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## Original Article

# Postnatal BMI changes in children with different birthweights: A trial study for detecting early predictive factors for pediatric obesity

Yuichi Nakagawa[1, 2], Toshiki Nakanishi[2], Eiichiro Satake[2], Rie Matsushita[2, 3], Hirokazu Saegusa[4], Akira Kubota[5], Hiromune Natsume[6], Yukinobu Shibata[7], and Yasuko Fujisawa[2]

[1]*Department of Internal Medicine and Pediatrics, Shiraume Toyooka Hospital, Shizuoka, Japan*

[2]*Department of Pediatrics, Hamamatsu University School of Medicine, Shizuoka, Japan*

[3]*Department of Pediatrics, Kikugawa General Hospital, Shizuoka, Japan*

[4]*Department of Pediatrics, Enshu General Hospital, Shizuoka, Japan*

[5]*Department of Pediatrics, Chutoen General Medical Center, Shizuoka, Japan*

[6]*Department of Pediatrics, Kosai General Hospital, Shizuoka, Japan*

[7]*Department of Pediatrics, Hamamatsu Red Cross Hospital, Shizuoka, Japan*

**Abstract.** The purpose of this study was to clarify the degree of early postnatal growth by birthweight and detect early predictive factors for pediatric obesity. Body mass index (BMI) and degree of obesity were examined in children in the fourth year of elementary school and second year of junior high school. Their BMI at birth and three years of age were also examined. Based on birthweight, participants were divided into three groups: low (< 2500 g), middle (2500–3500 g), and high (> 3500 g). Furthermore, according to the degree of obesity, they were divided into two groups: obese (20% ≤) and non-obese (20% >). The change of BMI from birth to three years of age (ΔBMI) showed a strong inverse relationship with birthweight and was significantly different among the three birthweight groups (low > middle > high). The ΔBMI and BMI at three years of age were higher in obese than in non-obese children and showed significant positive correlations with the degree of obesity. Early postnatal growth might be determined by birthweight and was higher in obese than in non-obese children. The ΔBMI from birth to three years of age and BMI at age of three years could be predictive factors for pediatric obesity.

**Key words:** BMI, birthweight, pediatric obesity, predictive factors

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Corresponding author: Yuichi Nakagawa, M.D., PhD, Department of Internal Medicine and Pediatrics, Shiraume Toyooka Hospital, 185-19 Shimokanzo, Iwata, Shizuoka 438-0126, Japan
E-mail: ynyuichi@kbd.biglobe.ne.jp



## Introduction

Size at birth and growth during early infancy have been recognized as important indicators of maternal and offspring health and early childhood survival (1, 2). The occurrence of "catch-up" growth following low birthweight and "catch-down" growth following high birthweight is well documented. Ong *et al.* (3) reported that approximately 30% of all newborn infants show a significant degree of rapid postnatal or catch-up growth and 25% of all newborn infants with relatively increased adiposity at birth show slow postnatal or catch-down growth. Catch-up and catch-down growth are believed to be compensatory phenomena.

Some studies have reported that rapid growth following low birthweight is an important cause in developing diseases later in adulthood (cardiovascular risk factors) (4–9). Other studies have reported that children with a high birthweight relative to gestational date are prone to developing insulin resistance later in life (10, 11). However, most patients with cardiovascular risk factors have a normal birthweight. Based on these data, we questioned how growth during the prenatal and postnatal periods was related to the induction of obesity or metabolic syndromes and speculated that the optimal growth during the early postnatal period for different birthweights was extremely important for a healthy life in later years. However, the range of early postnatal growth for different birthweights has not been clarified. Therefore, we aimed to elucidate this range and detect early predictive factors for pediatric obesity by comparing early postnatal body mass index (BMI) changes between obese and non-obese children.

## Participants and Methods

### Participants

We measured the body weight and height of boys and girls in the fourth year of elementary school (n = 1114: 572 boys/542 girls) and second year of junior high school (n = 1407: 730 boys/677 girls) during a school medical examination. We collected data regarding their body weight and height at birth and three years of age from guardians or parents by using questionnaires with their consent. We obtained and examined data from 1001 (515 boys/486 girls) elementary school children and 1222 (625 boys/597 girls) junior high school children in this study.

