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The LMS Method and Its Extention for Constructing Smoothed Centile Curves of Weight for Age for 5-10 Years Children

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Abstract-Now–a-days, reference centile curves are widely used in medical professions for monitoring growth of an individual child. The requirement of centile curves in spite of simple reference range arises when the response variable strongly dependents on some covariate such as age. So the distribution of study variable changes according age. The LMS method & its extension LMSP method (BCPE distribution) & LMST method (BCT distribution) are popular methods for constructing smoothed centile curves. LMS method deals with skewed and normal peaked data, while LMSP & LMST are flexible methods for skewed & kurtotic data. The LMS method summarizes the changing distribution of study variable by smoothed curves of parameters. That is skewness parameter (L), median (M), and coefficient of variation (S). These smoothed parameters are obtained by method of maximization of penalized likelihood function. The smoothing parameters, their respective smoothed curves and final smoothed centiles can be obtained within a special software GAMLSS.

The present study is carried out on weight of 5-10 years English medium school boys from Kolhapur district of Maharashtra. We assumed children going to English medium school are from well-to-do family & are healthy. So the growth curves being developed remains to be standard & may be used as reference growth curves. These centile curves generated by using Box Cox t distribution applying log link function for μ (BCTo) are assessed for goodness of fit.

***Key* words:** Hight for age, weight for age, BMI for age, Growth curves for 5-10 year age group.

1. INTRODUCTION

In pediatric age group (birth to 18 years of age), growth and development are considered together. The term ‘growth’ refer to increase in the physical size of the body and ‘development’ to increase in skills and functions as age advances. Normal growth and development take place only if there is optimal nutrition from recurrent episodes of infections and from adverse genetic and environmental influences [1]. The assessment of growth is essential in child health concern to evaluate the nutritional status and for the recognition of growth failure. Reference data are fundamental for growth monitoring and they help doctors and policymakers to diagnose health status or any health problem [2].

Growth pattern of pediatric population is time dependant and hence it is suggested that references should be updated regularly so that they reflect current growth patterns of children and are representative of secular trends [3]. Especially developing contries, country like India, is in a stage of nutritional transition and thus it is essential to update growth references regularly[4].

In 2006, WHO developed the first single uniform global growth standard as prescriptive chart for the children under the age of 5 years with encouragement to all countries for its applicability [5]. The data collected was multi country, including India, and community-based (Multicentre Growth Reference Study-MGRS) [6].
Further WHO stated that it would not be possible to have prescriptive growth standards for children between 5-18 years of age. Since environmental factors in this age group cannot be controlled. Thus charts developed by the WHO for 5-18 year old children are based on statistical reconstruction of 1977 National Centre for Health Statistics data and are called growth references and not standards[7]. Nutritional, environmental and genetic factors, and timing of puberty play a major role on

growth of children above the age of 5 years. Country-to-country and region-to-region variation is impact of these factors on growth reflects in differing growth patterns amongst different population. Hence, it is necessary to have country-specific growth charts to monitor growth of children between 5-18 years[8].

Growth chart is a visual picture of growth reference. It expresses growth in percentiles. For clinical purpose growth chart is a helpful and powerful graphic design. Hence reference centile curves are used widely in medical practice as a growth screening tool. Centiles are more pleasing to the eye when smoothed appropriately. Small changes in the covariate are likely to lead to continuous changes in the measurement, so that the centiles ought to change smoothly[9].

There are several methods available for centile curve smoothing. But Lamda-Mu-Sigma [9] and its extension LMSP (BCPE) method [10]& LMST (BCT) method [11] are popular methods for curve smoothing.

Present study was carried out to focus on the path to determine and develop regional growth standards for weight for age of boys of 5-10 years based on healthy children from affluent families of Kolhapur district.

2. METHODOLOGY

School children in the age group 5-10 studying in private English medium school situated in 12 different talukas in Kolhapur district were studied from June 2016-march 2017. One English medium school was selected randomly from each talukas. Each & every children (except mentally or physically abnormal) of age group 5-10 years from selected school were studied. Children attending English medium school were considered to represent the USES. Because their parents are eligible to paid fee for education and are cautious regarding children's growth & development. So these children were considered as healthy children from affluent families. Prior consent for the study was taken from the school administration.
The individual child data, demographic and anthropometric, was recorded on predesigned proforma. Subject's weight without foot wares & with light cloths was measured using digital weighing machine.

3. RESULT ANALYSIS

Recorded data was classified according to age, sex & Taluka. There were ten age group 5-5.5 yr., 5.5-6 yr., …… 9.5-10 yr. Minimum sample size criteria (atleast 26) was determined for each age group sexwise for weight on the basis of findings of Vaman Khadilker et al[R 8]. Using sample size determination method $n=(Z_{1-\alpha/2}{}^2*SD^2)/(Median*€)^2$, taking €= precision of 10% . The data was further cleaned by removing outliers. Talukawise equality in genderwise proportion was assesed by applying Chi-square test. ANOVA revealed no significant difference in talukawise height and weight for each study age group. On the basis of the ANOVA result, agewise data of all study talukas were clubed into single data set as a representative of whole district.

Discriptive statistics Mean, S.D. & percentiles for anthropometric variables were calculated to summarize the data. Because of statistical variation in the reference sample empirical percentile curves are generally irregular, some type of smoothing over weight was required to apply. To achive this purpose LMST method (Box-Cox t distribution) was used to analyse the data. The scatter diagram of weight against age showed the gradual growth in weight as age advances with some exceptions **(Fig 1).** The correlation coefficient (r) between the explanatory variable (Age) and the response variable (height) is 0.681 ($p<0.01$) also indicating the relationship not exactly but nearly linear. Hence essentiality of the age transformation before exercising smoothing of centile curves is terminated.

