Chronicles of Biomedical Sciences
ISSN:3065-923X
Homepage: https://cbsciences.us/index.php/cbs

Charting New Paths: Standard Growth Charts for Pakistani Children (6-24 Months) using Multiple Indicator Cluster Survey Data

Muhammad Aasim[1,2], Sohail Chand[2].

[1]NHRC, HRI-NIH Research Centre, Shaikh Zayed Medical Complex Lahore, Pakistan.
[2]College of Statistical Sciences, University of the Punjab, Lahore, Pakistan.

ORIGINAL ARTICLE

Received on: January 08, 2025.

Accepted on: January 29, 2025.

Published on: January 30, 2025.

Keywords: Child development; Cluster Survey; Growth charts; Multiple Indicator; Pakistani children.

Corresponding author: Dr. Muhammad Aasim
aasim.phrc@gmail.com

ABSTRACT

Background: Reliable growth charts are vital for child health monitoring, with chart development based on empirical data and statistical traits. The World Health Organization (WHO) growth standards are used to monitor children's growth worldwide. Recent studies emphasize the need for customized country-specific standards. In Pakistan, reference charts exist, but a standard chart for under-two children is absent due to financial constraints.

Objective: This study employs the Novel Case Selection Method (NCSM) to derive variables from Multiple Indicator Cluster Survey (MICS) data for crafting growth charts for children aged 6 to 24 months.

Methods: Employing NCSM along with an algorithm for age-appropriate complementary feeding, this study selects 6,085 cases from 28,256 (aged 6-24 months) MICS data, forming the basis for standard growth chart creation. Using GAMLSS models with RefCurve_0.4.2, three families (Box Cox Cole and Green, Box Cox Power Exponential, Box Cox T) and three smoothing techniques (cubic splines, penalized splines, polynomial splines) are compared based on criteria including global deviance, Akaike Information, and Bayesian Information. Two models each for Height-for-Age (H/A) and Weight-for-Age (W/A), categorized by gender, yield standard growth curves compared with WHO 2006 standards.

Results: The study's NCSM, combined with considerations for complementary feeding and other WHO criteria, selects 6085 cases from MICS data with 28256 available. Optimal choices for male and female W/A, and female H/A curves are BCPE. Conversely, male H/A curves align with different parameters (BCT). The indigenous standard curves developed for Pakistan show distinct trajectories compared to WHO standards.

Conclusion: The necessity of establishing indigenous pediatric growth standards is evident in the observed disparities with WHO standards. These disparities highlight the need for context-specific benchmarks to accurately assess nutritional status and growth in Pakistani children.

Citation: Aasim M, Chand S. Charting new paths: standard growth charts for Pakistani children (6-24 months) using multiple indicator cluster survey data. Chron Biomed Sci. 2025;2(1):41. Available from: https://cbsciences.us/index.php/cbs/article/view/41.

Introduction

The prevailing practice in monitoring children's growth and estimating stunting and wasting involves the application of the World Health Organization (WHO) standards [1]. These standards, while widely utilized not only in Pakistan but also in various developing and underdeveloped nations, have been recognized as not universally applicable due to genetic and socio-economic disparities among countries [2]. Unlike the most developed and some developing countries that have devised their own indigenous growth standards and reference charts [3], Pakistan lacks a comprehensive standard chart, particularly for children under the age of two years. This paper elucidates the imperative of indigenous growth charts tailored to Pakistan's context and outlines the challenges and methodologies associated with their development [4][5].

Studies in Pakistan over recent years have sought to explore the growth patterns of specific age groups and monitor their growth using WHO standards or CDC references. However, these efforts have been fragmented and not inclusive of the entire pediatric population. The need for context-specific indigenous growth charts is widely acknowledged, especially considering the diversity in genetic and socio-economic factors within Pakistan [4][5].

Recent Studies in Pakistan

Pakistan has seen a rise in studies assessing growth patterns in various age groups. One study evaluated the nutritional status of children aged 5 to 12, estimating overweight and obesity prevalence using WHO 2007 standards [6]. In 2012, a national study examined 12,837 children aged 3 to 16. It developed percentile charts for ages 5 to 14 and compared them to CDC references [7]. In 2018, a study focused on 9,515 children aged 4 to 15 in four Pakistani cities, excluding Punjab, the most populated province of Pakistan. Its main aim was to assess tooth eruption patterns among healthy children [8].

Recent Cross-Sectional Studies

In 2022, Asif et al. conducted a study using a dataset of 10,782 children aged 2 to 19 from a multiethnic anthropometric survey in 2016. They generated H/A z scores for boys and girls, comparing these with WHO references [9]. Additionally, a study published in 2023 utilized data from the 2018 National Nutritional Survey of Pakistan. This study introduced the initial set of Pakistani reference growth charts for children aged 0 to 5, though the 3-month interval might not suit those under two [10].

Additionally, it's worth mentioning that the adherence to the requirements for standard growth charts, as outlined by WHO criteria, was not strictly observed in these studies. As a result, these charts are characterized as reference charts rather than standards [9][10].

Challenges in Establishing Indigenous Growth Charts

Developing indigenous growth charts is a recognized need [3][4][10][11][12], but it's complex due to factors like national representation, case selection, and model choice. The criteria for inclusion are stringent, involving assessments of age-appropriate complementary feeding, absence of severe illness, full-term birth, birth order up to four, non-congested household conditions, and non-smoking mothers [1]. Gathering national anthropometric data adhering to these criteria is challenging. Leveraging multiple indicator survey (MICS) data, known for robustness [13], emerges as a viable solution. The Novel Case Selection Method (NCSM), initially proposed for 0 to 24 months [14], has gained attention. It considers exclusive breastfeeding during 0-6 months and other factors [15]. NCSM, coupled with MICS data, aids selecting suitable cases for growth standards for children aged 6 to 24 months.

Importance of Cross-Sectional Datasets

Cross-sectional datasets, including MICS, are valuable for global studies, facilitating both standard and reference benchmarks. This approach's widespread applicability is seen in various research endeavors [2][3][5][10]. The Multiple Indicator Cluster Survey (MICS) are distinctive due to their comprehensive nature. They capture anthropometric measures, socio-demographic, and nutritional data. This supplemental information plays a crucial role in selecting cases for standard development. Some dataset variables are directly accessible and contribute to the research process. Further variables can be derived from existing data. This comprehensive data approach underscores the richness and potential of MICS datasets for accurate standards and references [14][15].

