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POSSIBLE VALIDATION OF MATHEMATICAL DEFINITION OF CHILDHOOD OBESITY BASED ON ANTHROPOMETRIC DATA COLLECTED DURING 1998-2013[¶]

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ABSTRACT

Childhood obesity appears, when there develops a discrepancy between energy intake and expenditure, causing to disturb the original steady state and formation of a fresh steady state at a higher level, which results in increased body-fat storage. Balance needs to be created between tissue synthesis (height gain) and fat storage (mass gain) in order to avoid children becoming obese. There are a number of definitions of childhood obesity given by various researchers, notable among them are those working with the European Childhood Obesity Group (ECOG). During 2013-2017, the First- to the Fifth-Generation Solutions of Childhood Obesity were proposed by our group. The last one consisted of a mathematical definition of childhood obesity. It related the logical definition, 'a child is considered to be obese if the incumbent is recommended to lose net weight during a course of the next 6 months based on the youngster's mass-management goals generated from Growth-and-Obesity Vector-Roadmap' to the mathematical criterion, 'a child is classified as obese if the difference between the youngster's mass percentile (at the most-recent checkup) and reference percentile exceeds +15'. This paper explores the proposed mathematical definition by applying this criterion to anthropometric data collected during 15 years ending in 2013. Data were investigated by changing the value of difference around +15. Best results were obtained when the parameter was set equal to +15. Out of 1183 children (302 males, 881 females), 124 had the difference greater than +15. Among these 124 children, 38 showed true obesity according to the logical definition.

Keywords: Anthropometry, body-mass index (*BMI*), *BMI*-based-optimal mass, estimated-adult *BMI*, height-percentile-based-optimal mass, Growth-and-Obesity Vector-Roadmap

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

Obesity has become a global problem among youngsters. Childhood obesity may be associated with severe physical, psychological and social consequences, which may be due to socioeconomic disparity among different strata of society. The condition is a precursor to adult obesity and diabetes. Hence, it is utmost significance to diagnose the condition at an early stage to plan and to implement efficient and effective intervention strategies.

In the absence of a universally agreed definition of childhood obesity, it becomes difficult to deal with the problem, as it is not possible to decide which group of youngsters to treat and which not to treat.

In this work, a recently proposed mathematical relationship is investigated for possible validation based on anthropometric data collected indigenously during 1998-2013.

DEFINITIONS OF CHILDHOOD OBESITY

Obesity develops when there develops an imbalance between intake and output of energy, which disturbs the original steady state and results in formation of a fresh steady state at a higher level, resulting in increased body-fat

[¶]Application of model proposed in PhD dissertation of the second author, registered from Department of Physics, University of Karachi, under supervision of the first author

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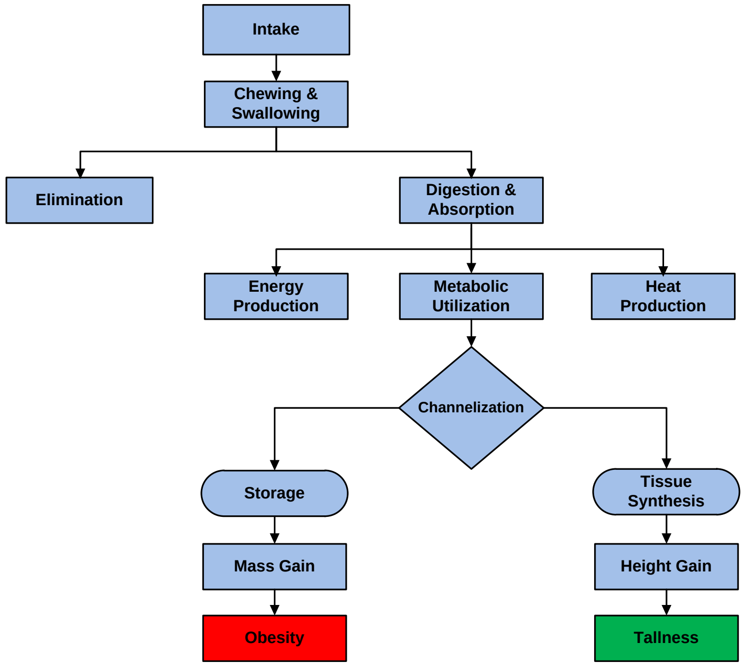

Fig. 1. Childhood obesity may be managed through a delicate balance between storage (mass gain resulting in 'obesity') and tissue synthesis (height gain resulting in 'tallness')

storage (Wabitsch, 2000). The fragile balance between tissue synthesis (height gain) and fat storage (mass gain) must be mathematically modeled to understand the mechanism of obesity (Figure 1). Height gain could be understood on the basis of impulse-response model (Figure 2). Growth-hormone and sex-hormone releases trigger phase transitions from infancy-to-childhood and child-hood-to-puberty, respectively, resulting in rapid gain of height. According to Poskitt (1995), representing European Childhood Obesity Group (ECOG), non-availability of a proper definition of childhood obesity is a matter of concern for researchers. A relative *BMI* (body-mass index) may be taken as *BMI* of a 50th *centile* youngster — *BMI* (Keys *et al.*, 1972) is obtained from the expression $\frac{\mu}{h^2}$ (μ represents mass in *kg* and *h* height in *m*). In a subsequent work, Poskitt (2000) observes that the concept of relative *BMI* has been largely accepted despite considerable imprecision in defining obesity. In a 2001 paper, she declares that *BMI* can not be visualized as offering the 'best' definition, although it might be accepted as the most 'useful' and 'practical' one for clinical, epidemiological and population-research purposes (Poskitt, 2001). She, further, asserts that work on definition is necessary and needs continuing reassessment, although one cannot wait for the perfect definition. Cole *et al.* (2000) defines childhood obesity on the basis of pooled-international data. He links childhood obesity to adult-obesity-cutoff point of *BMI* to be 30 kg/m^2. Flegal *et al.* (2010) divided *BMI*-for-age categories into three ranges**:** 'normal' (*most unlikely* to have high adiposity), 'intermediate' and 'high' (*most likely* to have high adiposity). Rolland-Cachera *et al.* (2011), on behalf of ECOG, defined three main cutoffs of *BMI* distribution status from the age of 5 *years*, constituting four ranges**:** 'thin', 'normal', 'overweight' and 'obese'. Zhao and Grant (2011) are of the opinion that obesity involves interactions between genetic and environmental factors, identifying obesity as excess of body fat. Skinner and Skelton (2014) use *BMI* percentiles to define overweight (*BMI* greater than 85th percentile) and obesity (*BMI* greater than 95th percentile) in children. Al-Gindan *et al.* (2015) remark that *BMI* remains the most common method for classifying fatness and thinness, despite having a weaker correlation with body-fat content. Ogden *et al.* (2016) are of the opinion that *BMI* is an imperfect measure of health risk and body fat. The main argument is that there are ethnic and racial differences in body fat at the same *BMI* level. Further, the definition of obesity, among children, is purely statistical.

