Longitudinal study of body mass index and percentage of overweight in Japanese children grouped by maturity

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Abstract. Childhood obesity is a known risk factor for adult diseases, making its evaluation highly important. However, the evaluation is complex because there is no gold standard method. Body mass index (BMI) and percentage of overweight (POW) are widely used in Japan. However, they have the following limitations: it is difficult to set cutoffs for BMI because it dynamically varies in childhood, and POW has not been studied extensively, especially regarding its difference during maturity. Therefore, our study analyzed BMI/POW in Japanese children grouped by maturity. We used longitudinal school check-up data collected from elementary and junior high schools in 20 municipalities. We made percentile curves of BMI/POW and calculated the percentage of participants considered overweight/obese by sex, age, and maturity. Maximum increment age (MIA) was calculated using the graphical fitting method. We included 35,461 subjects aged 15 in 2018. Early-maturing children had higher BMI. The difference among maturity groups decreased by shifting the percentile curves by differences in MIA. Therefore, the use of BMI might lead to the overestimation of overweight/obesity in early-maturing children and underestimation in late-maturing children. The POW percentile curves were “N”-shaped around the MIA, indicating the inappropriate evaluation during this period. The percentile curves of children categorized as overweight/obese were also “N”-shaped, confirming that MIA affects the evaluation of childhood obesity. The possibility of overestimation/underestimation needs verification with the data of accurate age, pubertal changes, and adult diseases. In conclusion, it is difficult to evaluate childhood obesity only with height and weight.

Key words: Childhood obesity, Body mass index, Percentage of overweight, Maturity

CHILDHOOD OBESITY is an important health problem, and it is a known risk factor for diseases, such as type 2 diabetes mellitus [1, 2], coronary heart disease [3], hyperlipidemia [4], and fatty liver [4, 5]. This condition has gained importance in terms of its high prevalence. The World Health Organization reported that more than 340 million (>18%) of children aged 5–19 yrs were overweight or obese in 2016, showing a dramatically increased proportion since 1975 [6]. In Japan, which also has an increasing number of overweight and obese children [7], it is necessary to prevent adult diseases by accurately evaluating childhood obesity and educating high-risk children.

The common methods for evaluating childhood obesity in Japan include body mass index (BMI) and percentage of overweight (POW). In addition to being widely used to evaluate obesity, studies show that BMI [8, 9] and POW [10] are associated with fat mass accumulation. Although these methods are quite similar in that they measure weight and height, they are different in that BMI is used internationally [11], while POW is used only regionally, i.e., in Japan.

However, thus far, there is no gold standard technique available for evaluating obesity in children. For BMI, the cut-off points for adults, i.e., 25 kg/m² for overweight and 30 kg/m² for obesity, cannot be applied to children because BMI dynamically changes in childhood; it increases throughout elementary and junior high school age, especially approximately within the age of 11–15 yrs [12]. Some methods have been developed to apply the BMI cut-off points for children [13, 14]. However, none of them reached a consensus. In this situation, the lack of studies on BMI application to children has caused scarcity of evidence in Japanese children. Additionally, a study revealed that BMI transition differs depending on maturity [15], making the criterion for childhood obesity more complex. Regarding POW, there are not enough studies that consider maturity during the assessment. Due to the differences among individuals in child growth, it is
important to consider the maturity of children when analyzing child somatotypes.

This study aimed to analyze BMI and POW application in Japanese children grouped by maturity and identify factors that should be considered when judging childhood obesity in clinical situations.

Materials and Methods

Study design and setting

This retrospective and longitudinal study used school check-up data collected from elementary and junior high schools, which is the School Health Record (SHR) database collected by the SHR Division of the Real World Data Co. Ltd. [16] and held by the Health, Clinic, and Education Information Evaluation Institute in Japan [17, 18]. The children included in this study were born in 2003 and were observed until 2018 (aged 15 yrs), and they lived in 20 municipalities. The municipalities included cities and suburbs located across Japan. The inclusion criterion was the availability of data on sex, height, and weight for at least one yr. We excluded cases with missing data on sex or height and weight.

Measurements

School check-up variables included sex, cities wherein their schools were located, and height and weight from the 1st grade in elementary school to the last grade in junior high school. Height and weight were measured annually by school nurses and teachers. For the analysis, we used information on the height and weight measured each yr and sex.

