z) = \frac{STATUS_{\pm}^{REF}(\mu)}{100}$$

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

Fig. 5*b*. Formulae for refined and complex (real part) statuses (pertaining-to-mass) and color codes used to represent depictive status (pertaining-to-mass)

SALIENT FEATURES

In Growth-and-Obesity Vector-Roadmaps 4.0 as well as Growth-and-Obesity Vector-Roadmaps 4.0, percentile of reference height is taken as maximum of 4 CDC percentiles, viz. percentile of measured height, $P_{CDC}(h)$, percentile of army-cutoff height, P_{AC}, percentile of community-based-median height, P_{median}, and percentile of mid-parental height, P_{MP} (Table 2)**:**

(1) $$P_{ref} = max\,(P_{AC}, P_{CDC}(h), P_{median}, P_{MP})$$

Growth-and-Obesity Vector-Roadmap 4.0 is applicable for youngsters below the age of 9.5 *years*. From the age of 9.5 *years* till the age of 20 *years*, Growth-and-Obesity Scalar-Roadmap 4.0 is used. Complete range of applicability of various roadmaps is included in Table 3. In case of the Pakistani boys and girls, percentiles of army-cutoff height (Kamal *et al.*, 2017*c*) are 2.72^{P} (2.71801459103645…. to be exact) and 19.36^{P} (19.356609323536863…

Table 3. Roadmap applicability in various age ranges

Age Range	*Periods of Growth*	*Roadmap*	*Stage of Puberty*$^{\mu}$	*Tanner Score*
$A < 9.5$ *years*	Earlier childhood	Vector-Roadmap 4.0$^{\oplus}$	Prepubertal	1
9.5 *years* $\le A < 12.0$ *years*	Later childhood	Scalar-Roadmap 4.0$^{\otimes}$	Peripubertal	2
12.0 *years* $\le A < 13.5$ *years*	Transition	Scalar-Roadmap 4.0	Pubertal	3
13.5 *years* $\le A < 20.0$ *years*	Adolescence	Scalar-Roadmap 4.0	Adolescent	4
$A \ge 20.0$ *years*	Adulthood	Obesity Roadmap 2.5	Adult	5

$^{\oplus}$ Growth-and-Obesity Vector-Roadmap 4.0
$^{\otimes}$ Growth-and-Obesity Scalar-Roadmap 4.0
$^{\mu}$ Stages of puberty related to Tanner score as well as mathematical definitions of early, delayed, excessively-early, excessively-delayed and precarious puberty in Kamal *et al.* (2017*b*); age ranges in first column are loosely connected to these stages

to be exact), both of which are lesser than the assumed median 40^{P} — true median needs to be determined from the indigenously-collected data of the Pakistani children. For the Pakistani children, equation (1) takes the form for boys as well as girls as

$$P_{\mathrm{ref}} = max\left(40^{\mathrm{P}},\, P_{\mathrm{CDC}}(h),\, P_{\mathrm{MP}}\right) \tag{2}$$

Modified status (pertaining-to-height) is, now, replaced with refined status (pertaining-to-height) by redefining $h_{\min}$ and $h_{\max}$ (Figure 5*a*). Similarly, refined status (pertaining-to-mass) is replaced with refined status (pertaining-to-mass) by redefining $\mu_{\min}$ and $\mu_{\max}$ (Figure 5*b*). Figure 6 lists different sections profile portion of Growth-and-Obesity Scalar- and Vector-Roadmaps 4.0. Height-gain-target-achievement index and mass-management-target-achievement index, giving an idea on how effective are the interventions in terms of lifestyle adjustment, diet and exercise plans, are obtained using the expressions given in Figure 7. Categories of nutritional status are now enhanced to 23 from the previously used 19 categories (Kamal *et al.*, 2020), which are given in Figure 8 and explained in Table 4. Timeline of addition of new categories to nutritional status is available in Table 5.

Detailed methods for generating Growth-and-Obesity Scalar-Roadmap 4.0 and Growth-and-Obesity Vector-Roadmap 4.0 are given in Additional File 1. Color-coding used in these roadmaps is explained in Additional File 2.

SAMPLE GROWTH-AND-OBESITY ROADMAPS 4.0

Sample Growth-and-Obesity Scalar-Roadmap 4.0 of Z. J. is given in Additional File 4. Sample Growth and Obesity Vector Roadmap of T. J. is given here. At the time of his first checkup, the following summary was provided by mother (text in parenthesis added by the first author)**:** **"**T. J. is my last child (3 older sisters; born

Header

*Added in Actual Report***:** Name (in place of initials) • NGDS/SGPP Identification Number (actual) • Father's Name • School • GR (General Register) Number • Address • Telephone (Landline/Cell) Number • e-mail

*Sample Report***:** Initials • NGDS/SGPP Identification Number (both camouflaged to protect identity) • Gender • Date of Birth (*year-month-day*) • Gender-Specific-Adult-Army-Cutoff Height (*cm*) — corresponding CDC percentile in parentheses • Father's Height (*cm*) • Mother's Height (*cm*) • Gender-Specific-Target (Adult-Mid-Parental) Height (*cm*) — corresponding CDC percentile in parentheses

Vital Statistics

*Added in Actual Report***:** Scanned Signatures (actual) • Section (along with class) • Dress Code • Behavior Code

*Sample Report***:** Photograph • Scanned Signatures (camouflaged initials in place of actual signatures to protect identity) • Class • Date of Checkup (*year-month-day*) • Time of Checkup • Age (*year-month-day*) • Age (*decimal year*)

Height Data

(Measured) Height (*cm*) • Height (*ft-in*) • CDC Percentile-of-Height • Scaled Percentile-of-Height • Current-Age-Median Height (*cm*) • Difference of Measured Height and Current-Age-Median Height (*cm*) • Current-Age-Army-Cutoff Height (*cm*) • Difference of Measured Height and Current-Age-Army-Cutoff Height (*cm*) • Current-Age-Mid-Parental Height (*cm*) • Difference of Measured Height and Current-Age-Mid-Parental Height (*cm*) • Estimated-Adult Height (*cm*) • Estimated-Adult Height (*ft-in*) • Modified Status (pertaining-to-height) • Depictive Status (pertaining-to-height)

Mass (Weight) Data

Net Mass (*kg*) • Net Weight (*lb-oz*) • CDC Percentile-of-Net-Mass • Scaled Percentile-of-Net-Mass • Percentile-of-*BMI*-based-Optimal-Mass • Reference-*BMI*-based-Optimal-Mass (*kg*) • Difference of Net Mass and Reference-*BMI*-based-Optimal-Mass (*kg*) • Height-Percentile-based-Optimal-Mass (*kg*) • Difference of Net Mass and Height-Percentile-based-Optimal-Mass (*kg*) • Estimated-Adult Mass (*kg*) • Estimated-Adult Weight (*lb-oz*) • Modified Status (pertaining-to-mass) • Depictive Status (pertaining-to-mass)

Combined Data (Height and Mass)

Away-from-Normality Index • Polar Angle (*degree*) • Enhanced Nutritional Status • Estimated-Adult *BMI* (kg/m^2) • Estimated-Adult-Specific *BMI* • Build

