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Big data-based reference centiles for body composition in Korean children and adolescents: a cross-sectional study

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Abstract

Background The changes in body composition during puberty not only contribute to the differences in body composition between adult males and females but also have associations with growth problems and metabolic disorders, including obesity. Therefore, understanding the changes in body composition during the pubertal period and analyzing reference values based on race and gender are essential research resources. The objective of this study was to generate reference centiles for body composition on a monthly basis using an extensive dataset of body composition information from Korean children and adolescents.

Methods A total of 88,069 measurements from 22,515 children (11,062 boys and 11,453 girls) aged 7–16 years using a bioelectrical impedance analysis were included in the study after performing a Z-score-based data management procedure. Height, weight, body fat mass (BFM), and fat-free mass (FFM) were measured and used to derive body fat percentage (BF%), body mass index (BMI), fat mass index (FMI), and fat-free mass index (FFMI). Sex- and age-specific centiles were estimated using generalized additive models for location, scale, and shape with the Box-Cox Cole and Green distribution (i.e., lambda-mu-sigma method).

Results The sex- and age-related disparities in body composition were most pronounced when weight was partitioned into BFM and FFM. In boys, the FFM increased markedly during pubertal growth spurts, whereas BFM remained relatively stable. In girls, the BFM increased steadily, whereas the rate of FFM increased slowly. The BMI increased steadily with age in both sexes. However, when BMI was parsed into FMI and FFMI, it became clear that the FFMI increased substantially during pubertal growth in boys, whereas the FMI peaked around age 11 and then declined. Conversely, the FMI increased steadily in girls, albeit with a slowing rate in the increase of the FFMI beginning around age 12.

Conclusions This study produced age- and sex-specific reference percentiles for body composition indices in Korean children and adolescents using extensive biometric data.

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Keywords Puberty, Body composition, Obesity, Reference chart, Bioelectrical impedance analysis, Growth, Body fat mass, Fat-free mass, Body mass index

Introduction

Pediatric obesity has been increasing in prevalence worldwide over the past several decades. This rise is accompanied by an increase in the incidence of chronic diseases, such as type 2 diabetes mellitus, metabolic syndrome, cardiovascular disease, and non-alcoholic fatty liver disease in children and adolescents, thereby escalating public health risks and increasing healthcare costs [1–6]. Global estimates for the prevalence of childhood obesity demonstrate significant variability across different countries and regions, consistently revealing an upward trend [7]. The Global Burden of Disease Obesity Collaborators reported a global childhood obesity prevalence of 5.0% in 2015, accounting for 107.7 million children affected worldwide. This figure represents a doubling of the prevalence since 1980 in over 70 countries, with a continual increase observed in most other nations [8]. More recent studies have further illuminated this trend. A 2023 meta-analysis, encompassing data from 154 countries or regions, including references from the World Health Organization, the International Obesity Task Force, and the U.S. Centers for Disease Control and Prevention, identified an overall obesity prevalence of 8.5% among children and adolescents. Notably, a 1.5-fold increase in obesity prevalence was observed when comparing the periods from 2000–2011 to 2012–2023 [9]. Racial and ethnic disparities in obesity prevalence were also highlighted in this study, with the Hispanic population exhibiting the highest prevalence at 23.55%. In contrast, the Asian population, the focus of our study, demonstrated the lowest prevalence at 10.0%. Despite this relatively lower prevalence in Asia, the region has experienced a significant rise in obesity rates over recent decades, likely driven by rapid economic growth [10]. In Korea, which is the primary focus of this analysis, the prevalence of obesity among children aged 2–18 years increased from 8.6% in 2001 to 9.8% in 2017, as documented by the Korea National Health and Nutrition Examination Survey (KNHANES) [11]. This trend aligns with the broader pattern observed across Asia, reflecting the global secular increase in obesity prevalence. Among the various factors contributing to pediatric obesity, dietary intake, lifestyle, physical activity, and genetic predispositions are significantly influenced by the specific characteristics of each country [12]. These factors contribute to the observed differences in obesity prevalence across different countries and ethnic groups. Therefore, when analyzing pediatric obesity, there is a pressing need to establish and employ country-specific and time-specific reference standards to accurately assess and interpret the unique contributing factors and related body composition data within each population.

The body mass index (BMI) is a commonly used measure of obesity [13–16]. This classification, based on BMI was established under the assumption that BMI may reflect excessive fat accumulation [17]. However, the BMI does not distinguish between fat and lean body mass, which means that it can misclassify individuals as being obese when they are actually healthy, or vice versa [18, 19].