Fig. 2 depicts that the distribution of weight looks like Gaussian but in real it was not true. The skewness can be easily seen from the figure while kurtosis is difficult to identify. The figure also depicts that weights between 16 kg and 21.5 kg are more common than expected under Gaussian distribution. This indicates tall pick. Further the weights in right half of the plot have slower decline, depicting longer tail compared with left tail. This shows positive skewness. This is the kind of pattern observed graphically in weights of the children. The descriptive statistics for the respective data **(Table 1)** showed that the distribution is highly skewed and leptokurtic. As ($|Sk|>0.5$ & $z=|Sk|/[SE (Sk)]$) =16.875>2, null hypothesis of Sk=0 is rejected. Similarly ($|Kurt|>1.0$ & $z=|Kurt|/[SE(Kurt)]$)=22.06 is also >2, null hypothesis of Kurt=0 is also rejected. This concludes that the distribution is not Gaussian.

Above findings suggests to undertake LMSP or LMST method to determine centiles instead of z score method that used when the response variable follows normal distribution. The lms () function automatically apply LMST method to the weight data.

The respective model name, its global deviance and edf for all parameters were displayed at model number 1 in **table 2.** The function 'find hyper' was implemented to determine optimum values (edf) of μ, σ, ν, τ in view of minimizing the global deviance. The respective hyper parameter values for BCPE distribution (LMSP method) are (0.1, 1.3649, 0.1, 0.1) and for BCT distribution (LMST method) which are (0.1, 1.2423, 0.1, 0.1) with penalty k=2. These values were introduced in GAMLSS model to determine centiles using BCPE distribution and BCT distribution with named LMSP $(BCPEo)^{\$}$ model and LMST $(BCTo)^{\$}$ model in **table 2** respectively. On the basis of AIC of lms function automatic selected model LMST $(BCTo)^{\#}$, LMSP $(BCPEo)^{\$}$ model and LMST $(BCTo)^{\$}$ (table 3), there was only small variation in lms function model LMST $(BCTo)^{\#}$and LMST $(BCT)^{\$}$ model. Both these models are fitted by using BCTo distribution. **Table 3** showed that model LMST $(BCTo)^{\#}$ is adequate for the data with smallest AIC.

For the final model selection we choose different values of k. **Table 4** gives respective models, their global deviance & edfs for all parameters for a particular value of k using LMST $(BCTo)^{\#}$ **Table 4** indicates that as penalty increases global deviance also increases slightly while degrees of freedom become decreases and its results smoothing will be more fine. If higher degrees of freedom used it gives complex curves & smoothing will not be so smooth. On the other side if lower degrees of freedom used then model becomes underfitted. From **table 4** it clear that as k ranging from 2-3 there was no significant difference in model fitting. As k>3 model becomes changed BCTo→BCCGo which does not smooth the parameter of kurtosis. To avoid this bias leading reduction in growth model accuracy it was decided to keep penalty $2 \leq k \leq 3$. To achive the objective of finding least edf that will still provide a good fit to the observed trend of L, M, S &P values over time points [12]. We decided to select the final model with k=3.The final model is y ~ BCT (2.0667, 3.022, 2, 2). The plot of fitted model for the median μ obtained from BCT (2.0667, 3.022, 2, 2) represents the trend of the observed data appropriately **(Fig. 3).** The fitted models for μ, σ, ν, τ given by this BCT model are displayed in **fig 4.**

The fitted model for μ indicates that the median weight of EMS boys gradually increases. The fitted model for sigma indicates that the coefficient of variation increases rapidly up to age 7, in between 7-9 years rate of increment little be small, after 9 years again it increases rapidly. The fitted model for nu indicates that the distribution of weight of EMS boys aged 5-10 years is highly positively skewed (since $\nu<0$ for all ages). The fitted model for tau indicates the distribution of weight of EMS boys that is leptokurtic. As age advances tau is going to increasing and the distribution tends to normal (because as $\tau \rightarrow\infty$ BCT converge to normal).

Fig. 5 displays the normalized quantile residuals from the chosen model BCT (2.0667, 3.022, 2, 2). Panel (a) & (b) plot the residuals against the fitted values of μ and against index respectively. This both presentations show random scatter of residuals around the horizontal line at 0. The panel (c) & (d) provide the kernel density estimate and normal Q-Q plot, respectively. The graphical presentation (c) & also coefficient of skewness and coefficient of kurtosis (Table 5) indicates kernel density estimate of the residuals is approximately normal. Q-Q plot shows one outlier at the upper tail and one partial outlier at lower tail, however this plot is approximately linear. Overall **fig. 5** conveys that Box-Cox t distribution provides adequate fit to the data. In addition, the summary statistics of quantile residuals; mean corresponding to zero, variance close to one, coefficient of skewness near to zero & coefficient of kurtosis corresponding to 3 suggests residuals are approximately normally distributed as required for the adequate model. Similar to Q-Q plot, Filleben probility plot correlation coefficient [13] which is the product moment correlation coefficient between the ordered observations $y_{(i)}$ & the ordered statistic medians M_i for a standardized normal distribution revealed r=0.9994 determined the linearity of a probability plot.