Fig. 6. Sections of Growth-and-Obesity Scalar- and Vector-Roadmaps 4.0 (profile portion)

Height-Gain-Target-Achievement Index

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

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

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

$h_C = 100\,\%$

Target critically achieved

Height attained exactly equal to the assigned target

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

$h_C = 100\,\% \uparrow$

Target over-achieved

Height attained exceeding the assigned target

Else

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

Target under-achieved

Height attained not reaching up to the assigned target

Mass-Management-Target-Achievement Index

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

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

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

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

$\mu_C = 100\,\%$

Target critically achieved

Mass within the normal range

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

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

Target under-achieved

Lesser mass outside the normal range

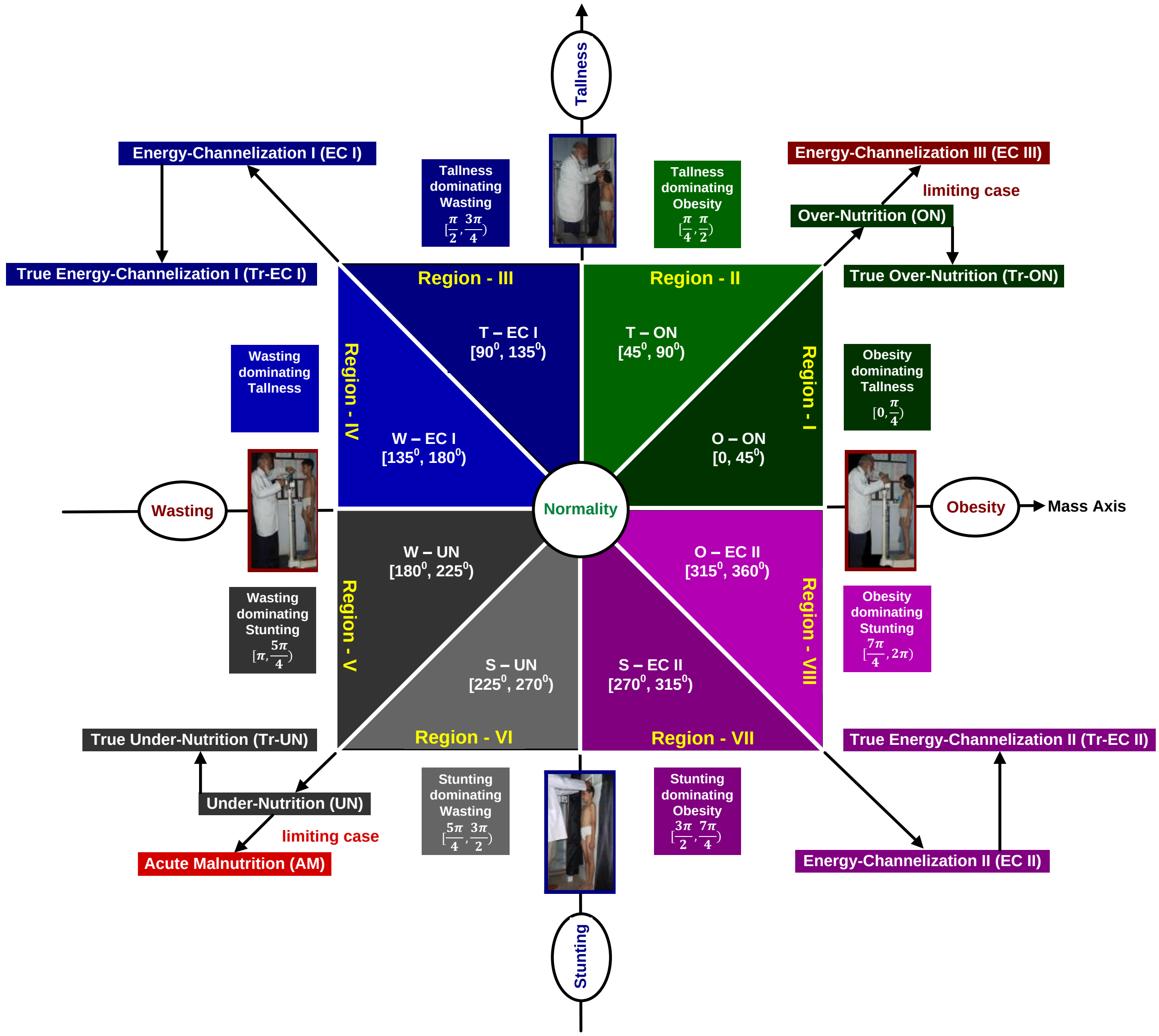
Else $\mu\,(A_0 + 6\,months) > \mu_{\text{max}}^{\text{Targeted}}(A_0 + 6\,months)$,

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

Target under-achieved

Excess mass outside the normal range

Fig. 7. Achieving height-gain- and mass-management targets at the end of 6 *months*, expressed as percentage — adapted from Figure 10 of Kamal *et al.* (2020)



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

ON: Over-**N**utrition | **UN: U**nder-**N**utrition
EC I: Energy-**C**hannelization **I** | **EC II: E**nergy-**C**hannelization **II**

Limiting Cases (6)

EC III: Energy-**C**hannelization **III**, also called Puberty-Induced Energy-Channelization; limiting case of **ON**

AM: Acute **M**alnutrition, causing frequent illnesses during the childhood period; limiting case of **UN**

Tr-ON: True **O**ver-**N**utrition	**Tr-UN: Tr**ue **U**nder-**N**utrition
Tr-EC I: True **E**nergy-**C**hannelization **I**	**Tr-EC II: Tr**ue **E**nergy-**C**hannelization **II**

Extended Categories (8) — open intervals specify polar-angle range in degrees (inside the right-angled triangles) and in radians (inside the rectangles)

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

Special Categories (5) — refined statuses (pertaining-to-height) and (pertaining-to-mass) denoted as height status and mass status, respectively

Obesity: height status zero; mass status positive
Tallness: height status positive; mass status zero
Wasting: height status zero; mass status negative
Stunting: height status negative; mass status zero
Normality: height status zero; mass status zero

Fig. 8. Enhanced-nutritional-status classification into 23 categories — 4 new categories introduced