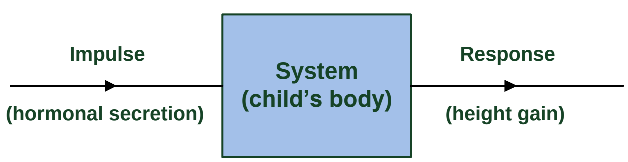

Fig. 2. Impulse-response model

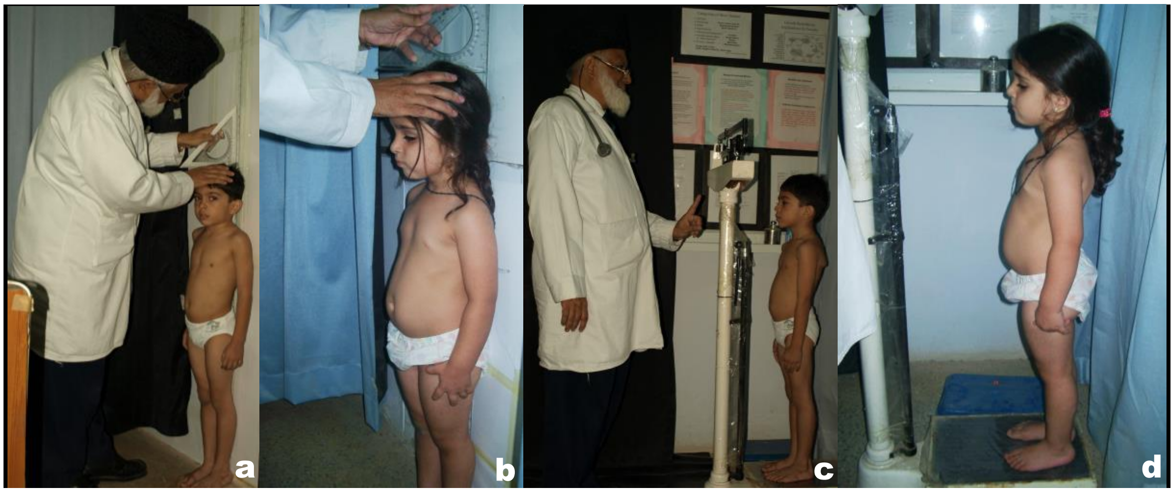

Fig. 3*a-d*. Height and mass measurements performed in SF-Growth-and-Imaging Laboratory

THE NGDS PILOT PROJECT

The NGDS (National Growth and Developmental Standards for the Pakistani Children) Pilot Project was initiated in 1998 under the directives of Chancellor, University of Karachi/Governor Sindh. It complies with the applicable ethical and human-right protocols (Kamal *et al.*, 2002). Appendix A summarizes these protocols.

Project Protocols

The NGDS Pilot Project was conducted in 4 representative schools (one civilian and one each operated by Pakistan Army, Pakistan Navy and Pakistan Air Force). 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. The checkups are conducted giving due regard to participants' comfort, confidentiality, dignity, privacy and safety. Additional File 1 (http://www.ngds-ku.org/Papers/J46/Additional_File_1.pdf) gives details of the checkup protocols.

Anthropometric Techniques

Heights, h, and masses, μ, were measured by reproducible anthropometrists as per laid-down procedures (Kamal *et al.*, 2013) given in Additional File 2 (http://www.ngds-ku.org/Papers/J46/Additional_File_2.pdf), abbreviated from the detailed description appearing in the official manual of the NGDS Pilot Project (Kamal, 2006) to least counts of 0.1 *cm* (1998-2011, setsquare set); 0.01 *cm* (2012-2015, Vernier scale — Kamal, 2010); 0.005 *cm* (2016-present, enhanced-Vernier scale — Kamal *et al.*, 2016*b*) and 0.5 *kg* (1998-2011, bathroom scale); 0.01 *kg* (2012-2015, modified-beam scale — Kamal, 2010); 0.005 *kg* (2016-present, enhanced-beam scale — Kamal *et al.*, 2016*b*), respectively, before 12 o'clock, with the children totally stripped except briefs or panties (Figure 3). The measuring instruments were calibrated at the start of each daily session and zero errors subtracted from the measured values. Complete undressing ensured that the measurers were able to ascertain proper posture (elbows and knees not flexed, Frankfort horizontal/auriculo-orbital plane parallel to floor, heels/toes not lifted, feet together for height measurement/feet apart for mass measurement) and complete inhaling (assists in assuming upright posture).

Modeling of Childhood-Obesity Problem by the NGDS Team

Childhood-obesity modeling started in 2002. Below is given a summary of various models developed in SF-Growth-and-Imaging Laboratory**:**

*KFA Model***:** KFA (Kamal-Firdous-Alam) model assumed that height and mass curves behaved linearly provided the measurements were conducted with a span of half-a-year — this supposition was reasonable for a large portion of the ICP curve (Kamal *et al.*, 2002; 2004). There were exceptions in the regions where phase transitions (infancy to childhood, childhood to puberty) occurred, identified by a rapid change in growth rate. For all the other regions, linear interpolation was employed to evaluate height at a certain age grid. Adult-Mid-parental (Target) heights for females and males were computed and desired heights at reference age grids were determined by the technique of backward extrapolation.

*KJR Model***:** KJR (Kamal-Jamil-Razzaq) model (Kamal *et al.*, 2014*b*) was extended from KFA model (Kamal *et al.*, 2004). This model was based on 'Growth-and-Obesity-Moving Profiles' of youngsters. Real-time data were used

September 4, 2013	1st-Generation Solution of Childhood Obesity (Kamal *et al.*, 2013*d*)
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)

Fig. 4. Solutions of childhood-obesity problem proposed in SF-Growth-and-Imaging Laboratory, University of Karachi

to generate moving profiles. The concepts of height (growth) velocity and mass-gain (-loss) rate were replaced by trajectories representing height and mass. The model introduced the concepts of pseudo-gain of height/mass (physical gain accompanied by drop in percentile) and energy channelization (coexistence of stunting and obesity, coexistence of tallness and wasting).

KJK Model: KJK (Kamal-Jamil-Khan) model (Kamal *et al.*, 2011) gave a snapshot of growth- and-obesity statuses of a child in terms of 'Growth-and-Obesity Profiles' of the entire family on the basis of a single check up. The model defined 'height-percentile-based-optimal mass', μ_{opt}, such that percentile of optimal mass matches height percentile. Further, the model used only two terms 'obese' and 'wasted', in place of a number of terminologies, namely, 'fat', 'overweight', 'obese', 'lean', 'underweight', 'wasted'. The model evaluated height and percentiles of a youngster using a new mathematical-statistical technique, 'box interpolation'. The model introduced 'status (pertaining-to-mass)' to describe severity of wasting or obesity in the form of percentage and 'status (pertaining-to-height)' to describe the extent of stunting or tallness in the form of percentage.

KJ Model: The models described above are unable to generate 'Growth-and-Obesity Profiles' of a family in which the parents are still growing, *i. e.*, the mother (father) has not reached her (his) 19th (21st) birthday. KJ (Kamal-Jamil) model addresses this problem (Kamal and Jamil, 2012). Height percentiles of mother and father were evaluated using box interpolation. The model introduced 'estimated-adult *BMI*', which provided a rough estimate of stunting or obesity at the age of 20 *years*. The model highlighted the consequences of underage marriages on the health of young female and her offspring from physiological and psychological perspectives and discussed such marriages from the perspectives of biology, control theory and physics. The work differentiated between 'age of puberty' and 'age of marriage'.

KJ-Regression Model: KJ-Regression model has proposed methods to compute optimal masses of youngsters and adults, whose heights and masses fall below 3rd percentile or above 97th percentile (Kamal and Jamil, 2014). The model was able to generate 'Extended CDC (Centers for Disease Control and Prevention) Growth Tables' and 'Extended CDC Growth Charts', which included height and mass values for 0.01th to 3rd percentiles using linear interpolation as well as height and mass values for 97th to 99.99th percentiles using sigmoid function.

Solutions of Childhood-Obesity Problem Proposed by the NGDS Team

During 2013-2017, 1st- to 5th-generation solutions of childhood obesity were proposed (Figure 4). 1st- to 3rd-generation solutions are summarized in Kamal (2015*c*). Below are the main highlights of the attempted solutions**:**

Growth-and-Obesity Scalar-Roadmaps: These are generalization of ''Growth-and-Obesity-Moving Profiles' (Kamal *et al.*, 2014*b*). The word 'moving profile' was borrowed from 'moving average', a terminology in statistics, and propagated the concept from the 'snap shot' health status to a 'time series' giving 6-*month* average (Kamal *et al.*, 2004). The doctors are more interested in such indicators these days. An example could be cited from blood work of a patient. The blood glucose, fasting and random, is not as reliable as HBA_1C. Growth-and-Obesity Scalar-Roadmaps give month-wise height- and mass-management goals for the next 6 *months* based on reference height at the end of 6-*month* period, corresponding to reference percentile taken as the maximum of percentiles of army-cutoff height, mid-parental height and measured height (Kamal *et al.*, 2015). See Appendix A for explanation.