In particular, BMI-based classification methods exhibit low reliability in children and adolescent populations, among whom body composition changes dynamically with growth and developmental stages [20, 21]. Furthermore, because body composition varies according to race and gender, analyzing reference body composition data for Korean children and adolescent populations is valuable for future research related to childhood and adolescent obesity. Bioelectrical impedance analysis (BIA) is a simple, non-invasive, and low-cost method for estimating body fatness, consequently serving as a practical approach for assessing fat and lean mass [22]. By normalizing body fat mass (BFM) and fat-free mass (FFM; total body mass – BFM) in relation to height, the BMI can be deconstructed into two distinct components: the fat mass index (FMI; derived from BFM in kg divided by height in meters squared) and fat-free mass index (FFMI; obtained from FFM in kg divided by height in meters squared).

This study aimed to establish monthly reference centiles for anthropometric and body composition measures in Korean children and adolescents using bioelectrical impedance analysis with large-scale data.

Methods

Study sample

The Global Prediction Co., Ltd. (GP) has been conducting a mixed longitudinal study of Korean children and adolescents since 2013. The GP cohort study is a large-scale study that includes elementary-, middle-, and high-school students (aged 7–18 years[1]) in South Korea, specifically in Gwangmyeong City, Gyeonggi Province. Each year, an average of 35 schools participate in the study, and data are collected by visiting schools at least twice a year. As of April 30, 2023, the study has accumulated 588,546 data points on 96,485 children and adolescents (50,480 boys and 46,005 girls) who were born

[1] In this study, each age group includes individuals from 0 to 11 months of age. For example, the 7-year-old group consists of children aged 7 years and 0 months to 7 years and 11 months.

between 1998 and 2020. After completing a data-management procedure using robust statistical methods, we included a total of 88,069 measurements from 22,515 children, comprising 11,062 boys and 11,453 girls aged 7–16 years. The children were individually coded, and the data were anonymized. A portion of the GP Cohort data was used in the present study. This study was approved by the Institutional Review Board (IRB) of Yonsei Medical University, and the need for informed consent was waived because this was a de-identified retrospective study. (IRB No. 4-2023-1288).

Measurement of anthropometric parameters and body composition

The height, weight, and body composition of the participants were measured by highly trained personnel who conducted all measurements in accordance with established standard operating procedures.

The stadiometer usage and height measurement followed CDC (Centers for Disease Control and Prevention) guidelines, with the following detailed procedures: [12]

The stadiometer was mounted on the wall for this purpose, and the child is asked to remove any footwear and/or head ornaments before taking the measurement. With the buttocks, the shoulder blades, and the back of the head against the board, the head is oriented in the Frankfurt horizontal plane (FH plane), and the headpiece is firmly placed on the head. The reading is noted to the nearest tenth of a centimeter. The head is in the Frankfurt horizontal plane when the horizontal line from the ear canal to the lower border of the orbit is parallel to the floor. The line must also intersect the vertical backboard perpendicularly. The child should be asked to take a deep breath and stand as tall as possible. A deep breath straightens the spine and allows more accurate and consistent measurements.

The InBody models J10 and J30 are devices that analyze weight and body composition through bioelectrical impedance analysis, and the examinations were conducted according to the manual provided by InBody Co., Ltd. Participants were instructed to stand for five minutes before the examination, and the examination was conducted if at least two hours had passed since the last meal. Before the examination, participants were instructed to use the restroom, wash their hands thoroughly, and return. Examinations were preferably conducted in the morning at schools, and apart from assisting participants in adopting the standard standing posture for the examination, there was no physical contact between the subjects and the examiners during the examination.

Height (cm), weight (kg), FFM (kg), and BFM (kg) were measured, followed by the calculations of BF%, BMI, FFMI, and FMI, as follows.

$$BF\%\ (\%) = \frac{BFM\ (kg)}{Weight\ (kg)} \times 100\ (\%)$$

$$BMI\ (kg/m^2) = \frac{Weight\ (kg)}{Height\ (m)^2}$$

$$FFMI(kg/m^2) = \frac{FFM\ (kg)}{Height\ (m)^2}$$

$$FMI(kg/m^2) = \frac{BFM\ (kg)}{Height\ (m)^2}$$

$$BMI = FFMI + FMI$$

Data management

The data collected from the devices were centralized on a server and subjected to a data-cleaning procedure to identify and rectify any measurement or transcription errors [30]. The data-processing procedure consisted of four steps. First, to remove outliers, the Z-score was calculated for each measurement. For height and weight, the Z-score was obtained based on the LMS curves of the 2017 Korean national growth chart (KNGC 2017) [31]. For body composition data, because monthly LMS values for Korean children and adolescents aged 7–16 years are not available, the LMS curve was first pre-estimated using raw data. The Z-score of the body composition value was then calculated using these pre-estimated LMS values. Second, values with absolute Z-scores of at least 3 SD were removed from the analysis. Third, to obtain within-individual measurement consistency, Z-score variations between two successive measurements were calculated. The distribution of these variations was described and thresholds were defined as absolute Z-score variations greater than the 95th percentile of their distributions. Measurements that exceeded these thresholds back and forth were removed. Fourth, to minimize the bias introduced by multiple measurements from the same individuals, the average of measurements was used when more than one measurement was performed within the 6-month periods (from January to June and July to December) each year. This ensured that each student was represented by a single data point for each time period while still retaining the information from the data.