Model Selection and Methodology

Among various modeling options, the Generalized Additive Models for Location, Scale, and Shape (GAMLSS) emerge as the preferred choice for growth chart development [16]. This model encompasses three families—Box-Cox Cole and Green (BCCG) [17], Box-Cox Power Exponential (BCPE) [18][19], and Box-Cox T (BCT) [20]—catering to different data characteristics. To achieve smooth output curves that allow for interpolation and extrapolation between data points, three smoothing techniques—penalized splines, cubic splines, and polynomial—are employed within the GAMLSS framework [21].

This study addresses the necessity of indigenous growth charts for Pakistan, given the limitations of using global standards. The utilization of the NCSM for case selection from MICS data, coupled with GAMLSS modeling techniques, offers a comprehensive approach to growth charts development. The resulting indigenous growth charts cater to Pakistan's unique characteristics and can potentially offer more accurate assessments of child growth and nutritional status. The paper underscores the importance of context-specific growth charts in promoting accurate health monitoring and underscores the value of rigorous methodologies for their creation.

Methods:

This section is divided into three parts: the application of the NCSM and case selection from the MICS dataset, model selection and fitting, and the generation of charts using the best-fit models, followed by a comparison with the WHO standards.

Selection of Cases through NCMS

The NCSM (14) (15) is applied to the MICS dataset, involving a stepwise process of case selection based on predefined criteria. Out of a total of 28,256 cases aged 6 to 24 months, cases are excluded for various reasons: those with birth intervals less than 2 years, never breastfed, maternal smoking, twin or unknown singleton status, living in congested households, and those not meeting WHO nutritional criteria [22] [23]. Nutritional status is defined based on variables related to liquids and solids intake [also detailed in our previous study [15] in table S1 and S2, which are transformed into specific criteria based on age groups (6-9 months, 9-12 months, and 12-24 months). The algorithmic approach helped refine the selection, yielding 2,442 cases for the 6-9 months age group, 1,323 cases for the 9-12 months age group, and 5,904 cases for the 12-24 months age group.

In the context of the 6-9 months age group, an analytical infusion was initiated through the introduction of two novel variables M_1 and M_2.

The first, M_1 was formulated as the aggregate of two pre-existing variables x_7 and x_8 . x_7 held binary values representing milk consumption the previous day (1 for consumed, 0 for not consumed), while x_8 reflected the same for formula milk. $M_1 = x_7 + x_8$, categorically captured milk and formula consumption, yielding values of 0, 1, or 2. (Table S4)

The second variable, M_2 was constructed by summating four distinct variables: x_4, x_5, x_6 and x_9. These variables denote the intake of various liquid types, ranging from plain water to other liquids. M_2 was calculated as:

$$M_2 = x_4 + x_5 + x_6 + x_9$$

It was designed to quantify the variety of liquids consumed, with values spanning 0 (none) to 4 (all four types). (details in Table S5)

When both variables were studied the total number of cases with available information were 3109, while 59 were missing on either of the variable. The distribution of cases by two variables is given in the table S6.

The meticulous application of exclusion criteria resulted in the removal of 667 cases for still being exclusive breastfed and an additional 59 cases due to incomplete data. Consequently, the final dataset for analysis consisted of 2442 cases of children aged 6-9 months

For the 9-12 months age group, the methodology mirrored the previous steps with certain specific conditions. Here 18 cases were missing on M_1, while 1226 were neither having milk nor formula. Details can be seen in table S7.

When examined for M_2, 450 of the cases were not consuming any liquid while 40 cases had no information on M_2. (Table S8)

Both variable presented simultaneously the total number of cases with available information on both variables were 2228 as detailed in table S9. Notably, cases where $M_1 = \mathbf{0}$ and $M_2 < \mathbf{2}$ were excluded. This condition ensured that children either consumed milk, formula, or a combination of at least two types of liquids.

The rigorous application of these conditions led to the exclusion of 905 cases from the initial 2,280, alongside an additional 52 cases due to incomplete M_1 or M_2 data. This meticulously executed process culminated in a dataset of 1,323 cases aged 9-12 months.

For the age group of 12-24 months, which initially comprised 11,323 cases, the focus shifted to fulfilling WHO nutritional criteria. Nutrition variables related to solids are considered and are grouped into three categories and outlined in table S10.

Milk and its products: Represented by the variable S_1**:**

$$S_1 = y_1 + y_2 + y_{14}$$

Vegetables and fruits: Represented by the variable S_2

$$S_2 = y_4 + y_5 + y_6 + y_7 + y_8 = \sum_{i=4}^{8} \boldsymbol{y_i}$$

Protein & fats: Represented by the variable S_3

$$S_3 = y_9 + y_{10} + y_{11} + y_{12} + y_{13} = \sum_{i=9}^{13} \boldsymbol{y_i}$$

Using these three variables, three pairs of solids combinations, presenting nutritional values, N_1, N_2 and N_3 are created as detailed in Table S11 to S13:

Here

$$N_1 = [1;\ if\{S_1 \geq 1, S_2 \geq 1\}; else = 0]$$

This N_1 suggests that at least one item from both "Milk and its products" and "vegetables and fruits" is consumed

Those taking Solids_combination1 (Milk + F&V): $(N_1 = 1)$ = 3482

The second combination is labeled as N_2 and is considered with this condition as:

$$N_2 = [1;\ if\{S_1 \geq 1, S_3 \geq 1\}; else = 0]$$

Here $N_2 = 1$ suggests that at least one item from both "Milk and its products" and "protein and fats" is consumed. Those taking Solids combination (Milk + P&F): $(N_2 = 1)$ = 2212

Here

$$N_3 = [1;\ if\{S_2 \geq 1, S_3 \geq 1\}; else = 0]$$

Here $N_3 = 1$ suggests that at least one item from both "vegetables and fruits" and "protein and fats" is consumed

Those taking Solids_combination3 (F&V + P&F): $(N_3 = 1)$ = 4335

Since these combinations are binary in nature (either used or not used), they are summed up to form a new variable called "N"; $N = \sum_{k=0}^{3} N_k$

This variable indicated, what number of combinations the child has consumed out of 3, which sums up the nutritional state of children, as detailed in table S14.

Children with $N = 0$ are excluded from the analysis. Also there was no case which consumed two of the combinations of solids. Additionally, 514 cases that having missing data on any of the three combinations are also excluded. This process led to a final dataset of 5904 cases for the age group of 12-24 months (as presented in Table S14).