Growth-and-Obesity Vector-Roadmaps: 'Growth-and-Obesity Vector-Roadmaps' (Kamal *et al.*, 2016*a*) have entries identical to 'Growth-and-Obesity Scalar-Roadmaps' for the ages during which actual checkups are conducted. The main difference is in height- and mass-management goals. These goals are computed by fitting a parabolic curve to desired trajectories of height and mass originating at the age of most-recent checkup and terminating at the reference age, taken as 10 *years*, lower limit of the peripubertal phase (defined as the age, when the child is about to enter puberty, marked by rate of height gain approaching zero), in such a way that slope of desired trajectory matches with the reference trajectory (both slopes vanish, reference trajectory becomes tangent). Such a mechanism generates softer targets, which are easier to achieve. The end result is that correction is achieved

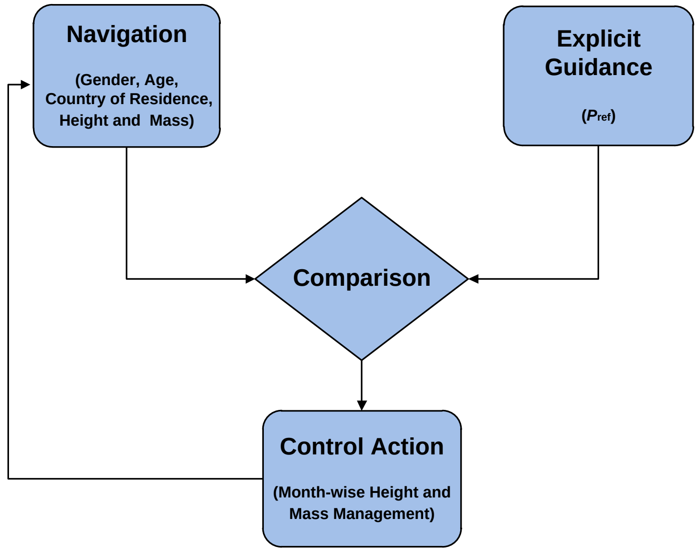

Fig. 5. Navigation, guidance and control loop applied to the problem of childhood obesity

by the end-of-childhood phase. Navigation, guidance and control loop, which forms the basis of 'Growth-and-Obesity Vector-Roadmap', is shown in Figure 5.

*Sample Vector-Roadmap***:** Appendix B outlines procedures of generating Growth-and-Obesity Scalar- and Vector-Roadmaps. Sample Vector-Roadmap of a child, classified as obese (M.E./SGPP-KHI-20100421-03/01), is given in Tables 1*a*, *b*. Step-by-step calculations of this Vector-Roadmap are given in Additional File 3 (http://www.ngds-ku.org/Papers/J46/Additional_File_3.pdf). Guidance, navigation and control-action trajectories are shown in Figure 6.

*Software to Generate Growth-and-Obesity Vector-Roadmap***:** Growth-and-Obesity-Vector Roadmap Software, named as SOFTGROWTH2, was developed and tested to generate reports for the students of a local school, participating in the study. The software was developed in Microsoft Visual Studio (Visual Basic Dot Net 2008). Salient features of SOFTGROWTH2 are listed below (block diagram and flow chart of SOFGROWTH2 are shown in

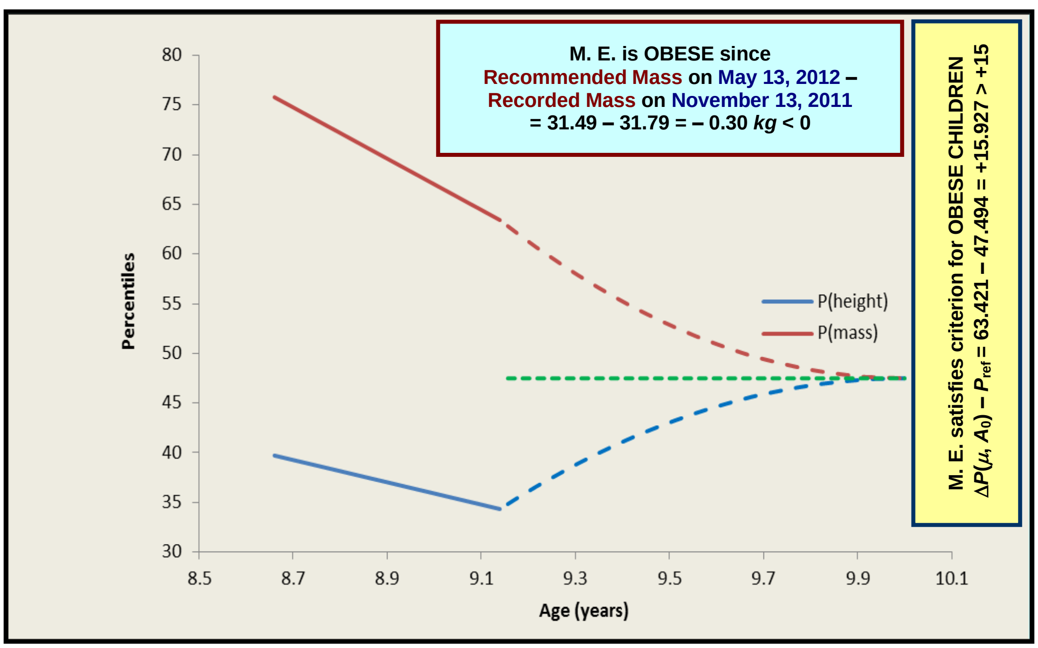

Fig. 6. Time evolution height and mass percentiles of M. E. for her two checkups in the age range 8.66-9.14 *years* (navigational trajectories**:** solid curves), including the desired course-of-action (guidance trajectory**:** green-dashed line) and recommended intervention (control action**:** blue-dashed for height-percentile curve and maroon-dashed for mass-percentile curve)

Table 1*a*. Growth-and-Obesity Vector-Roadmap 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*)	8.66	9.14
Dress Code	0/0.5	0/0.5
Behavior Code	0	0
Height, *h* (*cm*)	129.50[£]	131.00[£]
Height (*ft-in*)	4 *ft* 2.98 *in*	4 *ft* 3.57 *in*
Percentile-of-Height, *P*(*h*)	39.73[£]	34.33[£]
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_{ref}[∀]	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*
Percentile-of-Net-Mass, $P(\mu)$	75.79	63.42
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**
Percentile-of-*BMI*-based-Optimal-Mass, $P(\mu_{BMI})$	64.46	62.05
$\Delta P = P(\mu_{BMI}) - P(h)$[Ø]	+24.74	+27.71
BMI-based-Optimal-Mass, μ_{BMI} (*kg*)	30.03	31.56
$\Delta\mu(kg) = \mu_{BMI} - \mu_{opt}$[Ø]	+3.46	+4.11
Estimated-Adult *BMI* (kg/m^2)	25.43	24.16
Nutritional Status	**EC II**[⊆]	**EC II**
$P(h) + P(\mu)$	115.51	97.76
Build	**Medium**	**Medium**

[§]The superscript P stands for percentile.
[£]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).
[∀]See appendix for explanation of reference height and percentile-of-reference-height.
[Ø]The difference of *BMI*-based-optimal mass and height-percentile-based-optimal mass as well as the corresponding percentiles is included in Growth-and-Obesity Vector-Roadmap of M. E. to give an idea of magnitudes of these masses and their percentiles — compare with Table A1*a* of Kamal (2017).
[⊆]Energy-Channelization II (Kamal *et al.*, 2014*b*)