Table 4. Description of categories of enhanced nutritional status

Name	*Modified Status (pertaining-to-height)*	*Modified Status (pertaining-to-mass)*	*Remarks*
Obesity	$STATUS_{\pm}^{REF}(h)=0$	$STATUS_{\pm}^{REF}(\mu)>0$	----
O-ON	$STATUS_{\pm}^{REF}(h)>0$	$STATUS_{\pm}^{REF}(\mu)>0$	$\lvert STATUS_{\pm}^{REF}(h)\rvert < \lvert STATUS_{\pm}^{REF}(\mu)\rvert$
ON	$STATUS_{\pm}^{REF}(h)>0$	$STATUS_{\pm}^{REF}(\mu)>0$	$\lvert STATUS_{\pm}^{REF}(h)\rvert = \lvert STATUS_{\pm}^{REF}(\mu)\rvert$
Tr-ON	$STATUS_{\pm}^{REF}(h)>0$	$STATUS_{\pm}^{REF}(\mu)>0$	True Obesity *combined with* True Tallness
EC III	$STATUS_{\pm}^{REF}(h)>0$	$STATUS_{\pm}^{REF}(\mu)>0$	$A > A_{Onset-Puberty}$ $P_{Scaled}(h)+P_{Scaled}(\mu)>150^{\supset}$
T-ON	$STATUS_{\pm}^{REF}(h)>0$	$STATUS_{\pm}^{REF}(\mu)>0$	$\lvert STATUS_{\pm}^{REF}(h)\rvert > \lvert STATUS_{\pm}^{REF}(\mu)\rvert$
Tallness	$STATUS_{\pm}^{REF}(h)>0$	$STATUS_{\pm}^{REF}(\mu)=0$	----
T-EC I	$STATUS_{\pm}^{REF}(h)>0$	$STATUS_{\pm}^{REF}(\mu)<0$	$\lvert STATUS_{\pm}^{REF}(h)\rvert > \lvert STATUS_{\pm}^{REF}(\mu)\rvert$
EC I	$STATUS_{\pm}^{REF}(h)>0$	$STATUS_{\pm}^{REF}(\mu)<0$	$\lvert STATUS_{\pm}^{REF}(h)\rvert = \lvert STATUS_{\pm}^{REF}(\mu)\rvert$
Tr-EC I	$STATUS_{\pm}^{REF}(h)>0$	$STATUS_{\pm}^{REF}(\mu)<0$	True Wasting *combined with* True Tallness
W-EC I	$STATUS_{\pm}^{REF}(h)>0$	$STATUS_{\pm}^{REF}(\mu)<0$	$\lvert STATUS_{\pm}^{REF}(h)\rvert < \lvert STATUS_{\pm}^{REF}(\mu)\rvert$
Wasting	$STATUS_{\pm}^{REF}(h)=0$	$STATUS_{\pm}^{REF}(\mu)<0$	----
W-UN	$STATUS_{\pm}^{REF}(h)<0$	$STATUS_{\pm}^{REF}(\mu)<0$	$\lvert STATUS_{\pm}^{REF}(h)\rvert < \lvert STATUS_{\pm}^{REF}(\mu)\rvert$
UN	$STATUS_{\pm}^{REF}(h)<0$	$STATUS_{\pm}^{REF}(\mu)<0$	$\lvert STATUS_{\pm}^{REF}(h)\rvert = \lvert STATUS_{\pm}^{REF}(\mu)\rvert$
Tr-UN	$STATUS_{\pm}^{REF}(h)<0$	$STATUS_{\pm}^{REF}(\mu)<0$	True Wasting *combined with* True Stunting
AM	$STATUS_{\pm}^{REF}(h)<0$	$STATUS_{\pm}^{REF}(\mu)<0$	$P_{Scaled}(h)+P_{Scaled}(\mu)<6$
S-UN	$STATUS_{\pm}^{REF}(h)<0$	$STATUS_{\pm}^{REF}(\mu)<0$	$\lvert STATUS_{\pm}^{REF}(h)\rvert > \lvert STATUS_{\pm}^{REF}(\mu)\rvert$
Stunting	$STATUS_{\pm}^{REF}(h)<0$	$STATUS_{\pm}^{REF}(\mu)=0$	----
S-EC II	$STATUS_{\pm}^{REF}(h)<0$	$STATUS_{\pm}^{REF}(\mu)>0$	$\lvert STATUS_{\pm}^{REF}(h)\rvert > \lvert STATUS_{\pm}^{REF}(\mu)\rvert$
EC II	$STATUS_{\pm}^{REF}(h)<0$	$STATUS_{\pm}^{REF}(\mu)>0$	$\lvert STATUS_{\pm}^{REF}(h)\rvert = \lvert STATUS_{\pm}^{REF}(\mu)\rvert$
Tr-EC II	$STATUS_{\pm}^{REF}(h)<0$	$STATUS_{\pm}^{REF}(\mu)>0$	True Obesity *combined with* True Stunting
O-EC II	$STATUS_{\pm}^{REF}(h)<0$	$STATUS_{\pm}^{REF}(\mu)>0$	$\lvert STATUS_{\pm}^{REF}(h)\rvert < \lvert STATUS_{\pm}^{REF}(\mu)\rvert$
Normality	$STATUS_{\pm}^{REF}(h)=0$	$STATUS_{\pm}^{REF}(\mu)=0$	----

$^{\supset}$ $A_{Onset-Puberty}$ denotes age of onset of puberty; $P_{Scaled}(h)$ and $P_{Scaled}(\mu)$ represent scaled percentiles of height and mass, respectively (Kamal *et al.*, 2017*b*)

Table 5. Timeline of addition of new categories to nutritional status

Timeline	*Categories*	*Listing*	*First Mention*
Before 2014	13	ON, UN, AM	--------
January 2014	16	ON, UN, AM **New categories introduced** EC I, EC II, EC III	Kamal (2014); Kamal *et al.* (2014*b*)
October 2018	10	AM, EC III **Categories scrapped** ON, EC I, UN, EC II **New categories introduced** O-ON, T-ON, T-EC I, W-EC-I, W-UN, S-UN, S-EC II, O-EC II	Kamal *et al.* (2018)
January 2020	19	AM, EC III **Categories reintroduced with definitions modified from Kamal *et al.* (2014*b*)** ON, EC I, UN, EC II **Definitions modified from Kamal *et al.* (2018)** O-ON, T-ON, T-EC I, W-EC I, W-UN, S-UN, S-EC II, O-EC II **New categories introduced** Normality, Obesity, Tallness, Wasting, Stunting	Kamal *et al.* (2020)
January 2021	23	Normality, Obesity, O-ON, ON, EC III, T-ON, Tallness, T-EC I, EC I, W-EC I, Wasting, W-UN, UN, AM, S-UN, Stunting, S-EC II, EC II, O-EC II **New categories introduced** Tr-ON, Tr-UN, Tr-EC I, Tr-EC II	This work

September 23, 1996, November 6, 1997, December 24, 2000) and his BW (birth weight, actually birth mass) was 3.4 *kg*. Now he is 4 *years* old and his weight is almost 13 *kg*. He likes to eat every type of food and, also, likes to drink milk. He takes proper diet, but he is, still, slim. Also, he is hyperactive boy. He is very intelligent and too much naughty. He is active in studies and games. He is, also, an angry and (a) stubborn child."

Tables 6*a-e* give Growth-and-Obesity Vector-Roadmap 4.0 of T. J., who came to Growth-and-Imaging Laboratory along with his 3 sisters accompanied by both parents. More data and graphs for T. J. and his parents are included in Additional File 3. Case number given in Growth-and-Obesity Vector-Roadmap 4.0 is not the one used to register the family. In addition, initials T. J. of the child entered here are not the first alphabets of child's name. These measures are taken to protect privacy of families. Unusual circumstances in the city of Karachi on the day of first checkup were the reason for the checkup to be conducted at noon instead of the first half of the day.

Table 6*a* exhibits **pseudo-gain of height** as well as **pseudo-gain of mass** between 2^{nd} and 3^{rd} checkups height pick-up from **101.80 *cm*** to **105.40 *cm***, CDC percentile-of-height dropping from **20.33^{P}** to **18.07^{P}**; mass put-on from **15.40 *kg*** to **16.20 *kg***, CDC percentile-of-net-mass dropping from **17.01^{P}** to **11.91^{P}**). Pseudo-gains of height and mass were defined in Kamal *et al.* (2014*b*).