Fig.6 displays detailed age group-wise diagnostic plots for the residuals using worm plot which gives de-trended normal Q-Q plot of residuals in each age-interval. The warm plot identifies the lack of model fitting for a particular age interval. In this multiple worm plot the range of age split into nine non-overlapping intervals with roughly equal numbers of observations ranging from 77-79. The ten age ranges are listed in **table 6** and displayed in horizontal steps in the chart above the worm plots. The individual worm plots corresponding to these nine age intervals are read along rows from bottom left to right, in the steps. The points in each of these nine worm plots lie within the two elliptic curves that is within 95% confidence intervals. This suggests the developed model is adequate and fit to the data within all the age-intervals.

The fit within age group is further investigated by Q statistics and Z statistics for testing normality of the residuals within age groups. Modulos value of Z statistics should be less than 2. If $|Z_{gj}| > 2$ be considered as inadequacy in the model fitting. Where g for age group and j for parameter (g=1, 2….9, j=1, 2, 3, 4). **Table 6** gives values of Z_{gj} obtained from the chosen fitted BCT model. It shows that all $|Z_{gj}|$ values are less than 2. Visual inspection of Z statistics **(Fig. 7)** discussed as blue colour indicates that Hence the fitted model is best.

The Q statistics are calculated by $Q_j = \sum_{g=1}^{9} Z_{gj}^2$ for j=1,2,3,4. Significant values of Q1, Q2, Q3, Q4 statistics indicates possible inadequacy in the model for parameter μ, σ, ν and τ respectively. Which may be overcome by increasing degrees of freedom in the model for the particular parameter. **Table 6** gives Q statistics Q1, Q2, Q3, Q4 for testing mean, variance, skewness and kurtosis respectively of the residuals (within nine age groups listed in **table 6**) with their approximate test p-values. It provides fitted BCT model is completely acceptable.

On the basis of various diagnostics tools the BCT model for weight data proved to be best. Hence centiles are obtained by model BCT (2.0667, 3.022, 2, 2). **Table 8** showed actual mean and percentiles values for weight data. Table 8 showed smooth centile values from the fitted model BCT.

Environmental factors are the major determinants of disparities in physical growth[14]. Due to changing pattern of growth in a population over time. Growth references are recommended to be updated regularly [15]. The growth charts for children from Hong Kong [16], Mainland China [17], National Center for Health statistics (NCHS) growth curves for US children [14] and UK curves[18] were revised time to time. All these updated reports indicate a clear secular trend, with increase in height and weight over time.

A secular trend in anthropometric parameters is also evident from regional reports of India of some decades [2, 19, 20, 21, 22, 23]. The first Indian attempt at evaluating the growth of normal Indian children was made by the ICMR during 1956 to 1965 which involved subjects predominantly drawn from the LSES[19]. Several studies tried to reformulate reference data, with small sample sizes and regional recruitment [20, 21, 22]. In 1992, the results of a large multicentre survey of growth and development of Indian children from the USES were published [23]. It was conducted simultaneously in 12 cities from different parts of India.

Since India is a large country with a diverse genetic pool, the question arises that whether regional charts should be constructed [20]. The method suggested by the WHO MGRS (standardized site effects) to assess inter-regional differences is also for 0-5 years age group[6].

The above discussion results that the pattern of growth of population changes with time and also with place. Hence it is essential to construct rigional growth charts and update them regularly. Growth chart is a graphical tool for assessing the growth of the children. Growth chart consists of various centile curves at different ages, which are smoothed appropriately. There are various methods available for centile curve smoothing. But the LMS method of curve smoothing was widely accepted for constructing centile curves [14, 18, 24, 25, 26]. Since the present study growth charts are developed by using LMS method.

It is also argued that the growth of children of higher socioeconomic status is similar throughout the world, irrespective of ethnic background [27, 28]. In addition environmental rather than genetic differences are believed to be the principal determinants of disparities in physical growth [29]. Hence, in developing countries, it is recommended to use unified curves based on subjects with minimum nutritional constraints and full access to health care [21, 30], which is attempted by including Indian children from affluent families in present study.

In view of forecasting regional variation in the growth charts we compaired median weight of present study with WHO reference data (2007) & Khadilkar et al 2015.
Studies carried out in the past few decades revealed that worldwide children population have become taller and heavier [6, 24]. Same picture displayed here. That is WHO growth references are heavier than IAP growth standards and the present study. Also IAP growth standards are heavier than present state level study.

4. CONCLUSIONS

The Box-Cox t distribution (LMST method) provide appropriate model for a dependent variable weight (y) which is skewed and leptokurtic. The parameters of the model are related to location, scale, skewness and kurtosis and are modeled as smooth nonparametric function of explanatory variable age. In LMST method centile curves are summarized by these four smoothed parameters curve. Procedure for fitting LMST method is calculation intensive and cannot be used without the help of appropriate software. GAMLSS software in R language provide simple explicite model fitting and diagnostics. LMST method is generalization of LMS method. Which is highly suitable for skewed and leptokurtic data.