Table 1*b*. Month-wise targets determined using Growth-and-Obesity Vector-Roadmap for M. E. based on her last checkup[@]

Date of Last (*Second*) *Checkup* (*year-month-day*)**:** 2011-11-13 • *Decimal Age*, A_0 = 9.139726027 *years*
P_{ref} = 47.49439769505168 • $P(h, A_0)$ = 34.33112094538 • $P(\mu, A_0)$ = 63.421313127254

Target Date	$P(h)^{\Sigma}$	*Height Target*		$P(\mu)^{\Sigma}$	*Mass Target*	
		cm	*ft-in*		*kg*	*lb-oz*
December 13, 2011	36.7317573114	131.80	4 *ft* 3.89 *in*	60.5233369020	31.64	69 *lb* 12.17 *oz*
January 13, 2012	38.9507195795	132.59	4 *ft* 4.32 *in*	57.8371257620	31.52	69 *lb* 7.93 *oz*
February 13, 2012	40.9109422021	133.33	4 *ft* 4.49 *in*	55.4641373064	31.44	69 *lb* 5.11 *oz*
March 13, 2012	42.5136569503	134.00	4 *ft* 4.76 *in*	53.5239374786[¥]	31.40[¥]	69 *lb* 3.83 *oz*
April 13, 2012	43.9801337595	134.66	4 *ft* 5.02 *in*	51.7486633344[¥]	31.42[¥]	69 *lb* 4.51 *oz*
May 13, 2012	45.1564444151	135.29	4 *ft* 5.26 *in*	50.3246558907[¥]	31.49[¥]	69 *lb* 7.00 *oz*

[Σ]Percentiles-of-height and -mass, $P(h)$ and $P(\mu)$, added to provide easy comparison with output screen shown in Figure 8*b* — compare with Table A1*b* of Kamal (2017).
[@]Lifestyle adjustment, diet and exercise plans to achieve these goals are prepared and placed in Additional File 4 (http://www.ngds-ku.org/Papers/J46/Additional_File_4.pdf). These are prepared based on the guidelines proposed earlier (Kamal *et al.*, 2013*a*; *b*; *c*).
[¥]4th- and 5th-*month* as well as 5th- and 6th-*month* recommendations exhibit pseudo-gain of mass (Kamal *et al.*, 2014*b*) — in the first case there is a mass gain from 31.40 *kg* to 31.42 *kg* with percentile drop from 53.52 to 51.75, whereas in the second case there is a mass gain from 31.42 *kg* to 31.49 *kg* with percentile drop from 51.75 to 50.32.

Figures 7*a*, *b*)**:**

a) Input data could be entered manually or read through text file.
b) Data were validated (no undefined or out-of-bound values).
c) Age was calculated and interval identified, $A \geq 30$ *years*, 20 *years* $\leq A < 30$ *years*, $A < 20$ *years*, (A represented age in *years*).
d) If $A \geq 30$ *years*, optimal mass was calculated using standard *BMI* (*i. e.*, 24 kg/m^2).
e) If 20 *years* $\leq A < 30$ *years*, Obesity Profile was generated by using linear interpolation.
f) Month-wise recommendations were generated to put on/lose mass (weight).
g) For $A < 20$ *years*, Growth-and-Obesity Profile was generated by using box-interpolation technique.

