Balkan Med J 2023;40:271-8

Body Mass Index Growth Curves for Birth to 24 Months Children in Ankara with RefCurv Software

Eda Çakmak[1], Serhat Kılıç[2], Pınar Özdemir[3], Ergun Karaağaoğlu[4]

[1]Department of Audiology, Faculty of Health Sciences Başkent University, Ankara, Turkey
[2]Department of Pediatrics, Faculty of Medicine, Başkent University, Ankara, Turkey
[3]Department of Biostatistics, Faculty of Medicine, Hacettepe University, Ankara, Turkey
[4]Department of Biostatistics, Faculty of Medicine, Lokman Hekim University, Ankara, Turkey

Background: It is important to monitor the development of infants and children during their growth period. Various anthropometric parameters of children are measured at regular intervals after birth, and their general health and nutrition and physiological needs are assessed based on these measurements.

Aims: To construct the current body mass index (BMI) percentiles and compare them with the literature reports and World Health Organisation (WHO) data.

Study Design: Cross-sectional study.

Methods: This study is a cross-sectional research on 1,345 boys and 1,364 girls of age ranging from 0 to 24 months; their BMIs were measured at the Başkent University Hospital from January 2018-December 2021. The BMI growth curves for either gender were constructed according to the LMS method by using RefCurv 0.4.2. software. The "*gamlss*" package was employed for the selection of model parameters in fitting the BMI growth curves, and the model performance was evaluated with reference to the generalized Akaike information criterion (GAIC).

Results: According to gender, smoothed BMI growth curves were constructed in the 3rd-97th percentiles. The model adequacy of the fitted growth curves was evaluated with the worm plot. The fit of the BMI model to the data was found to be sufficient, with 95% of the BMI values occurring between two elliptic curves.

Conclusion: The study shows a slight increase in BMI percentile values obtained by gender compared to WHO standards.

INTRODUCTION

Monitoring the growth phase of children from their birth is the best approach to summarize the change in their health status. Growth is one of the most important indicators in the development of a child, for the early diagnosis of potential diseases, and for the evaluation of their nutritional status. Parameters such as length/height, weight, head circumference, and body mass index are anthropometric indicators of the growth phase of children. These measurements help monitor the healthy development process of children according to their age.[1]

While monitoring the growth and development of children, comparisons are made with reference or standard growth curves for healthy children of that particular country and in terms of age groups and gender.[2,3] Growth charts act as a visual tool to follow the growth of children in developed or developing countries; it shows the distribution of anthropometric measurement that changes with age.[4]

Recently, the increase in overweight and obesity in children has been common. This is a risk factor that adversely triggers health in the future.[5] While the increase in obesity is higher in low-income and developing countries, a similar trend has been reported in other countries as well. In addition to acting as a risk factor for health, obesity is associated with other problems such as psycho-social, social, and economic problems, and planning of health services.[6,7]

Over one-third of US adults are obese.[8] Prevention of adult obesity requires identifying at-risk individuals at a time in life when the interventions may be most effective, which can be as early as infancy.[9,10,11] A major challenge in identifying infants at the highest risk for obesity is that there is currently no accepted definition for excess adiposity in infants under the age of 2 years. Currently, body

Corresponding author: Eda Çakmak, Department of Audiology, Faculty of Medicine, Başkent University, Ankara, Turkey
e-mail: edacakmak@baskent.edu.tr
Received: March 10, 2023 Accepted: May 11, 2023 Available Online Date: July 12, 2023 • DOI: 10.4274/balkanmedj.galenos.2023.2023-3-31

Available at www.balkanmedicaljournal.org
ORCID iDs of the authors: E.Ç. 0000-0002-1548-4314; S.K. 0000-0003-3705-4312; P.Ö. 0000-0001-6594-3200; E.K. 0000-0002-7024-7231. .
Cite this article as:
Çakmak E, Kılıç S, Özdemir P, Karaağaoğlu E. Body Mass Index Growth Curves for Birth to 24 Months Children in Ankara with RefCurv Software. *Balkan Med J.*; 2023; 40(4):271-8.

mass index (BMI) is used to address obesity in children and adults.[12]

Recent studies have suggested that BMI may be a useful index of adiposity in infancy while also providing information about potential obesity-related risks.[13-19]

This study aimed to first construct BMI growth curves according to gender in 0-2-year-old children. It is the display of the percentile value corresponding to the BMI measurement at a certain age with RefCurv software. Then, it aimed to compare the calculated BMI measurements by the WHO standards and those standardized for Turkey.

MATERIALS AND METHODS

Study Design and Population

This study is a cross-sectional research consisting of children (n = 1,345 boys and n = 1,364 girls) who were examined at the Başkent University Hospital between January 2018 and December 2021. For the data of the study, the necessary permissions were obtained from the Başkent University Hospital (document number: 31220125-20/10256). Ethics committee approval of the study was obtained from the Hacettepe University Ethics Committee (GO 20/757). The study was conducted in accordance with the latest principles of the Helsinki Declaration.

The inclusion criteria for children in this study included single-born children who had completed their gestational age and weighed ≥2,500 g; while those with serious or chronic diseases were excluded from the study.

The length and weight measurements of the infants attending the clinic were performed by pediatricians. The BMI was calculated according to the formula (weight-kg)/(length-m)^2. The naked weights were obtained on the Seca Model 834 electronic digital scale. The supine length of the infants was measured using the Seca 207 baby measuring rod.

Considering the need for sufficient sample size in each age group for the construction of growth curves, at least 100 samples were assessed for each age group.[20] The length, weight, and BMI were measured for the first 24 months of the study. The age groups consisted of 1-month intervals for the first 6 months and then 3-month intervals up to 18 months and 24-month measurements.

The LMS method was used to construct the growth curves. The three curves from which the method was named for the construction of percentile curves included the L curve (λ, Box-Cox power), M curve (μ, median), and S curve (σ, coefficient of variation).