Lifestyle adjustment, diet and exercise plans for children in this age group are available in Kamal and Khan (2020).

MATHEMATICS OF OBESITY AND WASTING BASED ON VERSION 4.0

Privacy-protection protocols are applied to the clinical-case examples presented below and in Additional Files, as explained in the case of T. J.

Table 6*a*. Growth-and-Obesity Vector-Roadmap 4.0 of T. J. (SGPP-KHI-20070412-01/04) — 1st to 3rd checkups

Gender: Male • *Date of Birth* (*year-month-day*): 2003-04-20 • *Adult-Army-Cutoff Height*: 162.56 *cm* (2.72^P^)
Father's Height: 165.70 *cm* • *Mother's Height*: 155.73 *cm* • *Target* (*Adult-Mid-Parental*) *Height*: 167.22 *cm* (9.35^P^)

Checkup	*1st*	*2nd*	*3rd*
Photograph			
Scanned Signatures	*TJ*	*TJ*	*TJ*
Class	Montessori	Montessori	Montessori II
Date of Checkup (*year-month-day*)	2007-05-13	2007-10-21	2008-06-15
Time of Checkup	1200h	1030h	1030h
Age (*year-month-day*)	04-00-23	04-06-01	05-01-25
Age (*decimal year*), *A*	4.06	4.50	5.15
Height, *h* (*cm*) ⇐	98.47	**101.80**	**105.40**
Height (*ft-in*)	3 *ft* 2.77 *in*	3 *ft* 4.08 *in*	3 *ft* 5.50 *in*
CDC Percentile-of-Height ⇔	17.26^P^	**20.33^P^**	**18.07^P^**
Scaled Percentile-of-Height	23.21^P^	27.08^P^	24.24^P^
Current-Age-Median Height (*cm*) ⇐	101.51	104.43	108.64
Δ Height *with respect to* Current-Age-Median Height (*cm*)	–3.04	–2.63	–3.24
Current-Age-Army-Cutoff Height (*cm*) ⇐	94.25	96.89	100.98
Δ Height *with respect to* Current-Age-Army-Cutoff Height (*cm*)	+4.22	+5.01	+4.42
Current-Age-Mid-Parental Height (*cm*) ⇐	97.03	99.73	103.62
Δ Height *with respect to* Current-Age-Mid-Parental Height (*cm*)	+1.44	+2.07	+1.78
Estimated-Adult Height (*cm*)	169.67	170.56	169.90
Estimated-Adult Height (*ft–in*)	**5 *ft* 6.80 *in***	**5 *ft* 7.15 *in***	**5 *ft* 6.89 *in***
Refined Status (pertaining-to-height)	0	0	0
Depictive Status (pertaining-to-height)	Normal	Normal	Normal
Net Mass, *μ* (*kg*) ⇒	14.30	**15.40**	**16.20**
Net Weight (*lb-oz*)	31 *lb* 8.50 *oz*	33 *lb* 15.31 *oz*	35 *lb* 11.54 *oz*
CDC Percentile-of-Net-Mass ⇔	12.05^P^	**17.01^P^**	**11.91^P^**
Scaled Percentile-of-Net-Mass	16.46^P^	22.89^P^	16.28^P^
Percentile-of-Reference-*BMI*-based-Optimal-Mass ⇔	58.00^P^	58.00^P^	58.00^P^
Reference-*BMI*-based-Optimal Mass (*kg*) ⇒	16.10	17.15	18.46
Δ Mass *with respect to* Reference-*BMI*-based-Optimal Mass (*kg*)	–1.80	–1.75	–2.26
Height-Percentile-based-Optimal Mass (*kg*) ⇒	14.64	15.63	16.68
Δ Mass *with respect to* Height-Percentile-based-Optimal Mass (*kg*)	–0.34	–0.23	–0.48
Estimated-Adult Mass (*kg*)	59.12	60.85	59.08
Estimated-Adult Weight (*lb–oz*)	130 *lb* 5.91 *oz*	134 *lb* 2.88 *oz*	130 *lb* 4.23 *oz*
Refined Status (pertaining-to-mass)	–2.29%	–1.48%	–2.88%
Depictive Status (pertaining-to-mass)	1st-Deg Wasted	1st-Deg Wasted	1st-Deg Wasted
Away-from-Normality Index	0.0229	0.0148	0.0288
Polar Angle (*degree*)	180.00^o^	180.00^o^	180.00^o^
Enhanced Nutritional Status	Wasting	Wasting	Wasting
Estimated-Adult *BMI* (*kg*/*m*^2^)	20.54	20.92	20.47
Estimated-Adult-Specific *BMI*	0.856	0.872	0.853
Build	Small	Small	Small

Table 6*b*. Growth-and-Obesity Vector-Roadmap 4.0 of T. J. — 4th and 5th checkups

Checkup	*4th*	*5th*
Photograph		
Scanned Signatures	*TJ*	*TJ*
Class	Montessori III	II
Date of Checkup (*year-month-day*)	2009-02-08	2011-03-20
Time of Checkup	1037h	1037h
Age (*year-month-day*)	05-09-19	07-11-00
Age (*decimal year*), *A*	5.81	7.92
Height, *h* (*cm*) ⇐	109.73	122.60
Height (*ft-in*)	3 *ft* 7.20 *in*	4 *ft* 0.27 *in*
CDC Percentile-of-Height ⇔	19.81^P	20.90^P
Scaled Percentile-of-Height	26.43^P	27.79^P
Current-Age- Median Height (*cm*) ⇐	112.92	125.83
Δ Height *with respect to* Current-Age-Median Height (*cm*)	–3.19	–3.23
Current-Age-Army-Cutoff Height (*cm*) ⇐	104.73	116.82
Δ Height *with respect to* Current-Age-Army-Cutoff Height (*cm*)	+5.00	+5.78
Current-Age-Mid-Parental Height (*cm*) ⇐	107.51	119.87
Δ Height *with respect to* Current-Age-Mid-Parental Height (*cm*)	+2.22	+2.73
Estimated-Adult Height (*cm*)	170.41	170.73
Estimated-Adult Height (*ft–in*)	**5 *ft* 7.09 *in***	**5 *ft* 7.22 *in***
Refined Status (pertaining-to-height)	0	0
Depictive Status (pertaining-to-height)	**Normal**	**Normal**
Net Mass, μ (*kg*) ⇒	17.40	22.50
Net Weight (*lb-oz*)	38 *lb* 5.87 *oz*	49 *lb* 9.80 *oz*
CDC Percentile-of-Net-Mass ⇔	12.05^P	20.26^P
Scaled Percentile-of-Net-Mass	16.47^P	26.99^P
Percentile-of- Reference-*BMI*-based-Optimal-Mass ⇔	58.00^P	58.00^P
Reference-*BMI*-based-Optimal Mass (*kg*) ⇒	20.01	25.20
Δ Mass *with respect to* Reference-*BMI*-based-Optimal Mass (*kg*)	–2.61	–2.70
Height-Percentile-based-Optimal Mass (*kg*) ⇒	18.07	22.57
Δ Mass *with respect to* Height-Percentile-based-Optimal Mass (*kg*)	–0.67	–0.07
Estimated-Adult Mass (*kg*)	59.13	61.98
Estimated-Adult Weight (*lb–oz*)	130 *lb* 5.99 *oz*	136 *lb* 10.78 *oz*
Refined Status (pertaining-to-mass)	–3.72%	–0.33%
Depictive Status (pertaining-to-mass)	**1st-Deg Wasted**	**1st-Deg Wasted**
Away-from-Normality Index	0.0372	0.0033
Polar Angle (*degree*)	180.00^o	180.00^o
Enhanced Nutritional Status	**Wasting**	**Wasting**
Estimated-Adult *BMI* (*kg*/m^2)	20.36	21.27
Estimated-Adult-Specific *BMI*	0.848	0.886
Build	**Small**	**Medium**

