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Original Article

Changes in height standard deviation scores during early life are affected by nutrition

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Abstract ***Background***: Large changes in height standard deviation score (SDS) have been reported from birth to 3 years of age. We analyzed how early these changes start and whether they are affected by nutrition.

Methods: The longitudinal growth of 1,849 children born between March 1 2007 and August 31 2007 or between March 1, 2009 and August 31 2009 with five records from birth to 3 years of age was analyzed.

Results: The height SDS at birth was positively correlated with body mass index (BMI) SDS at birth ($r = 0.224$, $P < 0.0001$). The height SDS at birth decreased among children with a positive height SDS and increased among children with a negative height SDS. The changes occurred immediately after birth and became more modest as children aged. Regarding the change in the height SDS from birth to 3 years of age, 33.4% of children increased more than 0.5 SDs, 39.8% of children decreased more than 0.5 SDs, and 34.4% of children remained within ±0.5 SDs. The change in height SDS displayed a strong positive correlation with the change in weight during the four periods. From birth till 3 months, from 3 months till 6 months, from 6 months till 1.5 years, and from 1.5 years till 3 years.

Conclusions: The significant positive correlation between height SDS and BMI SDS suggests an effect of children's nutrition status *in utero*. The height SDS change started immediately after birth and the change was largest from birth to 3 months. A positive correlation between changes in height SDS and weight suggest that growth during early childhood depends on nutritional status.

Key words change in height SDS, DOHaD hypothesis, early childhood, infancy, nutrition.

In 1989, Karlberg mathematically analyzed the longitudinal growth data of 212 healthy children and developed the Infancy-Childhood-Puberty (ICP) model, in which childhood growth status was divided into infancy, childhood, and puberty.[1] He suggested that nutrition, growth hormones, and sex steroid hormones are important factors in each state, respectively.

In our previous study[2] examining the longitudinal growth data of children in Akita Prefecture, Japan, the percentage of children whose change in height standard deviation score (SDS) was greater than 0.5 standard deviations (SDs) from birth to 3 years of age was 74.2%, and changes in the height SDS among children with a positive height SDS tended to exhibit decreased changes, while those among children with a negative height SDS tended to exhibit increased changes. Since growth failure during infancy is reported to be affected by undernutrition,[3] nutrition is suggested to be important for growth during infancy.

A study was undertaken to investigate how the Great East Japan Earthquake affected the health of preschool children in the affected areas of the Tohoku Region. At the same time, data from unaffected areas in the Tohoku Region were collected as a control.[4] Having obtained significant growth data from typical children in unaffected areas from birth to childhood, apart from the main study, we analyzed how early the

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changes in height SDS began and whether these changes were affected by nutrition during infancy and early childhood in typical children.

Methods

The study group conducted a health examination survey of early childhood physical growth of children in nursery schools in the Tohoku areas affected by the Great East Japan Earthquake[4] and in other Tohoku areas that were not directly affected by the disaster. We used the longitudinal growth data of preschool children from Aomori, Akita, and Yamagata Prefectures, which were not directly affected by the disaster, in the present analyses. Since the growth of the children in affected area might be influenced by the disaster, we wanted to analyze the growth of typical children. Invitation letters to participate in the survey were distributed to 965 authorized nursery schools; 238 (25%) nursery schools from these three prefectures participated.[4] Among the 2,250 children who were born between March 1 2007 and August 31 2007, or those who were born between March 1 2009 and August 31 2009, we evaluated 1,849 children (905 boys and 944 girls) with complete growth records available at the following five time points: (i) at birth; (ii) during early infancy when children were aged 3 to 4 months (3 months); (iii) during late infancy when children were aged 6–10 months (6 months); (iv) at age of 1.5 years (1.5 years); and (v) over the age of 3 years and below the age of 4 years (3 years). In total, 401 children were excluded because of a lack of records. As approximately 42 100 children were born in 2007 and 2009 in these three prefectures, the subjects represented approximately 4.4% of all childbirths.

From birth to 1–2 years of age the body is usually measured in the supine position and in the standing position after 1 or 1.5 years. Measurement in the supine position is designated as "length" and measurement in the standing position is designated as "height". However, in this study both measurements are defined as "height" to avoid the use of complicated terminology.