Grouping

Subjects were divided into groups based on the maximum increment age (MIA), indicating when a child’s height-growth speed is the fastest. This reflects height growth and sexual maturity because the hypothalamus releases growth hormones during the pubertal period [19]. Also, studies show the association between peak height velocity and Tanner stage [20, 21], which is widely used for evaluating sexual maturity. In this study, the MIA was calculated using the graphical fitting method developed by Matsumoto et al. [22]. The formula is as follows:

\[ \text{MIA} = \text{A}_{\text{max}} + \left( \frac{I_{\text{max}} - I_1}{(I_{\text{max}} - I_1) + (I_{\text{max}} - I_{2})/2} \right) \]

where

- \( I_{\text{max}} \): maximum annual height growth
- \( I_1 \): annual height growth for one yr before the \( I_{\text{max}} \)
- \( I_{2} \): annual height growth for one yr after the \( I_{\text{max}} \)
- \( \text{A}_{\text{max}} \): age at which the \( I_{\text{max}} \) starts

Based on the calculated MIA, subjects were divided into three groups: early, average, and late maturity. According to previous research [15], each group included children who belonged to the 3–10, 25–75, and 90–97 percentiles of MIA for each sex, respectively. Some subjects were not included in any maturity group. Without accurate data on age, we regarded 1st graders in elementary school as 6.5-yr-olds, 2nd graders as 7.5-yr-olds, and the same applies hereafter. Unlike the five Tanner stages, “early,” “average,” and “late” are not stages, but groups in this study; therefore, subjects do not move from one to another.

BMI and POW

BMI was calculated as weight (kg)/height squared (m²). Overweight was defined according to the cut-off points defined as exceeding a BMI of 25 kg/m² for adults [13]. A BMI of 25 kg/m² is the cut-off point for overweight, including obesity, according to the International Obesity Task Force criteria [13]. Following MIA, we applied the cut-off point for 6.5 yrs to the 1st graders and 7.5 yrs to the 2nd graders of elementary school, and the same applies hereafter.

POW was calculated as \[ \frac{[ \text{weight (kg)} - \text{standard_weight (kg)} ] \times 100}{\text{standard_weight (kg)}} \]. Standard weight was based on the sex- and height-specific calculation method [23]. Since the 1st graders in elementary schools, who were the youngest subjects in this study, are 6 or 7 yrs, formulas for children aged ≥6 yrs were used for analyzing all the data. We did not use other sex-, height-, and age-specific methods when calculating standard weight as there were inaccuracies in the data on age. We defined subjects with a POW of ≥20 as overweight, in line with previous studies [24, 25].

Statistical analysis

The mean and standard deviation of each sex and age were calculated using weight, height, BMI, and POW. The mean values were compared between sexes using a t-test. The curves of the 90th, 75th, 50th, 25th, and 10th percentiles for BMI and POW were created for each sex and maturity group. We also calculated the percentage of subjects who were considered overweight or obese using BMI or POW for each sex, age, and maturity group. All statistical analyses were performed using Stata software (version 14.2, StataCorp LLC, College Station, Texas, USA).

Results

Among 35,461 subjects enrolled in our study, 18,115 (51.2%) were boys and 17,306 (48.8%) were girls.

Table 1 shows the characteristics of each sex. In both sexes, the mean weight, height, and BMI increased
### Table 1  Characteristics of subjects (N = 35,412)