### Methods

We calculated the BMI at birth, three years of age, and in the fourth year of elementary school or second year of junior high school. We also calculated the changes of BMI from birth to three years of age and degree of obesity (% overweight for standard weight). Based on birthweight, we divided the children into three groups: low (< 2500 g), middle (2500–3500 g), and high (> 3500 g). Furthermore, we divided the children into two groups, obese (20% ≤) and non-obese (20% >), according to the degree of obesity.

We analyzed the relationship between birthweight and the change of BMI from birth to three years of age (ΔBMI) and BMI at three years of age (3yBMI) of each birthweight group. We also compared the ΔBMI and 3yBMI between non-obese and obese children separately for boys in elementary school, girls in elementary school, boys in junior high school, and girls in junior high school. Furthermore, we compared the ΔBMI and 3yBMI between non-obese and obese children according to different birthweights. We analyzed the relationship between the ΔBMI and degree of obesity and between the 3yBMI and degree of obesity.

BMI was calculated according to the following formula: BMI = bodyweight/height$^2$ (kg/m$^2$). The degree of obesity was calculated based on the "Evaluation of Physical Build of Japanese Children" published by the Japanese Society for Pediatric Endocrinology (standard body weight was calculated by sex, age, and height). A child was classified as obese if his or her degree of obesity was over 20%. Informed consent was obtained from parents or guardians. The study protocol was approved by the institutional review board of Hamamatsu University School of Medicine.

### Statistics

Results are expressed as means ± standard deviation. Statistical difference was determined by the two-tailed Student's *t* test. A difference of $p < 0.05$ was considered significant. The correlation

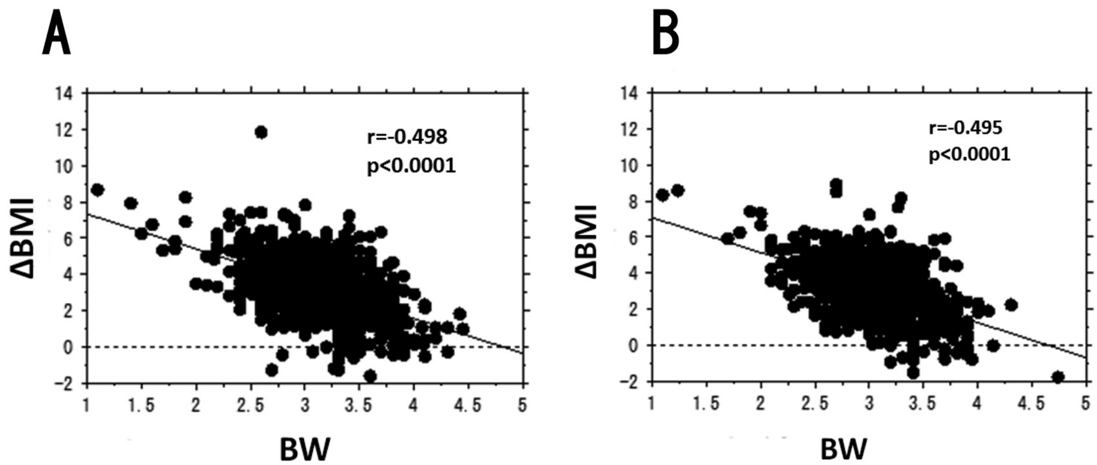


**Fig. 1.** The correlation between birthweight and ΔBMI during the early postnatal period. ΔBMI has a strict inverse correlation with birthweight. It is the change in BMI from birth to 3 yr of age. The data were obtained by combining the ΔBMI of children in elementary school and junior high school. A: Boys (n = 1140), B: girls (n = 1083), BW: birthweight.

coefficient between the ΔBMI and birthweight, between the ΔBMI and degree of obesity, and between the 3yBMI and degree of obesity was obtained using simple regression analysis.