Table 6*c*. Month-wise targets of height and mass (weight) range, determined using Growth-and-Obesity Vector-Roadmap 4.0 of T. J. based on his last checkup

Date of Last (Fifth) Checkup: March 20, 2011 • *Decimal Age*, $A_0 = 7.915068493$ *years*

$P_{\text{CDC}}(h, A_0) = 20.90034295858^{\text{P}}$ • $P_{\text{CDC}}(\mu, A_0) = 20.2555713827^{\text{P}}$

$P_{\text{ref}}(A_0) = 40.0000000000^{\text{P}}$ • $P_{\text{ref-BMI}}(A_0) = 57.99836171366995^{\text{P}}$

Target Date$^{\lambda}$	*Height Target*		*Range of Mass (Weight) Targets*	
	cm	*ft-in*	*kg*	*lb-oz*
March 20, 2011	**122.60**	**4 *ft* 0.27 *in***	**22.50**	**49 *lb* 9.80 *oz***
April 20, 2011	123.45	4 *ft* 0.60 *in*	22.88-23.05	50 *lb* 7.16 *oz* - 50 *lb* 13.08 *oz*
May 20, 2011	124.22	4 *ft* 0.91 *in*	23.24-23.55	51 *lb* 14.85 *oz* - 51 *lb* 14.85 *oz*
June 20, 2011	124.00	4 *ft* 1.21 *in*	23.62-24.03	52 *lb* 1.31 *oz* - 52 *lb* 15.73 *oz*
July 20, 2011	125.65	4 *ft* 1.47 *in*	23.96-24.49	52 *lb* 13.19 *oz* - 53 *lb* 15.91 *oz*
August 20, 2011	126.32	4 *ft* 1.73 *in*	24.30-24.96	53 *lb* 9.16 *oz* - 55 *lb* 0.43 *oz*
September 20, 2011	126.99	4 *ft* 1.99 *in*	24.63-25.42	54 *lb* 5.02 *oz* - 56 *lb* 0.74 *oz*

$^{\lambda}$ Dark green row represents values at the last checkup, which are taken as reference to generate 6 monthly recommendations

Instantaneous and True Tallness

New concepts 'instantaneous tallness' and 'true tallness' are introduced in this work. Logical and mathematical definitions are given in Table 7. L. G. (SGPP-KHI-20131021-02/01) demonstrates instantaneous and true tallness during all of her 4 checkups, Growth-and-Obesity Vector-Roadmap 4.0 of L. G. is shown in Additional File 4 (Tables AFIV-1*a-f*, Figure AFIV-1 — illustration of instantaneous and true tallness during all of her 4 checkups**:** Table AFIV-1*g*).

Instantaneous and True Stunting

New concepts 'instantaneous stunting' and 'true stunting' are introduced in this work. Logical and mathematical definitions are given in Table 8. G. R. (SGPP-KHI-20110412-02) demonstrates instantaneous and true stunting during all of her 4 checkups. Growth-and-Obesity Vector-Roadmap 4.0 of G. R. is shown in Additional File 4 (Tables AFIV-2*a-f*, Figure AFIV-2 — illustration of Instantaneous and true stunting during all of her 4 checkups**:** Table AFIV-2*g*).

Instantaneous and True Obesity

The definitions of 'instantaneous obesity' and 'true obesity' are modified based on version 4.0. Logical and mathematical definitions are given in Table 9. Z. J. (SGPP-KHI-20060412-01/01) demonstrates instantaneous and

Table 6*d*. Instantaneous and true obesity/wasting as well as instantaneous and true tallness/stunting during each checkup of T. J.

Checkup	*1st*	*2nd*	*3rd*	*4th*	*5th*
Instantaneous Tallness	Absent	Absent	Absent	Absent	Absent
True Tallness	Absent	Absent	Absent	Absent	Absent
Instantaneous Stunting	Absent	Absent	Absent	Absent	Absent
True Stunting	Present	Present	Present	Present	Present
Instantaneous Obesity	Absent	Absent	Absent	Absent	Absent
True Obesity	Absent	Absent	Absent	Absent	Absent
Instantaneous Wasting	Present	Present	Present	Present	Present
True Wasting	Present	Present	Present	Present	Present
True Over-Nutrition	Absent	Absent	Absent	Absent	Absent
True Energy-Channelization I	Absent	Absent	Absent	Absent	Absent
True Under-Nutrition	Absent	Absent	Absent	Absent	Absent
True Energy-Channelization II	Absent	Absent	Absent	Absent	Absent

Table 6*e*. Time slots, valid for the city of Karachi, Pakistan, for full body$^{\eta}$ sun-exposure$^{\kappa}$ of T. J. during 6-*month* period following his last (fifth) checkup to obtain the required doses of vitamin D

Date	*Safe Period* $^{\phi}$ *(a. m. – a. m.)*	*Intermittent Period* $^{\nu}$ *(a. m. – a. m.)*	*Prohibited Period (a. m.- p. m.)*	*Intermittent Period (p. m. – p. m.)*	*Safe Period (p. m. – p. m.)*
APRIL					
01	6: 24 - 7: 38	7: 39 - 8: 53	8: 54 - 4: 18	4: 19 - 5: 33	5: 34 - 6: 48
15	6: 10 - 7: 26	7: 27 - 8: 43	8: 44 - 4: 20	4: 21 - 5: 37	5: 38 - 6: 54
MAY					
01	5: 56 - 7: 15	7: 16 - 8: 35	8: 36 - 4: 22	4: 23 - 5: 42	5: 43 - 7: 02
15	5: 48 - 7: 08	7: 09 - 8: 29	8: 30 - 4: 27	4: 28 - 5: 48	5: 49 - 7: 09
JUNE					
01	5: 42 – 7: 06	7: 07 – 8: 31	8: 32 – 4: 17	4: 18 – 5: 52	5: 53 – 7: 17
15	5: 41 – 7: 03	7: 04 – 8: 26	8: 27 – 4: 37	4: 38 – 6: 00	6: 01 – 7: 23
JULY					
01	5: 45 - 7: 07	7: 08 - 8: 30	8: 31 - 4: 40	4: 41 - 6: 03	6: 04 - 7: 26
15	5: 51 - 7: 12	7: 13 - 8: 34	8: 35 - 4: 41	4: 42 - 6: 03	6: 04 - 7: 25
AUGUST					
01	5: 59 - 7: 19	7: 20 - 8: 40	8: 41 - 4: 35	4: 36 - 5: 56	5: 57 - 7: 17
15	6: 06 - 7: 24	7: 25 - 8: 43	8: 44 - 4: 29	4: 30 - 5: 48	5: 49 - 7: 07
SEPTEMBER					
01	6: 12 - 7: 28	7: 29 - 8: 45	8: 46 - 4: 18	4: 19 - 5: 35	5: 36 - 6: 52
15	6: 18 - 7: 32	7: 33 - 8: 47	8: 48 - 4: 07	4: 08 - 5: 22	5: 23 - 6: 37