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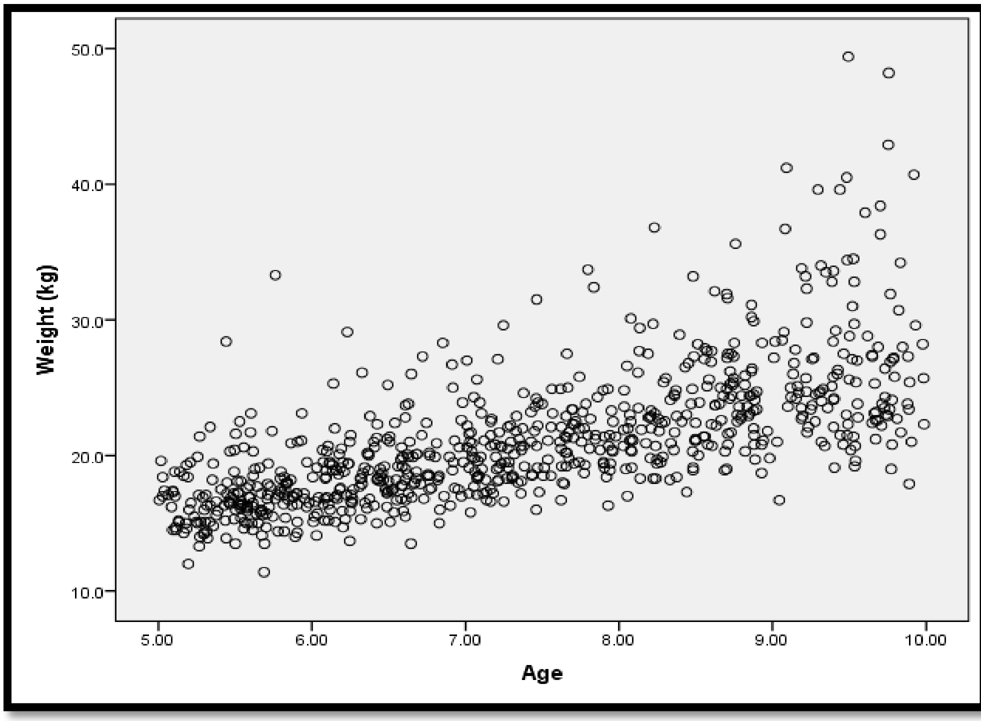

Fig 1: Scatter plot of weight data of boys.

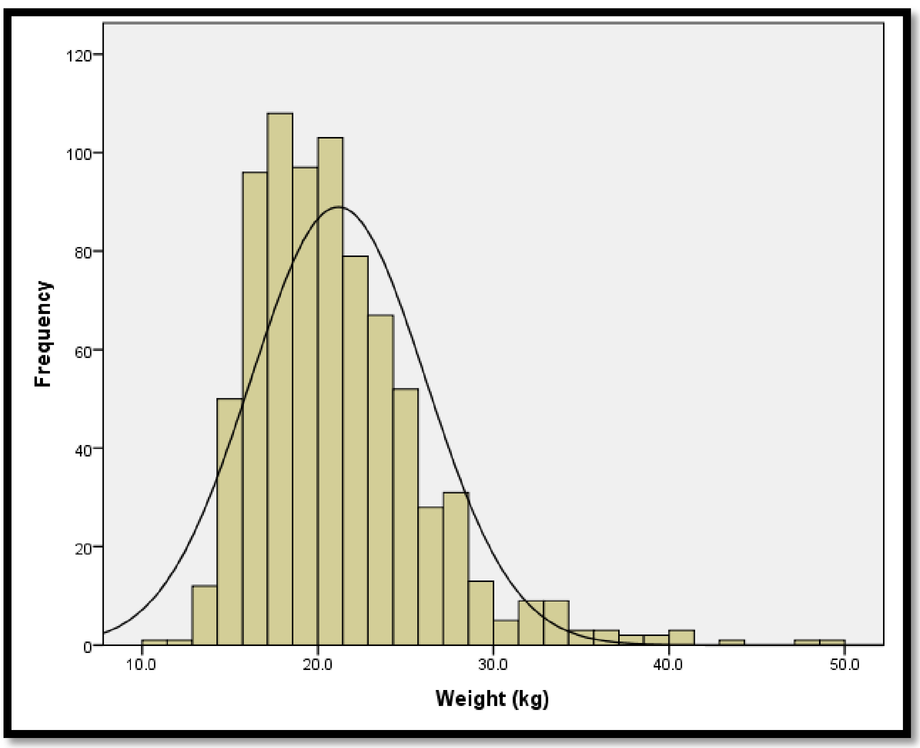

Fig 2: Weight distribution of 5-10 year EMS boys.