Statistical analysis

Sex-specific patterns corresponding to age (measured in months) for height, weight, and body composition were formulated utilizing generalized additive models for location, scale, and shape (GAMLSS), using the Box-Cox Cole and Green (BCCG) distribution, which is referred to as the LMS method [23–25]. The fundamental goal of this method involves the mitigation of skewness and the normalization of reference data through the application of an age-specific Box-Cox transformation. The introduction of the BCCG distribution within the LMS framework permits a departure from the conventional normal distribution, which is facilitated by the integration of three key parameters: skewness (L), median (M), and variation (S). To attain the desired curves, penalized cubic P-splines were chosen as smoothing functions for these parameters. We employed R version 4.2.2. and GAMLSS version 5.4.12.

Smoothed LMS curves for the 3rd, 5th, 10th, 15th, 25th, 50th (median), 75th, 85th, 90th, 95th, and 97th percentiles of height, weight, FFM, BFM, BF%, BMI, FFMI, and FMI according to month are presented as values and a percentile curve (hereafter referred to as the GP growth chart henceforth). Specifically, we conducted a comparative analysis between the GP growth charts for height and weight and KNGC 2017. This involved a visual assessment, where we graphically illustrated the percentile curves from both datasets.

To facilitate a more detailed comparative analysis, we focused on the 10th, 50th, and 90th percentiles for height and weight. We calculated the corresponding values for these percentiles using the LMS parameters from the GP growth charts and compared them directly with the corresponding percentile values from KNGC2017. This direct comparison allows for a straightforward assessment of the differences between the two datasets at each percentile level (Table 1). The differences are expressed in the original units of the measurements (centimeters for height and kilograms for weight), and the corresponding standard deviations are provided in parentheses below each difference value. Additionally, we standardized the percentile values from both the GP growth charts and KNGC2017 by converting them to standard deviation scores using the LMS values from the GP growth charts and presenting the deviation of their differences (Supplementary Fig. A3).

All statistical analyses were performed using Python version 3.9.7 and R version 4.2.2. $P \leq 0.05$ was considered statistically significant.

Results

Descriptive statistics

After the completion of the data-management procedures, a total of 88,069 measurements were collected from 22,515 children (11,062 boys and 11,453 girls). The distribution of observations within each sex and age subgroup is presented in Table 2 and depicted in Supplementary Fig. A1 [see Additional file 1]. On average, each child had three measurements (with an interquartile range of 2–5). Among the children, 16.5% had a single measurement, 31.0% had two measurements, and 52.5% had three or more measurements. The mean values for height, weight, FFM, BFM, body fat percentage (BF%), BMI, FFMI, and FMI were computed for each age and sex group, as presented in Table 2. The mean curves depicted in Supplementary Fig. A2 provide a visual representation of changes in body composition with age [see Additional file 1].

Height and weight growth curves compared with KNGC2017

The smoothed LMS curves for height and weight of children and adolescents aged 7–16 years (84–192 months) are visually represented in Figs. 1 and 2. A visual comparison of the GP growth curve (solid black) and the Korean national growth curves (dashed red) revealed that the shapes of the two curves were nearly identical. Compared with the height growth chart, the weight growth chart exhibited some minor differences. Regarding the weight, the GP growth chart was generally lower than the corresponding values in the KNGC2017, especially before 10 years (120 months) of age. In middle adolescence (age, 14 years [168 months] or more), this discrepancy became more pronounced, with the direction of the difference varying across different percentiles.

Table 1 presents a comparative analysis of the 10th, 50th, and 90th percentiles of the height and weight values between the GP growth chart and KNGC2017. Height according to the GP growth chart was on average 0.178 ± 0.148 cm (for boys) and 0.116 ± 0.116 cm (for girls) smaller than that of the KNGC2017. For weight, the observed difference was more pronounced than that obtained for height. Weight according to the GP growth chart was on average 0.442 ± 0.221 kg (for boys) and 0.454 ± 0.172 kg (for girls) smaller than that of the KNGC2017. Nevertheless, it is worth noting that the absolute magnitude of this size difference was not significant. Supplementary Fig. A3 illustrates the deviations in standard scores between the median values derived from the GP growth chart and KNGC2017, both referenced by the GP growth charts [see Additional file 1]. Regarding weight, the disparities were particularly noticeable before 10 years (120 months) and after 14 years (168 months).