## Results

The ΔBMI from birth to three years of age showed a strong inverse relationship with birthweight (boys: $r = -0.485$, $p < 0.0001$; girls: $r = -0.509$, $p < 0.0001$) (Fig. 1). The ΔBMI and 3yBMI of each birthweight group are shown in Figs. 2 and 3, respectively. The ΔBMI differed markedly among the three birthweight groups. It was the highest in the low-birthweight group and the lowest in the high-birthweight group. The 3yBMI was also different among the three birthweight groups. In contrast to the ΔBMI, the 3yBMI was the lowest in the low-birthweight group and the highest in the high-birthweight group. The obese children (both boys and girls) showed high ΔBMI and 3yBMI compared with the non-obese children both in elementary and junior high school (Figs. 4 and 5). Table 1 shows the ΔBMI and 3yBMI levels in non-obese and obese children by birthweight. The ΔBMI and 3yBMI tended to be higher in obese than in non-obese children, considering birthweight, except for the low- and high-birthweight girls in elementary school and the low-birthweight boys in junior high school. The ΔBMI and 3yBMI showed significant positive correlations with the degree of obesity in boys and girls in elementary school and junior high school (Figs. 6 and 7).

## Discussion

This study showed that the degree of BMI changes during the early postnatal period varied according to birthweight and the ΔBMI and 3yBMI could be predictive factors for pediatric obesity. Being overweight contributes to health problems even among children, including psychosocial consequences (12) and cardiovascular risk factors, such as hypertension, hyperlipidemia, or type 2 diabetes (13, 14). Furthermore, overweight children are more likely to become obese as adults (15, 16). Therefore, early prevention of obesity is very important.

Several authors (17–24) have proposed that there are critical periods during childhood that influence the development of obesity, including

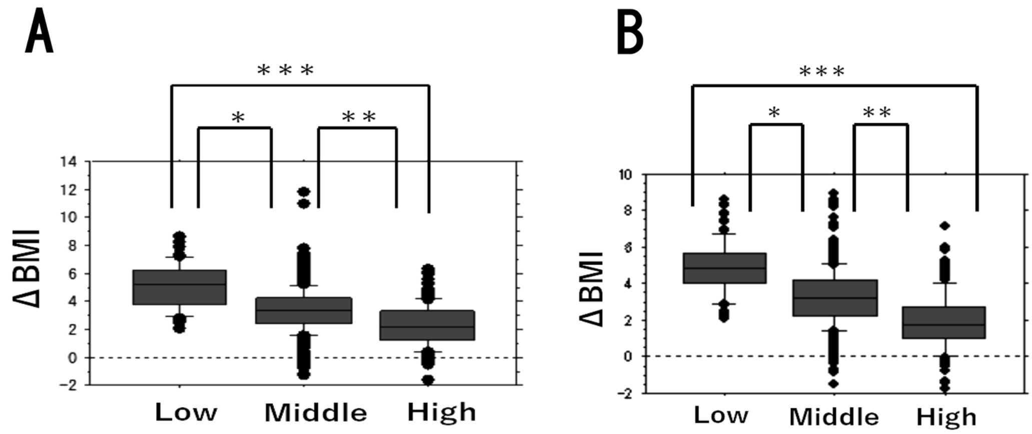


**Fig. 2.** ΔBMI for different birthweight groups. Low indicates birthweight < 2500 g. Middle indicates birthweight between 2500–3500 g. High indicates birthweight > 3500 g. ΔBMI is the change in BMI from birth to 3 yr of age. * significant difference ($p < 0.0001$) between low- and middle-birthweight groups. ** significant difference ($p < 0.0001$) between middle- and high-birthweight groups. *** significant difference ($p < 0.0001$) between low- and high-birthweight groups. The data were obtained by combining the data of children in elementary school and junior high school. A: Boys, low (n = 49), middle (n = 872), and high (n = 219). B: Girls, low (n = 63), middle (n = 867), and high (n = 153).