When we evaluated the transitional change in the median height SDS at birth, at age 3 months, age 6 months, and age 1.5 years, we divided the participants into the following eight SD groups: (i) less than −3.5(<−3.5); (ii) greater than or equal to −3.5 and less than −2.5 (≥−3.5 to <−2.5); (iii) greater than or equal to −2.5 and less than −1.5 (≥−2.5 to <−1.5); (iv) greater than or equal to −1.5 and less than −0.5 (≥−1.5 to <−0.5); (v) greater than or equal to −0.5 SDs and less than or equal to +0.5 (≥−0.5 to ≤+0.5); (vi) greater than +0.5 and less than or equal to +1.5 (>+0.5 < to ≤+1.5); (vii) greater than +1.5 and less than or equal to +2.5 (>+1.5 to ≤+2.5); and (viii) greater than +2.5 and less than or equal to +3.5 (>+2.5 to ≤+3.5). When we evaluated the change in the height SDS from birth to age 3 years, from birth to age 3 months, from age 6 months to age 1.5 years, and from age 1.5 years to age 3 years, we divided the change in the height SDS into the following five SD groups: (i) greater than +1.5 (>+1.5); (ii) greater than +0.5 and less than or equal to +1.5 (>+0.5 to ≤+1.5); (iii) greater than −0.5 and less than or equal to +0.5 (>−0.5 to ≤+0.5); (iv) greater than −1.5 and less than or equal to −0.5 (>−1.5 to ≤−0.5); and (v) less than or equal to −1.5 (≤−1.5).

We employed the standardized value of the year 2000 to calculate the height SDS and body mass index (BMI) SDS.[5] Significant differences in the height SDS between two time points among the height SD groups were evaluated by paired sign tests. The strength of a relationship was measured by Pearson's correlation coefficient and the significance was tested by Fisher's z transformation. $P < 0.05$ was defined as significant.

The study protocol was approved by the institutional review board of Tohoku University (No. 2012-1-125).[4]

Results

The clinical characteristics of the 1,849 subjects at birth and at age 3 years are shown in Table 1. There were no significant differences between boys and girls in clinical characteristics at birth. The percentages of premature labor were 6.3% and 4.3% and percentages of low birthweight were 7.3% and 9.0% in boys and girls, respectively.

Compared to national data from the 2000 annual report, the mean birthweight was approximately the same as the national mean value. Although the mean height SDS was slightly larger than the national mean value, the mean BMI SDS was almost the same. A positive correlation was observed between the height SDS and BMI SDS at birth ($r = 0.224$, $P < 0.0001$) (Fig. 1).

Children were divided into groups according to their height SDS at birth, and at age 3 months, 6 months and 1.5 years, and the median eight SDSs of the groups were followed-up to age 3 years. Figure 2 presents the number of children in the eight groups stratified by height SDS at birth and the change in their median height SDS from birth to age 3 years. The

Table 1 Clinical characteristics at birth and at age 3 years

Characteristics	Mean ± SD	Min. – Max.
Gestation (weeks)	38.9 ± 1.5	25 – 42
At birth		
Weight (g)	3,033 ± 424	582 – 4,940
Height (cm)	49.1 ± 2.3	29.2 – 55.1
Height SDS (SD)	0.19 ± 1.08	−9.2 – 3.17
BMI (kg/m^2)	12.5 ± 1.3	6.8 – 26.0
BMI SDS (SD)	−0.06 ± 1.10	−5.6 – 11.10
At 3 years		
Age (years)	3.5 ± 0.1	3.0 – 4.1
Weight (kg)	14.8 ± 1.7	10.0 – 23.7
Height (cm)	96.5 ± 3.6	85.1 – 111.0
Height SDS (SD)	0.06 ± 0.96	−3.3 – 4.22
BMI (kg/m^2)	15.8 ± 1.2	12.6 – 23.6
BMI SDS (SD)	0.33 ± 0.91	−2.6 – 4.36

BMI, body mass index; SD, standard deviation; SDS, standard deviation score.