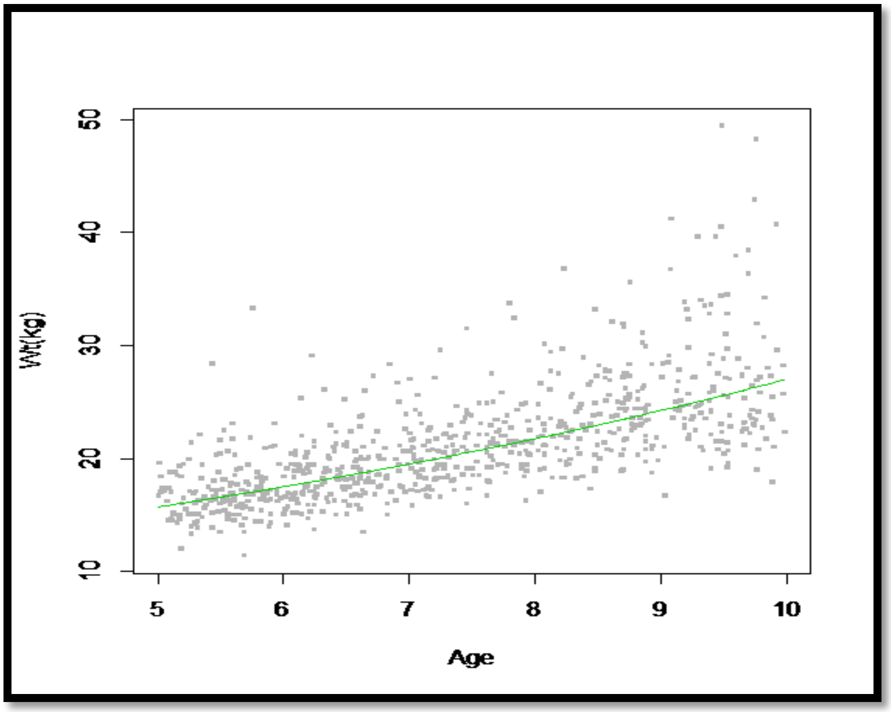

Fig. 3: Observed (dots) and fitted median μ (line) for weight of EMS students against age.

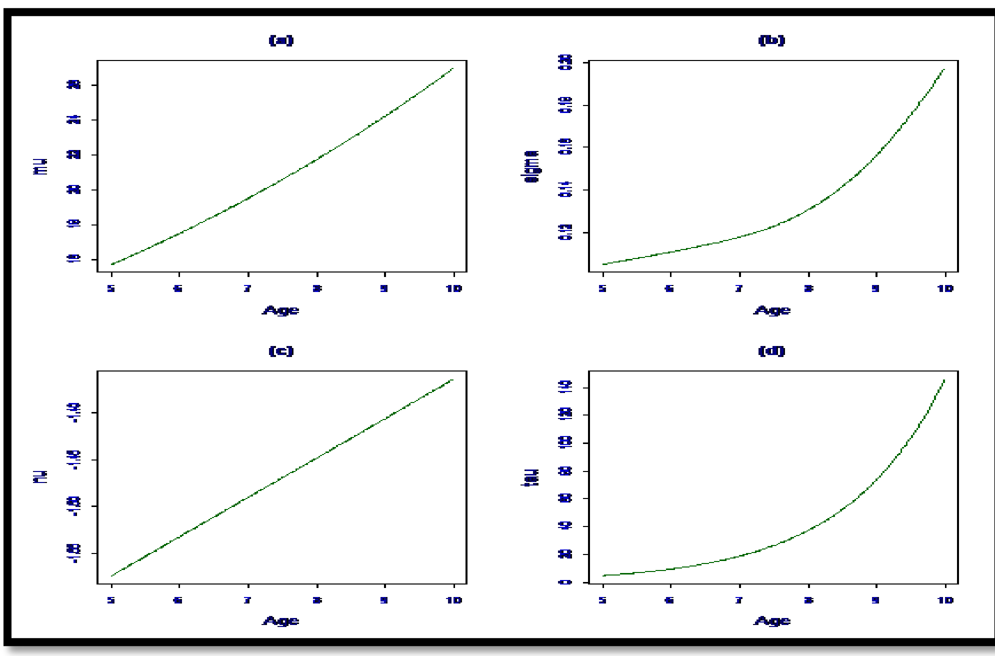

Fig. 4: The fitted parameters (a) μ, (b) σ, (c) ν, (d) τ from model BCT (2.0667, 3.022, 2, 2).

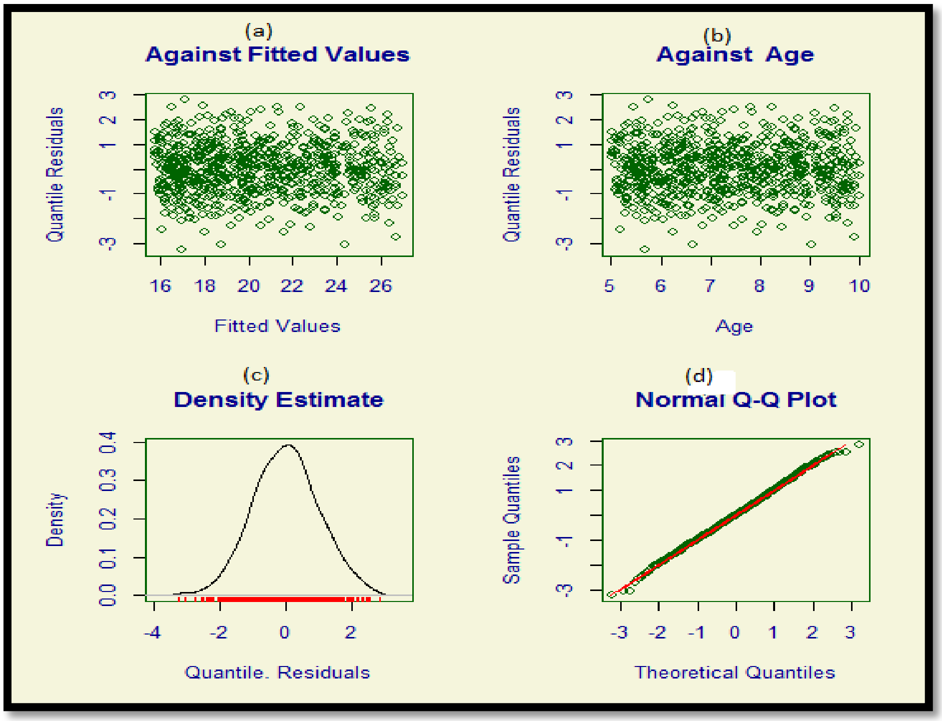

Fig 5: The residual plot from model BCT (2.0667, 3.022, 2, 2).