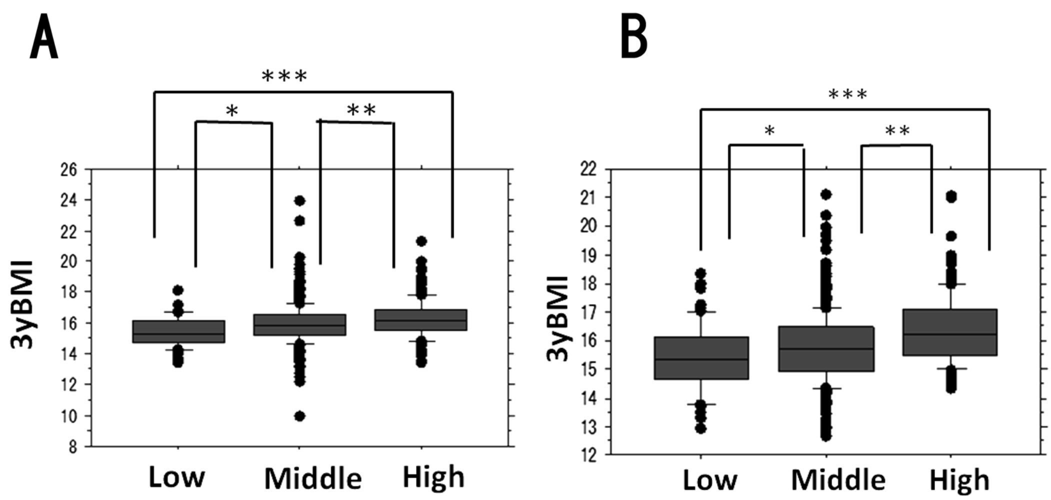


**Fig. 3.** 3yBMI for different birthweight groups. Low indicates birthweight < 2500 g. Middle indicates birthweight between 2500–3500 g. High indicates birthweight > 3500 g. 3yBMI is the BMI at 3 yr of age. * significant difference ($p < 0.05$) between low- and middle-birthweight groups. ** significant difference ($p < 0.0001$) between middle- and high-birthweight groups. *** significant difference ($p < 0.0001$) between low- and high-birthweight groups. The data were obtained by combining the data of children in elementary school and junior high school. A: Boys, low (n = 49), middle (n = 872), and high (n = 219). B: Girls, low (n = 63), middle (n = 867), and high (n = 153).