The Z-score of a child whose anthropometric measurements were known was calculated using the L, M, and S values determined from the reference population of children's peers by using Equation 2.1. The variable t indicates the age and the calculation of percentile values for the measurement of BMI at each time t is indicated by Equation 2.2. The Zα given in the equation represents the Z-score corresponding to the percentile value.[21]

2.1. $$Z = \frac{\left[{}^{BMI}/_{M(t)}\right]^{L(t)} - 1}{L(t)S(t)}$$

2.2. $$C_{100\alpha}(t) = M(t)[1 + L(t)S(t)\,Z_\alpha]^{1/L(t)}$$

The worm plot is a visual diagnostic tool used to evaluate the fit of a statistical model to the data. The use of worm plots in the growth curves evaluated the age-related normality of anthropometric measurements in the fitted model. In this study, the worm plots were used to evaluate the model fit of the length, weight, and BMI growth curves.[22]

Statistical analysis

Length, weight, and BMI growth curves were constructed by using the RefCurv 0.4.2. software[23] with the GAMLSS package 5.0-3.[24] The worm plots were created with the *R* 4.1.2 version.[25]

The LMS and LMSP methods are based on the BCCG (Box-Cox-Cole and Green) and BCPE (Box-Cox Power Exponential) distributions, respectively. To determine the best model, the Box-Cox power transformation at age (x= ageλ) which gives the smallest global deviance value, was determined by using the grid search approach. Cubic splines served smoothing functions in the curves. The generalized Akaike information criterion (GAIC) values were employed to evaluate the model performances so that the penalty coefficient was determined as #=3. In the GAMLSS package, the model parameters are selected with the find.hyper() command by using an automatic procedure.

The diagnoses of the models were examined by controlling the normalized quantile residuals and worm plots. When the model was fitted for each anthropometric measurement, it was observed that the residuals had a normal distribution, and the Q-Q plots were linear. The means of the residuals were 0, the variances were 1, the skewness coefficients were 0 and the kurtosis coefficients were 3, indicating a standard normal distribution.

RESULTS

According to the LMS method, the L, M, and S values for the length, weight, and BMI measurements of girls and boys as well as the percentile values between the 3rd and 97th percentiles are given in Tables 1-3. BMI Z-scores in the range of 3 standard deviations were calculated for each age group according to gender (Table 4).

The optimal model for obtaining the length growth curves of boys ($x = age^{\lambda=0.42}$, df(μ) = 7.8, df(σ)= 5.9, df(υ) = 2.1) and girls ($x = age^{\lambda=0.60}$, df(μ) = 8.9, df(σ) = 2.1, df(υ) = 2.1) were determined as BCCG, and the growth curves were constructed (Figure 1). The model performances for the length data were calculated as global deviance = 5670.87, AIC = 5702.47 and GAIC(#=3)= 5718.27 for boys and as global deviance = 5983.66, AIC = 6009.86 and GAIC(#=3)= 6022.96 for girls.

The optimal model for obtaining the weight growth curves of boys ($x = age^{\lambda=0.20}$, df(μ) = 5.8, df(σ) = 4.9, df(υ) = 2.1, df(τ) = 2.1) and girls ($x = age^{\lambda=0.25}$, df(μ) =8.3, df(σ)=6.3, df(υ)=3.1, df(τ)=5.1) were determined as BCPE, and the growth curves were constructed

TABLE 1. Length-for-age Percentiles of Children Aged 1-24 Months with the LMS Method.

Boys' percentiles (length in cm)																
Months	**n**	**Mean ± SD**	**L**	**M**	**S**	**3rd**	**5th**	**10th**	**15th**	**25th**	**50th**	**75th**	**85th**	**90th**	**95th**	**97th**
1	124	54.65 ± 1.92	2.495	54.703	0.035	50.90	51.40	52.16	52.66	53.38	54.70	55.97	56.63	57.07	57.72	58.14
2	114	58.59 ± 1.85	0.036	58.563	0.032	55.13	55.55	56.20	56.65	57.31	58.56	59.83	60.53	61.01	61.72	62.19
3	100	62.24 ± 1.61	-6.986	62.081	0.025	59.60	59.87	60.31	60.62	61.09	62.08	63.20	63.88	64.37	65.16	65.72
4	122	64.15 ± 1.77	1.332	64.166	0.028	60.75	61.18	61.84	62.29	62.95	64.16	65.37	66.01	66.45	67.09	67.51
5	127	66.59 ± 2.08	1.783	66.617	0.032	62.50	63.03	63.83	64.37	65.16	66.61	68.04	68.79	69.30	70.05	70.53
6	112	68.30 ± 2.18	-1.639	68.211	0.032	64.40	64.85	65.55	66.04	66.78	68.21	69.72	70.57	71.17	72.07	72.67
9	118	72.58 ± 1.93	-1.466	72.522	0.027	69.05	69.46	70.11	70.56	71.23	72.52	73.87	74.62	75.14	75.93	76.45
12	142	76.60 ± 2.07	-4.620	76.446	0.026	73.14	73.51	74.11	74.52	75.16	76.44	77.85	78.67	79.26	80.17	80.80
15	138	79.92 ± 2.05	3.208	79.981	0.026	75.83	76.38	77.21	77.75	78.55	79.98	81.35	82.07	82.55	83.25	83.69
18	127	82.92 ± 2.25	0.522	82.908	0.027	78.74	79.26	80.06	80.60	81.40	82.90	84.42	85.24	85.80	86.62	87.16
24	121	88.24 ± 2.88	3.630	88.365	0.032	82.56	83.35	84.52	85.29	86.40	88.36	90.21	91.17	91.80	92.72	93.30
Girls' percentiles (length in cm)																
Months	**n**	**Mean ± SD**	**L**	**M**	**S**	**3rd**	**5th**	**10th**	**15th**	**25th**	**50th**	**75th**	**85th**	**90th**	**95th**	**97th**
1	123	53.03 ± 1.92	-1.890	52.939	0.036	49.67	50.04	50.64	51.06	51.69	52.93	54.27	55.02	55.55	56.37	56.91
2	103	56.94 ± 1.76	-5.009	56.789	0.030	54.03	54.33	54.82	55.17	55.70	56.78	58.01	58.74	59.26	60.10	60.68
3	108	59.27 ± 1.91	2.790	59.328	0.032	55.54	56.04	56.79	57.29	58.02	59.32	60.58	61.23	61.67	62.31	62.72
4	122	62.20 ± 1.92	-2.155	62.110	0.031	58.79	59.17	59.78	60.21	60.85	62.11	63.45	64.21	64.74	65.55	66.10
5	113	64.26 ± 2.07	3.531	64.349	0.032	60.13	60.70	61.55	62.11	62.92	64.34	65.70	66.39	66.86	67.53	67.95
6	124	66.17 ± 2.39	-0.739	66.099	0.036	61.87	62.37	63.16	63.71	64.52	66.09	67.73	68.64	69.27	70.22	70.85
9	133	70.78 ± 2.53	-1.596	70.672	0.035	66.38	66.88	67.67	68.22	69.05	70.67	72.39	73.36	74.04	75.07	75.76
12	122	75.22 ± 2.31	-0.662	75.165	0.031	70.98	71.48	72.27	72.81	73.62	75.16	76.76	77.64	78.25	79.16	79.77
15	135	78.27 ± 2.46	1.798	78.301	0.032	73.46	74.08	75.03	75.66	76.59	78.30	79.97	80.86	81.46	82.33	82.90
18	129	82.03 ± 2.71	2.031	82.072	0.033	76.80	77.48	78.52	79.21	80.22	82.07	83.87	84.83	85.47	86.40	87.01
24	152	86.37 ± 2.71	1.299	86.342	0.031	81.26	81.90	82.88	83.55	84.53	86.34	88.14	89.10	89.75	90.71	91.33