Growth chart of body composition

The LMS curves obtained for FFM, BFM, BF%, FFMI, and FMI are presented in graphical form in Fig. 3. The dynamics of weight gain during puberty exhibited sex-specific patterns. The FFM in boys was consistently greater than that observed in girls for all percentiles. Focusing on the 50th percentile, the difference in FFM between boys and girls decreased gradually until it reached 0.89 kg at 10 years 10 months (130 months). Around 11 years 8 months (140 months), the FFM in boys had increased significantly, while that in girls had stagnated. By 15 years

Table 1 Anthropometric and body composition characteristics according to sex and age

Age (years)	Num. Obs.	Height (cm)		Weight (kg)		Fat-Free Mass (kg)		Body Fat Mass (kg)		BF%		BMI (kg/m^2)		FFMI (kg/m^2)		FMI (kg/m^2)	
(a) Boys																	
7	8,767	124.86	(5.07)	25.83	(4.06)	20.98	(2.29)	4.85	(2.48)	18.02	(6.53)	16.50	(1.85)	13.42	(0.74)	3.08	(1.48)
8	7,561	130.40	(5.28)	29.29	(5.12)	23.24	(2.62)	6.06	(3.28)	19.64	(7.48)	17.15	(2.27)	13.63	(0.82)	3.52	(1.81)
9	6,881	135.94	(5.55)	33.50	(6.34)	25.76	(3.08)	7.73	(4.10)	21.85	(8.02)	18.03	(2.62)	13.90	(0.90)	4.13	(2.07)
10	6,230	141.75	(6.06)	38.25	(7.68)	28.70	(3.77)	9.55	(4.99)	23.63	(8.47)	18.92	(2.94)	14.22	(1.02)	4.70	(2.32)
11	5,141	148.02	(6.97)	43.50	(8.94)	32.57	(5.11)	10.93	(5.71)	23.89	(8.90)	19.73	(3.15)	14.77	(1.25)	4.96	(2.51)
12	3,696	154.37	(7.71)	47.96	(9.75)	37.17	(6.52)	10.78	(6.00)	21.51	(9.00)	20.01	(3.21)	15.48	(1.52)	4.54	(2.52)
13	1,793	161.24	(7.52)	53.26	(10.44)	42.51	(7.04)	10.75	(6.23)	19.26	(8.64)	20.39	(3.29)	16.24	(1.63)	4.15	(2.45)
14	1,560	166.63	(6.59)	58.18	(10.37)	47.10	(6.62)	11.08	(6.25)	18.17	(7.87)	20.90	(3.26)	16.90	(1.60)	4.01	(2.30)
15	1,383	169.99	(5.89)	61.36	(9.78)	50.22	(6.23)	11.13	(5.90)	17.40	(7.18)	21.21	(3.10)	17.34	(1.61)	3.87	(2.09)
(b) Girls																	
7	8,874	123.62	(5.09)	24.91	(3.99)	19.67	(2.17)	5.24	(2.45)	20.25	(6.52)	16.23	(1.90)	12.83	(0.73)	3.40	(1.49)
8	8,196	129.55	(5.47)	28.21	(4.98)	21.87	(2.58)	6.34	(3.10)	21.49	(7.12)	16.73	(2.22)	12.99	(0.81)	3.74	(1.72)
9	8,143	135.76	(5.95)	32.25	(6.32)	24.48	(3.20)	7.77	(3.96)	22.91	(7.74)	17.40	(2.62)	13.23	(0.93)	4.17	(2.01)
10	7,664	142.49	(6.44)	37.13	(7.57)	27.75	(3.98)	9.38	(4.67)	24.08	(7.83)	18.17	(2.88)	13.60	(1.07)	4.58	(2.18)
11	5,086	148.47	(6.44)	41.66	(8.21)	31.04	(4.39)	10.63	(5.02)	24.44	(7.53)	18.81	(2.98)	14.02	(1.17)	4.79	(2.19)
12	3,108	153.37	(6.06)	45.81	(8.46)	33.78	(4.33)	12.02	(5.25)	25.27	(7.09)	19.40	(3.01)	14.32	(1.19)	5.09	(2.16)
13	1,581	157.04	(5.54)	49.56	(8.04)	35.84	(4.04)	13.72	(5.21)	26.90	(6.57)	20.07	(2.92)	14.51	(1.18)	5.56	(2.09)
14	1,510	158.90	(5.29)	52.15	(8.13)	36.80	(4.07)	15.36	(5.23)	28.77	(6.06)	20.63	(2.87)	14.55	(1.18)	6.08	(2.04)
15	1,019	159.85	(5.46)	53.36	(8.11)	37.36	(4.20)	16.00	(5.29)	29.37	(6.01)	20.86	(2.85)	14.59	(1.18)	6.27	(2.08)