This process of nutritional assessment of children for meeting minimum requirements of food supplementation in the age of 6 -24 months led to the selection of 9669 cases. The algorithmic approach was instrumental in refining case selection, culminating in 2,442 cases for the 6-9 months age bracket, 1,323 cases for 9-12 months, and 5,904 cases for 12-24 months.

Application of Illness Parameter

The methodology was further enriched by the introduction of an illness parameter, which contributed to the fine-tuning of case selection. Through this process, cases with severe illnesses were systematically excluded. Here four illness conditions already mentioned previously were initially considered and labelled as L_1, L_2, L_3 and L_4 their detail and frequency of children suffering is as under:

L_1: Diarrhea = 2371

L_2: Illness with fever = 3080

L_3: Illness with cough = 2565

L_4: Breathing issue with cough = 1625

With a detailed literature review and consultation with pediatricians, it was concluded that having either diarrhea or breathing problems with cough can lead to restrict growth acutely and chronically. So final criteria by introducing a new variable was laid down as:

$$L = [1{:}\ if\ (L_1 = 0, L_4 = 0); else = 0]$$

Those with $L = 0$ were excluded; those were 3330, and there were 6339 cases who neither had diarrhea, nor breathing issues with cough as depicted in table S15.

Additionally, general outliers in height and weight were removed. The remaining cases underwent comprehensive validation to ensure the integrity of height and weight values and the absence of severe illnesses. This phase of validation and refinement culminated in a high-quality dataset of 6,085 cases, forming the bedrock for subsequent analysis and growth chart development.

Participants with valid height and weight measurements, who were free from severe illness, were included in the analysis. Additionally, general outliers for height and weight were excluded, along with cases that had missing data for either height or weight.

Curve Estimation

For the estimation of targeted curves (Weight-for-Age and Height-for-Age) for each gender, Generalized Additive Models for Location, Scale, and Shape (GAMLSS) are employed. The RefCurve_0.4.2 package is used to optimize the degrees of freedom for L (Box-Cox power parameter), M (median), and S (coefficient of variation). The best-fitting models are chosen based on the lowest Bayesian Information Criterion (BIC) value. Different combinations of GAMLSS families (Box-Cox Cole and Green, Box-Cox Power Exponential, Box-Cox t) and smoothing methods (penalized splines, cubic splines, polynomial splines) are compared using Global Deviance (GD), Akaike Information Criterion (AIC), and Bayesian information criteria (BIC). The selected models are used for final estimations. The steps are briefly described in another study [15]. The curve parameters estimated for four curves are also detailed in S.

Comparison with WHO MCGRS

The developed indigenous Pakistani standards are compared with the WHO Multicenter Growth Standards (MCGRS) percentiles (3rd, 50th, and 97th) for the selected curves (Weight-for-Age and Height-for-Age) across both genders. The data for comparison is sourced from the WHO's official website.

This comprehensive methodology outlines the process of case selection, data refinement, model fitting, and eventual comparison with international standards, culminating in the development of indigenous growth charts for Pakistani children aged 6 to 24 months.

The distribution of these selected cases is outlined based on their province, residential area, and gender. Urban cases accounted for 29.9% of the total, with males constituting 51.4% of the selected sample. Among the provinces, Punjab exhibited the highest representation, encompassing 42.8% of the cases. (Refer to Table 1 for detailed information.

Results

Table 1: Distribution of selected cases by gender, area of residence and province

Province	Area	Gender					
		Male		Female		Total	
		n	%	n	%	n	%
KPK	**Urban**	100	1.6	86	1.4	186	3.1
	Rural	662	10.9	613	10.1	1275	21.0
	Total	762	12.5	699	11.5	1461	24.0
Punjab	**Urban**	409	6.7	382	6.3	791	13.0
	Rural	902	14.8	910	15.0	1812	29.8
	Total	1311	21.5	1292	21.2	2603	42.8
Sindh	**Urban**	321	5.3	296	4.9	617	10.1
	Rural	268	4.4	225	3.7	493	8.1
	Total	589	9.7	521	8.6	1110	18.2
Balochistan	**Urban**	113	1.9	110	1.8	223	3.7
	Rural	355	5.8	333	5.5	688	11.3
	Total	468	7.7	443	7.3	911	15.0
Total	**Urban**	943	15.5	874	14.4	1817	29.9
	Rural	2187	35.9	2081	34.2	4268	70.1
	Total	3130	51.4	2955	48.6	6085	100.0

The cases are further analyzed with respect to age and gender, and descriptive measures are calculated for their weight and length/height at each age category. Among these cases, there are 2,238 instances where the age ranged between 27 and 52 weeks. Out of these, 1,144 cases are males, while 1,094 are females. Additionally, there are 3,874 cases with an age above 1 year (52 weeks), out of which 1,986 are males and 1,861 are females. In total, the study encompasses 6,085 cases, with 3,130 males and 2,955 females. (Refer to Table 2 for a detailed breakdown of these figures.)

In this context, the optimal degrees of freedom remained consistent (L=0, M=1, S=0) across all the four models: Weight-for-Age (W/A) for males and females, and Height-for-Age (H/A) for males and females. The criterion for selection is the lowest Bayesian Information Criterion (BIC), with the corresponding BIC values for the selected optimum degrees of freedom as follows: 11,384.73 for W/A males, 10,534.96 for W/A females, 20,150.21 for H/A males, and 18,712.87 for H/A females.

The fitting process involved testing various combinations of families and smoothing techniques to achieve the best-fit models for the given degrees of freedom. Evaluation is conducted using three criteria: Global Deviance (GD), Akaike Information Criterion (AIC), and Bayesian Information Criterion (BIC). When considering the Weight-for-Age curves, all three criteria yielded the same results for the best-fit models. For both male and female Weight-for-Age curves, the optimal model is BCPE family with penalized splines (ps) as the chosen smoothing technique. Although cubic splines are slightly edged out (with a post-decimal difference of 0.08 for all three criteria), the penalized splines are deemed as the superior choice.