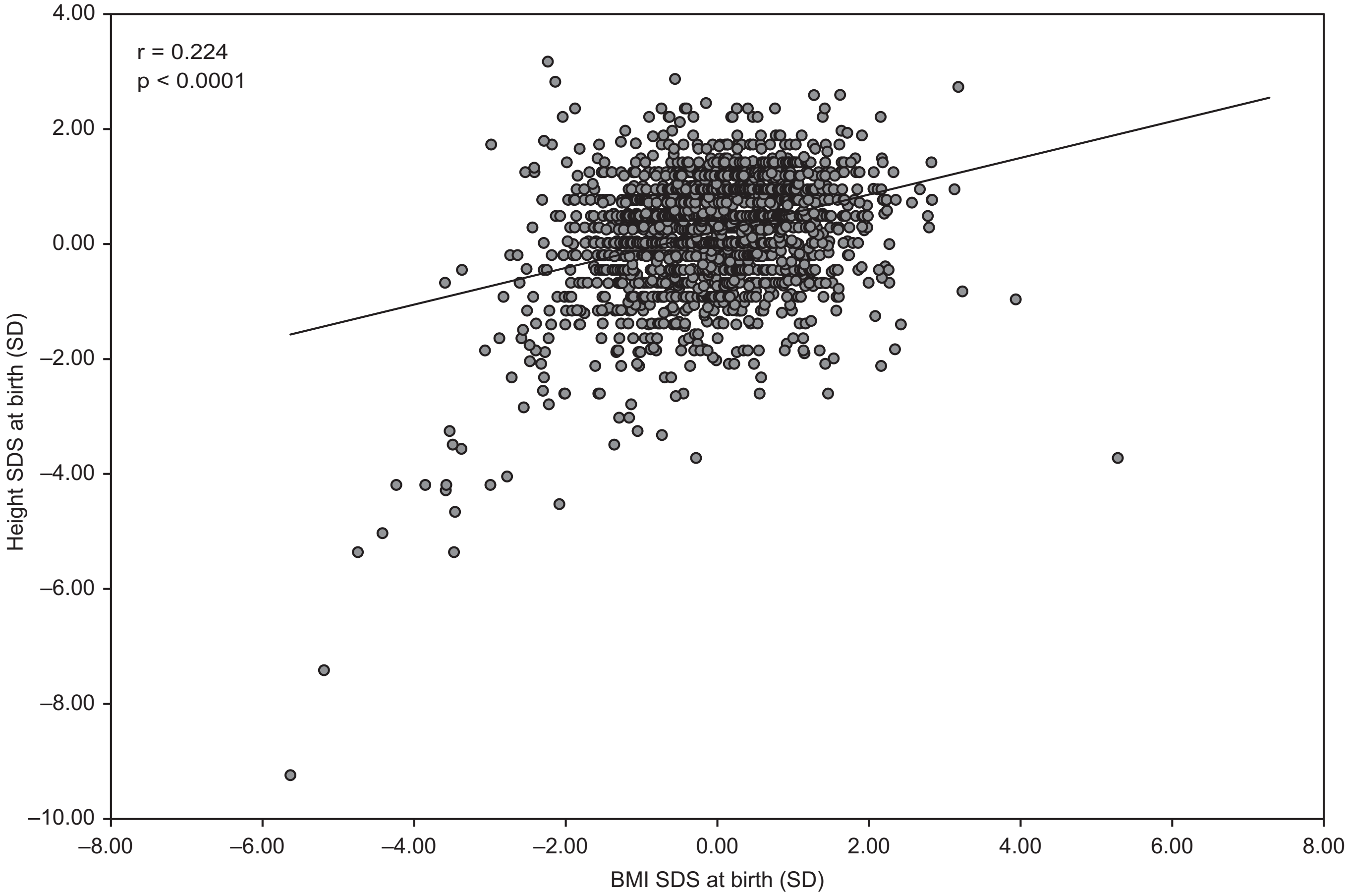

Figure 1 A significant positive correlation between the height standard deviation score (SDS) and body mass index (BMI) SDS at birth.

changes in the height SDS from birth to age 3 months were significant for all height SDSs in the at birth groups, except one (the >+2.5 SDs to ≤+3.5 SDs) group with a lower number. Therefore, the changes in the height SDS started from birth. There were significant differences in the height SDS between birth and age 3 years among all height SDSs in the at birth groups. The median height SDS of groups with positive scores at birth decreased, whereas the median height SDS of groups with negative scores at birth increased. The change was largest in the groups at the high and low ends. The degree of change over time was largest from birth to age 3 years and gradually changed after age 3 months. Groups with a positive median height SDS at birth remained positive at 3 years, although the scores decreased. Groups with a negative median height SDS also remained negative at age 3 years. A positive association was found between the height SDS at birth and the height SDS at age 3 years ($r = 0.287$, $P < 0.0001$) (refer to Supplemental Figures S1, S2, and S3).