#### Weight and height by sex

| characteristics    | gender |          |          | p-value |
|--------------------|--------|----------|----------|---------|
|                    | boys   | girls    |          |         |
| number of children | 18,115 (51.2) | 17,306 (48.8) |         |         |
| weight (kg), mean (SD) |        |          |          |         |
| 1st grade in ES    | 21.3 (3.4) | 20.9 (3.3) | <0.001   |         |
| 2nd grade in ES    | 23.9 (4.0) | 23.3 (3.8) | <0.001   |         |
| 3rd grade in ES    | 27.0 (5.1) | 26.4 (4.8) | <0.001   |         |
| 4th grade in ES    | 30.3 (6.2) | 29.8 (5.8) | <0.001   |         |
| 5th grade in ES    | 33.9 (7.3) | 33.9 (7.0) | 0.892    |         |
| 6th grade in ES    | 38.1 (8.5) | 38.8 (7.8) | <0.001   |         |
| 1st grade in JHS   | 43.7 (9.6) | 43.7 (8.1) | 0.626    |         |
| 2nd grade in JHS   | 48.7 (9.8) | 47.2 (7.6) | <0.001   |         |
| 3rd grade in JHS   | 53.7 (9.9) | 49.9 (7.5) | <0.001   |         |
| height (cm), mean (SD) |        |          |          |         |
| 1st grade in ES    | 116.5 (4.9) | 115.7 (4.9) | <0.001   |         |
| 2nd grade in ES    | 122.4 (5.2) | 121.5 (5.2) | <0.001   |         |
| 3rd grade in ES    | 128.1 (5.4) | 127.4 (5.5) | <0.001   |         |
| 4th grade in ES    | 133.4 (5.7) | 133.4 (6.1) | 0.717    |         |
| 5th grade in ES    | 138.8 (6.2) | 140.1 (6.8) | <0.001   |         |
| 6th grade in ES    | 144.9 (7.3) | 146.7 (6.7) | <0.001   |         |
| 1st grade in JHS   | 152.6 (8.1) | 151.9 (5.9) | <0.001   |         |
| 2nd grade in JHS   | 159.9 (7.7) | 154.9 (5.4) | <0.001   |         |
| 3rd grade in JHS   | 165.3 (6.7) | 156.5 (5.3) | <0.001   |         |

#### BMI and POW by sex

| characteristics    | gender |          |          | p-value |
|--------------------|--------|----------|----------|---------|
|                    | boys   | girls    |          |         |
| number of children | 18,115 (51.2) | 17,306 (48.8) |         |         |
| BMI (kg/m²), mean (SD) |        |          |          |         |
| 1st grade in ES    | 15.6 (1.7) | 15.6 (1.7) | <0.001   |         |
| 2nd grade in ES    | 15.9 (1.8) | 15.7 (1.8) | <0.001   |         |
| 3rd grade in ES    | 16.4 (2.2) | 16.2 (2.1) | <0.001   |         |
| 4th grade in ES    | 16.9 (2.6) | 16.6 (2.3) | <0.001   |         |
| 5th grade in ES    | 17.5 (2.8) | 17.2 (2.5) | <0.001   |         |
| 6th grade in ES    | 18.0 (2.9) | 17.9 (2.7) |          |         |
| 1st grade in JHS   | 18.6 (3.0) | 18.8 (2.8) | <0.001   |         |
| 2nd grade in JHS   | 18.9 (2.9) | 19.6 (2.8) | <0.001   |         |
| 3rd grade in JHS   | 19.6 (3.0) | 20.3 (2.8) | <0.001   |         |
| POW (%), mean (SD) |        |          |          |         |
| 1st grade in ES    | 3.2 (10.7) | 3.1 (10.7) | 0.348    |         |
| 2nd grade in ES    | 2.4 (11.3) | 2.6 (11.2) | 0.324    |         |
| 3rd grade in ES    | 3.2 (13.2) | 3.2 (12.5) | 0.708    |         |
| 4th grade in ES    | 3.5 (14.7) | 2.4 (13.4) | <0.001   |         |
| 5th grade in ES    | 3.3 (15.5) | 0.0 (13.8) | <0.001   |         |
| 6th grade in ES    | 2.4 (15.7) | -2.4 (13.8) | <0.001   |         |
| 1st grade in JHS   | 1.2 (15.6) | -2.1 (14.4) | <0.001   |         |
| 2nd grade in JHS   | -1.3 (14.3) | -0.2 (14.2) | <0.001   |         |
| 3rd grade in JHS   | -0.6 (14.7) | 2.7 (14.2) | <0.001   |         |

#### MIA by sex and maturity groups

| maturity groups | mean (SD) |          |          |         |
|-----------------|-----------|----------|----------|---------|
| total           | 12.2 (0.9) | 10.6 (1.1) | <0.001   |         |
| early           | 981       | 10.8 (0.3) | 8.76 (0.3) | <0.001 |
| average         | 7,011     | 12.3 (0.3) | 10.7 (0.4) | <0.001 |
| late            | 986       | 13.2 (0.6) | 12.2 (0.2) | <0.001 |