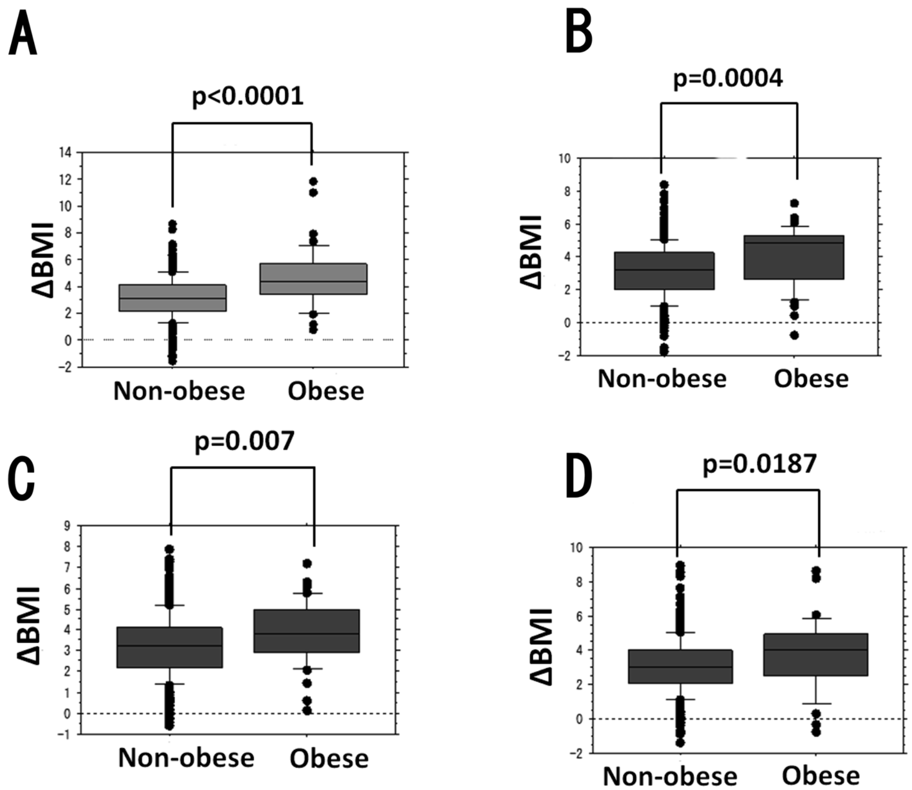


**Fig. 4.** The comparison of ΔBMI between non-obese and obese children. ΔBMI was significantly higher in obese children than in non-obese children in all four groups (boys in elementary school, girls in elementary school, boys in junior high school, and girls in junior high school). It is the change in BMI from birth to 3 yr of age. A: Boys in elementary school: non-obese (n = 466) and obese (n = 49). B: Girls in elementary school: non-obese (n = 444) and obese (n = 42). C: Boys in junior high school: non-obese (n = 583) and obese (n = 42). D: Girls in junior high school: non-obese (n = 564) and obese (n = 33).

gestation and early infancy. The accelerator hypothesis is well known in epidemiological studies of diabetes mellitus (25). Enhanced weight gain in infancy is associated with an increased risk of diabetes in childhood. Wadsworth *et al.* reported that early adiposity rebound is associated with an increased incidence of type 2 diabetes (26). However, it is unknown how the degree of catch-up growth induces obesity or diabetes. Furthermore, the period of catch-up growth critical for the induction of obesity or diabetes is controversial. Several studies have suggested that the critical period is within the first 4–24 months of life (17–20), while others report it as within the first 4–6 years (21–24).

Karaolis-Danckert *et al.* (27) have published data demonstrating that rapid growth during infancy and early childhood results in increased BMI and body fat percentage throughout childhood and an increased risk of being overweight at seven years of age, even among children of birthweight appropriate for their gestational age. Parsons *et al.* (28) also reported that the risk of adult obesity was higher among participants who had grown to a greater proportion of their eventual adult height by age of seven years. Barker *et al.* (29) reported that

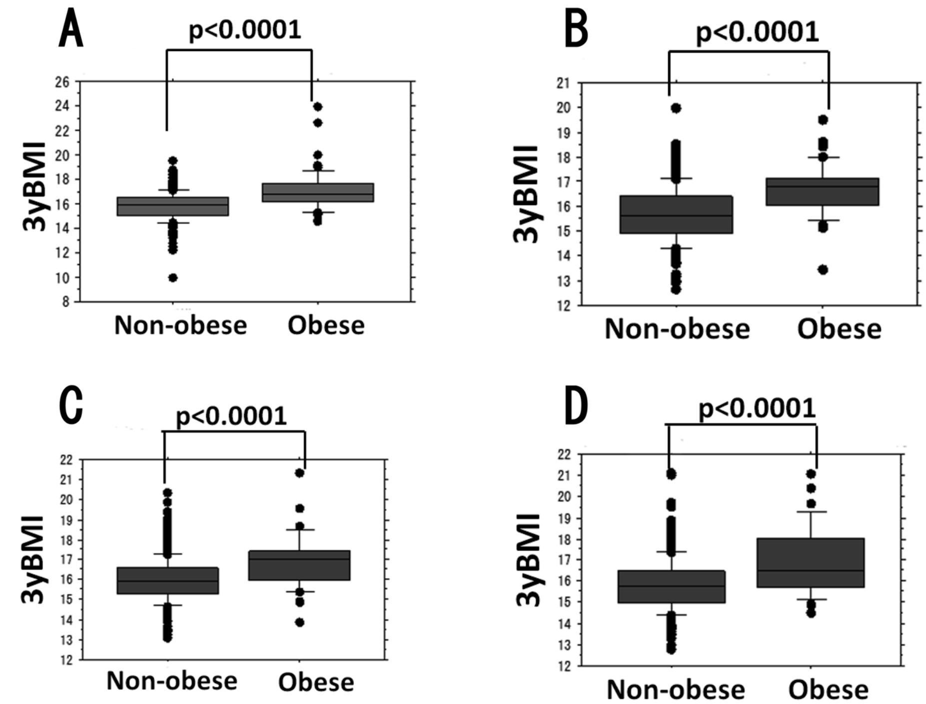


**Fig. 5.** The comparison of 3yBMI between non-obese and obese children. 3yBMI was significantly higher in obese than in non-obese children in all four groups (boys in elementary school, girls in elementary school, boys in junior high school, and girls in junior high school). It is the BMI at 3 yr of age. A: Boys in elementary school: non-obese (n = 466) and obese (n = 49). B: Girls in elementary school: non-obese (n = 444) and obese (n = 42). C: Boys in junior high school: non-obese (n = 583) and obese (n = 42). D: Girls in junior high school: non-obese (n = 564) and obese (n = 33).

