

GENERATING AND VALIDATING GROWTH-AND-OBESITY ROADMAPS FOR THE PAKISTANI CHILDREN[¶]

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ABSTRACT

'Growth-and-Obesity Profiles' of a family gave percentiles of height, mass, optimal mass and status, indicating obesity or wasting as percentage, for all family members. Additionally, for children, target height, current-age-mid-parental height and status, indicating tallness or stunting as percentage, were calculated. To compute parents' obesity profiles, gender-specific heights and masses were used to interpolate respective percentiles using age-20 values. Either parent was suggested to gain mass, if optimal mass exceeded actual mass. In case, value of optimal mass was lesser than actual mass, father was advised to reduce mass corresponding to that difference, provided the value was less than 10 kilograms, otherwise he should shed off 10 kilograms within the next 6 months. For mothers, currently married or recently divorced/widowed, the recommended suggestion to lose mass was computed by adding 5 kilograms to their mass, to account for possible pregnancy and the associated fetal mass. Up to the age of 30 years, optimal mass was taken as the mass corresponding to height percentile. For individuals older than 30 years, body-mass index (BMI) was considered to be the reference, computed by dividing mass in kilograms by square of height in meters. Optimal mass was determined by multiplying square of height with the ideal BMI value (24 kilogram/meter²). Linear interpolation was employed to compute target-height percentile. Box interpolation was used to determine child's height/mass percentiles. A comparison of optimal mass with actual mass determined whether the child was wasted or obese. A similar procedure was adopted to compute current-age-mid-parental height. Comparison of child's height with gender-specific-mid-parental height at current age, indicated whether the child was tall or stunted. When more than one profile (each profile representing a checkup) was available, 'Growth-and-Obesity Roadmap' was generated. This roadmap included month-wise recommendations to pick up height and put on or lose mass (weight). These recommendations were generated from the most-recent profile, in such a way that a child was not required to lose more than 10 kilograms within the next 6 months, in order to avoid any adverse health effects from a rapid loss of mass.

Keywords: Optimal mass, wasting, stunting, tallness, estimated-adult BMI, energy channelization

LIST OF ABBREVIATIONS

cm: centimeter(s) • *m*: meter(s) • *ft*: foot(feet) • *in*: inch(es) • *lb*: pound(s) • *oz*: ounce(s) • *kg*: kilogram(s)
BLA: Beacon Light Academy, Gulshan-é-Iqbal, Karachi **SF**: The Syed Firdous Growth-and-Imaging
BMI: Body-Mass Index Laboratory, University of Karachi
MP: Mid-Parental **SGPP**: Sibling Growth Pilot Project — a subproject of
NGDS: National Growth and Developmental Standards the NGDS Pilot Project
for the Pakistani Children **WHO**: World Health Organization

INTRODUCTION

One of the areas, which is of prime concern in the current civilization is the maintenance of proper weight-for-height (Mozaffarain *et al.*, 2011), which acts as deterrent to many diseases (Ludwig, 2007) and ensures a better body image in teenagers (Lee *et al.*, 2013). Life expectancy is reduced by presence of obesity during childhood and adolescence (Fontaine *et al.*, 2003). On the other hand, wasting is shown to be related to, not only, depression at the individual level, but also, suicidal rates at the population level (Barker *et al.*, 1995). Communities, worldwide, have considered it a health priority to measure heights and weights of children to determine prevalence of obesity (Wilkand *et al.*, 2002; Barthel *et al.*, 2001) and maintain updated growth charts (Karlberg *et al.*, 1999). However, very few studies of this sort have been done in Pakistan. Some recent work by local researchers, *e. g.*, Ramzan *et al.* (2008), Aziz *et al.* (2012) and Mushtaq *et al.* (2012) is worth mentioning.

The WHO Child Growth Standards, released in 2006, depict normal growth under optimal environmental conditions and can be used, universally, to evaluate children. These standards are independent of ethnicity, socio-economic status and feeding type (WHO Multicentre Growth Reference Study Group, 2006a; b). De Onis *et al.* (2012)

[¶]Main contribution of PhD dissertation of the second author, registered from Department of Physics, University of Karachi. The italic superscripts ^a, ^b, ^c, ..., appearing in the text, represent endnotes listed before references.

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scrutinized worldwide implementation of the WHO and found that countries have adopted and harmonized best practices in child-growth assessment.

There are issues of defining optimal weight (Cole *et al.*, 2000; Hermanussen and Meigen, 2003) and then devising ways to achieve that (Kamal *et al.*, 2013d). Another problem arises, in the absence of reliable growth charts for third-world countries, where researchers have no option, but to use charts from other populations, like NCHS (Ayatollahi, 1993) and sometimes use statistical methods to adjust these charts to local population (Abolfotouh *et al.*, 1993; Al Frayh and Bangboye, 1993). Some preliminary work has been started by various groups (Kamal *et al.*, 2004; Aziz *et al.*, 2012; Mushtaq *et al.*, 2012).

This work describes a method to generate Growth-and-Obesity Roadmaps of Pakistani children, which is an extension of Growth-and-Obesity Profiles, described in an earlier work (Kamal *et al.*, 2011). The prime contribution of this piece of research is month-wise recommendation to gain height and put on/lose weight based on mathematical calculations. This is very important for the health of a child, as an excess reduction of weight may have adverse effects on the health of a child. On the other hand, if the required amount of weight is not reduced, the child remains obese and all the health risks of obesity apply. Studies have indicated that even a small amount of weight increase in childhood elevates coronary-heart-disease risk factor in adulthood (Baker *et al.*, 2007; Bibbins-Domingo *et al.*, 2007).