Table 2: Distribution of cases by age and gender with descriptive measure for weight and Length/height for each age

Age (weeks)	Weight (Kgs)						Length/height (cm)					
	Male			Female			Male			Female		
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
27	66	7.0	1.2	54	6.3	1.0	66	66.4	4.7	54	63.8	5.2
28	59	7.1	1.3	65	6.8	1.0	59	66.4	5.7	65	65.0	5.1
29	66	7.2	1.4	50	6.7	1.2	66	65.7	5.3	50	65.6	5.7
30	59	7.3	1.3	54	7.1	1.3	59	66.5	7.1	54	66.3	6.9
31	69	7.6	1.4	50	7.1	1.7	69	67.1	6.2	50	67.2	6.7
32	67	7.5	1.3	56	7.0	1.3	67	68.1	5.7	56	66.1	5.3
33	59	7.5	1.6	67	7.3	1.1	59	67.6	6.5	67	67.2	4.7
34	50	7.5	1.1	55	7.3	1.5	50	69.5	7.2	55	66.9	4.9
35	52	7.6	1.0	46	6.9	1.0	52	68.2	3.8	46	65.1	5.1
36	49	7.7	1.4	68	7.3	1.5	49	68.7	5.1	68	66.7	6.2
37	57	7.9	1.4	54	7.3	1.5	57	68.7	6.5	54	66.8	4.9
38	40	7.9	.9	45	7.3	1.5	40	69.6	3.5	45	66.8	5.4
39	52	8.1	1.4	47	7.8	1.2	52	70.1	6.5	47	68.0	4.9
40	27	8.1	1.3	33	7.2	1.2	27	70.2	6.4	33	68.7	4.8
41	27	8.3	1.4	22	7.7	1.4	27	71.0	4.2	22	68.9	5.6
42	29	8.6	2.3	32	7.7	1.1	29	72.0	6.6	32	69.1	3.0
43	39	8.2	1.2	40	7.6	1.1	39	69.8	5.5	40	67.7	4.9
44	24	8.6	1.4	32	7.7	1.1	24	71.6	3.2	32	68.8	5.3
45	39	8.3	1.7	33	7.6	1.2	39	70.7	5.4	33	71.2	7.2
46	28	8.0	1.7	27	8.0	1.3	28	68.3	7.0	27	69.5	4.7
47	27	8.4	1.2	25	7.6	1.4	27	71.0	6.3	25	70.1	5.7
48	22	8.3	1.7	29	8.3	1.5	22	71.6	6.7	29	69.5	5.0
49	37	8.7	1.3	31	7.9	1.3	37	73.2	7.7	31	69.8	5.2
50	29	8.7	1.6	20	8.1	1.4	29	72.4	4.8	20	70.3	4.0
51	39	8.3	1.2	37	8.1	1.2	39	72.7	6.0	37	71.3	7.6
52	32	8.7	1.2	22	8.1	1.0	32	72.9	5.7	22	73.7	7.2
Total	**1144**	**7.8**	**1.4**	**1094**	**7.3**	**1.4**	**1144**	**69.0**	**6.2**	**1094**	**67.5**	**5.8**
53	31	8.9	1.2	46	8.2	1.6	31	74.3	5.4	46	71.8	6.3
54	46	8.7	1.3	44	8.2	1.3	46	73.4	5.4	44	72.0	4.7
55	36	8.7	1.6	46	8.3	1.5	36	73.2	5.2	46	71.3	5.8
56	47	8.6	1.8	43	8.5	1.3	47	74.1	7.5	43	72.6	4.9
57	39	9.1	1.4	33	8.5	1.6	39	72.5	6.4	33	72.4	5.1
58	38	9.3	1.7	40	8.8	1.1	38	74.7	5.7	40	74.0	5.6
59	43	8.9	1.4	40	8.6	1.4	43	75.0	5.5	40	73.1	4.8
60	29	9.0	1.7	43	8.6	1.2	29	75.5	5.1	43	73.5	5.2
61	50	9.1	1.3	44	8.8	1.5	50	74.2	5.6	44	75.2	4.9
62	47	9.5	1.9	43	8.4	1.3	47	75.6	6.5	43	72.1	5.6
63	39	9.1	1.5	42	8.8	1.8	39	74.9	6.3	42	74.9	5.7
64	41	8.9	1.4	37	8.8	1.2	41	72.9	6.5	37	73.4	5.3
65	30	9.0	1.6	36	9.2	1.4	30	74.6	6.9	36	74.9	7.3

66	49	9.2	1.5	40	8.7	1.3	49	75.9	5.2	40	74.8	3.9
67	31	8.8	1.4	36	9.0	1.9	31	74.3	6.0	36	73.8	5.4
68	52	9.7	1.7	52	8.8	1.8	52	76.2	4.2	52	73.4	6.6
69	45	9.2	1.5	52	8.8	1.7	45	75.2	5.2	52	73.8	6.0
70	48	9.2	1.2	36	9.0	1.7	48	76.3	6.8	36	75.6	6.6
71	39	9.2	1.5	34	8.8	1.2	39	76.9	5.1	34	74.2	7.5
72	49	9.4	1.6	26	8.9	1.3	49	76.2	6.0	26	76.6	6.8
73	50	9.3	1.5	39	9.2	1.4	50	75.2	6.2	39	76.2	4.8
74	53	9.6	1.5	42	9.2	1.4	53	76.8	7.3	42	75.7	6.3
75	54	9.9	1.5	47	8.6	1.3	54	76.6	6.8	47	75.2	5.1
76	31	9.2	1.5	28	9.5	1.4	31	76.2	7.2	28	76.0	6.4
77	34	10.1	1.6	49	9.2	1.5	34	78.7	4.6	49	76.0	5.0
78	45	9.5	1.5	49	9.1	1.4	45	76.6	6.2	49	76.0	5.4
79	37	9.4	1.1	39	9.4	1.5	37	75.5	5.2	39	75.0	7.4
80	54	9.3	1.5	51	9.6	1.5	54	76.3	5.3	51	78.1	3.9
81	41	9.2	1.8	39	9.5	1.6	41	76.3	8.2	39	78.2	6.0
82	37	9.8	1.8	43	9.2	1.5	37	77.4	7.4	43	76.9	6.4
83	36	9.8	1.2	34	9.4	1.7	36	78.5	4.2	34	77.4	5.1
84	38	9.9	1.5	37	9.4	1.6	38	79.3	5.4	37	78.4	7.0
85	34	9.7	1.3	24	9.3	1.5	34	79.9	4.2	24	76.4	5.2
86	40	10.0	1.2	37	10.0	1.5	40	78.6	6.9	37	78.6	4.9
87	34	10.1	1.5	34	9.7	2.0	34	80.6	5.9	34	77.4	7.7
88	31	10.0	2.0	28	9.6	1.1	31	78.9	6.6	28	78.0	5.5
89	35	10.2	1.5	26	9.8	1.8	35	79.3	6.0	26	78.0	4.8
90	37	10.2	1.7	29	9.9	1.1	37	80.3	5.7	29	79.5	6.2
91	38	10.3	1.5	31	9.3	1.9	38	81.9	4.7	31	76.9	6.7
92	25	10.8	1.3	24	9.6	1.7	25	81.5	4.1	24	78.3	6.7
93	31	10.5	1.7	28	9.9	1.7	31	80.5	4.9	28	78.1	4.8
94	30	10.1	1.9	23	9.0	1.5	30	79.8	7.3	23	75.4	7.1
95	38	10.5	1.8	29	9.6	1.0	38	80.6	5.6	29	79.6	6.0
96	29	10.1	1.7	35	9.4	1.9	29	79.9	7.5	35	78.3	6.9
97	33	10.3	1.6	26	10.2	1.9	33	81.4	5.2	26	81.1	4.8
98	26	10.4	1.6	24	9.6	1.4	26	78.7	7.3	24	78.8	3.4
99	29	10.6	1.6	19	9.8	1.9	29	81.1	8.0	19	80.0	7.0
100	36	10.0	1.8	26	10.1	1.8	36	79.0	7.8	26	79.7	7.3
101	26	10.2	1.6	34	10.2	1.1	26	80.1	4.3	34	81.8	5.1
102	31	10.4	1.6	30	10.1	1.6	31	81.2	7.1	30	80.3	6.2
103	31	10.0	1.8	25	10.3	1.8	31	78.9	6.9	25	81.7	6.3
104	33	10.4	1.7	19	10.0	1.7	33	79.6	8.1	19	79.4	7.2
Total	**1986**	**9.6**	**1.6**	**1861**	**9.1**	**1.6**	**1986**	**77.1**	**6.6**	**1861**	**75.9**	**6.3**
Total	**3130**	**8.9**	**1.8**	**2955**	**8.5**	**1.8**	**3130**	**74.1**	**7.5**	**2955**	**72.8**	**7.4**