Table 2 Differences in height and weight percentiles between the GP growth chart and KNGC2017 growth charts

Percentile	10th	50th	90th
Panel (a) Boys			
Height (cm)	0.265	−0.178	0.001
(Std. Dev.)	(0.169)	(0.148)	(0.302)
Weight (kg)	−0.446	−0.442	−0.314
(Std. Dev.)	(0.363)	(0.221)	(0.372)
Panel (a) Girls			
Height (cm)	0.245	−0.116	0.056
(Std. Dev.)	(0.116)	(0.116)	(0.217)
Weight (kg)	−0.410	−0.454	−0.204
(Std. Dev.)	(0.248)	(0.172)	(0.446)

11 months (191 months), the difference in FFM between boys and girls became 14.09 kg. Conversely, the opposite pattern was observed for BFM. In girls, the BFM was consistently greater than in boys from 7 years (84 months) to 8 years 8 months (104 months). Around 9 years 9 months (117 months), the BFM of boys overtook that of girls. By 11 years 7 months (139 months), the BFM in girls became greater again. By 15 years 11 months (191 months), the BFM in girls was 5.71 kg greater than the BFM in boys. In summary, the weight gain in boys was characterized by the augmentation of the FFM, whereas girls displayed an increased BFM accumulation. Shifting the focus to the BF%, it became apparent that boys experienced a peak of 23.71% around 11 years (132 months), whereas the BF% in girls exhibited a steady increase, which was particularly prominent after 11 years 6 months (138 months).

This distinction became even more pronounced when examining the body composition indices. BMI, which is derived from weight, exhibited an increase across all percentiles for both sexes, without showing distinctive patterns between boys and girls. However, after decomposing BMI into its constituent components of FFMI and FMI, a discernible trend emerged. In terms of FFMI, the boys consistently outpaced the girls across all percentiles. At the 50th percentile, the growth trajectories exhibited similarities until approximately 11 years 1 month (133 months), maintaining a difference of around 0.65 kg/m2. Subsequently, a significant surge in boys' FFMI was observed, coinciding with a deceleration in the increase in the FFMI in girls, leading to a marginal increase after 13 years 1 month (157 months). Consequently, the divergence widened considerably, reaching 2.98 kg/m2 by 15 years 11 months (191 months). Regarding the FMI, boys and girls exhibited distinct patterns. For boys, the FMI peaked at 11 years 2 months (134 months), whereas the FMI of girls increased steadily until the end of the pubertal growth spurt. This divergence resulted in the FMI of boys surpassing that of girls from 9 years 8 months (116 months) to 11 years 7 months (139 months), followed by a shift, as the FMI of girls surpassed that of boys, thus widening the gap to 2.70 kg/m2 by 15 years 11 months (191 months).

Discussion

This study provided age- and sex-specific reference percentiles for FFM, BFM, BF%, BMI, FFMI, and FMI among Korean children and adolescents. The study was

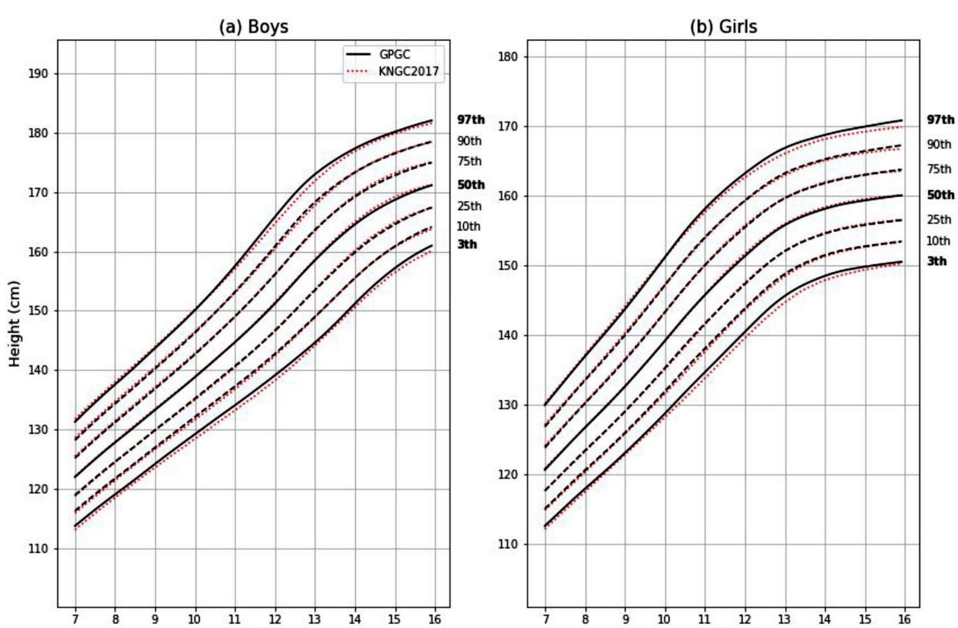

Fig. 1 GP percentile curves for height in (**a**) boys and (**b**) girls compared with KNGC2017