Abbreviations: SD, standard deviation; ES, elementary school; JHS, junior high school
annually. Although there was a trend in these three variables, showing a higher mean value of boys than that of girls, as to weight in the 6th grade in elementary school (38.1 vs. 38.8 kg); height in the 5th (139 vs. 140 cm), and 6th (145 vs. 147 cm) grades in elementary school; and BMI in the 1st (18.6 vs. 18.8 kg/m$^2$), 2nd (18.9 vs. 19.6 kg/m$^2$), and 3rd (19.6 vs. 20.3 kg/m$^2$) grades in junior high school, and the mean values of boys were lower than those of girls. The mean POW of boys varied from –1.26% to 3.51%, while that of girls varied from –2.37% to 3.21%. After dividing into maturity groups, 981, 7,011, and 986 boys and 1,108, 7,915, and 1,109 girls belonged to the early, average, and late groups, respectively. Mean MIA was higher in boys than in girls overall (12.2 vs. 10.6 years old) and in each maturity group (10.8 vs. 8.76, 12.3 vs. 10.7, and 13.2 vs. 12.2 years old).

Fig. 1a shows the percentile curves of BMI, the curve
of cut-off points for overweight/obesity, and the average MIA in each maturity group in Japanese children. In both sexes, all years, and all percentiles, the BMI value was lowest in the late maturity group and highest in the early maturity group; the cut-off curves almost accompanied the 75th and 90th percentile curves in the early and average maturity groups, respectively, and exceeded the 90th percentile curves in the late maturity group. The difference between the maturity groups was larger in higher percentiles, as the intervals between percentiles were larger in the earlier maturity groups. In both sexes and all maturity groups, the slope of the curve of cut-off points almost agreed with those of percentile curves. However, in boys of higher percentiles in each maturity group the percentile curves declined once and surged again near the MIA, which led to misalignment with the cut-off curves. Detailed percentile values are shown in Table 2.

As shown in Fig. 1a, shifting the horizontal axis by the difference in the average MIA of each group decreased the gaps between the maturity groups; however, the BMI values of the earlier maturity groups tended to be higher than those of the later maturity groups, especially in higher percentiles and older age groups (Fig. 1b). However, there were cases in which earlier maturity group values were lower than those of the later maturity group, such as the 10th percentiles of girls of older ages.

Fig. 2 shows the percentile curves of POW, cut-off value (20%), and average MIA in each maturity group among Japanese children. Similar to BMI, in both sexes, earlier maturity groups showed higher POW values, and the difference was larger in higher percentiles. In both sexes, all maturity groups, and almost all percentiles, the curves surged, declined, and then surged again, resulting in an “N” shape. For boys, the slopes of “N” were sharper in the higher percentiles and the earlier maturity groups, whereas in the lower percentiles of the later maturity groups, the curves gradually declined. For girls, the sharpness of the “N” shape did not differ by maturity groups. Comparing the “N” shape with the average MIA of that group, we could observe that the lines are in the decreasing sections of “N.” Detailed percentile values are shown in Table 3.

Fig. 3 shows the proportion of children by maturity group categorized as overweight/obese based on BMI or POW. In both sexes, the earlier maturity groups tended to have higher proportions of overweight/obese children.

### Table 2  BMI percentile values by maturity groups

| Boys | Early | Average | Late |
|------|-------|---------|------|
|      | 10    | 25      | 50   | 75   | 90   | 10    | 25    | 50    | 75    | 90    | 10    | 25    | 50    | 75    | 90    |
| 1st grade in ES | 14.40 | 15.18  | 16.02 | 17.08 | 18.54 | 14.02 | 14.66 | 15.42 | 16.34 | 17.55 | 13.92 | 14.51 | 15.20 | 15.95 | 16.81 |
| 2nd grade in ES | 14.61 | 15.40  | 16.34 | 17.57 | 19.50 | 14.14 | 14.79 | 15.57 | 16.56 | 17.96 | 14.01 | 14.57 | 15.27 | 16.11 | 16.90 |
| 3rd grade in ES | 14.88 | 15.90  | 16.97 | 18.72 | 20.98 | 14.38 | 15.06 | 15.97 | 17.28 | 19.14 | 14.25 | 14.81 | 15.58 | 16.60 | 17.53 |
| 4th grade in ES | 15.55 | 16.49  | 17.75 | 19.97 | 22.48 | 14.61 | 15.40 | 16.41 | 18.05 | 20.25 | 14.38 | 14.97 | 15.87 | 17.06 | 18.39 |
| 5th grade in ES | 16.02 | 17.00  | 18.32 | 20.36 | 23.57 | 14.88 | 15.74 | 16.89 | 18.80 | 21.31 | 14.53 | 15.22 | 16.21 | 17.47 | 19.38 |
| 6th grade in ES | 16.40 | 17.41  | 18.62 | 20.34 | 23.23 | 15.36 | 16.24 | 17.48 | 19.43 | 22.17 | 14.85 | 15.56 | 16.60 | 18.08 | 20.44 |
| 1st grade in JHS | 17.08 | 18.10 | 19.41 | 21.32 | 24.24 | 16.00 | 16.88 | 18.09 | 19.82 | 22.42 | 15.32 | 16.13 | 17.29 | 18.98 | 21.32 |
| 2nd grade in JHS | 17.62 | 18.72 | 20.03 | 21.88 | 24.74 | 16.54 | 17.43 | 18.57 | 20.01 | 22.10 | 15.83 | 16.72 | 17.73 | 18.94 | 20.76 |
| 3rd grade in JHS | 18.11 | 19.14 | 20.74 | 22.63 | 25.40 | 17.08 | 18.04 | 19.29 | 20.82 | 22.93 | 16.46 | 17.32 | 18.31 | 19.65 | 21.50 |