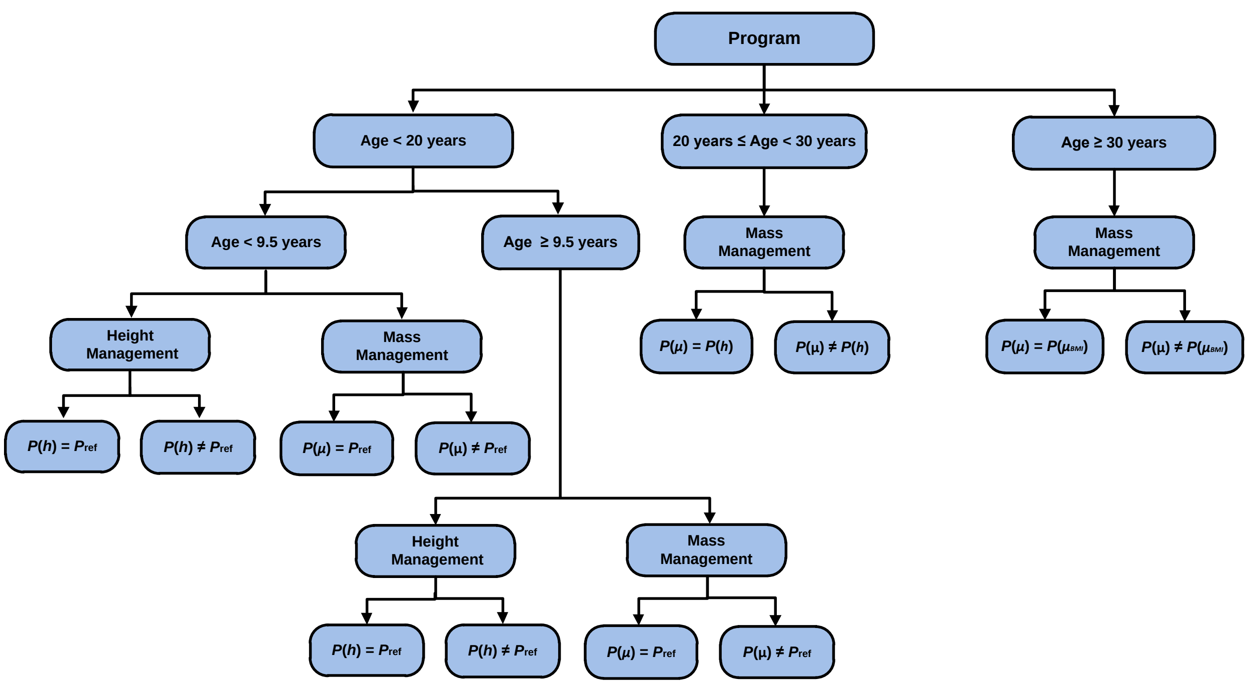

Fig.7*a*. Block diagram of software

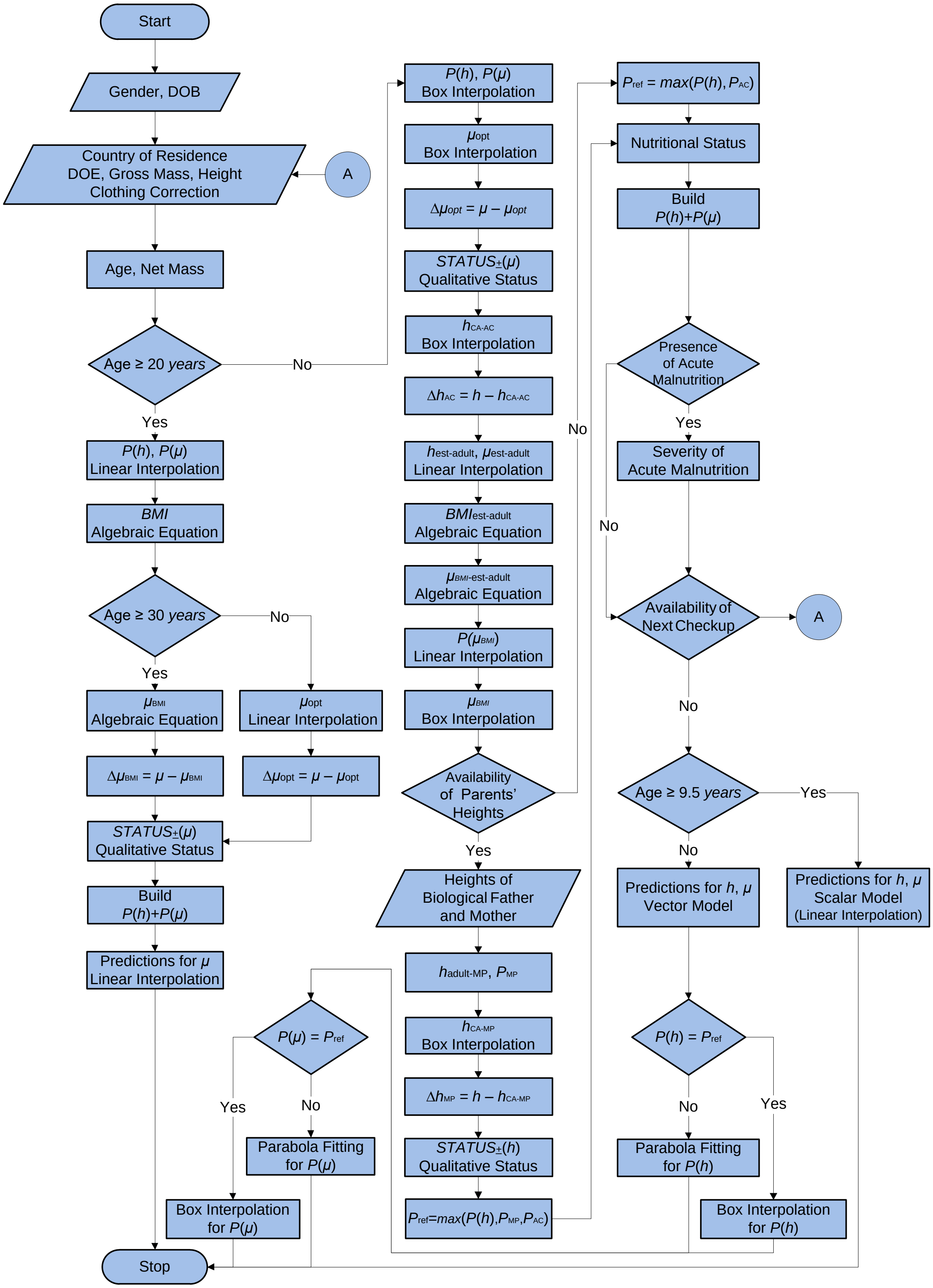

Fig. 7*b*. Flow chart of software

- When heights of parents were available, the software generated Growth-and-Obesity Profile and reference percentile was calculated as maximum of the percentiles of height, mid-parental height and army-cutoff height.

- When heights of parents were not available, only Obesity Profile was generated and reference percentile was calculated as maximum of the percentiles of height and army-cutoff height.
- In both of the above, nutritional status and build were calculated.
- When AM (acute malnutrition) was present, 'Severity of Acute Malnutrition' was, also, calculated.

h) For $A < 9.5 years$, the software was able to compare percentile of height, $P(h)$, and percentile of mass, $P(\mu)$, with reference percentile, P_{ref}.

- When percentile of height, $P(h)$, matched with reference percentile, P_{ref}, percentile of height, $P(h)$, was calculated by box interpolation. Otherwise, the software fitted parabolic curve to calculate percentile of height, $P(h)$, for height management. Same procedure was applied to percentile of mass depending on match with reference percentile.

i) Month-wise recommendations for children were generated to gain height and put on/lose mass (weight).
j) Output was displayed on screen as well as stored in data file.
k) Software generated detailed report in MS-word.

Screenshots of front end and result generated are shown in Figures 8*a*, *b*. Algorithm of the software is given in Additional File 5 (http://www.ngds-ku.org/Papers/J46/Additional_File_5.pdf). Appendix C lists a description of additional resources available to understand this work.

Definitions of Childhood Obesity Proposed by the NGDS Team

Childhood 'true obesity' was defined as the condition in which a child was required to lose net mass at the end of 6-*month* period as compared to current mass based on 'Growth-and-Obesity Vector-Roadmap' recommendations (Kamal, 2016). A mathematical criterion was proposed according to which a child should be classified as obese if the difference of incumbent's percentile of mass at the most-recent checkup and the reference percentile exceeds +15 (Kamal, 2017).

POSSIBLE VALIDATION OF MATHEMATICAL DEFINITION OF CHILDHOOD OBESITY

Growth-and-Obesity Vector-Roadmaps of 1183 children (302 boys, 881 girls, mean age 8.08 *years*, standard deviation 2.23 *years*) were generated using SOFTGROWTH2. Anthropometric data were collected during 1998-2013

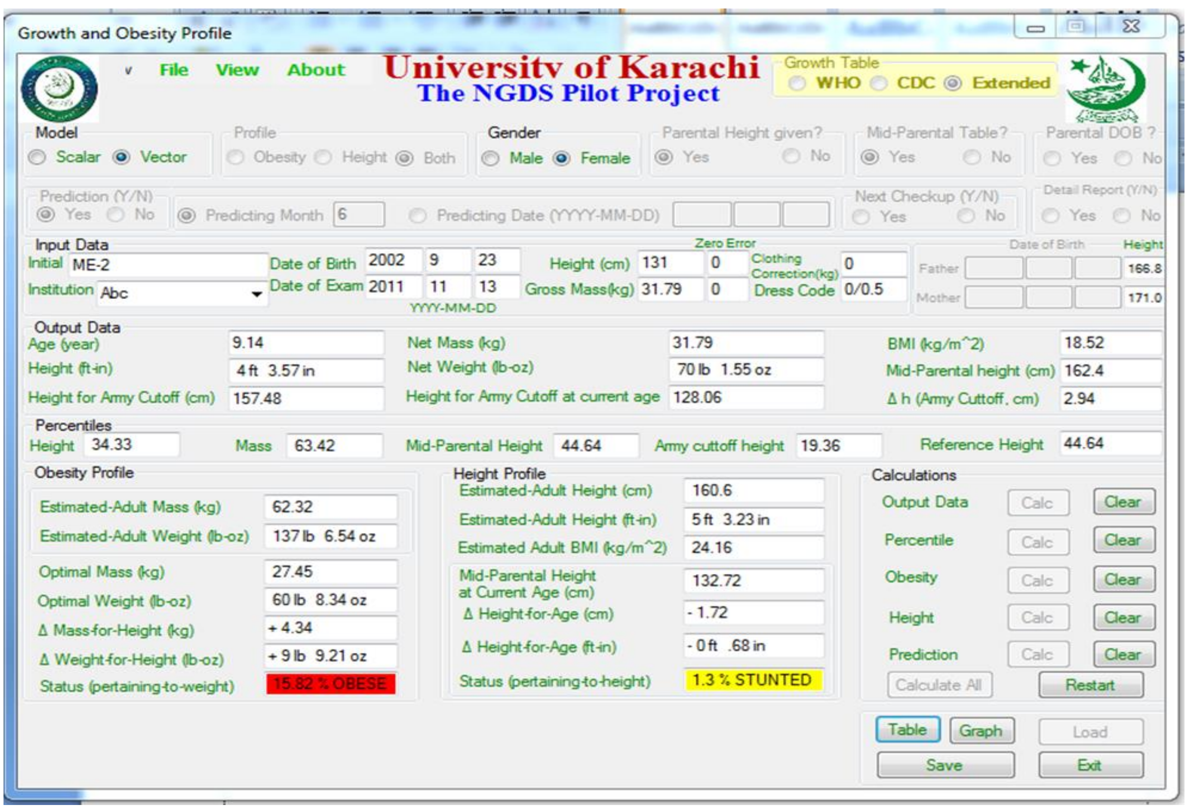

Fig. 8*a*. Screenshot of front end of software (2nd checkup of M. E. processed)