MID-PARENTAL HEIGHT, STUNTING AND TALLNESS

For the purpose of generating growth-and-obesity roadmaps, stunting and tallness were defined by taking mid-parental height as reference. To compute adult-mid-parental (target) height of a boy (h_{MP-BOY}) or a girl ($h_{MP-GIRL}$) from biological father's height (F) and biological mother's height (M) using the expressions (1a, b) — all heights are in *cm* (Chianese, 2005; Karlberg, 1996; Tanner *et al.*, 1970):

$$(1a) \quad h_{MP-BOY} = \frac{F+M}{2} + 6.5 \text{ cm}$$

$$(1b) \quad h_{MP-GIRL} = \frac{F+M}{2} - 6.5 \text{ cm}$$

Target heights may vary by 5 *cm* on either side. A child was declared to be stunted, when the individual's height percentile, $P(h)$, was lesser than percentile of mid-parental height, $P(h_{MP})$, as given in (2a):

$$(2a) \quad P(h) < P(h_{MP}) \text{ or } \Delta h = h - h_{\text{current-age-MP}} < 0, \text{ for a stunted child}$$

For a tall child, the reverse was true, as represented in (2b):

$$(2b) \quad P(h) > P(h_{MP}) \text{ or } \Delta h = h - h_{\text{current-age-MP}} > 0, \text{ for a tall child}$$

Quantitative estimates of tallness and stunting in terms of percentages (Kamal *et al.*, 2011) were given by taking current-age-mid-parental height as reference, listed in equations (3a-c).

If $STATUS(h) > 1\%$

$$(3a) \quad STATUS(h) = 100 \frac{|h - h_{\text{current-age-MP}}|}{h_{\text{current-age-MP}}} \% \text{ STUNTED, if } h < h_{\text{current-age-MP}}$$

$$(3b) \quad STATUS(h) = 100 \frac{|h - h_{\text{current-age-MP}}|}{h_{\text{current-age-MP}}} \% \text{ TALL, if } h > h_{\text{current-age-MP}}$$

Else if $STATUS(h) \leq 1\%$

$$(3c) \quad STATUS(h) = 100 \frac{|h - h_{\text{current-age-MP}}|}{h_{\text{current-age-MP}}} \% (\mp)$$

In equation (3c), (–) was taken if $h < h_{\text{current-age-MP}}$ and (+) if $h > h_{\text{current-age-MP}}$. This was the normal range, indicating that the child had excess (lesser) height compared with current-age-mid-parental height. However, the individual was not considered stunted or tall.

Excessive stunting may be indicative of acute malnutrition, if associated with wasting, or energy-channelization problem, if accompanied by obesity. Excessive tallness may suggest over-nutrition, if associated with obesity, or

4 th -Degree Stunted	$STATUS_{\pm}(h) < -30$
3 rd -Degree Stunted	$-30\% \leq STATUS_{\pm}(h) < -20\%$
2 nd -Degree Stunted	$-20\% \leq STATUS_{\pm}(h) < -10\%$
1 st -Degree Stunted	$-10\% \leq STATUS_{\pm}(h) < -1\%$
Normal	$-1\% \leq STATUS_{\pm}(h) < +1\%$
1 st -Degree Tall	$+1\% \leq STATUS_{\pm}(h) < +10\%$
2 nd -Degree Tall	$+10\% \leq STATUS_{\pm}(h) < +20\%$
3 rd -Degree Tall	$+20\% \leq STATUS_{\pm}(h) < +30\%$
4 th -Degree Tall	$STATUS_{\pm}(h) \geq +30\%$

Fig. 1. Suggested classification and color-coding for status (pertaining-to-height) expressed as percentage (http://www.ngds-ku.org/Papers/J35/Fig_1.htm)

energy-channelization problem, if accompanied by wasting (Kamal and Jamil, 2014). The last condition, also, poses health risks, in particular, scoliosis (Kamal *et al.*, 2013c).

Use of absolute value in the formulae for $STATUS(h)$ poses some mathematical problems. The function, defined by equations (3a, b) is continuous, but not differentiable. Hence, this function cannot be processed using mathematical and computational tools, in particular, when there is a need to compute rates of change. A similar problem arose in discarding the use of mean deviation in favor of standard deviation for the purpose of statistical analysis. A moment-generating function could not be written for the former. This was the basis of selecting sample size large enough so that the assumption that the data are normally distributed is valid. Abandoning modulus sign and admitting both positive (indicating tallness) and negative (indicating stunting) values, would make the above function a true algebraic function and it would become natural to plot it on number line of a graph paper. A definition of algebraic status (pertaining-to-height) is given in equation (4).

$$(4) \quad STATUS_{\pm}(h) = 100 \frac{h - h_{\text{current-age-MP}}}{h_{\text{current-age-MP}}} \%$$

A classification of tallness and stunting, suggested by the authors, is given in Figure 1.

BODY-MASS INDEX (BMI)

In 1832, Adolphe Quetelet proposed this index, recognized by peers as ‘Quetelet Index’ (Eknayan, 2008), renamed later as ‘Body-Mass Index’ (Keys *et al.*, 1972). Apell *et al.* (2011) discussed physics of body-mass index (BMI). BMI of a person is computed by dividing mass, μ , of an individual (in kg) by square of height of that person, h (in m) and is expressed in kg/m^2 — cf. equation (5)

$$(5) \quad BMI = \frac{\mu}{h^2}$$

Table 1 gives BMI classification for adults. The authors replaced the terminologies ‘underweight’ and ‘overweight’ with ‘wasted’ and ‘obese’ preceded by appropriate adjectives, to indicate severity. For children, BMI range, used for estimating statuses for adults, cannot be used — BMI tables are needed for interpretation (Kamal *et al.*, 2013d).

Table 1. WHO classification^a of body-mass index, applicable to adult population

Descriptive Label	BMI Values
Excessively Wasted	$BMI < 15$
Severely Wasted	$15 \leq BMI < 16$
Wasted	$16 \leq BMI < 18.5$
Normal	$18.5 \leq BMI < 25$
Obese	$25 \leq BMI < 30$
Moderately Obese	$30 \leq BMI < 35$
Severely Obese	$35 \leq BMI < 40$
Excessively Obese	$BMI \geq 40$

ESTIMATED-ADULT BMI

Introduced in 2012, equation (6) could be used to compute ‘estimated-adult BMI’ by substituting mass and height of a growing boy or girl by the respective estimated-adult values^b, $\mu_{\text{est-adult}}$ and $h_{\text{est-adult}}$, which provided a snapshot of status of obesity of children, when they reach adulthood — boys at the age of 21 years and girls 19 years (Kamal and Jamil, 2012).

$$(6) \quad BMI_{\text{est-adult}} = \frac{\mu_{\text{est-adult}}}{(h_{\text{est-adult}})^2}$$

$BMI_{\text{est-adult}}$ could be interpreted on the basis of Table 1.