SD, standard deviation

TABLE 2. Weight-for-age Percentiles of Children Aged 1-24 Months with the LMS Method.

Boys' percentiles (weight in kg)																
Months	**n**	**Mean ± SD**	**L**	**M**	**S**	**3rd**	**5th**	**10th**	**15th**	**25th**	**50th**	**75th**	**85th**	**90th**	**95th**	**97th**
1	124	4.45 ± 0.44	2.027	4.469	0.099	3.53	3.66	3.85	3.98	4.15	4.46	4.75	4.90	5.00	5.14	5.23
2	114	5.80 ± 0.45	-2.044	5.747	0.077	5.06	5.13	5.25	5.33	5.47	5.74	6.07	6.26	6.41	6.65	6.82
3	100	6.60 ± 0.36	-2.827	6.567	0.053	6.01	6.07	6.17	6.24	6.34	6.56	6.81	6.97	7.08	7.25	7.38
4	122	7.04 ± 0.41	1.472	7.049	0.059	6.24	6.34	6.50	6.61	6.76	7.04	7.32	7.47	7.57	7.71	7.81
5	127	7.74 ± 0.48	1.196	7.748	0.063	6.81	6.93	7.11	7.23	7.41	7.74	8.07	8.25	8.36	8.54	8.65
6	112	8.17 ± 0.56	0.807	8.174	0.069	7.12	7.25	7.45	7.59	7.79	8.17	8.55	8.76	8.90	9.11	9.24
9	118	9.23 ± 0.50	6.552	9.306	0.051	8.00	8.23	8.54	8.72	8.95	9.30	9.59	9.73	9.82	9.94	10.02
12	142	10.08 ± 0.66	-2.899	10.003	0.063	9.03	9.13	9.30	9.42	9.61	10.00	10.46	10.75	10.96	11.31	11.56
15	138	10.78 ± 0.59	-1.905	10.750	0.054	9.79	9.90	10.07	10.19	10.37	10.75	11.16	11.40	11.57	11.84	12.03
18	127	11.38 ± 0.76	-0.921	11.332	0.066	10.07	10.21	10.44	10.60	10.84	11.33	11.85	12.16	12.37	12.70	12.92
24	121	12.57 ± 1.03	0.917	12.576	0.083	10.62	10.86	11.24	11.49	11.87	12.57	13.28	13.66	13.91	14.30	14.55
Girls' percentiles (weight in kg)																
Months	**n**	**Mean ± SD**	**L**	**M**	**S**	**3rd**	**5th**	**10th**	**15th**	**25th**	**50th**	**75th**	**85th**	**90th**	**95th**	**97th**
1	123	4.05 ± 0.40	1.869	4.072	0.099	3.23	3.35	3.52	3.63	3.79	4.07	4.33	4.47	4.56	4.69	4.77
2	103	5.11 ± 0.39	1.676	5.122	0.077	4.34	4.45	4.60	4.70	4.85	5.12	5.38	5.51	5.60	5.73	5.82