| Girls | Early | Average | Late |
|-------|-------|---------|------|
|       | 10    | 25      | 50   | 75   | 90   | 10    | 25    | 50    | 75    | 90    |
| 1st grade in ES | 14.23 | 14.99  | 15.94 | 17.20 | 18.71 | 13.87 | 14.49 | 15.29 | 16.20 | 17.33 | 13.57 | 14.12 | 14.88 | 15.67 | 16.45 |
| 2nd grade in ES | 14.42 | 15.19  | 16.19 | 17.71 | 19.27 | 13.94 | 14.59 | 15.41 | 16.39 | 17.58 | 13.60 | 14.19 | 14.91 | 15.65 | 16.55 |
| 3rd grade in ES | 14.74 | 15.65  | 16.85 | 18.57 | 20.42 | 14.12 | 14.84 | 15.76 | 16.93 | 18.49 | 13.72 | 14.39 | 15.15 | 16.00 | 16.99 |
| 4th grade in ES | 15.05 | 16.00  | 17.38 | 19.20 | 21.30 | 14.32 | 15.11 | 16.13 | 17.50 | 19.28 | 13.81 | 14.51 | 15.34 | 16.39 | 17.52 |
| 5th grade in ES | 15.65 | 16.72  | 18.34 | 20.15 | 22.49 | 14.66 | 15.50 | 16.63 | 18.09 | 19.94 | 13.89 | 14.66 | 15.54 | 16.65 | 18.29 |
| 6th grade in ES | 16.40 | 17.63 | 19.31 | 21.44 | 23.59 | 15.30 | 16.24 | 17.45 | 18.88 | 20.73 | 14.16 | 14.97 | 15.86 | 17.04 | 18.76 |
| 1st grade in JHS | 16.96 | 18.40 | 20.22 | 22.38 | 24.62 | 16.12 | 17.17 | 18.53 | 20.05 | 22.02 | 14.65 | 15.54 | 16.62 | 17.85 | 19.57 |
| 2nd grade in JHS | 17.81 | 19.10 | 20.79 | 22.95 | 25.02 | 16.98 | 18.05 | 19.40 | 20.91 | 22.59 | 15.61 | 16.54 | 17.57 | 18.81 | 20.02 |
| 3rd grade in JHS | 18.34 | 19.62 | 21.19 | 23.31 | 25.46 | 17.63 | 18.75 | 20.10 | 21.65 | 23.35 | 16.38 | 17.38 | 18.59 | 19.89 | 21.23 |

Abbreviations: ES, elementary school; JHS, junior high school
with both BMI and POW. For BMI in boys and POW in both sexes, the curves showed an “N”-shape. The turning points were in younger ages in the earlier maturity groups, and they almost matched those of the curves of the sex and maturity groups shown in Fig. 2. For BMI in girls, the curve of the early maturity group showed mountain-like shapes, while those of the average and late maturity groups showed marginal changes. In both sexes, the difference among the maturity groups was smaller in POW than in BMI. The detailed values are listed in Table 4.

**Discussion**

In this study, we showed the longitudinal BMI and POW percentile curves of Japanese children by maturity group. We found that early-maturing children tended to show higher BMI and POW than later maturity children of the same age. This tendency was stronger in BMI and higher percentiles. The curves showing the ratio of children categorized as overweight/obese in each sex and the maturity group were “N”-shaped, except those of BMI in girls.