Figure 3 presents the distribution of the height SDS at age 3 years by groups based on the height SDS at birth. The height SDS distribution in groups with a positive median height SDS at birth decreased, while the height SDS in groups with a negative median height SDS at birth increased at age 3 years. The percentage of children whose height SDS remained unchanged from birth to age 3 years was 35.0% in total.

Figure 4 presents the proportion of children based on the change in the height SDS from birth to age 3 years. The percentages of children whose change in height SDS was within ±0.5 SDs was 34.4%, of those whose change in height SDS was greater than +0.5 SDs was 25.7%, and those whose change in height SDS was greater than −0.5 SD was 39.8%.

The proportions of children showing changes in their height SDS from birth to age 3 months, from 3 months to 6 months, from 6 months to 1.5 years, and from age 1.5 years to age 3 years are presented in Figure 5. Children exhibited the largest changes from birth to age 3 months, as follows: 38.8% of children remained unchanged, 32.2% of children grew to greater than 0.5 SDs and 29.0% of children demonstrated a decrease in their height SDS of greater than 0.5 SDs. The proportion of children whose height SDS remained unchanged increased as the children aged, and the height SDS of approximately 60% of children remained unchanged after age 6 months. After age 6 months, the proportion of children with a change in their height SDS greater than +0.5 SDs was 20.0%, while the proportion less than −0.5 SDs was 16.2%.

Among the clinical factors at birth, the height SDS showed a significant negative correlation with the change in the height

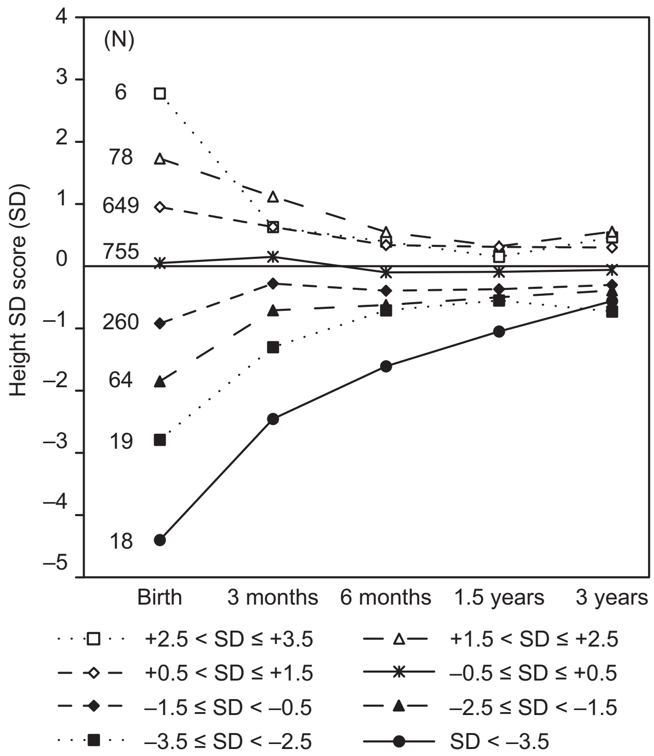

Figure 2 Change in the median height standard deviation (SD) score over time from birth to age 3 years by height SD score group at birth. There were significant differences in the height SD score between at birth and at age 3 years among all height SD scores at birth groups (the ≥–0.5 to ≤+0.5 SDs group, $P < 0.01$; the >+2.5 SDs to ≤+3.5 SDs group, $P < 0.05$; other groups, $P < 0.0001$). The changes in height SD scores from birth to age 3 months were significant in all height SD scores at birth groups (the –≥–0.5 to ≤+0.5 SDs group, $P < 0.05$; the other groups, $P < 0.0001$) except one (the >+2.5 SDs to ≤+3.5 SDs group with only six children).