TABLE 2. Continued

Months	n	Mean ± SD	L	M	S	3rd	5th	10th	15th	25th	50th	75th	85th	90th	95th	97th
Girls' percentiles (weight in kg)																
3	108	5.66 ± 0.48	1.621	5.678	0.086	4.70	4.83	5.02	5.15	5.34	5.67	6.00	6.17	6.28	6.44	6.55
4	122	6.31 ± 0.56	-0.435	6.281	0.088	5.35	5.45	5.62	5.74	5.92	6.28	6.66	6.89	7.05	7.29	7.45
5	113	6.98 ± 0.73	2.395	7.034	0.104	5.40	5.64	5.99	6.20	6.51	7.03	7.50	7.74	7.89	8.11	8.25
6	124	7.47 ± 0.73	0.859	7.468	0.099	6.09	6.26	6.52	6.70	6.97	7.46	7.96	8.23	8.42	8.69	8.87
9	133	8.59 ± 0.83	1.054	8.602	0.097	7.02	7.22	7.52	7.73	8.03	8.60	9.16	9.46	9.66	9.96	10.16
12	122	9.86 ± 0.91	2.341	9.917	0.093	7.91	8.20	8.62	8.89	9.26	9.91	10.51	10.81	11.01	11.30	11.48
15	135	10.44 ± 0.82	2.461	10.489	0.079	8.71	8.96	9.33	9.57	9.90	10.48	11.02	11.30	11.48	11.74	11.90
18	129	11.28 ± 0.85	-0.603	11.233	0.075	9.81	9.97	10.23	10.41	10.68	11.23	11.82	12.16	12.40	12.76	13.01
24	152	12.21 ± 0.97	0.683	12.203	0.079	10.43	10.65	10.98	11.21	11.55	12.20	12.85	13.21	13.45	13.82	14.05

SD, standard deviation; LMS, Lambda-Mu-Sigma

TABLE 3. BMI-for-age Percentiles of Children Aged 1-24 Months with the LMS Method.

Months	n	Mean ± SD	L	M	S	3rd	5th	10th	15th	25th	50th	75th	85th	90th	95th	97th
Boys' percentiles (BMI in kg/m²)																
1	124	14.87 ± 1.12	1.207	14.882	0.076	12.72	12.99	13.42	13.70	14.12	14.88	15.64	16.04	16.32	16.72	16.98
2	114	16.89 ± 1.04	1.917	16.922	0.062	14.83	15.11	15.52	15.80	16.20	16.92	17.62	17.98	18.22	18.57	18.80
3	100	17.05 ± 0.86	2.533	17.085	0.050	15.34	15.58	15.93	16.16	16.49	17.08	17.65	17.94	18.13	18.41	18.59
4	122	17.13 ± 1.03	-1.516	17.050	0.060	15.36	15.55	15.85	16.06	16.39	17.05	17.78	18.20	18.50	18.97	19.30
5	127	17.49 ± 1.18	0.250	17.458	0.067	15.36	15.61	16.00	16.28	16.68	17.46	18.26	18.70	19.01	19.46	19.76
6	112	17.55 ± 1.26	-0.627	17.479	0.071	15.38	15.61	16.00	16.27	16.67	17.48	18.35	18.85	19.20	19.73	20.09
9	118	17.54 ± 0.96	2.707	17.589	0.055	15.58	15.85	16.27	16.53	16.92	17.59	18.22	18.55	18.76	19.07	19.27
12	142	17.20 ± 1.10	0.226	17.168	0.064	15.20	15.43	15.80	16.06	16.44	17.17	17.92	18.34	18.62	19.05	19.33
15	138	16.90 ± 1.08	-1.303	16.823	0.063	15.07	15.26	15.58	15.80	16.14	16.82	17.57	18.01	18.32	18.80	19.13
18	127	16.56 ± 0.99	0.785	16.549	0.006	14.70	14.93	15.29	15.53	15.88	16.55	17.22	17.58	17.83	18.20	18.44
24	121	16.15 ± 1.08	-1.428	16.068	0.065	14.36	14.54	14.85	15.07	15.40	16.07	16.81	17.24	17.56	18.04	18.38
Girls' percentiles (BMI in kg/m²)																
Months	**n**	**Mean ± SD**	**L**	**M**	**S**	**3rd**	**5th**	**10th**	**15th**	**25th**	**50th**	**75th**	**85th**	**90th**	**95th**	**97th**
1	123	14.40 ± 1.09	-0.003	14.359	0.076	12.44	12.67	13.02	13.27	13.64	14.40	15.11	15.53	15.82	16.27	16.56
2	103	15.76 ± 0.94	2.673	15.809	0.060	13.82	14.09	14.50	14.77	15.14	15.81	16.42	16.74	16.95	17.25	17.44
3	108	16.12 ± 1.17	0.793	16.115	0.073	13.93	14.20	14.62	14.90	15.32	16.12	16.91	17.34	17.63	18.07	18.35
4	122	16.33 ± 1.34	-0.906	16.229	0.080	14.09	14.33	14.71	14.98	15.39	16.23	17.15	17.68	18.07	18.67	19.07
5	113	16.88 ± 1.35	1.642	16.914	0.080	14.22	14.58	15.11	15.47	15.98	16.91	17.81	18.28	18.59	19.05	19.34
6	124	17.05 ± 1.27	0.556	17.031	0.074	14.73	15.01	15.44	15.74	16.19	17.03	17.88	18.35	18.68	19.15	19.47
9	133	17.15 ± 1.31	-0.468	17.079	0.076	14.87	15.12	15.52	15.80	16.23	17.08	17.98	18.50	18.86	19.42	19.80
12	122	17.42 ± 1.34	1.268	17.431	0.077	14.85	15.18	15.68	16.02	16.51	17.43	18.32	18.80	19.13	19.60	19.90
15	135	17.04 ± 1.00	1.974	17.065	0.059	15.05	15.32	15.72	15.98	16.37	17.07	17.73	18.07	18.31	18.64	18.86
18	129	16.78 ± 1.16	0.131	16.748	0.069	14.69	14.93	15.32	15.58	15.98	16.75	17.54	17.98	18.28	18.74	19.04
24	152	16.37 ± 1.12	0.607	16.313	0.068	14.27	14.52	14.91	15.17	15.57	16.31	17.06	17.47	17.75	18.17	18.45

SD, standard deviation; LMS, Lambda-Mu-Sigma; BMI, body mass index

(Figure 2). Model performances for weight data were calculated as global deviance = 2241.57, AIC = 2271.37 and GAIC(#=3) = 2286.27 for boys and as global deviance = 2779.92, AIC = 2825.52 and GAIC(#=3) = 2848.32 for girls.