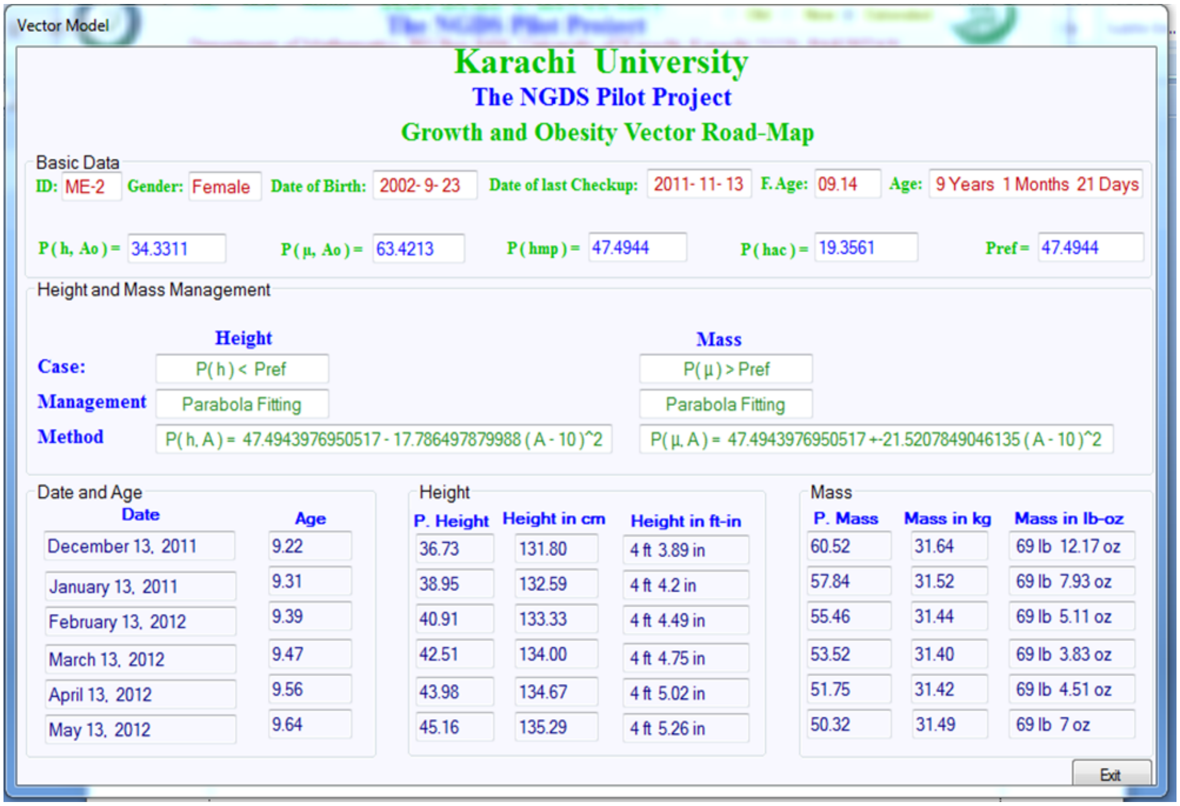

Fig. 8*b*. Screenshot of results generated from software (2^{nd} checkup of M. E.)

based on convenience sampling drawn from Army Public School, 'O' Levels, Bahria College, NORE I, Fazaia (PAF) Degree College, Faisal and Beacon Light Academy, all of them located in Karachi, Pakistan.

The data were classified into three categories, difference of percentiles of mass at the most-recent checkup and the reference percentile negative, between zero and +15, exceeding +15. In each of these categories, number of children recommended to lose mass, maintain the same mass, gain mass within the next 6 months were determined. The parameter +15 was varied and data analyzed again to determine the best threshold value of difference for efficient and effective classification of obesity.

RESULTS AND DISCUSSION

Results are summarized in Table 2. Out of 124 children, 28 showed true obesity, whereas 186 needed to gain weight within the next 6 *months*. Hence, the criterion $\Delta P > +15$ correctly predicts 'true obesity' in 22.58% of cases.

Table 2. Analysis of data to determine the number of children, who could be classified as obese or wasted

$\Delta P = P(\mu, A_0) - P_{\text{ref}}$	*Number of Children*	$\Delta\mu = \mu(A_0 + 6 months) - \mu(A_0)$		
		Negative[#]	*Zero*	*Positive*
$\Delta P > +15$[∃]	**124**	**38**	**0**	**186**
$0 < \Delta P \le +15$[Ξ]	135	8	0	127
$\Delta P \le 0$[Ω]	924	0	0	924
Total	1183	46	0	1137

[#]'True obesity'
[∃]Criterion to classify a child 'obese' as suggested in (Kamal, 2017)
[Ξ]Suggested criterion to classify a child in the category to monitor for obesity or wasting
[Ω]Suggested criterion to classify a child as wasted — 'true wasting' defined as the condition in which is child is recommended, *not only*, to gain mass, *but also*, climb on the trajectory of percentile-of-mass within the next 6 *months*

Data were re-run after varying the parameter, +15. However, these re-runs indicated no improvement in obesity prediction.

The management of childhood obesity may be visualized as a problem of energy-channelization by establishing balance between 'storage', (resulting in weight gain and subsequent obesity, if not associated with an equivalent pick up in height) and 'tissue synthesis' (resulting in height gain/tallness, which may end up making the child wasted if not accompanied by an equivalent weight put on), as shown in Figure 1. Optimal-mass management could be achieved through dynamical-system approach (Kamal *et al.*, 2016*a*) or optimization approach — optimal solution of lifestyle adjustment combined with appropriate diet and exercise plans (Kamal, 2015*b*; Kamal *et al.*, 2014*b*). There are indica-tions that childhood obesity influences pubertal height-gain (Holmgren *et al.*, 2017). Quality of life improvement was observed during commu-nity-based overweight and obesity treatment (Mollerup *et al.*, 2017). A structured fitness (Kamal and Khan, 2013) and physical education (Kamal and Khan, 2014) program is essential to improve body image in children. However, prior to enrolling in such a program, the child should be subjected to a thorough psychological and physical examination combined with (health-related + skill-related) fitness testing (Kamal *et al.*, 2017*a*).

FUTURE DIRECTIONS

A number of areas related to childhood obesity need further investigation. There is a need to deeply understand *BMI* (Apell *et al.*, 2011), estimated-adult *BMI* (Kamal and Jamil, 2012), *BMI*-based-optimal mass (Kamal, 2017) and height-percentile-based-optimal mass (Kamal *et al.*, 2004; 2011). The two optimal masses need to be integrated for the purpose of generating optimal-mass management targets within the next 6 *months* based on recommendations of Growth-and-Obesity Vector-Roadmap (Kamal *et al.*, 2016*a*).

The definition of 'true wasting' needs to be related to difference of percentiles of mass at the most-recent checkup and the reference percentile. Suggested criterion to classify a child as wasted, when the reference percentile exceeds percentile of mass at the most-recent checkup, needs to be investigated to determine the number of children, who are recommended to gain mass as well as increase their mass percentile, over a period of half-a-*year*.