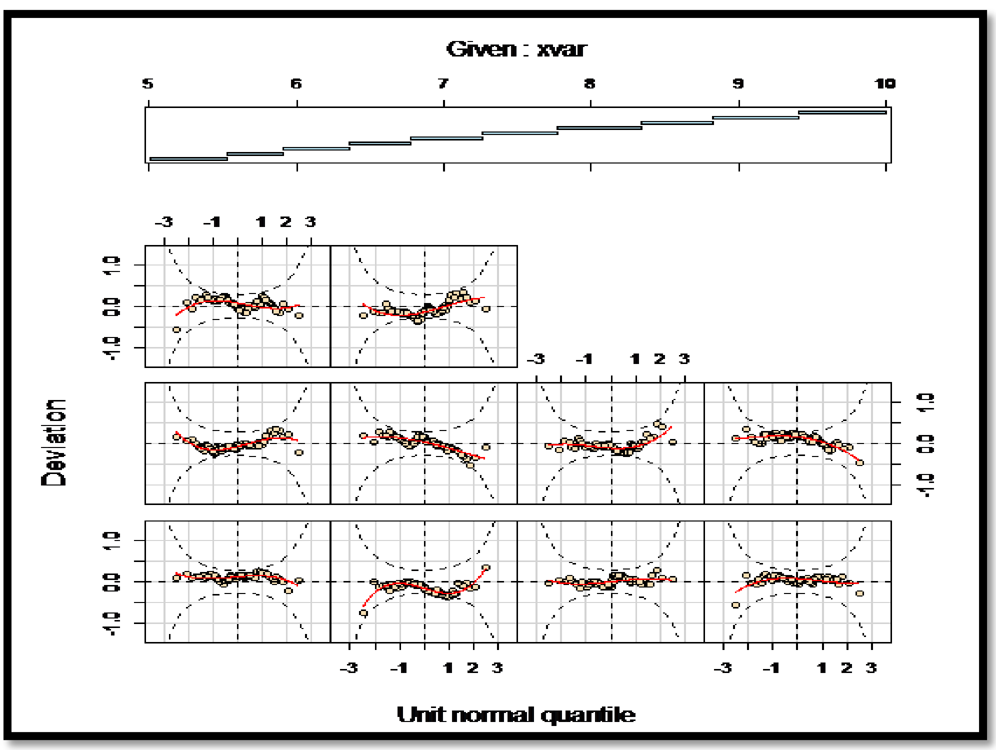

Fig 6: Worm plot of the residuals from the model BCT (2.0667, 3.022, 2, 2).

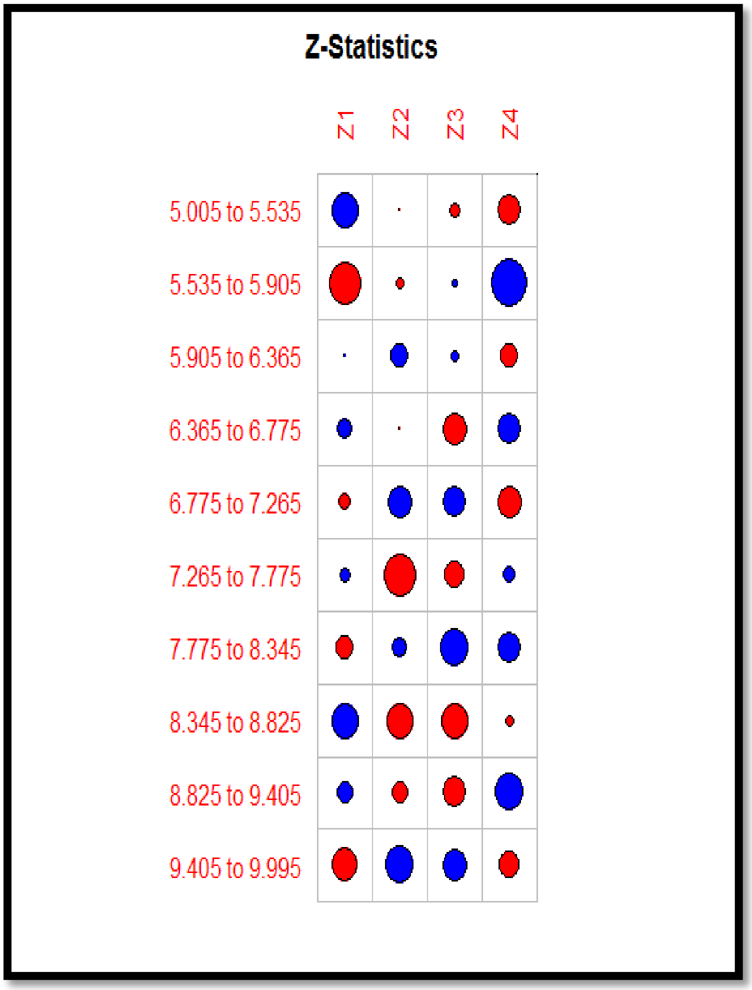

Fig 7: Visual inspection of Z statistics from the model BCT (2.0667, 3.022, 2, 2)