The optimal model for obtaining the BMI growth curves of boys was determined as BCCG (x = age$^{\lambda=0.01}$, df(μ) = 7.2, df(σ) = 2.1, df(υ) = 2.1), while the model performances for BMI data were calculated as global deviance = 3987.02, AIC = 4009.82 and GAIC(#=3)= 4021.22. The optimal model for obtaining the BMI growth curves of the girls was determined as BCPE (x = age$^{\lambda=0.15}$, df(μ) = 6.3, df(σ) = 4.9, df(υ) = 2.1, df(τ) = 2.1), while the model performances for BMI data were calculated as global deviance = 4322.80, AIC = 4353.60 and GAIC(#=3) = 4368.99. Accordingly, the growth curves were constructed (Figure 3).

From the smoothed growth curves constructed according to the LMS method with the RefCurv software, the percentile in which any child falls can be checked. Figure 4 shows the BMI of 17.376 kg/m^2 at age 6 months for boys corresponding to the 46.653th percentile (L = -0.62, M = 17.479, S = 0.071 for 6 months boys).

TABLE 4. BMI-for-age z-scores of Children Aged 1-24 Months with the LMS Method

Boys' Z-scores (BMI in kg/m^2)							
Months	**-3SD**	**-2SD**	**-1SD**	**Median**	**1SD**	**2SD**	**3SD**
1	11.40	12.58	13.74	14.88	16.00	17.11	18.20
2	13.44	14.69	15.84	16.92	17.94	18.91	19.84
3	14.15	15.22	16.20	17.09	17.91	18.68	19.40
4	14.54	15.27	16.10	17.05	18.16	19.47	21.03
5	14.21	15.23	16.32	17.46	18.66	19.92	21.24
6	14.31	15.26	16.31	17.48	18.80	20.28	21.97
9	14.14	15.44	16.57	17.59	18.51	19.37	20.16
12	14.11	15.08	16.10	17.17	18.29	19.48	20.72
15	14.21	14.97	15.83	16.82	17.97	19.31	20.90
18	13.63	14.59	15.56	16.55	17.55	18.56	19.58
24	13.53	14.26	15.10	16.07	17.20	18.55	20.19
Girls' Z-scores (BMI in kg/m^2)							
Months	**-3SD**	**-2SD**	**-1SD**	**Median**	**1SD**	**2SD**	**3SD**
1	11.43	12.33	13.30	14.38	15.49	16.71	18.03
2	12.36	13.67	14.80	15.99	16.71	17.54	18.31
3	12.67	13.79	14.94	16.04	17.30	18.50	19.72
4	13.06	13.97	15.02	16.27	17.63	19.29	21.27
5	12.46	14.04	15.52	16.88	18.23	19.49	20.70
6	13.43	14.59	15.79	17.08	18.31	19.63	20.99
9	13.75	14.74	15.85	17.06	18.45	19.99	21.73
12	13.26	14.68	16.07	17.41	18.76	20.06	21.34
15	13.72	14.92	16.02	17.03	18.04	18.97	19.86
18	13.57	14.57	15.62	16.74	17.93	19.20	20.54
24	13.12	14.15	15.21	16.23	17.43	18.59	19.77

SD, standard deviation; BMI, body mass index

The model adequacy of the BMI growth curves by gender was examined with the help of a worm plot (Figure 5). When the fit of the model selected with the worm plots was evaluated, 95% of the data was found to be between two elliptic curves in the graphs obtained for all age groups.

BMI 50th percentile values by gender were compared for the present study, the Neyzi et al.[28] study, and the WHO study (Figure 6).

DISCUSSION

Growth curves are the best indicators to summarize the changes in a child's general health beginning from birth. These curves help understand the extent to which physiological needs are met during the growth and development of a child in a typical society by monitoring the nutritional status and assessing early diagnosis of potential diseases.[26]

In this study, the length, weight, BMI percentiles, and BMI Z-scores of the children were calculated according to their gender.

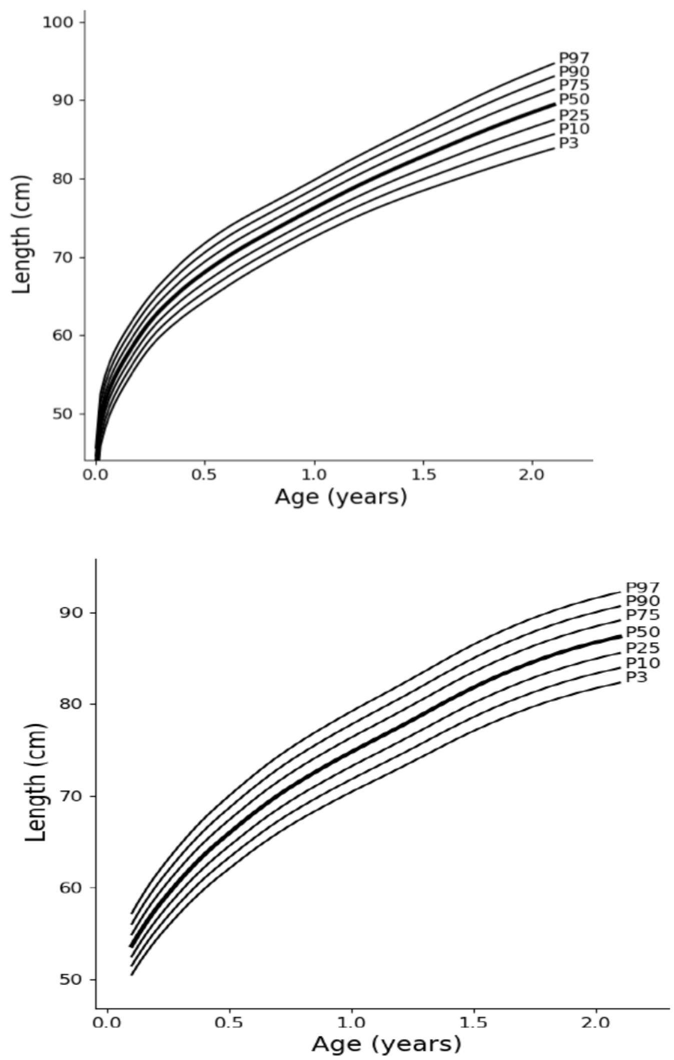

FIG. 1. Length-for-age growth curves of the boys and girls.