Table 3: Selection of optimum degrees of freedom and optimum model for each of the four curves (6-24 months)

			Weight for age		Height for age	
			Male	**Female**	**Male**	**Female**
			Optimal Degrees of freedom for L, M & S			
Parameters (Test range)	**L (0-3)**		0	0	0	0
	M (0-3)		1	1	1	1
	S (0-3)		0	0	0	0
	BIC		11384.73	10534.96	20150.21	18712.87
Family	**Smoothing**	**Criterion**	**Estimates**			
BCCG	**Ps**	**GD**	11328.39	10479.02	20093.87	18656.93
		AIC	11342.39	10493.02	20107.87	18670.93
		BIC	11384.73	10534.96	20150.21	18712.87
	Cs	**GD**	11328.49	10479.11	20093.94	18656.99
		AIC	11342.49	10493.11	20107.94	18670.99
		BIC	11384.83	10535.04	20150.28	18712.93
	Poly	**GD**	11356.51	10503.40	20117.95	18679.88
		AIC	11368.51	10515.40	20129.95	18691.88
		BIC	11404.8	10551.35	20166.24	18727.83
BCPE	**Ps**	**GD**	**11229.35**	**10360.16**	19713.49	**18301.79**
		AIC	**11245.35**	**10376.16**	19729.49	**18317.79**
		BIC	**11293.74**	**10424.09**	19777.88	**18365.72**
	Cs	**GD**	11229.45	10360.24	19713.60	18301.99
		AIC	11245.45	10376.24	19729.60	18317.99
		BIC	11293.84	10424.17	19777.99	18365.92
	Poly	**GD**	11258.83	10389.55	19739.29	18339.13
		AIC	11272.83	10403.55	19753.29	18353.13
		BIC	11315.17	10445.49	19795.63	18395.06
BCT	**Ps**	**GD**	11233.05	10370.54	**19656.03**	18320.13
		AIC	11249.05	10386.54	**19672.03**	18336.13
		BIC	11297.44	10434.47	**19720.42**	18384.06
	Cs	**GD**	11233.14	10370.65	19656.20	18320.23
		AIC	11249.14	10386.65	19672.20	18336.23
		BIC	11297.53	10434.58	19720.59	18384.16
	Poly	**GD**	11262.45	10399.95	19720.68	18353.77
		AIC	11276.45	10413.95	19734.68	18367.77
		BIC	11318.79	10455.89	19777.02	18409.71
Value of τ *for selected models*			**1.410044**	**1.347331**	**1.725658***	**1.059004**

** This value is for the selected model BCT-ps (H/A male) while other three values are for BCPE-ps*

However, when assessing the Height-for-Age curves, the same BCPE family with penalized splines (ps) is the ideal model for females, mirroring the Weight-for-Age curves. Yet, for the Height-for-Age curve in males, the best-fit model is identified as the BCT family with penalized splines (ps) as the smoothing technique. Across all the fitted models, polynomial smoothing techniques consistently resulted in larger values for all three evaluation criteria. (For a comprehensive overview of these findings, refer to Table 3).

The four selected models are employed to generate standard growth curves for W/A, and H/A for each gender. When examining the Weight-for-Age curves, males displayed higher medians, 3rd percentiles, and 97th percentiles compared to females. The median weight for males initiated at 7.19 kilograms at 27 weeks (6 months) of age and progressed to 10.56 kilograms at 104 weeks (24 months) of age. Correspondingly, the 97th percentile values are 9.90 kilograms and 13.74 kilograms, while the 3rd percentile values are 4.95 kilograms and 7.28 kilograms, respectively. Over the span of 27 to 104 weeks of age, the median weight increased by 3.37 kilograms, whereas the changes for the 97th and 3rd percentiles are 3.84 kilograms and 2.33 kilograms, respectively.