SDS from birth to age 3 months ($r = -0.536$, $P < 0.0001$) and from birth to age 3 years ($r = -0.658$, $P < 0.0001$). Additionally, the change in the height SDS from birth to age 3 years showed a strong positive correlation with the change in weight from birth to age 3 years ($r = 0.500$, $P < 0.0001$). The correlations between the change in the height SDS and the change in the weight during the four periods (from birth to age 3 months, from age 3 months to age 6 months, from age 6 months to age 1.5 years, and from age 1.5 years to age 3 years) were also significant (r = 0.309, 0.237, 0.255, and 0.377, respectively; $P < 0.0001$).

Discussion

This study confirmed a previous study[2] showing the largest changes in height SDS from birth to age 3 years during infancy, childhood, and puberty and the direction of the change toward the mean height SDS. Moreover, this study demonstrated that the largest change in height SDS was observed from birth to age 3 months. Therefore, it was demonstrated that the change in height SDS in children started immediately after birth. Since the value of the height SD is smallest and height growth velocity is largest in early life, it is possible that a small change in height will exaggerate the change in the height SDS. However, an important aspect to consider is that the directionality of the change in height SDS continues until the child reaches age 3 years.

Regarding the BMI SDS, in the group categorized by height SDS at birth, we observed a significant positive correlation between height SDS at birth and BMI SDS: groups with a lower height SDS at birth had a lower BMI SDS, while those with a higher height SDS at birth had a higher BMI SDS. Based on this finding, it can be concluded that children's nutritional status *in utero* is reflected in the height SDS at birth. The so-called catch-up among groups with short height SDS at birth and low BMI SDS at birth may be explained by the Developmental Origin of Health and Disease (DOHaD) hypothesis, advocated by Gluckman et al.,[6,7,8] that is, fetuses exposed to low nutrition react irreversibly in terms of metabolic and endocrine functions to adjust themselves to the fetal environment (fetal programming). Since they tend to have a relative excess of nutrients after birth, they show catch-up growth and increase their height SDS. Similarly, the "catch-down" phenomenon among groups with a high height SDS and a high BMI SDS at birth might be explained by relative undernutrition after birth, resulting from fetal programming to react irreversibly to an excess of nutrients *in utero*. Regarding the change in the height SDS observed in groups stratified by the height SDS at birth, the largest change was observed from birth to age 3 months, which contributed to approximately half of the changes during this time. We assumed that the effect of fetal programming occurred immediately after birth. Since these changes continued up to age 3 years, nutrition status *in utero* appears to affect the degree of catch-up or catch-down up to at least 3 years. Our previous study from children in Akita Prefecture[2] confirmed that the mean height SDS of groups stratified at age 3 years did not change significantly after 3 years of age up to the onset of puberty, therefore, children's nutrition status *in utero* may exert an effect up to age 3 years.

Although children with a taller height at birth tended to catch-down and those with a short height at birth tended to catch-up, children with taller heights at birth still had taller heights at age 3 years than those with short heights at birth.

The change in the height SDS showed a significant positive correlation with the change in weight at any time point, and children with a large change in weight had a large change in height SDS. A positive correlation between the change in the height SDS and the change in weight suggested that height growth during early childhood depends on nutritional status, as reported previously.[3]

As shown in Figure 3, the groups, except for those with the highest and lowest height SDSs at birth, consisted of children with (i) no change in their height SDS from birth, (ii) those with catch-up, and (iii) those with catch-down. Children in groups with lower height SDSs had a high percentage of