low BMI at two years of age and increased BMI from two to 11 yr of age were associated with an increase in fasting insulin concentrations. These data are mainly for low-birthweight infants. High birthweight is also a risk factor for obesity or diabetes (10, 11); however, most individuals who develop diabetes have normal birthweights.

Gluckman *et al.* (30–33) have hypothesized that greater disease risk is created by a mismatch between the environment predicted during the plastic phase of development and the actual environment experienced in the postplastic phase; this might contribute to the current epidemics of type 2 diabetes and obesity. Ong *et al.* (34) introduced the idea that nutritional strategies that promote catch-up growth should include monitoring of weight-for-length and adiposity and the concept of "healthy catch-up growth" should be the goal of future research.

From these ideas, we hypothesized that there is optimal growth for different birthweights and the risk of developing a metabolic syndrome is increased when the increase in early postnatal BMI is over the optimal growth for a particular birthweight. To test our hypothesis, we analyzed early postnatal BMI changes by different birthweights and compared them between non-obese and obese children.

The ΔBMI showed a markedly inverse correlation with birthweight. It was significantly different among the three birthweight groups. It was the highest in the low-birthweight group

**Table 1** Comparison of ΔBMI and 3yBMI between non-obese and obese children among different birthweight groups

| | | | ΔBMI | 3yBMI |
|---|---|---|---|---|
| BE | L | N (20) | 5.04 ± 1.87 | 15.3 ± 1.0 * |
| | | O (3) | 7.15 ± 0.81 | 16.8 ± 1.2 |
| | M | N (366) | 3.19 ± 1.42 *** | 15.7 ± 1.1 *** |
| | | O (37) | 4.58 ± 2.16 | 16.9 ± 1.8 |
| | H | N (80) | 2.06 ± 1.43 ** | 16.1 ± 1.1 *** |
| | | O (9) | 3.58 ± 2.00 | 17.8 ± 1.2 |
| GE | L | N (29) | 4.91 ± 1.44 # | 15.5 ± 1.3 # |
| | | O (0) | 0 | 0 |
| | M | N (364) | 3.18 ± 1.41 *** | 15.6 ± 1.1*** |
| | | O (32) | 4.78 ± 1.27 | 16.7 ± 1.1 |
| | H | N (51) | 1.65 ± 1.49 | 16.2 ± 1.0 |
| | | O (10) | 1.62 ± 1.30 | 16.7 ± 1.0 |
| BJ | L | N (24) | 4.99 ± 1.32 | 15.5 ± 1.0 |
| | | O (2) | 4.57 ± 1.41 | 15.4 ± 0.7 |
| | M | N (438) | 3.36 ± 1.36 * | 15.9 ± 1.0 *** |
| | | O (31) | 3.88 ± 1.46 | 16.7 ± 1.2 |
| | H | N (121) | 2.26 ± 1.42 * | 16.1 ± 1.1 ** |
| | | O (9) | 3.52 ± 1.73 | 17.8 ± 1.7 |
| GJ | L | N (33) | 4.72 ± 1.33 # | 15.2 ± 1.1 # |
| | | O (1) | 8.61 | 17.8 |
| | M | N (448) | 3.12 ± 1.41 ** | 15.7 ± 1.1 *** |
| | | O (23) | 3.99 ± 1.68 | 16.7 ± 1.5 |
| | H | N (83) | 2.00 ± 1.45 | 16.4 ± 1.2 ** |
| | | O (9) | 2.44 ± 2.33 | 17.6 ± 2.1 |

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.0001$, # not done. BE: boys in elementary school, GE: girls in elementary school, BJ: boys in junior high school, GJ: girls in junior high school, L: low-birthweight group, M: middle-birthweight group, H: high-birthweight group, N: non-obese, O: obese, 3yBMI: BMI at 3 yr of age, ΔBMI: the change of BMI from birth to 3 yr of age. Numbers in parentheses indicate the number of children.

and the lowest in the high-birthweight group. These results suggest that the early postnatal period is the recovery phase for growth, which is deviated during the fetal period, and the catch-up growth in low-birthweight children and catch-down growth in high-birthweight children are the physiological events for the recovery of deviated growth during the fetal period.