OPTIMAL MASS (WEIGHT), WASTING AND OBESITY

The term ‘optimal mass’ was, first, mentioned 10-year ago (Kamal *et al.*, 2004), with rigorous definition provided 3-year ago as the mass, μ_{opt} , corresponding to height percentile (Kamal *et al.*, 2011). If $P(\mu_{\text{opt}})$ and $P(h)$ represented percentiles of optimal mass and height, respectively, then these percentiles were related by equation (7)

$$(7) \quad P(\mu_{\text{opt}}) = P(h)$$

For the purpose of generating growth-and-obesity roadmaps, if the mass of an individual was lesser than optimal mass, then the incumbent was wasted; whereas if it was more than optimal mass, it represented obesity, according to the inequalities (8a, b)

$$(8a) \quad \Delta\mu = \mu - \mu_{\text{opt}} < 0 \text{ or } P(\mu) < P(h), \text{ for a wasted child}$$

$$(8b) \quad \Delta\mu = \mu - \mu_{\text{opt}} > 0 \text{ or } P(\mu) > P(h), \text{ for an obese child}$$

Quantitative estimates of wasting and obesity were given in equation (9a, b) by taking optimal mass as reference (Kamal *et al.*, 2011).

If $STATUS(\mu) > 1\%$

$$(9a) \quad STATUS(\mu) = 100 \frac{|\mu - \mu_{\text{opt}}|}{\mu_{\text{opt}}} \% \text{ WASTED, if } \mu < \mu_{\text{opt}}$$

$$(9b) \quad STATUS(\mu) = 100 \frac{|\mu - \mu_{\text{opt}}|}{\mu_{\text{opt}}} \% \text{ OBESE, if } \mu > \mu_{\text{opt}}$$

Else if $STATUS(\mu) \leq 1\%$

$$(9c) \quad STATUS(\mu) = 100 \frac{|\mu - \mu_{\text{opt}}|}{\mu_{\text{opt}}} \% (\mp)$$

In equation (9c), (–) was taken if $\mu < \mu_{\text{opt}}$ and (+) if $\mu > \mu_{\text{opt}}$. This was the normal range, indicating that the child had excess (lesser) mass compared with optimal mass. However, the individual was not considered wasted or obese.

Both excessive obesity and wasting are associated with health risks. Excessive obesity may be indicative of over-nutrition, if associated with tallness, or energy-channelization problem, if accompanied by stunting. Childhood obesity has been declared epidemic by the US First Lady, Michelle Obama (S. Z. Yanovski and J. A. Yanovski, 2011). According to Ludwig (2007), obesity in children is associated with cardiovascular, gastrointestinal, musculo-skeletal, neurological, psychosocial, pulmonary and renal problems. He classified into 4 phases the long-term effects of obesity epidemic. Phase I, from 1970 till 2007, exhibited increasing cases of obesity due to lack of awareness of its adverse effects. Phase II emerged in the following years with serious medical conditions, such as type-II diabetes, fatty liver and many psychosocial problems. In Phase III, the situation, further, worsened and life-threatening diseases, like coronary heart disease, kidney failure *etc.* increased mortality rate and shortened life expectancy of American population. In Phase IV, the prevalence of weight-related diseases would accelerate more resulting in non-genetic influences in the offspring, if this trend continues. In an e-communication to one of our group members, Ludwig explained: “Phase IV of the epidemic would develop slowing over time, as obese children grow up and give birth to the next generation of children” (Kamal and Jamil, 2012). Excessive wasting may be indicative of under-

4 th -Degree Wasted	$STATUS_{\pm}(\mu) < -30$
3 rd -Degree Wasted	$-30\% \leq STATUS_{\pm}(\mu) < -20\%$
2 nd -Degree Wasted	$-20\% \leq STATUS_{\pm}(\mu) < -10\%$
1 st -Degree Wasted	$-10\% \leq STATUS_{\pm}(\mu) < -1\%$
Normal	$-1\% \leq STATUS_{\pm}(\mu) < +1\%$
1 st -Degree Obese	$+1\% \leq STATUS_{\pm}(\mu) < +10\%$
2 nd -Degree Obese	$+10\% \leq STATUS_{\pm}(\mu) < +20\%$
3 rd -Degree Obese	$+20\% \leq STATUS_{\pm}(\mu) < +30\%$
4 th -Degree Obese	$STATUS_{\pm}(\mu) \geq +30\%$

Fig. 2. Suggested classification and color-coding for status (pertaining-to-mass) expressed as percentage (http://www.ngds-ku.org/Papers/J35/Fig_2.htm)

nutrition, if associated with stunting, or energy-channelization problem, if accompanied by tallness (Kamal and Jamil, 2014).

The arguments, which motivated the authors to introduce $STATUS_{\pm}(h)$ are, equally, applicable to define algebraic status (pertaining-to-mass), admitting both positive (indicating obesity) and negative (indicating wasting) values, through equation (10)

$$(10) \quad STATUS_{\pm}(\mu) = 100 \frac{\mu - \mu_{\text{opt}}}{\mu_{\text{opt}}} \%$$

A classification of obesity and wasting, suggested by the authors, is given in Figure 2.

THE NGDS PILOT PROJECT

In 1998, the NGDS Pilot Project (<http://ngds.uok.edu.pk>) was launched after ‘Institutional Review Process’, which incorporated existing ethical and human-right standards applicable in Pakistan (Kamal *et al.*, 2002; 2004). ‘Opt-in policy’ was implemented by requiring the parents to complete and sign ‘Informed Consent Form’^c. A subproject of the NGDS Pilot Project, named as SGPP (Sibling Growth Pilot Project), served local families, who reported to SF-Growth-and-Imaging Laboratory for detailed checkup after filling out ‘SGPP Participation Form’^d.