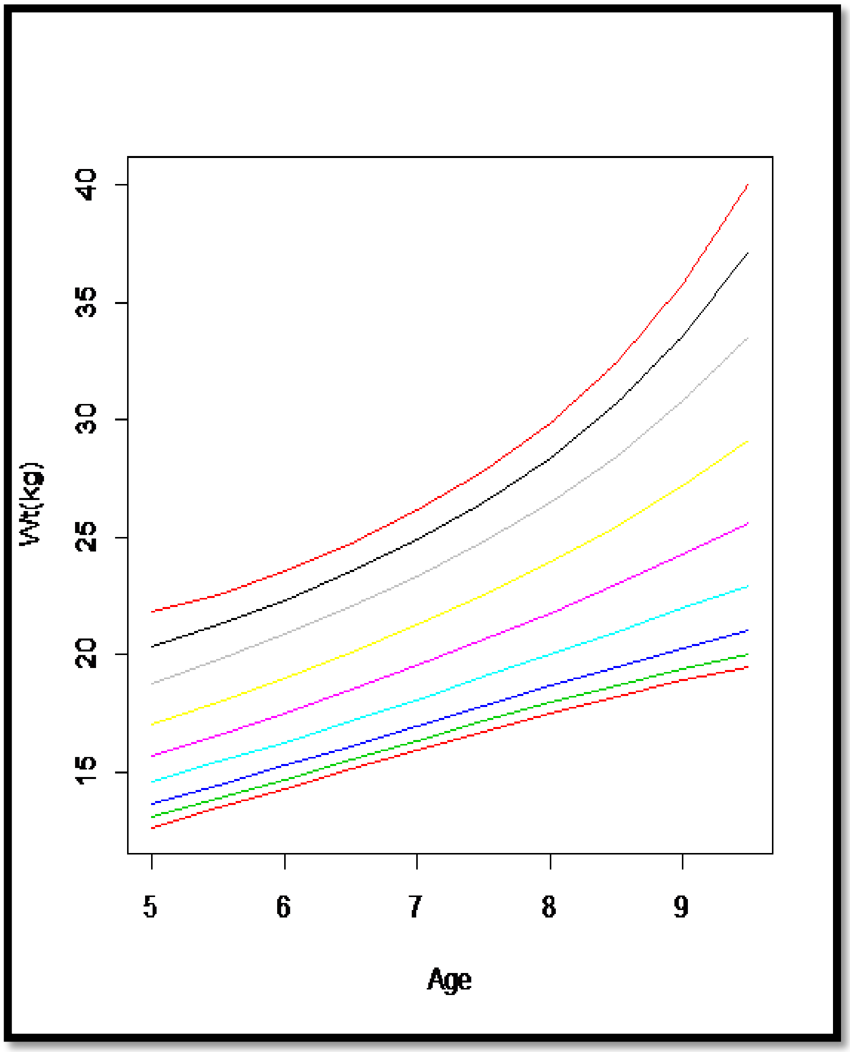

Fig 8: Smoothed centile curves of weight data of boys from the fitted model BCT (2.0667, 3.022, 2, 2)

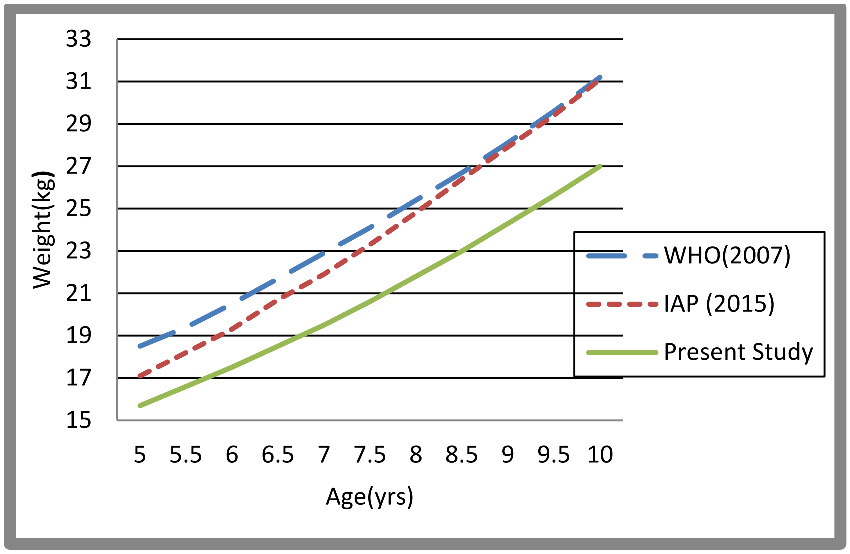

Fig 9: Comparison of median weight for age of boys.

Table 1: Descriptive statistics of weight of EMS boys.

Parameter	value
N	777
Mean	21.164
Median	20.4
Mode	17.2
Std. deviation	4.9764
Variance	24.764
Skewness	1.485
SE of Skewness	0.088
Kurtosis	3.861
SE of Kurtosis	0.175
Minimum	11.4
Maximum	49.4

Table 2: GAMLSS models using BCPEo distribution and BCTo distribution.

Model No.	Model	GD	μ	Σ	ν	τ
1	LMST (BCTo)#	3856.008	2.0665	3.2367	2	2
2	LMSP (BCPEo)$	3856.845	2.1	3.3649	2.1	2.1
3	LMST (BCTo)$	3855.876	2.1	3.2423	2.1	2.1

Table 3: GAIC (2) for different models

Model	Df	AIC
LMST (BCTo)#	9.3032	3874.615
LMSP (BCPEo)$	9.6653	3876.176
LMST (BCTo)$	9.5419	3874.96

Table 4: GAMLSS models with different values of penalty k

Penalty k	Model	GDEV	μ	σ	N	τ
2	BCTo	3856.008	2.0665	3.2367	2	2
2.5	BCTo	3856.371	2.0667	3.0795	2	2
3	BCTo	3856.526	2.0667	3.022	2	2
3.5	BCCGo	3855.624	2.2803	3.1051	2	0
4	BCCGo	3864.8	2.1908	3.0474	2	0
Log(n)=6.65	BCCGo	3866.3	2.0657	2.7699	2	0

Table 5: Summary of the Quantile Residuals

Mean	-0.0004
Variance	1.0006
Coef. Skewness	-0.0011

Coef.Kurtosis	2.9514
Filliben correlation coefficient	0.9994

Table 5: Z statistics for model BCT (2.0667, 3.022, 2, 2).