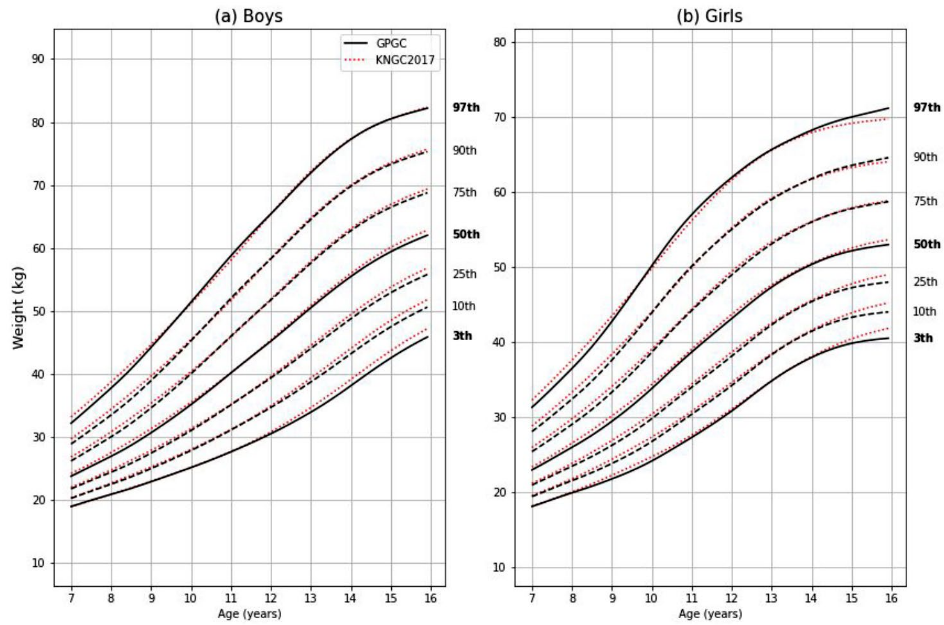

Fig. 2 GP percentile curves for weight in (**a**) boys and (**b**) girls compared with KNGC2017

conducted using a large sample of 22,515 participants aged 7–16 years, thus notably surpassing the sample sizes of prior investigations conducted among Korean adolescents. Based on this standardized dataset, we created smoothed LMS percentile charts for body composition indices. The reference curves indicated the existence of significant sex- and age-specific differences that captured the changes that occurred during the pubertal growth period.

Boys consistently had greater FFM than girls, with the difference narrowing until age 11. After age 11, boys' FFM increased significantly, but this increase lessened at higher percentiles. In contrast, girls' BFM and BF% increased during adolescence, while boys' BFM increased between ages 11 and 12 before plateauing. This indicates that boys' weight gain during adolescence is primarily due to increased FFM, while girls' weight gain is due to increased BFM. Consequently, BF% in girls continually increased, whereas it peaked at age 11 in boys and then gradually decreased. In the analysis of body composition indices, BMI increased across all percentiles for both boys and girls. When separated into FFMI and FMI, boys had significantly higher FFMI than girls in all quantiles. Both groups grew similarly until age 11, after which boys' FFMI increased rapidly, while girls' FFMI increased until age 13. Boys' FMI peaked at 11 years, while girls' FMI continued to rise during adolescence. Consequently, although BMI steadily increased for both, boys' BMI declined alongside the significant increase in FMI, while girls' BMI plateaued with an increasing FMI.

Kim et al. in 2013 and Park et al. in 2015 conducted similar analyses on age-specific references for body composition in Korean children and adolescents [26, 27]. These studies utilized KNHANES data, providing the advantage of nationwide data coverage. However, Kim et al.'s data included 1,579 individuals, while Park et al.'s data comprised 2,123 individuals, analyzing body composition on a yearly basis. This results in a quantitative disparity compared to our study, which analyzed data on a monthly basis, utilizing big data comprising 588,546 data points from 96,488 individuals. Additionally, the use of the DXA method in these prior studies introduces qualitative differences compared to our study, which employed BIA measurements. Moreover, previous studies focused on a limited age range of 10 to 18 years, making direct comparisons difficult due to the lack of clear pre-pubertal data. Despite the above differences, our comparison of height and weight measurements with the nationwide KNGC 2017 data from KNHANES confirmed no significant differences in trajectory between our study's data and the nationwide data. Although our study primarily sourced data from the non-metropolitan region of Gwangmyeong City in Gyeonggi Province, potentially limiting its representation of the general Korean populace, its robustness remains notable. Gwangmyeong City is situated within the Seoul-Gyeonggi region, encompassing 44.5% of the Korean population under 20, thereby lending credibility to our findings. Consequently, the LMS curve derived from our study echoed trends observed in prior research employing nationwide datasets, thereby reinforcing the validity of our results. However, when comparing absolute values rather than trajectories, our findings indicated a lower average weight across age groups compared to the KNGC