For BMI, it would be natural that early-maturing children showed higher BMI because the BMI increases as they become older or mature. This is supported by the results that differences in BMI values among the maturity groups decreased when shifting the curves according to MIA differences. Therefore, it is assumed that applying the same BMI cut-off values to children of all maturity groups leads to an overestimation of overweight/obesity in early-maturing children and an underestimation of that of late-matured children. This tendency was stronger in boys of higher percentiles.

Our finding that BMI percentile curves are very different among maturity groups is in line with that of previous studies [15, 26], both of which mentioned the inaccuracy of applying BMI-for-age percentiles for children of all maturity levels. Moreover, obesity overestimation in BMI has been shown in a study using bioelectric impedance analysis (which includes fat-free mass, fat mass, and body fat percentage) [27].
### Table 3  POW percentile values by maturity groups

|        | boys               | girls              |        |
|--------|--------------------|--------------------|--------|
|        | early              | average            | late   |
|        | 10                 | 25                 | 50     | 75     | 90     | 10     | 25     | 50     | 75     | 90     | 10     | 25     | 50     | 75     | 90     |
| 1st grade in ES | −5.53              | −0.45              | 4.89   | 11.62  | 20.83  | −7.37  | −3.23  | 1.83   | 7.81   | 15.39  | −7.95  | −3.87  | 0.85   | 5.69   | 11.48  |
| 2nd grade in ES | −6.41              | −1.64              | 4.32   | 11.98  | 23.65  | −8.66  | −4.36  | 0.64   | 7.02   | 15.40  | −8.89  | −5.13  | −0.86  | 4.62   | 10.19  |
| 3rd grade in ES | −6.96              | −1.76              | 5.42   | 15.91  | 27.73  | −9.37  | −5.06  | 0.77   | 8.59   | 19.11  | −9.55  | −6.11  | −0.81  | 5.18   | 10.92  |
| 4th grade in ES | −6.84              | −1.35              | 6.64   | 18.54  | 33.05  | −10.49 | −5.82  | 0.58   | 9.63   | 22.49  | −11.45 | −7.49  | −1.79  | 5.12   | 13.55  |
| 5th grade in ES | −8.72              | −3.31              | 4.28   | 16.40  | 31.75  | −11.66 | −6.51  | 0.27   | 10.96  | 24.51  | −12.98 | −8.33  | −2.27  | 4.98   | 15.96  |
| 6th grade in ES | −12.35             | −7.13              | −0.57  | 8.96   | 23.07  | −12.41 | −7.07  | −0.08  | 10.45  | 25.01  | −13.92 | −9.29  | −2.55  | 5.29   | 18.26  |
| 1st grade in JHS| −12.48             | −6.52              | 0.05   | 10.06  | 25.30  | −14.01 | −8.96  | −2.45  | 6.61   | 20.04  | −14.09 | −9.43  | −2.22  | 6.77   | 19.10  |
| 2nd grade in JHS| −10.88             | −5.26              | 1.09   | 10.93  | 25.70  | −14.97 | −10.49 | −4.39  | 3.08   | 13.49  | −15.96 | −11.47 | −5.63  | 0.73   | 11.50  |
| 3rd grade in JHS| −9.31              | −3.53              | 3.93   | 14.10  | 27.62  | −14.19 | −9.16  | −2.84  | 4.99   | 15.57  | −16.66 | −12.05 | −6.56  | 0.53   | 9.96   |

Abbreviations: ES, elementary school; JHS, junior high school.

**Fig. 3** The proportion of children categorized as overweight/obese in BMI/POW by maturity groups. Abbreviations: BMI, body mass index; POW, percentage of overweight; MIA, maximum increment age.
Whereas this study suggests that early maturing children tend to be mistakenly sorted as overweight/obese, some studies report that early maturity in girls is associated with obesity evaluated by BMI [28-30]. Our results indicate that they could have failed to consider the possibility of overestimation but do not deny the statement itself that early-maturing children tend to be overweight/obese, which would support the earlier-maturing group has a stronger tendency to be overweight/obese, which would support the first statement.

The POW percentiles showed their characteristics, which dropped near the MIA and increased again. The “N” shapes would mean that the POW values become apparently low as the height increases more sharply than the weight in the period around the MIA. This would lead to the underestimation or overestimation of overweight/obesity during this period. This error is especially complex in boys because the sharpness of the “N” shape is different among percentiles.