In practice, after calculating the L, M, and S values of children in each age group, a series of statistical formulations percentile values were obtained. In the construction of growth curves, it is very important to provide flexibility in the curves by selecting the optimal model. In this study, the growth curves were constructed by considering model performances to determine the optimal model for length, weight, and BMI measurements. In this study, we used the RefCurv software to examine which child corresponds to which percentile. Thus, a graphic representation of the percentile value of a child whose body mass index is known for age was presented in this study.

The length, weight, and BMI percentiles calculated by the WHO[27] and Neyzi et al.[28] were compared with our data. According to the

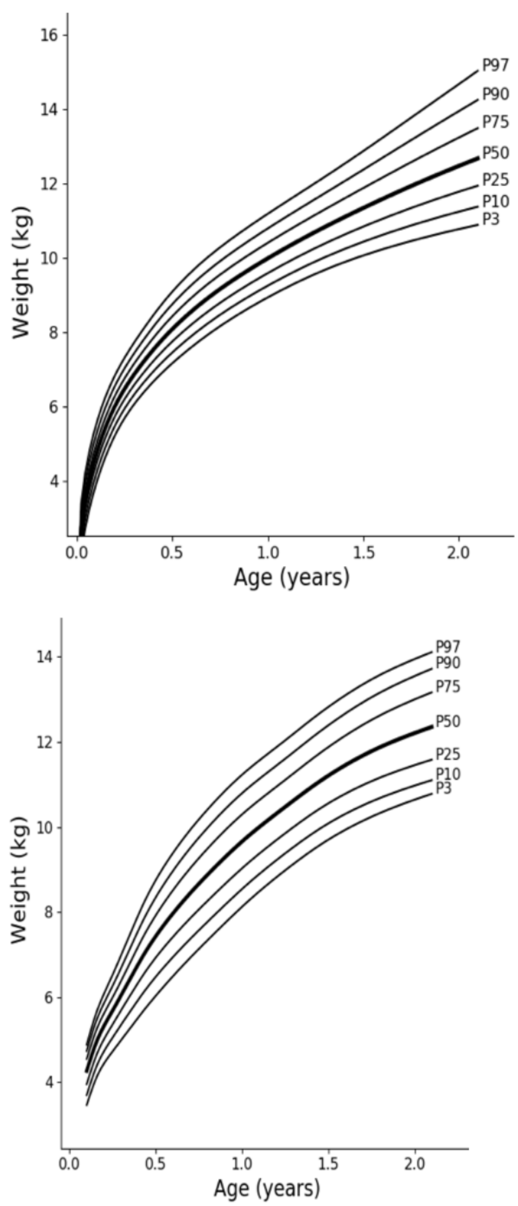

FIG. 2. Weight-for-age growth curves of the boys and girls.

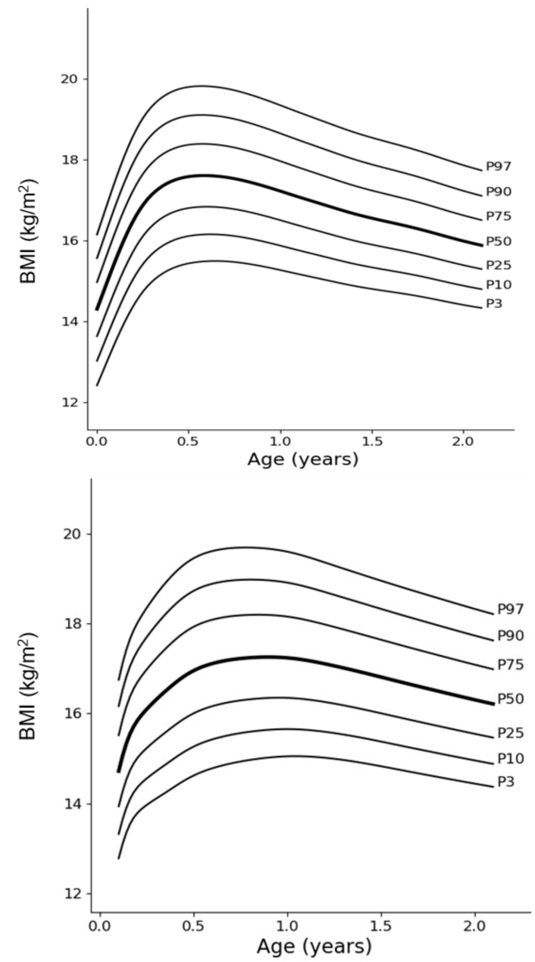

FIG. 3. BMI-for-age growth curves of the boys and girls.

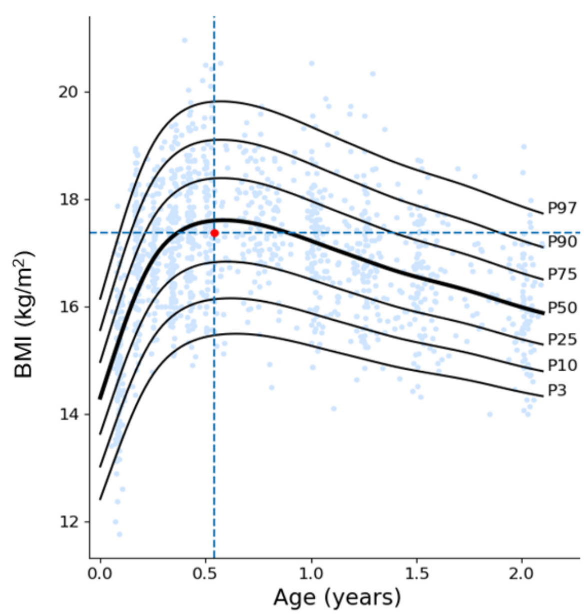

FIG. 4. BMI percentile value of a 6-month-years boy.