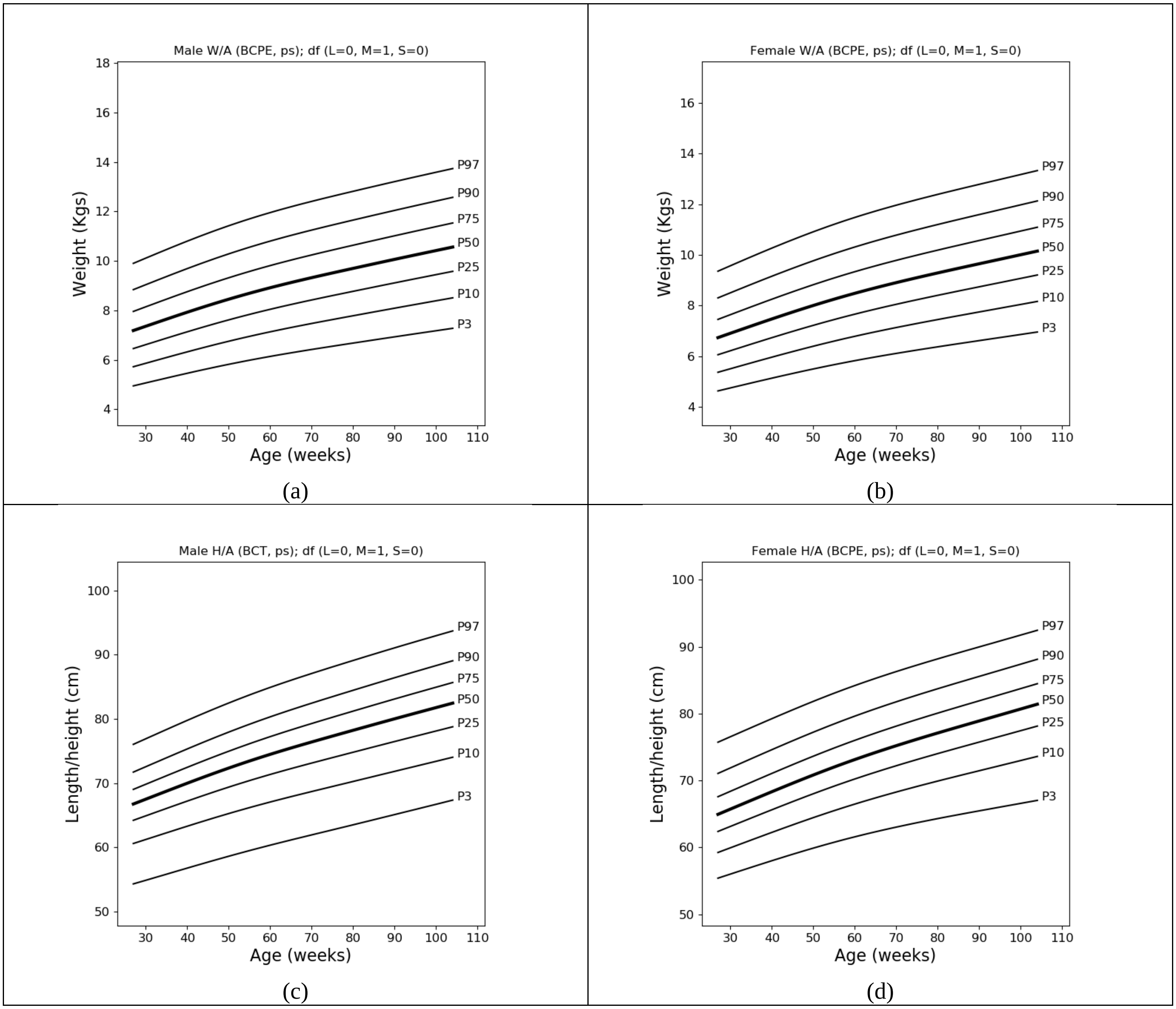

Figure 1: Fitted standard curves for Pakistani children of age 6-24 month; measured at weekly interval for W/A and H/A for two genders

Conversely, for females, the median weight ranged from 6.73 kilograms to 10.5 kilograms, undergoing a change of 3.77 kilograms. The 97th percentile values ranged from 9.36 kilograms to 13.33 kilograms, with a change of 3.97 kilograms, while the change for the 3rd percentile is 2.32 kilograms, varying between 4.93 kilograms and 6.95 kilograms. This indicates that the rate of change for females is slightly higher for the median and 97th percentile, but identical for the 3rd percentile. (Refer to Figure 1 (a) & (b) for visualization.) For height, the charts portray lower median heights for females in comparison to males. At 27 weeks of age, the median height for males is 66.76 centimeters, whereas for females, it is 64.94 centimeters. At 104 weeks of age, the respective median heights are 82.47 centimeters for males and 81.40 centimeters for females.