$^{\eta}$ T. J. barefooted, bareheaded, dressed in briefs only (all clothing above the waist removed), eyes protected through UV-cutoff glasses, engaged in light exercises/free play — if sitting for drawing, jigsaw puzzles, painting, singing, story telling/listening, his back should be towards the sun

$^{\kappa}$ 10-15-*minute* guarded-graduated sun exposure (Kamal and Khan, 2018)

$^{\phi}$ Safe-exposure duration is when the sun has not reached 18^{o} after rising or is at an angle less than 18^{o} before setting; children may be exposed to direct sunlight (suitable for summer months)

$^{\nu}$ Intermittent-exposure duration is when the sun is at an angle between 18^{o} and 36^{o} (end-points included) after rising or between 36^{o} and 18^{o} (end-points included) before setting; children may be allowed to play in the shade with brief periods of sun exposure (suitable for winter months); complete 12-*month* entries appear in Kamal and Khan (2020)

true obesity during all of her 3 checkups. Growth-and-Obesity Scalar-Roadmap 4.0 of Z. J. is shown in Additional File 4 (Tables AFIV-3*a-e*, Figure AFIV-2 — illustration of Instantaneous and true obesity during all of her 3 checkups: Table AFIV-2*f*).

Instantaneous and True Wasting

The definitions of 'instantaneous wasting' and 'true wasting' are modified based on version 4.0. Logical and mathematical definitions are given in Table 10. T. J. demonstrates true and instantaneous wasting during all of his 5 checkups. Growth-and-Obesity Vector-Roadmap 4.0 of T. J. is included in Tables 10*a-f*. Illustration of instantaneous and true wasting during all of his 5 checkups is included in Additional File 3 (Table AFIII-1).

Table 7. Logical and mathematical definitions of instantaneous tallness and true tallness (new concepts)

	Instantaneous Tallness	*True Tallness*
Logical Definition	$h - max\ (h_{CA\text{-}AC},\ h_{CA\text{-median}},\ h_{CA\text{-}MP}) > 0$	$P(h, A_0) - P^{Targeted}(h, A_0 + 6\ months) = 0^{\forall}$
Mathematical Definition	$STATUS_{\pm}^{REF}(h) > 0$	$P_{ref}(A_0) - P_{CDC}(h, A_0) = 0$

$^{\forall}$ Reference percentile is equal to CDC percentile of height, hence the child is not recommended to climb on the height-percentile trajectory. Instead, the youngster is recommended to stay on the trajectory as illustrated by the mathematical definition

Table 8. Logical and mathematical definitions of instantaneous stunting and true stunting (new concepts)

	Instantaneous Stunting	*True Stunting*
Logical Definition	$h - min\,(h_{CA\text{-}AC}, h_{CA\text{-}median}, h_{CA\text{-}MP}) < 0$	$P(h, A_0) - P^{Targeted}(h, A_0 + 6\ months) < 0^{\partial}$
Mathematical Definition	$STATUS_{\pm}^{REF}(h) < 0$	$P_{ref}(A_0) - P_{CDC}(h, A_0) > 0$

$^{\partial}$ The youngster is recommended to climb on the height-percentile trajectory.

DISCUSSION AND CONCLUSION

Childhood obesity has become a pandemic, which is influenced by interactions between genetic and environmental factors. Since adult obesity is based on trends of obesity during childhood and adolescence, mathematical-statistical modeling is needed to propose solutions to keep in check the health status of future leaders of this nation. In this paper, the first- to the eighth-generation solutions of childhood obesity, presented during 2013-2020, have been enhanced and the ninth-generation solution formulated. Future work should focus on extending Growth-and-Obesity Vector-Roadmaps 4.0 to include still-growing parents. 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 and improvement of subject alignment based on posture monitoring during height and mass recording using moiré fringe topography and dotted-rasterstereography. In addition, Growth Charts and Tables for the Pakistani children should be constructed to avoid using patchwork, like scaling of CDC Growth Charts and Tables. 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. Our focus should shift from *Gross National Wealth* to *Gross National Happiness*.

Table 9. Logical and mathematical definitions of instantaneous obesity and true obesity (modified definitions)

	Instantaneous Obesity	*True Obesity*
Logical Definition	$\mu - max\,(\mu_{opt}, \mu_{ref\text{-}BMI}) > 0$	$\mu_{max}^{Targeted}(A_0 + 6\ months) - \mu(A_0) < 0$
Mathematical Definition	$STATUS_{\pm}^{REF}(\mu) > 0$	$P_{CDC}(\mu, A_0) - max\,(P_{ref}(A_0), P_{ref\text{-}BMI}(\mu, A_0)) > 13.5$

DEDICATION

The first author (SAK) would like to dedicate this paper to his first teacher and role model Professor Inayat Ali Khan (May 10, 1935, Tonk, British India – July 26, 2020, Karachi, Sindh, Pakistan). An educationist and a poet, Professor Khan migrated to Pakistan at the time of partition and stayed in Hyderabad, Sindh. He completed his SSC (Matriculation) Examination from Government High School, Risala Road, Hyderabad and HSC (Intermediate) Examination from City College, Hyderabad, followed by BT (Bachelor of Teaching) from University of Sindh, Jamshoro. He completed his MA in Urdu from the same university, topping the list of candidates of the entire university. He wrote textbooks for schools for Sindh Textbook Board and got prize for 6 of his books. He wrote stories for children and two books of poems. His poetry *Bool Meeri Machli* is a very common rhyme read and recited by children all over Pakistan. His handwriting was pleasing to eyes. SAK got his good handwriting (both in English and Urdu) from the efforts of his first teacher. May Allah rest his soul in eternal peace!

Table 10. Logical and mathematical definitions of instantaneous wasting and true wasting (modified definitions)

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

$^{\chi}$ The incumbent is recommended to climb on the mass-percentile trajectory.

ADDITIONAL RESOURCES

Additional File 1 https://www.ngds-ku.org/Papers/J59/Additional_File_1.pdf elaborates method of construction of Growth-and-Obesity Scalar-Roadmap 4.0 as well as Growth-and-Obesity Vector-Roadmap 4.0.

Additional File 2 https://www.ngds-ku.org/Papers/J59/Additional_File_2.pdf explains color-coding used in Obesity Roadmap 2.5, Growth-and-Obesity Scalar-Roadmap 4.0 as well as Growth-and-Obesity Vector-Roadmap 4.0.

Additional File 3 https://www.ngds-ku.org/Papers/J59/Additional_File_3.pdf depicts Obesity Roadmap 2.5 of parents of T. J.; navigation, guidance and control trajectories for Growth-and-Obesity Vector-Roadmap 4.0 of T. J., height-gain-target-achievement and mass-management-target-achievement indices for the second, the third, the fourth and the fifth checkups as well as illustration of instantaneous wasting and true wasting during all 5 checkups of T. J.