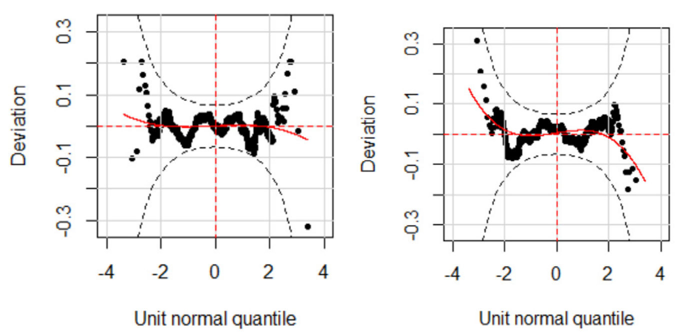

FIG. 5. Worm plots for fitted growth model by gender.

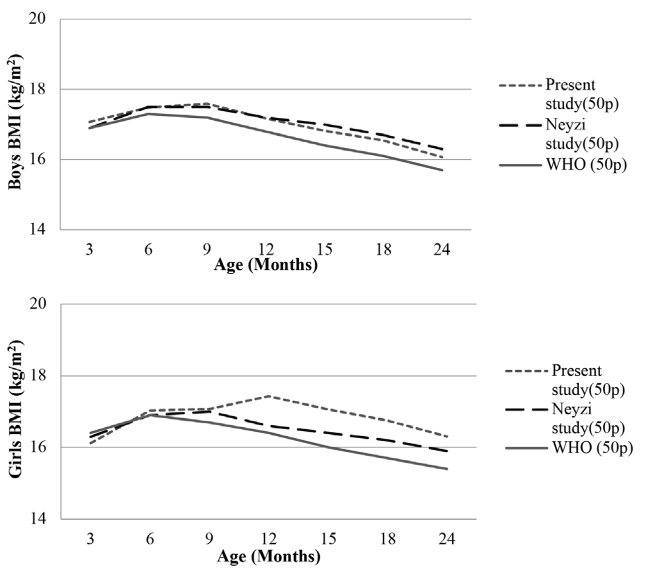

FIG. 6. Comparison of 50th percentiles with data from the present study, Neyzi et al.'s study, and the WHO standard by gender.

50th percentile length values specified by the WHO, Neyzi et al.[28], and our study with gender, the length measurements of both boys and girls were found to be very close to each other based on their age groups when examined at 3-month intervals from the 3rd to the 24th month. We also observed that the lengths of Turkish children aged 12-24 months were approximately 0.5-1 cm taller than that specified by the WHO standards. When the percentile values of the WHO, Neyzi et al.[28], and our study were examined, the weight measurements in the 50th percentile for both girls and boys were found to be close to each other until the first 9 months. However, from the 9th month onward, girls were approximately 500 g to 1 kg heavier in different age groups, while boys were more overweight by approximately 400-500 g.

When comparing the 50th percentile BMI values for boys by the WHO, the values specified by Neyzi et al.[28] and our values were very similar up to until the first 5 months, while some differentiation was observed from the 6th month onward. According to the WHO standards, the BMI values of 9-month-old children were approximately 0.370-0.450 kg/m^2 lower than our calculated values. In addition, the BMI values obtained from the 9th month onward were slightly lower than those reported by Neyzi et al.'s[28] study. When comparing the 50th percentile BMI values for girls, the values we obtained for the first 6 months were quite similar to those specified by the WHO standards. However, from the 6th month onward, it was observed that the BMI values of the Turkish children were higher than those of the WHO standards. In particular, the BMI values of those aged 12-18 months for girls in our study were approximately 1 kg/m^2 higher than the corresponding WHO standards.

While the optimal model for the construction of growth curves for boys was the LMS method, the LMSP method was used for girls. Worm plots were constructed according to the selected optimal model. Thus, the fit of the selected model to the data was evaluated. The shape of the worms indicated the discordance between the model and the data. The closer the data points were to the line, the closer the distribution of residuals to the standard normal distribution. Deviations from this line indicated a deviation from linearity and the degree of fit to the data. Thus, there existed a close relationship between the effective degrees of freedom of the fitted BMI model and the worm shapes.

Study Limitations

The limitations of the present study are that, although the growth curves constructed by gender include the Ankara sample, it would have been more appropriate to work with a larger sample that represented the entire population for constructing appropriate growth percentiles.

In conclusion, the implementation of the RefCurv software was not encountered in the construction of the growth curves in the literature. BMI growth curves were constructed with the RefCurv software for ease of practice and demonstration of the graphical interface. Although the current length, weight, and BMI measurements in this study were representative of only the Ankara sample, they can serve as reference values for overweight and obesity assessments in children in the future. Thus, we believe that the present findings will act as a guide for future studies.

Ethics Committee Approval: Ethics committee approval of the study was obtained from the Hacettepe University Ethics Committee (GO 20/757). The study was conducted in accordance with the latest principles of the Helsinki Declaration.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Authorship Contributions: Concept- E.Ç., E.K.; Design- E.Ç.; Data Collection or Processing- E.Ç., S.K.; Analysis or Interpretation- E.Ç.; Literature Search- E.Ç.; Writing- E.Ç.; Critical Review- E.Ç., S.K., P.Ö., E.K.

Conflict of Interest: No conflict of interest was declared by the authors.

Funding: The authors declared that this study received no financial support.