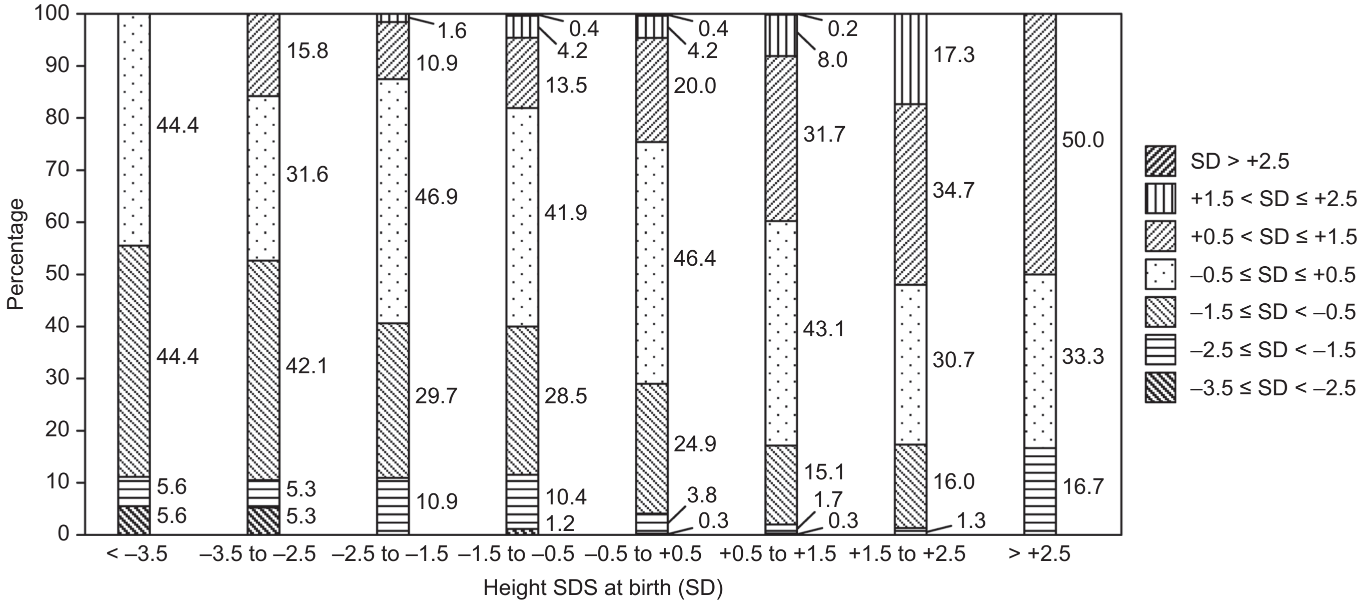

Figure 3 Distribution of the height standard deviation score (SDS) at age 3 years by the height SDS in the at birth groups. Approximately 90% of children whose height SDS at birth was less than −2.5 SDs caught up by −1.5 SDs or more at age 3 years. In contrast, the height SDS of 80% of children whose height SDS at birth was greater than +1.5 SDs, but less than or equal to +2.5 SDs, was +1.5 SDs or less at age 3 years. The percentages of children whose height SDS group remained unchanged from birth to age 3 years were 5.3% for the ≥−3.5 to <−2.5 SDs group, 10.9% for the ≥−2.5 to <−1.5 SDs group, 28.5% for the ≥−1.5 to <−0.5 SDs group, 46.4% for the ≥−0.5 to ≤+0.5 SDs group, 31.7% for the >+0.5 to ≤+1.5 SDs group and 17.3% for the >+1.5 to ≤+2.5 SDs group. Among the 55 children with a height SDS of −2.0 or less at birth, three children (5.5%) still had a height SDS of −2.0 or less at age 3 years, and among the 27 children with a height SDS of +2.0 or more at birth, three children (11.1%) still had a height SDS of +2.0 or more at age 3 years.

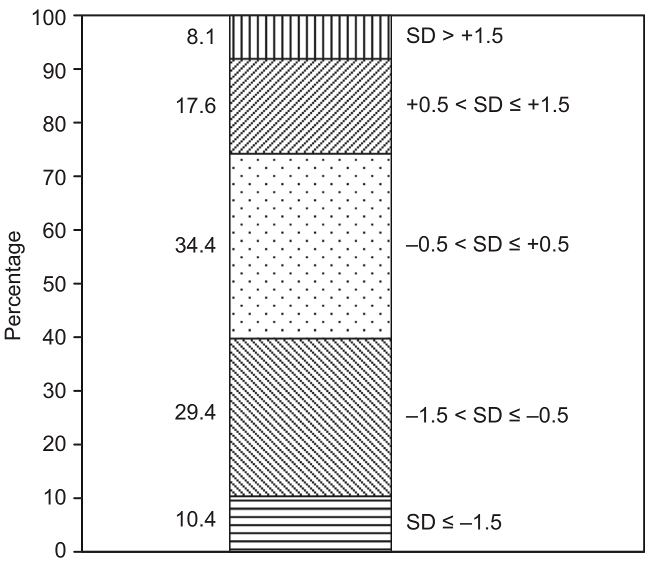

Figure 4 Proportion of children by the change in the height standard deviation (SD) score from at birth to age 3 years.