Additional File 4 https://www.ngds-ku.org/Papers/J59/Additional_File_4.pdf lists Growth-and-Obesity Vector-Roadmaps 4.0 of L. G., G. R. and Z. H. Z. as well as Growth-and-Obesity Scalar-Roadmap 4.0 of Z. J.

Additional File 5 https://www.ngds-ku.org/Papers/J59/Additional_File_5.pdf lists scenarios, in which a child is recommended to gain mass.

REFERENCES

Akram, H., G. Ashraf and M. A. Ijaz (2018). The impacts of complex social, environmental and behavioral factors on obesity. *International Journal of Basic Science in Medicine*, 3 (3): 94-98

Bramante, C. T., R. L. J. Thomson, W. L. Bennett, *et al.* (2019). Systematic review of natural experiments for childhood obesity prevention and control. *American Journal of Preventive Medicine*, 56 (1): 147-158

Brock, D-J. P., P. A. Estabrooks, H. M. Maurer, *et al.* (2019). Building and sustaining capacity to address childhood obesity: a 3-*year* mixed-methods case study of a community-academic advisory board. *Family and Community Health*, 42 (1): 62-79

Cole, T. J., M. C. Bellizzi, K. M. Flegal and W. H. Dietz (2000). Establishing a standard definition of child overweight and obesity worldwide: International survey. *British Medical Journal*, 320 (7244): 1240-1243

Freedman, D. S., L. K. Khan, W. H. Dietz, S. R. Srinivansan and G. S. Barenson (2001). Relationship of childhood obesity to coronary heart disease risk factors in adulthood: the Bogalusa Heart Study. *Pediatrics*, 108 (3): 712-718

Greydanus, D. E., M. Agana, M. M. Kamboj, *et al* (2018). Pediatric obesity: current concepts. *Disease-a-Month*, 64 (4): 98-156

Hardy, L. L., S. Mihrshahi, J. Gale, B. A. Drayton, A. Bauman and J. Mitchell (2017). 30-year trends in overweight, obesity and waist-to-height ratio by socioeconomic status in Australian children, 1985 to 2015. *International Journal of Obesity*, 41 (1): 76-82

Hossain, M., I. A. Zannat, S. Begum and S. Rahman (2019). Risk factors for overweight and obesity among children and adolescents in Bangladesh: a hospital-based study. *Bangladesh Journal of Child Health*, 43 (1): 9-14

Ickovics, J. R., K. O. Duffany, F. M. Shebl, *et al.* (2019). Implementing school-based policies to prevent obesity: cluster randomized trial. *American Journal of Preventive Medicine*, 56 (1): e1-e11

Kamal, S. A. (2010, March 22). Mathematics in the life sciences. *The First National Conference on Mathematical Sciences*, Golden Jubilee Celebration, Department of Mathematics, University of Karachi, Karachi, Pakistan, p. 19 (the Syed Firdous memorial lecture), abstract#10: https://www.ngds-ku.org/Presentations/Firdous.pdf

Kamal, S. A. (2014, May 17). Sports and anthromathematics. *The Fifty-Fifth Annual Prize Distribution Function*, Government College, Hyderabad, Pakistan (seminar), abstract: https://www.ngds-ku.org/Presentations/Sport_Mathematics.pdf

Kamal, S. A. (2015). Optimal-mass management in obese children. *International Journal of Biology and Biotechnology*, 12 (3): 381-391, full text: https://www.ngds-ku.org/Papers/J38.pdf

Kamal, S. A. (2017*a*). In search of a definition of childhood obesity. *International Journal of Biology and Biotechnology* (*Karachi*), 14 (1): 49-67, full text: https://www.ngds-ku.org/Papers/J45.pdf

Kamal, S. A. (2017*b*). Integration of *BMI*-based-optimal mass and height-percentile-based-optimal mass to propose the sixth-generation solution of childhood obesity. *International Journal of Biology and Biotechnology* (*Karachi*), 14 (4): 485-502, full text: https://www.ngds-ku.org/Papers/J49.pdf

Additional File 2 — *Height, Mass and MUAC* (*Mid-Upper-Arm Circumference*) *Measurements* (step-by-step proce-dures illustrated through labeled diagrams): https://www.ngds-ku.org/Papers/J49/Additional_File_2.pdf

Kamal, S. A., A. A. Naz and S. A. Ansari (2017*a*). Possible validation of mathematical definition of childhood obesity based on anthropometric data collected during 1998-2013. *International Journal of Biology and Biotechnology* (*Karachi*), 14 (2): 219-235 67, full text: https://www.ngds-ku.org/Papers/J46.pdf

Kamal, S. A., A. A. Naz, S. Musafar and S. A. Ansari (2016, February 12, 13). Growth-and-Obesity Vector-Roadmaps using enhanced anthropometric instruments: the fourth-generation solution of childhood obesity. *The Karachi Physics Society First National Conference on Multidisciplinary Topics in Physics*, Department of Physics, University of Karachi, Karachi, Pakistan, p. 56 (invited lecture), abstract#IT-04: https://www.ngds-ku.org/Presentations/Vector.pdf

Kamal, S. A., H. I. Azeemi and S. R. Khan (2017*b*). Psychological testing, physical examination and fitness testing of primary-school students for participation in gymnastic activities. *Pamukkale Journal of Sport Sciences*, 8 (2)**:** 15-40 — Table 4 connects Tanner scores with prepubertal, peripubertal, pubertal, adolescent and adult stages of puberty, full text**:** https://www.ngds-ku.org/Papers/J48.pdf

Kamal, S. A., M. J. Ansari, S. A. Ansari and A. A. Naz (2020). Two-parameter (height and mass) problem solved by fitting parabolic curve to construct Growth-and-Obesity Vector-Roadmap 3.0 — the eighth-generation solution of childhood obesity. *International Journal of Biology and Biotechnology* (*Karachi*), 17 (1)**:** 23-57, full text**:** https://www.ngds-ku.org/Papers/J54.pdf

Kamal, S. A., N. Jamil and S. A. Ansari (2018). Validation of concept of optimal mass in children and adults — the seventh-generation solution of childhood obesity. *International Journal of Biology and Biotechnology* (*Karachi*), 15 (4)**:** 613-638, full text**:** https://www.ngds-ku.org/Papers/J52.pdf

Kamal, S. A., N. Jamil and S. A. Khan (2011). Growth-and-Obesity Profiles of children of Karachi using box-interpolation method. *International Journal of Biology and Biotechnology* (*Karachi*), 8 (1)**:** 87-96, full text**:** https://www.ngds-ku.org/Papers/J29.pdf

Kamal, S. A., S. A. Ansari, M. Sarwar and A. A. Naz (2017*c*). Medical criteria for induction into the Armed Forces of Pakistan**:** cutoff heights for still-growing youth. *International Journal of Biology and Biotechnology v*, 14 (3)**:** 319-331, full text**:** https://www.ngds-ku.org/Papers/J47.pdf