The ΔBMI and 3yBMI of obese children were higher compared with those of non-obese children. Also, they showed markedly positive correlations with the degree of obesity. This suggests that obesity is induced when the increase in early postnatal BMI is over the optimal range and the degree of early postnatal growth is related to the severity of obesity.

We also analyzed the ΔBMI and 3yBMI between non-obese and obese children according to birthweight because they varied by birthweight. They tended to be higher in obese children than in non-obese children by birthweight. However, there was no further significant difference in the ΔBMI and 3yBMI between non-obese and obese children in consideration of birthweight.

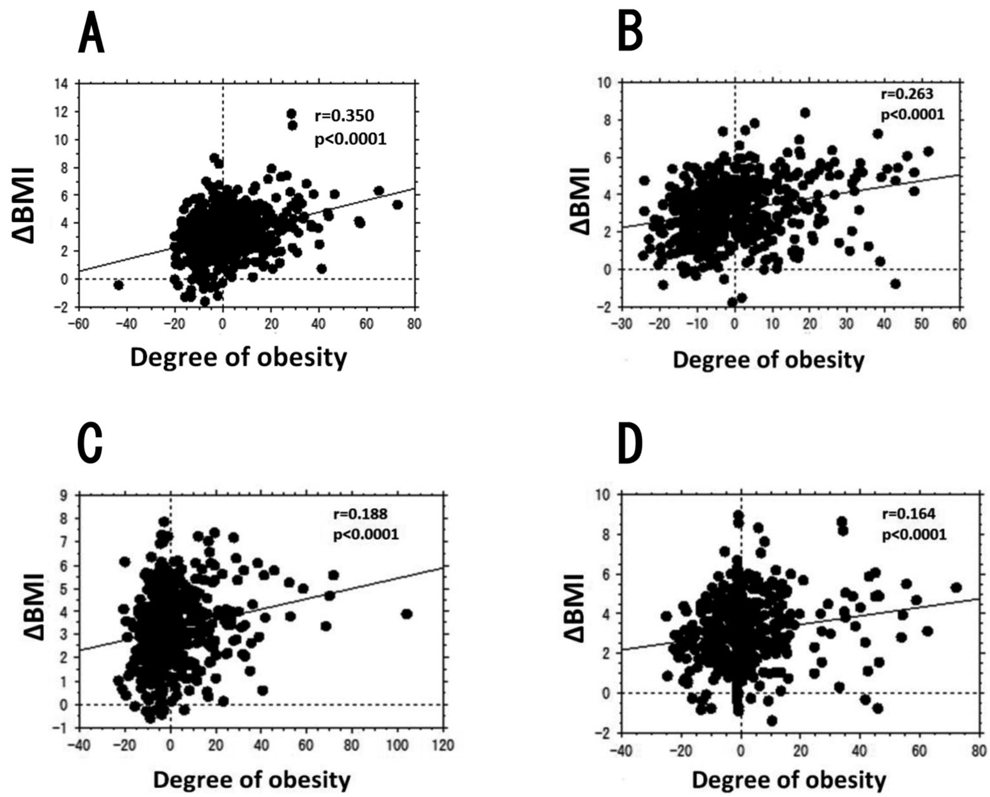


**Fig. 6.** The correlation between ΔBMI and the degree of obesity. ΔBMI was significantly positively correlated with the degree of obesity in all four groups (boys in elementary school, girls in elementary school, boys in junior high school, and girls in junior high school). It is the change in BMI from birth to 3 yr of age. A: Boys in elementary school (n = 515), B: girls in elementary school (n = 486), C: boys in junior high school (n = 625), and D: girls in junior high school (n = 597).