Group g	Age ranges in years	Z_{g1}	Z_{g2}	Z_{g3}	Z_{g4}
1	5.005 to 5.535	0.9735	-0.0009	-0.1936	-0.7120
2	5.535 to 5.905	-1.4118	-0.1254	0.0568	1.7860
3	5.905 to 6.365	0.0134	0.4487	0.1159	-0.4370
4	6.365 to 6.775	0.3425	-0.0006	-0.8195	0.7760
5	6.775 to 7.265	-0.2282	0.7873	0.7756	-0.8560
6	7.265 to 7.775	0.1780	-1.4573	-0.5513	0.2270
7	7.775 to 8.345	-0.4714	0.3344	1.0795	0.7110
8	8.345 to 8.825	1.0471	-0.9915	-1.0435	-0.1160
9	8.825 to 9.405	0.4072	-0.3602	-0.7402	1.1070
10	9.405 to 9.995	-0.8988	1.1453	0.8595	-0.5460

Table 6: Q statistics for model BCT (2.0667, 3.022, 2, 2) with their approximate test p-values in brackets.

Model	Q1	Q2	Q3	Q4
LMST (BCTo)[#]	5.4343(0.7040)	5.4972(0.7023)	5.1722(0.7390)	7.315(0.503)

Table7: Mean & Percentiles of Weight for age of Boys

Age_ Gr	**N**	**Mean**	**SD**	**3**	**10**	**25**	**50**	**75**	**90**	**97**
5-5.5 yrs	70	16.761	2.4557	13.378	14.3	15.1	16.5	18.05	19.59	22.009
5.5-6 yrs	95	17.259	2.7284	13.5	14.56	15.9	16.8	18	20.49	23.1

6-6.5 yrs	95	18.388	2.5843	14.628	15.3	16.6	18.3	19.5	21.24	25.396
6.5-7 yrs	75	19.38	2.8993	15.028	16.18	17.5	18.8	20.6	23.74	27.132
7-7.5 yrs	91	20.434	2.8482	16.456	17.2	18.4	20.1	21.8	23.9	27.7
7.5-8 yrs	68	21.571	2.9904	16.784	18.5	19.425	21.3	22.85	24.9	32.057
8-8.5 yrs	73	22.832	3.6811	17.498	18.6	20.35	22.4	24.65	27.62	32.518
8.5-9 yrs	80	24.413	3.3967	18.943	20.34	21.725	24.15	26.35	28.3	32.014
9-9.5 yrs	67	27.019	5.9775	19.164	21.4	23.4	25.1	29.1	34.86	41.172
9.5-10 yrs	63	26.583	6.02	18.912	20.74	22.6	25.4	28.8	35.58	43.324

Table 8: Smoothed centiles obtained from the model BCT (2.0667, 3.022, 2, 2)

Age	**C3**	**C5**	**C10**	**C25**	**C50**	**C75**	**C90**	**C95**	**C97**
5.0000	12.6640	13.0762	13.6756	14.6290	15.7282	17.0667	18.8075	20.38137	21.80739
5.5000	13.4988	13.8849	14.4665	15.4383	16.6043	18.0245	19.7871	21.27569	22.54557
6.0000	14.3160	14.6928	15.2755	16.2840	17.5285	19.0458	20.8697	22.33768	23.53613
6.5000	15.1325	15.5114	16.1086	17.1689	18.5045	20.1358	22.0567	23.55298	24.73826
7.0000	15.9526	16.3423	16.9654	18.0925	19.5352	21.3030	23.3594	24.92849	26.14744
7.5000	16.7634	17.1722	17.8334	19.0475	20.6232	22.5655	24.8154	26.5146	27.82073
8.0000	17.5381	17.9757	18.6901	20.0202	21.7714	23.9522	26.4903	28.40698	29.87765
8.5000	18.2556	18.7323	19.5174	20.9992	22.9825	25.4917	28.4532	30.71328	32.45945
9.0000	18.8971	19.4234	20.2981	21.9731	24.2596	27.2171	30.7935	33.58311	35.77423
9.5000	19.4606	20.0460	21.0279	22.9381	25.6058	29.1564	33.6009	37.18648	40.07926
10.0000	19.9684	20.6199	21.7225	23.9031	27.0254	31.3218	36.9369	41.67203	45.6349

Age	**5**	**5.5**	**6**	**6.5**	**7**	**7.5**	**8**	**8.5**	**9**	**9.5**	**10**
WHO(2007)[31]	18.5	19.4	20.5	21.7	22.9	24.1	25.4	26.7	28.1	29.6	31.2
IAP (2015)[8]	17.1	18.2	19.3	20.7	21.9	23.3	24.8	26.4	27.9	29.4	31.1
Present Study	15.7	16.6	17.5	18.5	19.5	20.6	21.8	23	24.3	25.6	27