Heights, h , and masses of families were measured by reproducible anthropometrists (Kamal and Razzaq, 2014) to accuracies of 0.01 cm and 0.01 kg, in the morning hours, as per protocols suggested elsewhere (Kamal, 2006, 2010). Parents were measured wearing minimal indoor clothing and the children were required to undress totally except briefs or panties (*cf.* Figure 3). Everyone removed shoes and socks as well as accessories for



Fig. 3. Height and mass of a boy measured in SF-Growth-and-Imaging Laboratory (http://www.ngds-ku.org/Papers/J34/Fig_3.htm)

measurements. A suitable clothing correction was subtracted from 'gross mass' (mass, with the subject wearing indoor clothing) to obtain 'net mass' (mass without any clothing on), μ , for father and mother. Since, the children had to be in underwear for their checkups, barefoot, stripped-to-waist, their recorded masses were, almost, equal to net masses and used without any clothing correction.

For measuring height (stature), the subject was aligned to mounted (engineering) tape and advised to keep hands straight and open, feet together, palms touching thighs and holding breath (attention position). Holding a pencil at eye level, head was straightened. For measuring mass, the subject was asked to stand in the center of beam scale with empty hands and feet separated, looking straight and holding breath (stand-at-ease position). The anthropometrist recorded height to nearest 0.01 *cm* and mass to nearest 0.01 *kg* (Kamal, 2010). Equipments were calibrated using a standard 100-*cm* ruler and a standard 2-*kg* mass. Zero errors were determined before starting each session and subtracted from the measured values.

A REVIEW OF GROWTH-AND-OBESITY MODELS

Correlation Model

This model was presented by Arglye, Scheult and Wooff 7-year ago (Arglye *et al.*, 2007) to statistically process child-growth data.

Main Contributions

- Fitted and modeled serial correlation structure of growth measurements of children.
- Eliminated the need of monitoring growth at specific ages.

ICP Model

The ICP (Infancy-Childhood-Puberty) Model is a time series, representing analysis of the longitudinal development of human body (Karlberg, 1987; 1996). Height of child (on *y* axis) is plotted as a function of age (on *x* axis). Moment of birth is taken as zero time, whereas zero height is the height at conception. Term of baby is *x* intercept and birth length is *y* intercept. Growth curve is split into 3 separate and partially superimposed components, viz. infancy, childhood and puberty. Infantile period begins before birth and continues up to 3 or 4 years of age. This period may be interpreted as postnatal continuation of 'fetal growth'. This model has been described in detail in one of our previous works (Kamal and Jamil, 2012).

Main Contributions

- Indicated that height curve is continuous, but not smooth, making height velocity undefined during phase transitions, *i. e.*, infancy-to-childhood phase and childhood-to-puberty phase.
- Gave mathematical expressions to represent height trajectory in infancy, childhood and puberty regions.
- Identified a decrease in growth (height) velocity as the child's age approaches the terminal part of a certain region and about to experience phase transition.

KFA Model

KFA (Kamal-Firdous-Alam) Model assumed that height and mass trajectories were, approximately, linear if the measurements were performed 6-month apart — assumption valid for most of the ICP curve (Kamal *et al.*, 2002; 2004). Exceptions were the regions characterized by a rapid growth-rate change — infancy-to-childhood phase and childhood-to-puberty phase. In other regions, linear interpolation was used to compute height at some age grid. Target heights for boys and girls were determined and backward extrapolation performed to evaluate desired heights at reference age grids.

Main Contributions

- Compared desired height (based on mid-parental height, extrapolated backward at a certain age grid, which the child has just passed) with interpolated-actual heights to determine if a child was tall or stunted.
- Employed a similar procedure for mass to classify a child as obese or wasted.
- Predicted height and mass 6-month down the road.

KJR Model

KJR (Kamal-Jamil-Razzaq) Model (Kamal *et al.*, 2014b) was an extension of KFA Model (Kamal *et al.*, 2004). This model generated 'Growth-and-Obesity-Moving Profiles' of children. When these moving profiles were generated for real-time data, these were termed as 'roadmaps' (Kamal *et al.*, 2013e; 2014a). Numerical examples of

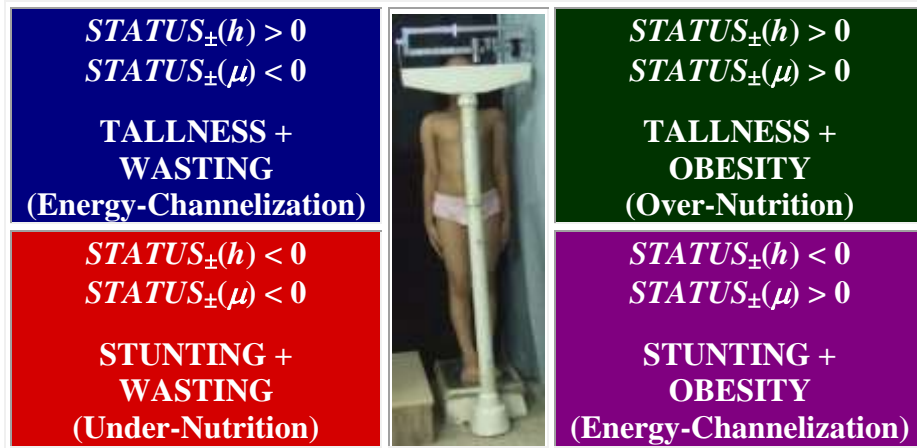


Fig. 4. Energy-channelization (coexistences of tallness and wasting as well as stunting and obesity), under-nutrition (coexistence of stunting and wasting) over-nutrition (coexistence of tallness and obesity) in terms of statuses, pertaining to mass [x axis — value increasing from left to right] and height [y axis — value increasing from bottom to top] (http://www.ngds-ku.org/Papers/J35/Fig_4.htm)

some of the important concepts introduced alongwith KJR Model (Kamal *et al.*, 2014b) and a subsequent seminar (Kamal, 2014b) are given elsewhere (Kamal and Jamil, 2014).