In this study, we had a small number of children. Therefore, we speculate that a further significant difference would occur if we increased our sample size. Further studies are needed to clarify the relationships between early postnatal growth, obesity induction, and birthweight.

Adair reported that early postnatal growth patterns differed according to relative weight at birth and relatively thin infants at birth had larger increases in BMI during the first six postnatal months in the Philippines (35). Kain *et al.* compared BMI growth characteristics of normal, overweight, and obese children from zero to five years of age. They reported that BMI Z differences between normal and obese children were significant from birth, similar to our results (36), and the differences were the greatest between 6–12 and 36–52 mo.

In this study, we could not obtain data before three years of age, gestational age, number of births, or mode of delivery. The addition of these data may have produced more interesting results. Further studies are needed to investigate these factors.

In conclusion, we demonstrated that early postnatal growth differs by birthweight and the growth range differs between obese and non-obese children. Analysis of early postnatal growth by birthweight might be useful to predict and prevent pediatric obesity. This study

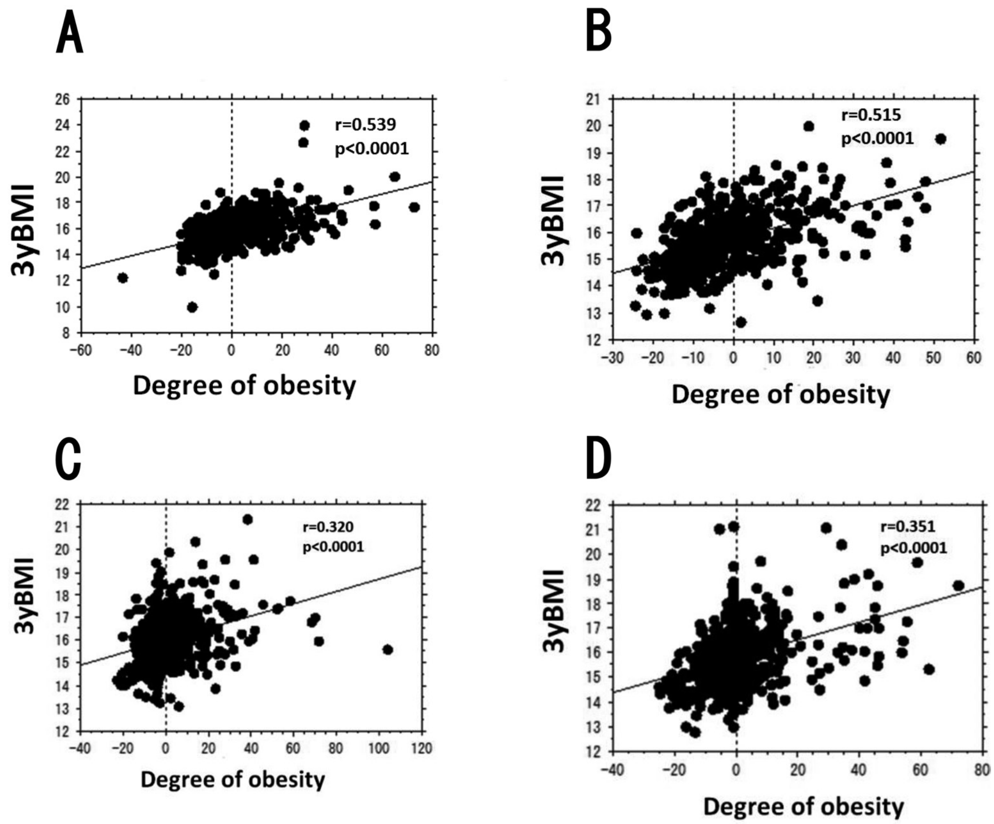


**Fig. 7.** The correlation between 3yBMI and the degree of obesity. 3yBMI was significantly positively correlated with the degree of obesity in all four groups (boys in elementary school, girls in elementary school, boys in junior high school, and girls in junior high school). It is the BMI at 3 yr of age. A: Boys in elementary school (n = 515), B: girls in elementary school (n = 486), C: boys in junior high school (n = 625), and D: girls in junior high school (n = 597).

suggests that the growth chart by birthweight is necessary.

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