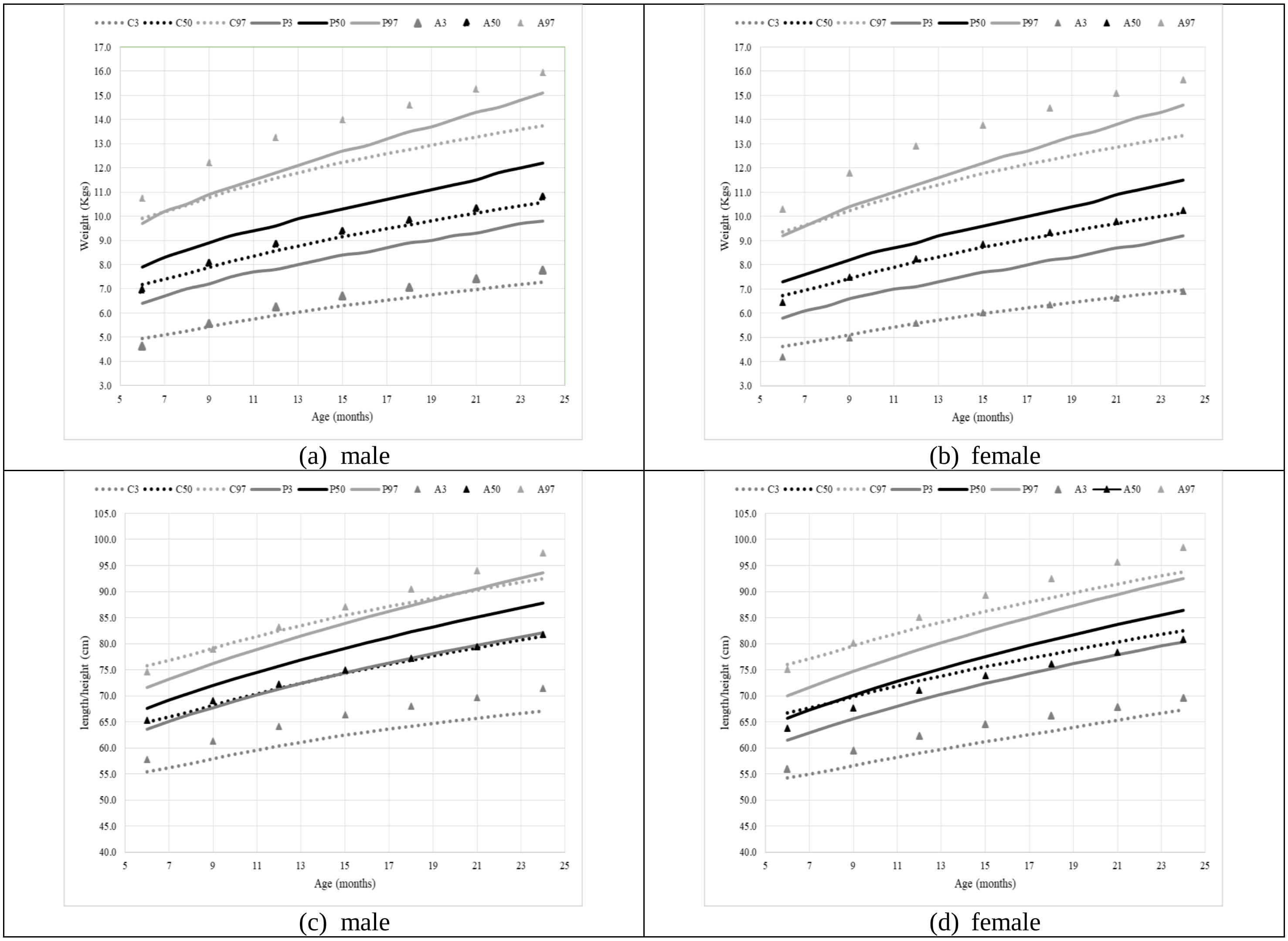

Figure 2: Comparison of selected percentiles of this study(C) with WHO standards (P) and Pakistani reference chart 2022 (A)

In terms of the 97th percentile, the height values at 27 weeks and 104 weeks are 76.05 centimeters and 93.71 centimeters for males, and 75.72 centimeters and 92.45 centimeters for females. (Refer to Figure 1 (c) and (d) for visual representation). To assess the compatibility of these newly developed Pakistani standards, a comparison is made with both the WHO standards and the latest Pakistani reference charts. The analysis revealed noteworthy differences in percentiles for W/A and H/A among the various standards.

For W/A, the 3rd percentiles in our standards are notably lower than those in the WHO standards. However, when compared to the Pakistani reference charts of 2022, the 3rd percentile in our standards coincides for both genders. The median values are also similar between the two Pakistani studies but are lower than the WHO standards by around 0.7 kilograms at 6 months and 1.5 kilograms at 24 months. The 97th percentiles in our standards initially aligned with the WHO standards between 6th and 12th months, but then diverged, with the difference progressively increasing. By 24 months of age, the WHO standards are almost 1.0 kilogram higher than our standards. In contrast, the Pakistani reference charts consistently displayed much higher 97th percentiles throughout the curve, with differences of around 1.0 kilogram at 6 months and over 2.0 kilograms for males and females at 24 months. (Refer to Figure 2(a, b) for graphical representation.)

Regarding H/A for males, the median of our standards coincides with the reference charts, while our 3rd percentiles are lower. Both Pakistani studies saw their medians aligning with the 3rd percentile of the WHO standards. The median heights in the WHO standards are almost 5.0 centimeters higher than those in both Pakistani studies at 6 months, and around 7.0 centimeters higher at 24 months. The 97th percentile for H/A in our standards matched the reference charts between 6 and 15 months, before registering lower values. The 97th percentiles in the WHO standards are lower than our study until 18 months, then coincides until 24 months. (Refer to Figure 2(c) for visualization.)

In the case of H/A for females, our 3rd percentiles are notably higher (with differences of approximately 7.2 centimeters at 6 months and 13.4 centimeters at 24 months) than the WHO standards. The median in our study aligned with the WHO median between 6 and 11 months, but is slightly lower until 24 months, with a difference of 3.93 centimeters. The 97th percentiles in the WHO standards begin at 70.0 centimeters at 6 months and reaches 92.5 centimeters at 24 months. In comparison, our study's 97th percentiles are 76.05 centimeters and 93.71 centimeters, while the Pakistani reference charts have values of 75.09 centimeters and 98.51 centimeters at 6 and 24 months, respectively. (Refer to Figure 2(d) for graphical representation).

Discussion

In this study, two crucial aspects of growth charts are addressed: data preparation and growth chart development. Data preparation was paramount, as it was essential to adhere to the WHO's criteria for developing growth standards [18]. To achieve this, the study needed a robust and nationally representative dataset, which is satisfied by utilizing MICS round 6 data for Pakistan. The NCSM structure has been outlined previously [14], and this study presented a detailed implementation of NCSM using algorithms for selecting cases to develop growth standards for children aged 6-24 months.

The selection criteria remains consistent with the 0-6 month standards [15], although detailed work was required to account for nutrition [age-appropriate complementary feeding] between 6 months and 24 months [22]. This is accomplished by using multiple variables from MICS data, which provides information on liquid and solid diets consumed by children on the day preceding data collection [24]. Despite potential inaccuracies, this approach is considered a proxy for assessing age-appropriate complementary feeding, which is crucial information.

The selection process also includes evaluating severe illnesses by considering four major illness records. The final criteria excludes cases with simultaneous diarrhea and breathing issues with cough, as these factors could acutely affect weight loss and height growth over time [25][26].

The resulting selected cases aged 6-24 months, meeting the defined criteria, comprised approximately 21.5% of the original sample. This portion after applying nutrition criteria is 34.2%. This percentage aligns closely with the National Nutritional Survey 2018, which reports corresponding figures for dietary diversity (14.2%), meal frequency (18.2%), and overall age-appropriate complementary feeding (35.9%) [27].

GAMLSS models, particularly the BCPE family with penalized splines (ps), emerged as the best fit for most (three) of the curves, including W/A and H/A. The choice of BCPE and the utilization of ps are consistent with previous studies [2][9][10][11][15] and demonstrates optimal results for these growth charts. However the H/A (Height-for-Age) curve among males, the best fit model is the Box-Cox t (BCT) family with penalized splines. This highlights that the variation in the data can lead to the selection of different families of GAMLSS models. In this specific case, the presence of heavy tails in the data contributed to the selection of the BCT family [19][20].

Comparing the smoothing methods, penalized splines (ps) displays a minimal difference over cubic splines (cs) for all the fitted models. Despite this minor difference, penalized splines are consistently superior to polynomial splines by a significant margin. This indicates that the penalized spline method offers better performance and accuracy in capturing the underlying trends in the data compared to polynomial splines.

Comparisons with the WHO standards underscores the importance of indigenous standard growth charts for individual countries [10][11][12]. The differences in 3rd percentiles of our charts for H/A in comparison to WHO standards suggested a potential need for revising estimates of stunting based on new indigenous standards. This adjustment can lead to more accurate policy decisions and resource allocation in developing countries. Similarly, the study highlights differences in estimates for overweight children, where our 97th percentile for W/A is lower than WHO standards, particularly for children aged 12 months and above.