Similar to BMI, a report showed an association between high POW values in childhood and the risk of adult diseases [35].

It is controversial whether obesity causes early maturity and vice versa, or whether there is another association. A well-known hypothesis is “the critical fat hypothesis” by Frisch, which states that a certain amount of body fat as a storage form of energy is essential for the onset of a girl’s first menstruation [38]. Some studies

Table 4 Numbers and percentages of children categorized as overweight/obese by maturity groups

|        | BMI     |         | POW     |         |
|--------|---------|---------|---------|---------|
|        | early   | average | late    | early   | average | late    |
| boys   |         |         |         |         |         |         |
| 1st grade in ES | 166 (16.92%) | 641 (9.14%) | 37 (3.75%) | 109 (11.12%) | 426 (6.08%) | 26 (2.64%) |
| 2nd grade in ES | 179 (18.25%) | 634 (9.04%) | 36 (3.65%) | 130 (13.25%) | 468 (6.68%) | 27 (2.74%) |
| 3rd grade in ES | 243 (24.77%) | 830 (11.84%) | 49 (4.97%) | 178 (18.14%) | 655 (9.34%) | 43 (4.36%) |
| 4th grade in ES | 283 (28.85%) | 1,018 (14.52%) | 59 (5.98%) | 227 (23.14%) | 856 (12.21%) | 57 (5.78%) |
| 5th grade in ES | 264 (26.94%) | 1,068 (15.23%) | 68 (6.90%) | 192 (19.59%) | 965 (13.76%) | 75 (7.61%) |
| 6th grade in ES | 210 (21.43%) | 1,097 (15.65%) | 85 (8.62%) | 124 (12.65%) | 970 (13.84%) | 87 (8.82%) |
| 1st grade in JHS | 229 (23.34%) | 932 (13.29%) | 90 (9.13%) | 131 (13.35%) | 706 (10.07%) | 96 (9.74%) |
| 2nd grade in JHS | 215 (21.92%) | 658 (9.39%) | 58 (5.88%) | 136 (13.86%) | 446 (6.36%) | 55 (5.58%) |
| 3rd grade in JHS | 227 (23.16%) | 693 (9.88%) | 59 (5.99%) | 166 (16.94%) | 517 (7.39%) | 45 (4.57%) |
| girls   |         |         |         |         |         |         |
| 1st grade in ES | 229 (20.67%) | 705 (8.91%) | 41 (3.70%) | 142 (12.82%) | 426 (5.39%) | 23 (2.08%) |
| 2nd grade in ES | 234 (21.12%) | 590 (7.45%) | 31 (2.80%) | 157 (14.17%) | 403 (5.09%) | 22 (1.98%) |
| 3rd grade in ES | 267 (24.12%) | 724 (9.15%) | 35 (3.16%) | 182 (16.44%) | 612 (7.73%) | 33 (2.98%) |
| 4th grade in ES | 258 (23.29%) | 749 (9.47%) | 30 (2.71%) | 139 (12.55%) | 727 (9.19%) | 38 (3.43%) |
| 5th grade in ES | 273 (24.68%) | 707 (8.93%) | 29 (2.61%) | 128 (11.57%) | 588 (7.43%) | 39 (3.52%) |
| 6th grade in ES | 307 (27.71%) | 642 (8.11%) | 23 (2.08%) | 151 (13.63%) | 370 (4.67%) | 45 (4.06%) |
| 1st grade in JHS | 318 (28.70%) | 775 (9.80%) | 24 (2.16%) | 189 (17.06%) | 422 (5.33%) | 26 (2.34%) |
| 2nd grade in JHS | 284 (25.63%) | 676 (8.54%) | 21 (1.89%) | 206 (18.59%) | 484 (6.12%) | 12 (1.08%) |
| 3rd grade in JHS | 246 (22.20%) | 700 (8.85%) | 27 (2.43%) | 240 (21.66%) | 673 (8.51%) | 27 (2.43%) |

Abbreviations: ES, elementary school; JHS, junior high school
Denominators for percentages were the number of subjects of each sex and maturity whose BMI/POW could be calculated.
support this finding by showing that high BMI affects adrenarche [39, 40] and leptin increases the secretion of gonadotropins [41], while others criticize by showing contradictory evidence in human data [42] or animal experiments [43, 44] or pointing out methodological problems [45]. The results of our study cannot support any of those because our study lacked data on sexual maturity, body fat, or adult diseases.