REFERENCES

1. Cole TJ. The use and construction of anthropometric growth reference standards. *Nutr Res Rev.* 1993;6:19-50. **[CrossRef]**
2. Cole TJ. The development of growth references and growth charts. *Ann Hum Biol.* 2012;39:382-394. **[CrossRef]**
3. Ohuma EO, Altman DG, International Fetal and Newborn Growth Consortium for the 21st Century (INTERGROWTH-21st Project). Design and other methodological considerations for the construction of human fetal and neonatal size and growth charts. *Stat Med.* 2019;38:3527-3539. **[CrossRef]**
4. Cole TJ. Growth charts for both cross-sectional and longitudinal data. *Stat Med.* 1994;13:2477-2492. **[CrossRef]**
5. De Onis M, Lobstein T. Defining obesity risk status in the general childhood population: which cut-offs should we use?. *Int J Pediatr Obes*. 2010;5:458-460. **[CrossRef]**
6. World Health Organization. Consideration of the evidence on childhood obesity for the Commission on Ending Childhood Obesity: report of the ad hoc working group on science and evidence for ending childhood obesity. Geneva, Switzerland; 2016. **[CrossRef]**
7. NCD Risk Factor Collaboration (NCD-RisC); Bentham J, Di Cesare M, et al. Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128.9 million children, adolescents, and adults. *Lancet.* 2017;390:2627-2642. **[CrossRef]**
8. Flegal KM, Carroll MD, Kit BK, Ogden CL. Prevalence of obesity and trends in the distribution of body mass index among US adults, 1999-2010. *JAMA*. 2012;307:491-497. **[CrossRef]**
9. Ekelund U, Ong KK, Linne Y, et al. Association of weight gain in infancy and early childhood with metabolic risk in young adults. *J Clin Endocrinol Metab*. 2007;92:98-103. **[CrossRef]**
10. Stettler N, Kumanyika SK, Katz SH, Zemel BS, Stallings VA. Rapid weight gain during infancy and obesity in young adulthood in a cohort of African Americans. *Am J Clin Nutr.* 2003;77:1374-1378. **[CrossRef]**
11. McCormick DP, Sarpong K, Jordan L, Ray LA, Jain S. Infant obesity: are we ready to make this diagnosis?. *J Pediatr.* 2010;157:15-19. **[CrossRef]**
12. Ogden CL, Carroll MD, Kit BK, Flegal KM. Prevalence of childhood and adult obesity in the United States, 2011-2012. *JAMA*. 2014;311:806-814. **[CrossRef]**
13. Roy SM, Chesi A, Mentch F, et al. Body mass index (BMI) trajectories in infancy differ by population ancestry and may presage disparities in early childhood obesity. *J Clin Endocrinol Metab.* 2015;100:1551-1560. **[CrossRef]**
14. Wen X, Kleinman K, Gillman MW, RifasShiman SL, Taveras EM. Childhood body mass index trajectories: modeling, characterizing, pairwise correlations and socio-demographic predictors of trajectory characteristics. *BMC Med Res Methodol.* 2012;12:38. **[CrossRef]**
15. Sovio U, Kaakinen M, Tzoulaki I, et al. How do changes in body mass index in infancy and childhood associate with cardiometabolic profi le in adulthood? Findings from the Northern Finland Birth Cohort 1966 Study. *Int J Obes (Lond)*. 2014;38:53-59. **[CrossRef]**
16. Johnson W, Choh AC, Lee M, Towne B, Czerwinski SA, Demerath EW. Characterization of the infant BMI peak: sex differences, birth year cohort effects, association with concurrent adiposity, and heritability. *Am J Hum Biol.* 2013;25:378-388. **[CrossRef]**
17. Slining MM, Herring AH, Popkin BM, Mayer-Davis EJ, Adair LS. Infant BMI trajectories are associated with young adult body composition. *J Dev Orig Health Dis.* 2013;4:56-68. **[CrossRef]**
18. Silverwood RJ, De Stavola BL, Cole TJ, Leon DA. BMI peak in infancy as a predictor for later BMI in the Uppsala Family Study. *Int J Obes (Lond).* 2009;33:929-937. **[CrossRef]**
19. Olsen IE, Lawson ML, Ferguson AN, et al. BMI curves for preterm infants. *Pediatrics*. 2015;135:572-581. **[CrossRef]**
20. Cole TJ. The LMS method for constructing normalized growth standards. *Eur J Clin Nutr.* 1990;44:45-60. **[CrossRef]**
21. Cole TJ, Green PJ. Smoothing reference centile curves: the LMS method and penalized likelihood. *Statistics in Medicine*. 1992;11:1305-1319. **[CrossRef]**
22. Buuren SV, Fredriks M. Worm plot: a simple diagnostic device for modelling growth reference curves. *Stat Med.* 2001;20:1259-1277. **[CrossRef]**
23. Winkler C, Linden K, Mayr A, et al. RefCurv: A software for the construction of pediatric reference curves. *Software Impacts.* 2020;6:100040. **[CrossRef]**
24. Rigby RA, Stasinopoulos DM. Generalized additive models for location, scale and shape. *Appl Statist.* 2005;54:507-554. **[CrossRef]**
25. R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria. **[CrossRef]**
26. Borghi E, de Onis M, Garza C, et al. Construction of the World Health Organization child growth standards: selection of methods for attained growth curves. *Stat Med.* 2006;25:247-265. **[CrossRef]**
27. World Health Organization. WHO Child Growth Standards: Length/Height-For-Age, Weight-For-Age, Weight-For-Length, Weight-For-Height and Body Mass İndex-For-Age: Methods and Development. Geneva: World Health Organization; 2006. **[CrossRef]**
28. Neyzi O, Bundak R, Gökçay G, et al. Reference values for weight, height, head circumference, and body mass index in Turkish children. *J Clin Res Pediatr Endocrinol.* 2015;7:280-293. **[CrossRef]**