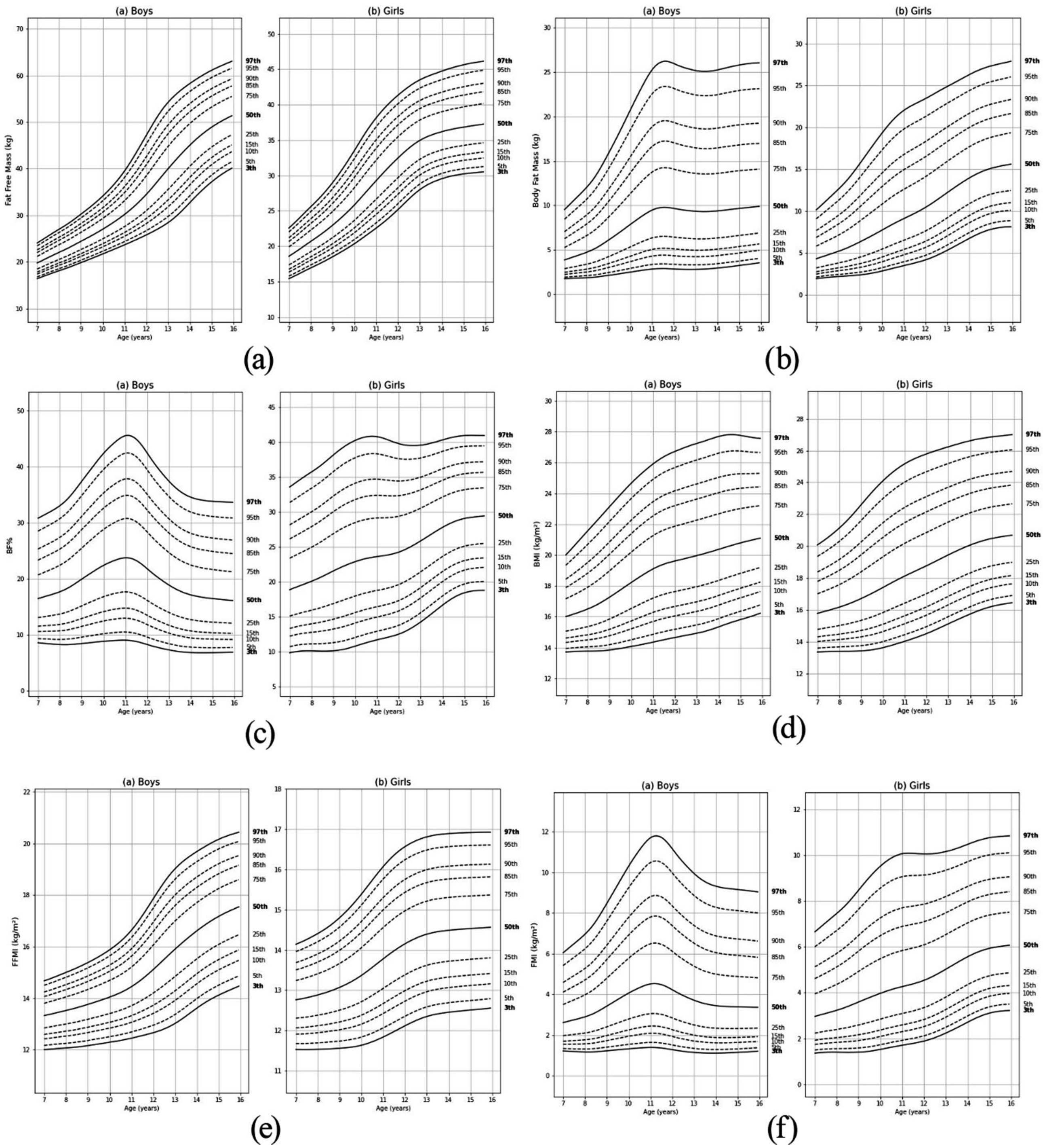

Fig. 3 Percentile curves for body composition in Korean children and adolescents. **a**. Percentile curves for FFM in (a) boys and (b) girls. **b**. Percentile curves for BFM in (a) boys and (b) girls. **c**. Percentile curves for BF% in (a) boys and (b) girls. **d**. Percentile curves for BMI in (a) boys and (b) girls. **e**. Percentile curves for FFMI in (a) boys and (b) girls. **f**. Percentile curves for FMI in (a) boys and (b) girls

2017 data. This aligns with reports suggesting a correlation between higher socioeconomic status and decreased risk of obesity, both in children and adults [28]. The cohort from Gwangmyeong City primarily represents a high-income demographic, potentially influencing the observed lower weights compared to the national average in South Korea.