Main Contributions

- Replaced the concepts of growth (height) velocity and rate of mass gain (loss) by height- and mass-percentile trajectories.
- Introduced the notions of pseudo-gain of mass, pseudo-gain of height, energy-channelization problem (stunting with obesity, wasting with tallness) — *cf.* Figure 4.

KJK Model

KJK (Kamal-Jamil-Khan) Model (Kamal *et al.*, 2011) gave procedures to generate ‘Growth-and-Obesity Profiles’ of a family, which consisted of Obesity Profiles of father and mother as well as Growth-and-Obesity Profile of each child based on a single check up.

Main Contributions

- Gave a formal definition of ‘optimal mass’, as the mass corresponding to percentile of height.
- Abandoned different terminologies, ‘fat’, ‘overweight’, ‘obese’, ‘lean’, ‘underweight’, ‘wasted’ in favor of ‘obese’ and ‘wasted’.
- Technique of ‘box interpolation’ was developed to compute percentiles of height and mass of child.
- ‘Status (pertaining-to-mass)’ was suggested to indicate severity of obesity or wasting in terms of percentage.
- ‘Status (pertaining-to-height)’ was introduced to give an impression of extent of tallness or stunting in terms of percentage.

KJ Model

KJ (Kamal-Jamil) Model presented a mathematical solution of the problem of generating ‘Growth-and-Obesity Profiles’ of children of a family, in which one or both parents were still growing (father’s age below 21 years; mother’s age below 19 years). Box interpolation was employed to compute percentiles corresponding to father’s and mother’s heights (Kamal and Jamil, 2012).

Main Contributions

- ‘Estimated-adult *BMI*’ was introduced, which gave a rough estimate of obesity or stunting, when the child becomes a fully-grown adult.
- Discussed the implications of childhood marriages on the health of mother and her children from psychological and physiological perspectives, taking into consideration points of view of various religious scholars as well as sociological theories.
- Early marriages have, also, been scrutinized from the perspectives of physics, biology and control theory.
- This work tried to elaborate difference between ‘age of puberty’ and ‘age of marriage’.

Table 2a. Adult-mid-parental (Target) and army-cutoff heights for S. Family

Father's Height: † 172.01 cm • Mother's Height: † 162.94 cm

Adult-Mid-Parental (Target) and Army-Cutoff Heights	Boy †		Girl †	
	Target	Army-Cutoff	Target	Army-Cutoff
Case Number	SGPP-KHI-20110614-01			
Height (cm)	173.98	162.56 cm	160.98	157.48 cm
Height (ft-in)	5 ft 8.49 in	5 ft 4.00 in	5 ft 3.38 in	5 ft 2.00 in
Percentile	35.68	2.72	36.49	19.36

GROWTH-AND-OBESITY ROADMAPS

Model Development

Dates of Birth and Checkups: The first step in generating 'Growth-and-Obesity Roadmaps' of a family was conversion of dates of birth and dates of measurement in fractional form and finding difference to compute age. Dates of birth and checkup were recorded as *YYYY-MM-DD* — year in four digits-month in two digits-day in two digits; ages as *YY-MM-DD* (year in two digits). Appendix A of (Kamal *et al.*, 2011) gave the detailed procedure.

Parents' Obesity Profiles: To compute Parents' Obesity Profiles, heights and masses, obtained from extended-gender-specific tables (http://www.ngds-ku.org/Papers/J34/Additional_File_3.pdf), were used to interpolate, linearly, percentiles of heights and masses of father and mother using upper bound of age (20 years), for which the anthropometric data were available. These tables contained heights and masses corresponding to 0.01th, 0.1th, 1st, 99th, 99.9th and 99.99th percentiles, in addition to values given in CDC Growth Tables (Kamal and Jamil, 2014).

Parents' Obesity Roadmaps: Father (Mother) was advised to put on mass (weight) corresponding to the difference obtained by subtracting net mass from optimal mass, if the value of former was lesser than that of later (weight in *pounds* and *ounces* 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 is under-10 kg, otherwise he should shed off 10 kg within the next 6 months. For mothers (married at the time of check up or divorced/widowed in the near past), 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. For males and females below or equal to the age of 30 years, mass corresponding to their height percentile was considered as optimal mass. For parents older than this age limit, the reference was *BMI* (body-mass index)^e. To compute optimal mass, square of height was multiplied with the ideal *BMI* value (24 kg/m²). Month-wise recommendations were generated for each parent.

Children's Growth-and-Obesity Profiles: 'Linear interpolation' was used to determine percentiles of target height (adult-mid-parental-height) for son or daughter from age-20-height values. Army-cutoff-height values (5 ft 4 in for males; 5 ft 2 in for females), applicable for induction into Pakistani military and paramilitary services, were converted into cm (1 ft = 12 in; 1 in = 2.54 cm) and respective percentiles computed using 'linear interpolation' (extended table was needed to compute percentile for males, as the value fell below 3rd percentile). Tables 2a, b give target and army-cutoff heights for S. and J. Families, respectively, the eldest sibling of the first family representing 'a wasted child' and that of the second family 'an obese child'. Child's height (mass) percentile was evaluated by the technique of 'box interpolation' (Kamal *et al.*, 2011). Estimated-adult height (mass) was computed using age-20 values. Equation (6) was used to evaluate estimated-adult *BMI*. Constant-age route was followed to compute optimal mass and, subsequently, determine obesity profile. A similar procedure was used to evaluate current-age-mid-parental height. To figure out whether the child was tall or stunted, the incumbent's height was compared with gender-specific-current-age-mid-parental height. Statuses (pertaining-to-height) and (pertaining-to-mass) were computed using equations (4) and (10), alongwith qualitative classifications based on Figures 1 and 2, respectively.