Already known on this topic

Childhood obesity a significant concern for public health

Obesity a complicated disease, which is influenced interactions between genetic and environmental factors

The true prevalence of childhood obesity not easy to quantify as there is currently lack of an internationally-accepted definition

BMI still the most popular method of categorizing thinness and fatness

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)

2012 Estimated-adult *BMI*

2013-2017 1st- to 5th-generation solutions of childhood obesity

2014 Energy-channelization I-III; pseudo-gain of mass and height; use of percentile trajectories of height and mass instead of growth (height) velocity and 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

This work adds

Validates mathematical definition of childhood obesity based on anthropometric data collected during 1998-2013 — A child is considered obese if the incumbent is recommended to lose net mass (weight) within the next 6 *months;* this happens when the difference of percentile of mass exceeds reference percentile (maximum of percentiles of measured height, mid-parental height and army-cutoff height) by 15

Proposes definition of 'true wasting' — A child is considered truly wasted if the youngster is suggested, *not only*, to gain mass, *but also*, to climb on percentile-of-mass trajectory within the next half-a-*year*

The next step

Validation of proposed mathematical definition of childhood wasting based on anthropometric data collected during 1998-2013 by the NGDS Team

Integration of height-percentile-based-optimal mass with *BMI*-based-optimal mass to propose smarter criteria for optimal-mass management

Mathematical criteria to classify normal, early, delayed and precarious puberty through scaled percentiles (based on the Pakistani standards)

Assignment of approximate Tanner scores to prepubertal, peripubertal, pubertal, adolescent and adult stages

A real understanding of childhood obesity cannot be achieved in peripubertal children because of associated puberty-induced energy-channelization, also termed as energy-channelization III (Kamal, 2014; Kamal and Jamil, 2014), in which a temporary drop in height percentile is accompanied by jump in mass percentile, as the child enters puberty. It becomes imperative that prepubertal, peripubertal, pubertal, adolescent and adult stages should be assigned approximate Tanner scores for puberty rating (Tanner, 1962).There is, also, a need to propose mathematical-statistical classification of normal, early, delayed and precarious puberty, so that a youngster should not be wrongly classified as experiencing precarious puberty. In peripubertal children, puberty rating should be conducted at every checkup (Kamal *et al.*, 2017*a*) and must be mentioned on graph of Growth-and-Obesity Vector-Roadmap (Figure 6).

CONCLUSION

This work tried to validate mathematical definition of childhood obesity proposed at the start of this year by comparing with the logical definition put forward last year. Software was developed to analyze the data. The work, also, proposed a criterion for 'true wasting', in which a child is suggested to gain net weight during the next half-a-*year* in such a way that mass percentile at the end of 6 *months* exceeds the value of mass percentile at the most-recent checkup. The authors hope that this effort helps in designing programs of management of childhood obesity resulting in improved psychological, physical and intellectual states of the leaders of tomorrow.

APPENDIX A: COMPLIANCE WITH ETHICAL STANDARDS

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

*Institutional Review***:** In 1998, the NGDS Pilot Project started under of directives of Chancellor, University of Karachi (Governor Sindh) after going through all the formalities of the institutional review process. The project protocols were prepared after taking into consideration North American and European, ethical and human-right standards. Details are given in Additional File 1.

*Informed Consent***:** For school studies, 'The Informed Consent Form' was employed, which was based on opt-in policy. This form is part of Additional File 1 and can, also, be downloaded from**:**

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

For detailed checkups in SF-Growth-and-Imaging Laboratory, 'The SGPP Participation Form' was used. This form is included in Additional File 1 as well as at the address**:** http://www.ngds-ku.org/SGPP/SGPP_form.pdf. Both forms required signatures of each parent as well as participating children. At the beginning of examination, verbal permission was obtained from the examinees and the attending parent(s).

*Privacy, Confidentiality, Comfort and Safety***:** Both acoustic as well as visual privacy was ascertained in SF-Growth-and-Imaging Laboratory. Initials of child included in this work and Additional File 3 do not correspond to first letters in her real name (as per confidentiality standards established by the NGDS Team). Same is true about case number as well as pictures of child appearing in the main document and the supplementary appendix. Comfort of patients was given due consideration. Although, both father and mother were encouraged to attend checkups to give history and share progress, same-gender parent was preferred to be present at the unclothed physical examination in the curtained-off area for utmost comfort of the youngster. Before checkups, school-checkup-room floor was mopped and sharp objects removed from floor. Chairs/benches were checked for sharp edges of wood/metal as well as both boundaries of the mounted engineering tape to safeguard abrasions and cuts of skin. In SF-Growth-and-Imaging Laboratory, the entire floor was black-tiled, street shoes were not allowed for anyone, floor mopped with dettol (chloroxylenol)-mixed water. Thermometer bulbs, when not in use, remained dipped in dettol-mixed water. Hand washing/sanitization was compulsory at the start of each checkup. Health professionals and anthropometrists were required to remove hand-worn chains, rings and wristwatches to prevent injury to children.

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

APPENDIX B: METHOD OF GENERATING GROWTH-AND-OBESITY VECTOR-ROADMAP

*Dress Code***:** Measurements, examinations and observations were effected by the nature and the amount of clothing present on a child or an adult. Dress code was entered with the findings (descriptive or quantitative) as a fraction, numerator (denominator) representing clothing superior (inferior) to transverse plane passing through the naval. A dress code 0/0.5 meant that a child was measured completely undressed wearing only short underpants.

*Behavior Code***:** Behavior code was ‘0’, when the child was relaxed and coöperative, ideal for taking measurements. However, the measurements could, also, be taken when behavior code was ‘1’, meaning the youngster was timid and shy, but coöperative. The measurements obtained, when behavior code was ‘2’ were not reliable and must be repeated. This behavior code represented a resistant and a nagging individual.

Dress code and behavior code are explained in Kamal *et al.* (2002) and Kamal (2006). As all children are weighed wearing only briefs or panties, their ‘net masses’ are taken to be equal to ‘gross masses’ (clothing correction negligible).

*Extended CDC Growth Charts and Tables***:** These charts and tables contained heights and masses of boys and girls corresponding to 0.01^{th}, 0.1^{th}, 1^{st}, 99^{th}, 99.9^{th} and 99.99^{th} percentiles, in addition to values given in CDC Growth Charts and Tables (Kamal and Jamil, 2014).

*Children's Growth-and-Obesity Profiles***:** Percentiles of MP (mid-parental), P_{MP}, as well as AC (army-cutoff) height, P_{AC} were determined using age-20-height values of Extended CDC Growth Tables employing the technique of ‘linear interpolation’. P_{MP} was the percentile corresponding to gender-specific-adult-mid-parental (target) height (in *cm*) given by $h_{\mathrm{MP}} = \dfrac{h_{\mathrm{F}} + h_{\mathrm{M}}}{2} \pm 6.5\ cm$, where h_{F} and h_{M} were heights of father and mother measured in *cm*; + sign taken for boys' target height; – sign for girl's target height. For the Pakistani males, P_{AC} (Kamal *et al.*, 2017*b*) comes out to 2.718014592103645…, corresponding to cutoff height 5 *ft* 4 *in* (162.56 *cm*), whereas for the Pakistani females the value is 19.35609323536863…, corresponding to cutoff height 5 *ft* 2 *in* (157.48 *cm*). Child's percentiles of height, $P(h)$, and mass, $P(\mu)$, were evaluated by the technique of ‘box interpolation’ (Kamal *et al.*, 2011). ‘Linear interpolation’ was employed to compute estimated-adult height, $h_{\mathrm{est-adult}}$, and mass, $\mu_{\mathrm{est-adult}}$, using the computed percentiles of height and mass as well as age-20 values. These values were substituted in the expression, $\dfrac{\mu_{\mathrm{est-adult}}}{h^2_{\mathrm{est-adult}}}$, $h_{\mathrm{est-adult}}$ in *m*, to compute estimated-adult *BMI*. Constant-age route was followed to compute height-percentile-based-optimal mass, μ_{opt}, and, subsequently, determine obesity profile.

‘*BMI*-based-Optimal Mass’, μ_{BMI}, for a growing child was computed in three steps. In the first step, ‘Estimated-Adult-*BMI*-based-Optimal Mass’ was evaluated using the expression $\mu_{\mathrm{BMI-est-adult}} = 24 h^2_{\mathrm{est-adult}}$, $h_{\mathrm{est-adult}}$ in *m*. In the second step, ‘Percentile for *BMI*-based-Optimal Mass’, $P(\mu_{\mathrm{BMI}})$, was estimated using linear interpolation applied to estimated-adult-*BMI*-based-optimal mass. In the third and the final step, box interpolation (Kamal *et al.*, 2011) was used to compute *BMI*-based-optimal mass at the given age.