This study has revealed the occurrence of significant variations in BMI based on age and gender, highlighting the limitations of using BMI as a direct indicator of body composition. Previous studies have shown that, in some cases, even when their BMI is within the normal range, up to 50% of children and adolescents may still have excessive BF% [29]. Conversely, in cases where BMI indicates obesity, 15.2% of individuals may still fall within the normal range for BF% [30]. Furthermore, several studies have reported an increased risk of obesity-related complications, such as cardiovascular diseases, when BF% increases, even in children and adolescents with a normal BMI [27, 31–33].

Additionally, there is growing interest in the associations between body composition and various pediatric diseases across multiple fields. As an example, an increase in BF% is known to be a risk factor for premature adrenarche and precocious puberty, while a decrease in FFMI is recognized as a characteristic of short stature in children [34–36]. Therefore, the Korean reference for body composition based on BIA presented here can provide a more effective foundation for predicting and monitoring various pediatric conditions. In particular, conditions such as precocious puberty or short stature often require a diagnosis before the typical onset of puberty. In this GP cohort study, we provided reference body composition data for the age range of 7–10 years, which has not been reported previously [27]. These additional data enhance its utility for clinical applications.

This study had several limitations. First, the age range was limited to 7–16 years. Given the increasing trend in obesity prevalence in children of all ages in our country, collecting reference data for a wider age range is essential [37]. The GP cohort study is ongoing, and it is expected to provide growth references for the entire child and adolescent period once a sufficient number of datasets are available. Second, we utilized BIA to assess body composition by deriving fat percentage from body fluid measurements. However, BIA measurements can be influenced by various factors, including body posture, obesity, malnutrition, body temperature, fluid and food intake, hydration and electrolyte balance changes, physical activity, prolonged supine position, examination procedures, and electrode placement methods [38]. To address these limitations, our study followed the standard guidelines provided by InBody Co., Ltd., and measurements were conducted by trained examiners. Nevertheless, limitations such as the inability to confirm uniform hydration status or electrolyte balance across all subjects and the lack of temperature measurements indicate that not all sources of measurement error could be fully controlled. However, because BIA has shown excellent test-retest reliability and moderate to strong correlations with DXA, especially in pediatric and adolescent cohorts, it continues to be an affordable, convenient, non-invasive, and highly reproducible method for assessing body composition in clinical settings for the pediatric population [39–41]. Third, the study did not fully utilize the longitudinal data available in the GP cohort. Longitudinal data can be used to track individual growth patterns over time, which can provide insights that are not possible to extract from cross-sectional data [42].

In this study, we provided age- and sex-specific reference percentiles for body composition indices among Korean children and adolescents based on a large biometric dataset. The alignment of the derived growth curves with existing national standards confirmed the statistical rigor of the methods used. The resulting smoothed percentile charts revealed distinct pubertal growth patterns, thus highlighting significant sex- and age-related disparities. The collective use of these references will facilitate an accurate clinical outcome assessment in pediatric patients and will provide policymakers with valuable insights for the development of relevant healthcare strategies.

Abbreviations

BFM	Body fat mass
FFM	Fat-free mass
BF%	Body fat percentage
BMI	Body mass index
FMI	Fat mass index
FFMI	Fat-free mass index
BIA	Bioelectrical impedance analysis

Supplementary Information

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Supplementary Material 1

Author contributions

D.C.; data collection, analysis, and interpretation of results. S.J.K.; draft manuscript preparation. J.S. and J.K.; study conception and design. All authors read and approved the final manuscript.

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Data availability

The data used in this study were provided by the Global Prediction Co., Ltd. Due to the sensitivity of personal information and privacy concerns involving children and adolescents' data, there are restrictions on sharing the raw dataset publicly. The data presented in this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

This study was approved by the Institutional Review Board (IRB) of Yonsei Medical University, and the need for informed consent was waived because this was a de-identified retrospective study. (IRB No. 4-2023-1288).

Consent for publication

Not applicable.

Competing interests
Dohyun Chun and Jihun Kim are employees and hold stocks of Global Prediction Co., Ltd. Seojung Kim and Junghwan Suh declare that they have no competing interests.

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