Table 2b. Adult-mid-parental (Target) and army-cutoff heights for J. Family

Father's Height: † 165.70 cm • Mother's Height: † 155.73 cm

Adult-Mid-Parental (Target) and Army-Cutoff Heights	Boy †		Girl †	
	Target	Army-Cutoff	Target	Army-Cutoff
Case Number	SGPP-KHI-20060412-01			
Height (cm)	167.22	162.56 cm	154.22	157.48 cm
Height (ft-in)	5 ft 8.49 in	5 ft 4.00 in	5 ft 3.38 in	5 ft 2.00 in
Percentile	35.68	2.72	36.49	19.36

Table 3a. Growth-and-Obesity Roadmap of Hr. S. — Eldest sibling of S. Family, exhibiting wasting


Gender: Female † • Date of Birth^f: 2005-04-10 • School: Withheld • GR Number: Withheld

Checkpoint	1 st	2 nd	3 rd
Case Number	SGPP-KHI-20110614-01/01 (NGDS-BLA-2011-5085/H)		
Photograph ^g			
	Larger-Size Photographs: http://www.ngds-ku.org/Papers/J35/Fig_5A.htm		
Scanned Signatures ^g	HrS	HrS	HrS
Class and Section	Withheld	Withheld	Withheld
Date of Checkup ^f	2012-07-15	2013-05-15	2013-11-21
Age ^h (year-month-day)	07-03-05	08-01-05	08-07-11
Age (decimal years)	7.26	8.10	8.62
Dress Code ⁱ	0/0.5	0/0.5	0/0.5
Behavior Code ^j	1	0	0
Cumulative-Scoliosis-Risk Weightage ^k	9.50	10.25	15.25
Height, <i>h</i> (cm)	119.36	124.53	126.45
Height (ft-in)	3 ft 10.99 in	4 ft 1.03 in	4 ft 1.78 in
Percentile-for-Height, <i>P</i> (<i>h</i>)	24.63	27.08	23.09
Estimated-Adult Height (cm)	158.87	159.33	158.46
Estimated-Adult Height (ft-in)	5 ft 2.55 in	5 ft 2.73 in	5 ft 2.39 in
Current-Age-MP Height (cm)	121.15	126.00	128.76
Δ Height <i>w. r. t.</i> Current-Age-MP (cm)	-1.79	-1.47	-2.29
Status (pertaining-to-height), <i>STATUS_±</i> (<i>h</i>)	-1.48%	-1.17%	-1.78%
Qualitative Status (pertaining-to-height)	1st-Degree Stunted	1st-Degree Stunted	1st-Degree Stunted
Current-Age-Army-Cutoff Height (cm)	118.28	122.99	125.64
Δ Height <i>w. r. t.</i> Army-Cutoff (cm)	+1.08	+1.54	+0.81
Reference Height (cm)	121.15	126.00	128.76
Percentile-for-Reference-Height	36.49	36.49	36.49
Age of Prediction, <i>A+</i> (years)	7.77	8.60	9.11
Reference Height at <i>A+</i> (cm)	124.14	128.67	131.23
6-Month-Height Management (cm)	+4.78	+4.14	+4.78
Month-Wise-Height Management (cm/month)	+0.80	+0.69	+0.80
Month-Wise-Height Management (in/month)	+0.31	+0.27	+0.31
Gross Mass (kg)	19.19	21.90	22.53
Clothing Correction (kg)	0	0	0
Net Mass, μ (kg)	19.19	21.90	22.53
Net Weight (lb-oz)	42 lb 5.02 oz	48 lb 4.63 oz	49 lb 10.86 oz
Percentile-for-Net-Mass <i>P</i> (μ)	8.13	14.74	10.30
Estimated-Adult Mass (kg)	47.60	49.68	48.46
Estimated-Adult Weight (lb-oz)	104 lb 15.37 oz	109 lb 8.67 oz	106 lb 13.82 oz
<i>BMI</i> : Body-Mass Index (kg/m ²)	13.47	14.12	14.09
Estimated-Adult <i>BMI</i> (kg/m ²)	18.86	19.57	19.30
Optimal Mass (kg)	21.15	23.47	24.39
Δ Mass-for-Height (kg)	-1.96	-1.57	-1.86
Status (pertaining-to-mass), <i>STATUS_±</i> (μ)	-9.28%	-6.68%	-7.61%
Qualitative Status (pertaining-to-mass)	1st-Degree Wasted	1st-Degree Wasted	1st-Degree Wasted
Optimal Mass for Reference Height at <i>A+</i> (kg)	23.57	25.98	27.64
6-Month-Mass Management (kg)	+4.38	+4.08	+5.11
Month-Wise-Mass Management (kg/month)	+0.73	+0.68	+0.85
Month-Wise-Mass Management (lb-oz/month)	+1 lb 9.75 oz	+1 lb 8.01 oz	+1 lb 13.98 oz
Nutritional Status	Under-Nutrition	Under-Nutrition	Under-Nutrition

Children's Growth-and-Obesity Roadmaps: To construct 'Growth-and-Obesity Roadmaps' of boys or girls (Table 3a lists 'Growth-and-Obesity Roadmap' for a wasted child, salient feature of which is month-wise recommen-

Table 3b. Growth-and-Obesity Roadmap of Z. J. — Eldest sibling of J. Family, exhibiting obesity

Gender: Female † • Date of Birth^f: 1996-09-23 • School: Withheld • GR Number: Withheld