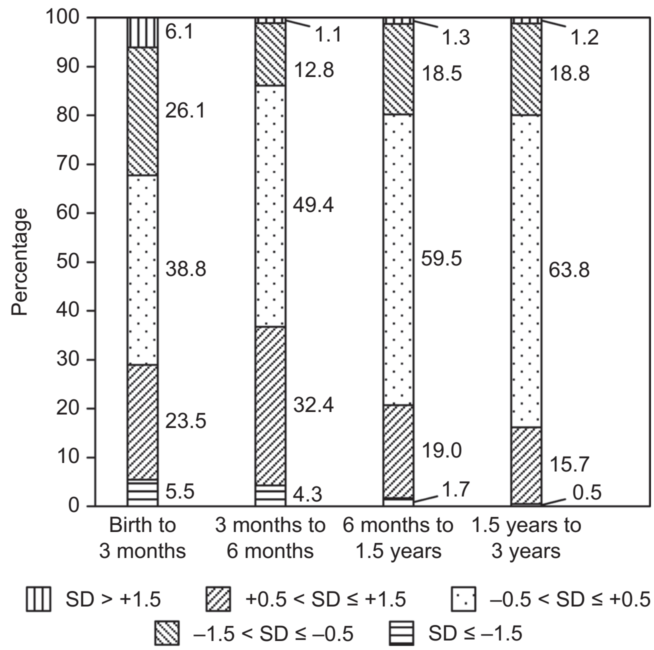

Figure 5 Distribution of children by the change in the height standard deviation (SD) score at each period.

catch-up, while children in groups with taller height SDSs had a high percentage of catch-down. In terms of the percentage of children with no change in their height SDSs from birth to age 3 years, children whose height SDS groups at birth showed nearly 0 SD were high while children whose height SDS groups at birth were far from 0 SD were low according to the SD degree.

The limitation of this study is the lack of background data that could affect postnatal growth, such as the heights of the parents, conditions of the mother during pregnancy, and feeding methods. It is well-known that a small baby tends to be born to a short mother. Complicating disease in pregnant mothers will affect the size of newborns. Bottle-fed newborns tend to grow better than breastfed infants. Therefore, there might be some bias selection by these factors. However, the large number of subjects would overcome the small differences derived from these factors.

As suggested by the ICP model,[1] this study also demonstrated the importance of nutrition for growth during early childhood. However, it is exceedingly difficult for mothers to feed infants who do not drink milk or eat weaning foods. The presence of catch-down growth in the height SDS in large newborns in a normal situation is useful information for mothers and doctors involved in child health survey programs.

Conclusions

Height SDS at birth showed a positive correlation with BMI SDS, which might influence a child's nutrition status *in utero*.

Changes in the height SDS from birth to age 3 years occurred immediately after birth. The height SDS of children with an initially positive height SDS decreased, whereas the height SDS of children with an initially negative height SDS increased. These changes were largest from birth to age 3 months and became more modest as children grew older. The positive correlation between the change in the height SDS and change in weight suggest that height growth during early childhood depends on nutritional status.

Acknowledgments

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Disclosure

The authors declare no conflict of interest.

Author contribution

T.T. conceptualized the study; T.T., N.K., S.Y., A.O., T.I., H.Y., Z.Y., S.T., H.M., M.I, M.K., S.C., M.H., S.Kuri., and S.Kure designed the study. T.T. conducted the study and data analysis; N.K., S.Y., and H.M. supported the study and gave intellectual input. T.T. and H.M. drafted the manuscript. All authors read and approved the final manuscript.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Figure S1. Changes in the median height SDS over time from an age of 3 months to an age of 3 years in the height SDS groups established at an age of 3 months.

Figure S2. Change in the median height SDS over time from an age of 6 months to an age of 3 years in the height SDS groups established at an age of 6 months.

Figure S3. Change in the median height SDS over time from an age of 1.5 years to an age of 3 years in the height SDS groups established at an age of 1.5 years.