Conclusion

This study emphasizes the value of the NCSM as a powerful tool for case selection in the development of indigenous standard growth charts, particularly in countries with available MICS round 6 data. Utilizing cross-sectional datasets for children under the age of 2 is feasible, and the GAMLSS model proves effective when considering data characteristics like skewness, kurtosis, and heavy tails. The study reinforces the notion that estimates made using WHO standards might lack accuracy due to genetic, socioeconomic, and cultural variations among global populations. Consequently, the justification for developed indigenous standards is clear and necessary.

Authors' contributions

ICMJE criteria	Details	Author(s)
1. Substantial contributions	Conception, OR	1
	Design of the work, OR	1
	Data acquisition, analysis, or interpretation	2
2. Drafting or reviewing	Draft the work, OR	1,2
	Review critically for important intellectual content	2
3. Final approval	Approve the version to be published	1,2
4. Accountable	Agree to be accountable for all aspects of the work	1,2

Acknowledgement

None

Funding

This research study received no specific grant from any funding agency.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The Ethics Review Committee of University of the Punjab, Lahore approved the study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Supplementary material

Available from URL: https://drive.google.com/file/d/1Yk_WunMhK6PvVT7KWOqPIeJQXi4na2Vl/view?usp=drive_link

References

[1]. WHO. WHO Child growth standards 2023 [Available from: https://apps.who.int/iris/bitstream/handle/10665/43413/924154693X_eng.pdf

[2]. Khadilkar V, Khadilkar AV, Kajale N. Indian growth references from 0-18-year-old children and adolescents-a comparison of two methods. Indian J Endo Metab. 2019;23(6):635.

[3]. Natale V, Rajagopalan A. Worldwide variation in human growth and the World Health Organization growth standards: a systematic review. BMJ Open. 2014;4(1):e003735.

[4]. Carroll AE. The trouble with growth charts. The New York Times, Parenting. 2020.

[5]. Chamidah N, Tjahjono E, Fadilah A, Lestari B, editors. Standard growth charts for weight of children in East Java using local linear estimator. J Physics: Conference Series; 2018: IOP Publishing.

[6]. Mushtaq MU, Gull S, Abdullah HM, Shahid U, Shad MA, Akram J. Prevalence and socioeconomic correlates of overweight and obesity among Pakistani primary school children. BMC Public Health. 2011;11(1):1-10.

[7]. Aziz S, Ain W, Majeed R, Khan MA, Qayum I, Ahmed I, et al. Growth centile charts (anthropometric measurement) of Pakistani pediatric population. J Pak Med Assoc. 2012;62(4):367.

[8]. Iftikhar S, Khan N, Siddiqui JS, Baig-Ansari N. Development of growth charts of Pakistani children aged 4-15 years using quantile regression: a cross-sectional study. Cureus. 2018;10(2).

[9]. Asif M, Aslam M, Mazhar I, Ali H, Ismail T, Matłosz P, et al. Establishing height-for-age z-score growth reference curves and stunting prevalence in children and adolescents in Pakistan. Int J Env Res Pub Heal. 2022;19(19):12630.

[10]. Akbar N, Aslam M, Petersen JH, Mustafa G. The 2022 Pakistani references from birth to 60 months for length/height, weight and body mass index. Acta Paediatr. 2023;112(6):1249-58.

[11]. Abtahi M, Doustmohammadian A, Abbdollahi M. Construction of national standards of weight and height and growth charts of Iranian children: a review article. Int J Prev Med. 2011;2(3):122-6.

[12]. Pérez-Bermejo M, Alcalá-Dávalos L, Pérez-Murillo J, Legidos-García ME, Murillo-Llorente MT. Are the growth standards of the world health organization valid for spanish children? The SONEV Study. Front Pediatr. 2021;9:700748.

[13]. Khan S, Hancioglu A. Multiple indicator cluster surveys: delivering robust data on children and women across the globe. Stud Fam Plann. 2019;50(3):279-86.

[14]. Aasim M, Chand S. Novel Methodology for the selection of cases from mics data for growth charts development

based on WHO criterion. Pak J Med Health Sci. 2022;16(11):138.
[15]. Aasim M, Chand S. Height-for-age and weight-for-age growth charts for Pakistani infants under six months: derived from a novel case selection method using multiple indicator cluster survey data. BMC Med Res Methodol. 2023;23(1):289.
[16]. Rigby RA, Stasinopoulos DM. Generalized additive models for location, scale and shape. J R Stat Soc Ser C Appl Stat. 2005;54(3):507-54.
[17]. Cole TJ, Green PJ. Smoothing reference centile curves: the LMS method and penalized likelihood. Statistics in medicine. 1992;11(10):1305-19.
[18]. Group WMGRS, de Onis M. WHO Child Growth Standards based on length/height, weight and age. Acta paediatrica. 2006;95:76-85.
[19]. Rigby RA, Stasinopoulos DM. Smooth centile curves for skew and kurtotic data modelled using the Box–Cox power exponential distribution. Statistics in medicine. 2004;23(19):3053-76.
[20]. Rigby RA, Stasinopoulos DM. Using the Box-Cox t distribution in GAMLSS to model skewness and kurtosis. Statistical Modelling. 2006;6(3):209-29.
[21]. Green P. BW Silverman in: Nonparametric regression and generalized linear models [M]. London: Chapman & Hall; 1994.
[22]. Dewey K. Guiding principles for complementary feeding of the breastfed child. 2003.
[23]. Shrestha R. Complementary Feeding: Principles, Characteristics & Benefits April 4, 2023. Available from: https://www.publichealthnotes.com/complementary-feeding-principles-characteristics-benefits/.
[24]. UNICEF. MICS round 6 data for Pakistan 2022 [Available from: https://mics.unicef.org/surveys.
[25]. Richard SA, Black RE, Gilman RH, Guerrant RL, Kang G, Lanata CF, et al. Diarrhea in early childhood: short-term association with weight and long-term association with length. Am J Epidemiol. 2013;178(7):1129-38.
[26]. WHO. Cough or difficulty in breathing. Pocket Book of Hospital Care for Children: Guidelines for the Management of Common Childhood Illnesses. 2nd ed. Geneva: World Health Organization; 2013.
[27]. UNICEF. Pakistan National Nutrition Survey 2018: Key Findings Report. . 2018.