A procedure similar to computing height-percentile-based-optimal mass was used to evaluate current-age-mid-parental height, $h_{\mathrm{CA\text{-}MP}}$. Algebraic status (pertaining-to-height), $STATUS_{\pm}(h)$, as well as algebraic status (pertaining-to-mass), $STATUS_{\pm}(\mu)$, computed and quantitative statuses (pertaining-to-height) and (pertaining-to-mass) were determined, nutritional status classified — AM**:** acute malnutrition $P(h) + P(\mu) < 6$ (see next paragraph); 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) $STATUS_{\pm}(h) > 0$, $STATUS_{\pm}(\mu) < 0$; EC II**:** energy-channelization II (stunting + obesity) $STATUS_{\pm}(h) < 0$, $STATUS_{\pm}(\mu) > 0$; EC III**:** energy-channelization III, also termed as puberty-induced energy-channelization (Kamal, 2015*b*) and built assigned — small $0 \le P(h) + P(\mu) < 50$; medium $50 \le P(h) + P(\mu) < 150$; big $150 \le P(h) + P(\mu) < 200$ (Kamal and Khan, 2015). For children suffering from acute malnutrition severity was computed using the equation (Kamal, 2015*b*)

$$Severity\ of\ Acute\ Malnutrition = 100\left(1 - \frac{P(h) + P(\mu)}{6}\right)$$

In this work, we are proposing a new definition of acute malnutrition, ‘a child is suffering from acute malnutrition if the sum of height and mass percentiles of the youngster falls below 6’, *i. e.*, $P(h) + P(\mu) < 6$, modified from the definition proposed earlier (Kamal and Jamil, 2014), which classified a child as acutely malnourished if the incumbent's individual height and mass percentiles each fell below 3, *i. e.*, $P(h) < 3$ and $P(\mu) < 3$.

*Children's Growth-and-Obesity Scalar-Roadmaps***:** Applicable in the age (A) range, $9.5\,years \le A < 20\,years$, one needs more than one checkup to construct ‘Growth-and-Obesity Scalar-Roadmap’, each checkup generating a profile. The percentile of reference height, P_{ref}, is given by the relation $P_{\mathrm{ref}} = \max(P(h), P_{\mathrm{MP}}, P_{\mathrm{AC}})$. Height-percentile-based-optimal mass, after 6 *months*, was computed based on estimated-reference height (6 *month* ahead in time scale). Recommendations to pick up height and gain or reduce mass (weight) were generated from the most-recent profile. Difference of measured height (current value) and reference height (after 6 *months*) was considered as guideline to set short-term goals to gain height within the next 6 *months*. Similarly, difference of measured mass (current value) and optimal mass (after 6 *months*) was considered as guideline to set short-term goals to gain (lose) mass within the next 6 *months*, if the value was negative (positive). Monthly recommendations to gain height or acquire (reduce) 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 from a rapid loss of mass.

6 recommendations (on date of checkup of each successive month) to achieve specific values of height and mass were obtained by linear interpolation taking the most-recent checkup and 6-*month*-down-the-road prediction as 2 fixed points. Note that linear interpolation is proposed in this work in contrast to dividing the 6-*month*-height or -mass gain into 6 equal parts, as presented in Kamal (2015*a*; *b*) and Kamal *et al.* (2015; 2016*a*; *b*). Linear interpolation gives better results as all 6 months do not have equal number of days.

*Children's Growth-and-Obesity Vector-Roadmaps***:** Applicable to children less than 9.5 *years* old, one needs to apply the concepts of navigational, guidance and control-action trajectories to generate 'Growth-and-Obesity Vector-Roadmap'.

The navigational trajectories for height and mass percentiles are obtained by fitting freehand curves to the respective height- and mass-percentile values, $P = P(h, A)$ and $P = P(\mu, A)$, respectively, the domain for navigational trajectory being $A_{\text{Enrolment}} \le A \le A_0$ ($A_{\text{Enrolment}}$ child's age at enrolment/first checkup, A_0 age at the most-recent checkup, when control action needs to be initiated). These trajectories are shown as solid-blue curve (navigational trajectory representing height) and solid-maroon curve (navigational trajectory representing mass) in Figure 6. The navigational trajectories are common for both Scalar- and Vector-Roadmaps.

Let $P(h, A_0)$ represent height percentile at the most-recent checkup. The guidance trajectory takes the form, $P = P_{\text{ref}}$, shown as green-dashed line in Figure 6, the domain for guidance trajectory being $A_0 \le A \le 10$ (10 *years* is the age, when control action is terminated).

A parabolic curve is fitted to generate trajectory of desired course-of-action, passing through A_0, the age when control action is initiated. It, smoothly, touches the guidance trajectory, $P = P_{\text{ref}}$, at the vertex $(10, P_{\text{ref}})$, in such a way that the guidance trajectory becomes tangent to parabola at this point. Percentile of height, *h*, and mass, μ, as a functions of age, *A*, take the form**:**

(A1*a*, *b*) $$P(h,A) = P_{\text{ref}}\text{; if } P(h,A_0) = P_{\text{ref}}\text{; } P(\mu,A) = P_{\text{ref}}\text{; if } P(\mu,A_0) = P_{\text{ref}}$$

(A2*a*, *b*) $$P(h,A) = P_{\text{ref}} - \left(P_{\text{ref}} - P(h,A_0)\right)\left(\frac{A-10}{A_0-10}\right)^2\text{, otherwise; } P(\mu,A) = P_{\text{ref}} - \left(P_{\text{ref}} - P(\mu,A_0)\right)\left(\frac{A-10}{A_0-10}\right)^2\text{, otherwise}$$

The recommendations for heights and masses are prepared by drawing lines parallel to the percentile (vertical) axis. Month-wise targets to pick-up height- and put-on/shed-off mass are determined by reading off values, where these desired course-of-action trajectories (dashed-blue and dashed-maroon curves, blue representing height trajectory, maroon mass trajectory) with lines parallel to the percentile axis, which is, actually, the vertical axis. These lines cross the age (horizontal) axis at the ages for which targets are proposed.

*Parents' Obesity Profiles***:** Percentiles of heights and masses of father and mother were determined by 'linear interpolation' from lesser and greater age-20 values of heights and masses read from extended-gender-specific tables. Algebraic and qualitative statuses (pertaining-to-mass) were calculated taking height-percentile-based optimal mass as reference if the parent's age fell in the range $20\,years \le A < 30\,years$. If the parent's age was above 30 years, *BMI*-based-optimal mass was taken as reference to compute statuses.

*Parents' Obesity Roadmaps***:** Father (Mother) was advised to put on mass (weight) corresponding to the difference obtained by subtracting net mass from reference mass, if the value of former was lesser than that of later (weight in *lb* and *oz* was obtained using the relations**:** 1 *kg* = 2.205 *lb*; 1 *lb* = 16 *oz*). In case, value of net mass was greater than optimal mass, father was suggested to lose mass corresponding to that difference, provided the value was under-10 *kg*, otherwise he should shed off 10 *kg* within the next 6 *months*. For expecting mothers, the recommendation to lose mass was computed by adding 5 *kg* to 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.

APPENDIX C: ADDITIONAL RESOURCES

Additional File 1 (http://www.ngds-ku.org/Papers/J46/Additional_File_1.pdf) contains description of institutional review process. This file explains the NGDS and the SGPP checkups as well as gives a virtual tour of SF-Growth-and-Imaging Laboratory.

Additional File 2 (http://www.ngds-ku.org/Papers/J46/Additional_File_2.pdf) outlines procedures of measurement of height and mass.

Additional File 3 (http://www.ngds-ku.org/Papers/J46/Additional_File_3.pdf) lists detailed calculations of Growth-and-Obesity Vector-Roadmap of M. E. (SGPP-KHI-20100421-03/01).

Additional File 4 (http://www.ngds-ku.org/Papers/J46/Additional_File_4.pdf) contains lifestyle adjustment, diet and exercise plans for children and their parents.

Additional File 5 (http://www.ngds-ku.org/Papers/J46/Additional_File_5.pdf) gives algorithm of the developed software.

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