Kamal, S. A., S. A. Ansari and S. S. Jamil (2014*a*, September 4). Growth-and-Obesity Enhanced-Roadmaps of children. *The Second Conference on Anthromathematics and Sport Mathematics in the Memory of* (*Late*) *Hussain Ahmed Bilgirami* (*ANTHROMATHEMATICS 2014*), Department of Mathematics, University of Karachi, Karachi, Pakistan and Government College, Hyderabad, Pakistan, p. 10 (concluding talk), abstract#Anthro 14-06**:** https://www.ngds-ku.org/Presentations/Enhanced.pdf

Kamal, S. A., S. A. Ansari and S. S. Jamil (2015). Generating and validating Growth-and-Obesity Roadmaps for the Pakistani children. *International Journal of Biology and Biotechnology* (*Karachi*), 12 (1)**:** 47-61, full text**:** https://www.ngds-ku.org/Papers/J35.pdf

Kamal, S. A. and S. A. Khan (2018). Overcoming vitamin-D deficiency in male gymnasts during preteen years. *The Sky* (*International Journal of Physical Education, Health, Sports and Allied Sciences*), 2**:** 60-75, full text**:** https://www.ngds-ku.org/Papers/J50.pdf

Existing knowledge — 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 wasting and obesity

Various definitions of obesity proposed include cutoff point of adult *BMI* as 30 kg/m^2, *BMI* ranges in childhood

Existing scenario — the NGDS Team (our group) contributions

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

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

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

2013-2020 1st- to 8th-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 0.01^P to 99.99^P (to handle extreme cases)

2015 Month-wise targets (next 6 *months*) to shed-off/put-on mass and pick-up height; 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 Definitions of childhood obesity and *BMI*-based-optimal mass; mathematical criteria to classify normal, early, delayed and precarious puberty through scaled percentiles; assignment of Tanner scores to prepubertal, peripubertal, pubertal, adolescent and adult stages

2018 Integration of height-percentile-based-optimal mass with *BMI*-based-optimal mass to modify definitions of statuses (pertaining-to-height) and (pertaining-to-mass), polar-coördinate representation of nutritional-status; fractional status (pertaining-to-height-and-mass)

2020 Introduction of specific *BMI*, height-gain-target-achievement index and mass-management-target-achievement index

This work adds

Reference height defined as the maximum of target height, adult-army-cutoff height and adult-median height (corresponding to 40^P)

Nutritional-status categories enhanced to 23; new categories introduced — true over-nutrition, true under-nutrition and true energy-channelization I and II; complex status — real part (mass) + imaginary part (height)

Proposed scenario — the next step

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

Kamal, S. A. and S. A. Khan (2020). Association of balanced diet and physical activity with fitness of young children and their parents. *The Shield* (*Research Journal of Physical Education and Sports Science*), 15**:** 119-147, full text**:** https://www.ngds-ku.org/Papers/J59.pdf

Kamal, S. A., S. Firdous and S. J. Alam (2004). An investigation of growth profiles of the Pakistani children. *International Journal of Biology and Biotechnology* (*Karachi*), 1 (4)**:** 707-717, full text**:** https://www.ngds-ku.org/Papers/J26.pdf

Kamal, S. A. and S. S. Jamil (2012). A method to generate Growth-and-Obesity Profiles of still-growing parents. *International Journal of Biology and Biotechnology* (*Karachi*), 9 (3)**:** 233-255, full text**:** https://www.ngds-ku.org/Papers/J30.pdf

Kamal, S. A. and S. S. Jamil (2014). KJ-regression model to evaluate optimal masses of extreme cases. *International Journal of Biology and Biotechnology* (*Karachi*), 11 (4)**:** 623-648, full text**:** https://www.ngds-ku.org/Papers/J34.pdf Additional File 3 — Extended Growth Tables and Extended Growth Charts**:** https://www.ngds-ku.org/Papers/J34/Additional_File_3.pdf

Kamal, S. A., S. S. Jamil and S. A. Ansari (2013, September 4, 5). Growth-and-Obesity Roadmaps of children. *The First Conference on Anthromathematics in the Memory of* (*Late*) *Syed Firdous* (*ANTHROMATHEMATICS 2013*), Department of Mathematics, University of Karachi, Karachi, Pakistan and Government College, Hyderabad, Pakistan, p. 8, abstract#Anthro13-02**:** https://www.ngds-ku.org/Presentations/Roadmap.pdf

Kamal, S. A., S. S. Jamil and U. A. Razzaq (2014*b*). Stunting induced by wasting — wasting induced by stunting**:** a case study. *International Journal of Biology and Biotechnology*(*Karachi*), 11 (1)**:** 147-153, full text**:** https://www.ngds-ku.org/Papers/J32.pdf

Karlberg, J. (1987). Modeling of human growth. *PhD Dissertation*, University of Göteborg, Göteborg, Sweden

Keys, A., F. Fidanza, M. J. Karvonen, N. Kimura and H. L. Taylor (1972). Indices of relative weight and adiposity. *Journal of Chronic Diseases*, 25 (6&7)**:** 329-343

Kumanyika, S. K. (2018). Supplement overview**:** What the healthy communities study is telling us about childhood obesity prevention in U. S. communities. *Pediatric Obesity*, 13 (Supplement 1)**:** 3-6 (editorial)

Kumar, S. and A. S. Kelly (2018). Review of childhood obesity**:** from epidemiology, etiology, and comorbidities to clinical assessment and treatment. *Mayo Clinic Proceedings*, 92 (2)**:** 251-265

Linchey, J. K., B. King, H. R. Thompson and K. A. Madsen (2019). Parent underestimation of child weight status and attitudes towards BMI screening. *Health Behavior and Policy Review*, 6 (3)**:** 209-218

Meldrum, D. R., M. A. Morris and J. C. Gambone (2017). Obesity pandemic**:** causes, consequences and solutions — but do we have the will? *Fertility and Sterility*, 107 (4)**:** 833-839

Merrotsy, A., A. McCarthy, J. Flack and T. Coppinger (2018). Obesity prevention programs in children**:** the most effective settings and components. A literature review. *Journal of Obesity and Chronic Diseases*, 2 (2)**:** 62-75

Nierop, A. F. M., A. Niklasson, A. Holmgren, L. Gelander, S. Rosberg and K. Albertsson-Wikland (2016). Modeling individual longitudinal human growth from fetal to adult life — QEPS I. *Journal of Theoretical Biology*, 406 (1)**:** 143-165

Ogden, C. L., M. D. Carroll, H. G. Lawman, *et al.* (2016). Trends in obesity prevalence among children and adolescents in the United States, 1988-1994 through 2013-2014. *Journal of the American Medical Association*, 315 (21)**:** 2292-2299

Palmer, L. A., K. J. McCarthy, D. F. Perkins, L. M. Borden and J. M. DiNallo (2018). Online child's health assessment tool for obesity prevention programming. *Journal of Youth Development*, 13 (3)**:** 237-258

Poskitt, E. M. E. (1995). Defining childhood obesity**:** the relative body mass index (*BMI*). *Acta Paediatrica*, 84 (8)**:** 961-963

Tanner, J. M., H. Goldstein and R. H. Whitehouse (1970). Standards for children's height at ages 2-9 years allowing for height of parents. *Archives of Diseases of Children*, 45 (244)**:** 755-762

(*Accepted for Publication***:** *December 2020*)