Checkup	1 st	2 nd	3 rd
Case Number	SGPP-KHI-20060412-01/01		
Photograph ^g			
Larger-Size Photographs: http://www.ngds-ku.org/Papers/J35/Fig_5B.htm			
Scanned Signatures ^g	ZJ	ZJ	ZJ
Class and Section	Withheld	Withheld	Withheld
Date of Checkup ^f	2007-05-13	2007-10-07	2008-06-15
Age ^h (year-month-day)	10-07-20	11-00-14	11-08-22
Age (decimal years)	10.63	11.04	11.73
Dress Code ⁱ	0/0.5	0/0.5	0/0.5
Behavior Code ^j	0	0	0
Cumulative-Scoliosis-Risk Weightage ^k	0.50	1.00	6.00
Height, <i>h</i> (cm)	136.41	139.70	146.53
Height (ft-in)	4 ft 5.71 in	4 ft 7.00 in	4 ft 9.69 in
Percentile-for-Height, <i>P</i> (<i>h</i>)	23.18	26.76	36.69
Estimated-Adult Height (cm)	158.49	159.27	161.01
Estimated-Adult Height (ft-in)	5 ft 2.40 in	5 ft 2.71 in	5 ft 3.39 in
Current-Age-MP Height (cm)	131.88	134.11	138.74
Δ Height <i>w. r. t.</i> Current-Age-MP (cm)	+4.53	+5.59	+7.79
Status (pertaining-to-height), <i>STATUS_±</i> (<i>h</i>)	+3.43%	+4.17%	+5.61%
Qualitative Status (pertaining-to-height)	1st-Degree Tall	1st-Degree Tall	1st-Degree Tall
Current-Age-Army-Cutoff Height (cm)	135.42	137.80	142.57
Δ Height <i>w. r. t.</i> Army-Cutoff (cm)	+0.99	+1.90	+3.96
Reference Height (cm)	136.41	139.70	146.53
Percentile-for-Reference-Height	23.18	26.76	36.69
Age of Prediction, <i>A+</i> (years)	11.14	11.54	12.23
Reference Height at <i>A+</i> (cm)	139.52	143.16	150.06
6-Month-Height Management (cm)	3.11	3.46	3.53
Month-Wise-Height Management (cm/month)	+0.52	+0.58	+0.59
Month-Wise-Height Management (in/month)	+0.20	+0.23	+0.23
Gross Mass (kg)	42.50	46.50	49.60
Clothing Correction (kg)	0	0	0
Net Mass, μ (kg)	42.50	46.50	49.60
Net Weight (lb-oz)	93 lb 11.40 oz	102 lb 8.52 oz	109 lb 5.89 oz
Percentile-for-Net-Mass <i>P</i> (μ)	78.36	82.41	80.85
Estimated-Adult Mass (kg)	67.98	70.54	69.56
Estimated-Adult Weight (lb-oz)	149 lb 14.41 oz	102 lb 8.52 oz	153 lb 5.97 oz
<i>BMI</i> : Body-Mass Index (kg/m ²)	22.84	23.83	23.10
Estimated-Adult <i>BMI</i> (kg/m ²)	27.07	27.81	26.83
Optimal Mass (kg)	30.94	33.16	37.82
Δ Mass-for-Height (kg)	+11.56	+13.34	+11.78
Status (pertaining-to-mass), <i>STATUS_±</i> (μ)	+37.35%	+40.24%	+31.16%
Qualitative Status (pertaining-to-mass)	4th-Degree Obese	4th-Degree Obese	4th-Degree Obese
Optimal Mass for Reference Height at <i>A+</i> (kg)	32.83	38.23	39.88
6-Month-Mass Management (kg)	-9.67	-8.27	-9.72
Month-Wise-Mass Management (kg/month)	-1.61	-1.38	-1.62
Month-Wise-Mass Management (lb-oz/month)	-3 lb 8.80 oz	-3 lb 0.69 oz	-3 lb 9.15 oz
Nutritional Status	Over-Nutrition	Over-Nutrition	Over-Nutrition

dition to gain mass; Table 3b shows ‘Growth-and-Obesity Roadmap’ for an obese child, with month-wise recommendation to lose mass), generalizations of ‘Growth-and-Obesity-Moving Profiles’, which were introduced

through KJR Model, described in the last section, one needed more than one profile — each profile represented a checkup (Kamal *et al.*, 2013e; 2014a). The maximum value from members (elements) of the following set, as given in (11)

$$(11) \quad \{h, h_{\text{current-age-MP}}, h_{\text{army-cutoff}}\}$$

(first member of this set is the measured height, second one is the current-age-mid-parental height and third one the army-cutoff height) gave the reference height. Optimal mass, after 6 *months*, was computed based on the 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 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). Month-wise 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.

A more efficient way is to deal with percentiles of height instead of the actual values. One of the advantages of this approach is that during subsequent profile generation, only percentile of current height needs to be computed, as gender-specific-army-cutoff-height percentile remains unchanged for a given country, say Pakistan (for males its value comes out to 2.718014592103645... and for females 19.35609323536863...), and gender-specific-MP-height percentile does not change for a given family. Further, it is the maximum of 3 percentiles that is needed to compute height 6-*month* down the road, not the actual height. To determine percentile of reference height, P_{ref} , select the larger value from the pair of values consisting of percentile of current height, $P(h)$, and maximum of gender-specific-army-cutoff-height percentile, $P_{\text{army-cutoff}}$, as well as gender-specific-MP-height percentile, P_{MP} . Equations (12a, b) explain this procedure

$$(12a) \quad P_{\text{max}} = \max(P_{\text{army-cutoff}}, P_{\text{MP}})$$

$$(12b) \quad P_{\text{ref}} = \max(P(h), P_{\text{max}})$$

Worked Examples: Additional File 1 (http://www.ngds-ku.org/Papers/J35/Additional_File_1.pdf) contains detailed Growth-and-Obesity Roadmaps of S. and J. Families (parents and all siblings), roadmaps of eldest sibling of each family are included in this paper as Tables 3a, b.

Validation

Children's Growth-and-Obesity Roadmaps were validated by predicting heights and masses on the day of second and subsequent checkups based on values of current and previous checkups. The predicted heights (masses) were compared using the formula:

$$(13) \quad \% \text{ matching} = 100 \left(1 - \frac{|\text{Predicted} - \text{Actual}|}{|\text{Actual}|} \right)$$

Results of prediction are reported in **Additional File 2** (http://www.ngds-ku.org/Papers/J35/Additional_File_2.pdf).

Software Development

Growth-and-Obesity-Roadmap Software (SOFT-GROWTH) was developed and tested to generate reports for the students of a local school, participating in the study.