Originally, BMI should be a “simple” index for evaluating obesity, according to the WHO [6]. For children, however, the distribution differs depending on sex, age, and race. Hence, we need different criteria according to various types of children. The same applies to POW, which requires different calculation formulas instead of different cutoffs. Moreover, this study shows that BMI and POW percentile curves were quite different among the maturity groups, which suggests an overestimation/underestimation of overweight/obesity in early/late-maturing children and those who are around the MIA. Thus, we should consider maturity groups, in addition to the factors mentioned above, to properly evaluate childhood obesity and the risks of developing adult diseases. Simply put, we need to use sex-, age-, race-, and maturity-dependent cut-offs in BMI as well as similar calculation formulas in POW. This is, however, quite difficult because detecting the maturity groups that children belong to is quite difficult when they are growing. Accordingly, evaluating childhood obesity only with height and weight is more difficult and requires more prudence than expected. The same applies to the Rohrer index, which is calculated as weight (kg)/height² (m²)*10 because it also focuses on height and weight balance.

The strengths of our study are as follows: long-term follow-up, a large number of subjects from different areas of Japan, and the use of school check-up data, which includes unbiased subjects. The number of subjects in this study (35,461), is quite large compared to that reported in previous studies showing longitudinal BMI percentile curves, decreasing skewness, and making the data more useful in clinical situations. This is particularly true when compared with studies on the BMI of Japanese children by maturity groups [15, 30]. Furthermore, the BMI percentile curves shown in our study are consistent with those of previous studies [26], which confirms the representativeness of our data. To the best of our knowledge, this is the first study showing the POW percentiles in Japanese children.

However, there were some limitations to our study. First, the age data were inaccurate. Since we used the school grade data, children treated at the same age would have an age difference of up to 364 days, making the MIA and maturity groups inaccurate. However, the same applies when we use accurate age data. It is important to note that BMI cut-off points were inaccurate; hence, we assumed that all children are the average age of the two ages that could exist in the grade. Regarding inaccurate age, we used the sex- and height-specific method, which produces fewer results than that by the other methods [23], to calculate the standard weight. This could have led to an overestimation of obesity.

Second, the period of the data was limited, which could have led to errors in exposure. Due to the of the lack of data on preschool or post-junior high school, the MIA of some students could not be calculated, i.e., the MIA of those who had grown most from the 1st to 2nd yr of elementary school or from the 2nd to 3rd yr of junior high school. Each case accounted for 4.0% (1,434) and 10.0% (3,560) of the total sample, respectively. The former was common in girls (908 vs. 526), while the latter was common in boys (3,276 vs. 284). Moreover, the MIA of those who had grown most in preschool or the post-high school period was inaccurately treated: the MIA of a child who had grown 6cm from the 1st to 2nd yr of junior high school, 5cm from the 2nd to 3rd, and 8 cm in the 1st to 2nd of high school, for instance, was calculated to be approximately 7. These errors can lead to an inappropriate maturity grouping.

Third, our method for maturity grouping was based only on height and not on pubertal changes. However, as mentioned in the Methods section, studies show the association between the timing of peak height velocity and the Tanner stage [20, 21].

Fourth, we used 20% as the cut-off point for POW; a study has reported that it corresponds to the 90th percentile of BMI in average height students. Considering that the BMI in the 90th percentile in our data was larger than the BMI cut-offs we used [13] in both sexes, all ages, and all maturity groups, it would have led to overweight and obesity underestimation in POW. This could explain why “only BMI” children were more than “only POW” children. However, the tendency that those who matured earlier tend to be “only BMI” did not change when the POW cut-off was changed to 10% or 30% (data not shown).

Fifth, we did not have fat mass data, which is well associated with metabolic factors. Further studies with such data are required to confirm whether certain maturity leads to overweight/obesity or overestimation/underestimation of it.

In conclusion, our study described the BMI and POW of Japanese children by maturity group. The percentile curves of both indexes were affected by maturity groups or MIA. BMI could lead to the overestimation of overweight/obesity in early-maturing children and the underestimation in late-maturing children, and POW leads to the inaccurate evaluation of overweight/obesity.
around the MIA; the latter error is more complex in boys. The criteria for childhood obesity are affected by MIA, in addition to age, sex, and race; therefore, evaluating childhood obesity by height and weight has become more complex.

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