Salient Features: The tool used was Microsoft Visual Studio (Visual Basic Dot Net 2008) and reports are saved in both word and excel files.

- Input data could be entered manually or read through word/excel file.
- Data were validated (no undefined or out-of-bound values).
- Age was calculated and interval identified, $A \geq 30$, $20 \leq A < 30$, $A < 20$, (A represented age in *years*).
- If $A \geq 30$, optimal mass was calculated using standard *BMI* (i. e., 24 kg/m^2).
- If $20 \leq A < 30$, Obesity Profile was generated by using linear interpolation.
- If $A < 20$, check was performed as to whether parental height was available or not. If the answer was in the affirmative, Growth-and-Obesity Profile was generated. Else, only Obesity Profile was generated. Both of these profiles were generated by using box interpolation, which included quantitative and qualitative statuses.
- Height and mass (weight) were predicted 6 *months* down the road (or any other date) based on reference

height.

- h) Month-wise recommendations generated to gain height and put on/lose mass (weight) for children.
- i) Detailed-report preparation in word file as well as excel file.

Technical Details: Additional File 3 (http://www.ngds-ku.org/Papers/I35/Additional_File_3.pdf) gives the algorithm, the flow chart and the screen shots.

Diet and Exercise Plans

These month-wise targets could be achieved by a suitable combination of diet, exercise and lifestyle adjustment (Kamal *et al.*, 2014b, 2014; Kamal and Khan, 2014). To increase height, the child's diet should be high in calcium and protein as well as fiber. Stunted children should do light-stretching exercises, wearing minimal clothing, in a park after sun has just come out. Such children may, also, be encouraged to exercise during TV-watching. In addition, parents should increase their sleep-duration to 9 hours or more (Kamal *et al.*, 2013b). To gain weight, a person's diet should include potato items as well as food with high-protein content. Such individuals should avoid food, which is rich in fiber. Their exercise routine should consist of heavy exercises. These exercises should be done consistently. However, their duration should be short during a typical day. To lose weight, a child should consume salad and yogurt. Obese child's routine for exercise should consist of light exercises, which should be done consistently. However, their duration should be long during a typical day (Kamal *et al.*, 2013d). One must realize that all diet-based interventions, for height and weight management, would be ineffective, if the child is suffering from vitamin-D deficiency (Kamal *et al.*, 2013a).

CONCLUSION AND FUTURE DIRECTIONS

Proper weight-for-height is the basis of lifelong physical, mental, emotional as well as social fitness (Kamal and Khan, 2013). In this work the authors have taken up the problem of optimal height and weight management in children. Since a child is growing, a proper recommendation to gain or lose weight cannot be made unless the growth pattern of child is modeled and optimal mass at a future date is determined on the basis of desired height on that date. The key contributions of this research are:

- Month-wise recommendations to gain height and put on/lose mass (weight)
- Statuses, pertaining-to-height and -mass, defined as (negative, zero and positive) real numbers, removing absolute values from the formulae, to make these quantities suitable for mathematical/statistical processing
- Qualitative statuses, pertaining-to-height and pertaining-to-mass defined by adding appropriate adjective (1st to 4th degree) to stunted/tall and wasted/obese
- Statuses, pertaining-to-height and pertaining-to-mass, shown in coordinate-system representation — over-nutrition (tallness + obesity) in 1st quadrant; energy-channelization (tallness + wasting) in 2nd quadrant; under-nutrition (stunting + wasting) in 3rd quadrant; energy-channelization (stunting + obesity) in 4th quadrant
- BMI-based definition of optimal mass for individual older than 30 years

Future work needs to focus on developing Pakistani Growth Charts based on standardized anthropometric protocols and proper statistical design (Kamal *et al.*, 2013f), preferably preparing charts for different somatotypes — ectomorph, mesomorph and endomorph. Some preliminary work in this direction has, already, been initiated (Aziz *et al.*, 2012; Kamal and Jamil, 2014; Mushtaq *et al.*, 2012). Another important development could be extension of this model to generate Growth-and-Obesity Roadmaps of still-growing parents by extending the method presented earlier (Kamal and Jamil, 2012).

The method proposed and the associated software may assist pediatricians, nutritionists, sport coaches and community-health professionals, involved in the health-protection and the well-being of children, to plan efficient and effective intervention strategies so that stunting, wasting and obesity may be prevented in the next generation of Pakistan, if combined with an approach to change community beliefs and attitude as well as create awareness about child obesity (Aslam *et al.*, 2013) based on facts instead of myths and assumptions (Casazza *et al.*, 2013).

ENDNOTES

^aThe terminologies underweight and overweight replaced by wasted and obese with appropriate adjectives

^bEstimated-adult height, $h_{\text{est-adult}}$, is the height at the age of 20 years corresponding to percentile of current height, computed using the technique of linear interpolation. Similar definition holds for estimated-adult mass, $\mu_{\text{est-adult}}$.

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

^dhttp://www.ngds-ku.org/SGPP/SGPP_form.pdf

^eFor adults older than 30 years, age-20 values of height and mass read from extended-gender-specific tables (http://www.ngds-ku.org/Papers/J34/Additional_File_3.pdf) may be misleading for the purpose of computing percentiles. The weight distribution changes, significantly, as years are added up to age of an individual. Hence, it is not recommended to evaluate such percentiles, as they are not needed to generate Obesity Profiles.

^fAll dates are given in the format YYYY-MM-DD (year-month-day).

^gPhotographs and scanned signatures on the day, check up was conducted. In order to protect the privacy of S. and J. Families, the photographs, inserted in these Growth-and-Obesity Roadmaps, do not show the actual children, although they are from the set of patients, who reported to SF-Growth-and-Imaging Laboratory for checkups.

^hAges are given in both formats: fractional years and YY-MM-DD (year-month-day).

ⁱDress Code is explained in (Kamal, 2006).

^jBehavior code is explained in (Kamal, 2006; Kamal *et al.*, 2002).

^kCumulative-Scoliosis-Risk Weightage (CSRW) is described in (Kamal *et al.*, 2013c).

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