Clinical Pediatric Endocrinology

Vol.31 / No.1
January 2022
pp 10–17

Original Article

# Preschool-children's height, trend, and causes: Japanese national surveys 1990–2010

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## Highlights

- National survey showed height of preschool children decreased from 1990 to 2000.
- Birthweight SD reduction consistently contributed to this decrease.
- We failed to find other maternal/child factors that consistently contributed.

**Abstract.** We observed trends in the height of children aged 3 to 6 in Japan using data from the National Growth Survey on Preschool Children in the years 1990, 2000, and 2010. Average standard deviation (SD) scores of height decreased from 0.39 (SD 1.02) in 1990 (n = 3,684) to 0.37 (SD 1.05) in 2000 (n = 2,981) and 0.33 (SD 1.07) in 2010 (n = 2,027). Mothers of children in later waves were taller, older, and more likely to be primiparous; children in later waves had shorter gestational age, lower birth weight, and were less likely to have been fed less with formula or solid foods before 6 mo. The only factor that consistently contributed to a reduction in children's height for both 1990–2000 and 2000–2010 was a reduction in birthweight SD score (indirect effect on height –1.5 [95% CI: –1.9, –1.1] mm for 1990–2000 and –1.2 [95% CI: –1.8, –0.8] mm for 2000–2010). Factors that contributed, although not significantly or consistently between the two periods, were changes in pre-pregnancy BMI, smoking during pregnancy, multiple pregnancies, gestational age, BMI at birth, and use of formula and solid foods before 6 mo. Secular increases in maternal age, height, and primiparity contributed to increasing children's height.

**Key words:** height, growth, epidemiology

Received: June 21, 2021 Accepted: August 4, 2021 Advanced Epub: November 1, 2021
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## Introduction

Japan experienced a spurt in adult height over the last century; however, recent large studies suggested that it has been declining in the last few decades (1, 2). Observational studies robustly show that shorter height is associated with a shorter life expectancy (3–6). Moreover, there is concern that Japan may experience a population-level decline in adult health, although it currently achieves the highest life expectancy in the world (7).

Recently, we conducted a large ecological study suggesting that the main contributors to this decline may lie in early childhood, as the decline in height is correlated highly with an increase in low birth weight births (7). However, this analysis was not conducted on individual data and had limitations as an ecological study; further, it was only able to observe basic maternal characteristics, such as maternal age and parity, which were available in the vital statistics database. Due to the lack of a nationally representative cohort data from birth to adulthood, individual analysis of how maternal and child factors contributed to the secular trend in adult height has not been possible. On the other hand, as height during early childhood correlates with adult height, understanding how varying maternal and child characteristics have contributed to the changes in children's height may help understand the contributing factors to the secular change observed among adults (8).

The National Growth Survey on Preschool Children is a decennial national survey on anthropometric measurements of preschool children, conducted on a nationally representative random sample of children (9–13). This database also collects detailed maternal and infant characteristics. Thus, in this study, we utilized data from 1990, 2000 and 2010 of this survey to investigate how height among children aged 3 to 6 has changed over the 20 years, as well as how changes in maternal and infant demographics have contributed to this change.

## Methods

### Study sample

We used data from the National Growth Survey on Preschool Children (9), a national survey conducted by the Ministry of Health, Labour and Welfare every 10 years starting from 1960. Its primary aim is to provide children's anthropometrics to update their growth curves.

The detailed methodology of the survey is described elsewhere (10–12). In brief, 3,000 census areas were randomly chosen based on the national census, for which all households with infants and toddlers who would be between 14 d to 2 yr of age at the point of survey were asked to participate. Similarly, 900 (750 in 1990) randomly chosen census areas would contact pre-school children aged 2 to 6. Municipality health centers would gather the children on the appointed day and conduct health examinations, and transfer pregnancy and delivery related information from the maternal and child handbook (14). An official documentation was used to record antenatal care, birth characteristics, and milestones of child development, and record results in a standardized format revised every 10 years. Home visits were made to children who failed to attend the examination. Non-respondents, despite multiple attempts to contact, were excluded. For the years 1990, 2000, and 2010, response rates were 90.8% (12,484/13,743), 81.3% (10,021/12,312), and 70.3% (7,652/10,880), respectively, with the sample size decreasing due to lower birth rate and lower response rate.

We limited our data to those of 9,257 children aged 3 to 6, as being small and failure to catch up during the first two years of life are considered risk factors for short adult height (15, 16). We further excluded 565 (6.1%) children with missing information on maternal age (n = 21); maternal height (n = 24); maternal weight (limited to waves 2000 and 2010) (n = 20); parity (n = 2); maternal smoking (n = 49); anemia during pregnancy (n = 70); multiplicity (n = 44); child sex (n = 16); gestational age (n = 24); birth weight (n = 21); birth length (n = 142); feeding practices during infancy (n = 113); and presence of medical conditions disabling measurement of height (n = 19). Thus, our final sample was 8,692 children (1990: n = 3,684; 2000: n = 2,981; and 2010: n = 2,027).

### Variables and measurement

All anthropometric measurements were conducted by trained nurses and public health personnel using standardized instruments and methods described in the manual (9). For children aged 2 to 6 yr, height was measured to the nearest millimeter standing upright using a stadiometer, and body weight was measured after stool and urine secretion, and rounded to the nearest 10 g. We calculated height z-scores based on the current age-and sex-specific Japanese growth standards (13) which were created using the 2000 survey results.

The mother's height was self-reported to the nearest centimeter. Gestational age at delivery (in completed weeks), parity, multiplicity, and birth anthropometrics [birth weight (in grams), birth length (in millimeters), and birth head circumference (in millimeters)] were based on health care professional documentation at birth provided in the maternal and child handbook. Data on maternal smoking, pregnancy complications (anemia, gestational diabetes, and pregnancy-induced hypertension), and feeding practices (breastfeeding, formula, or a combination of both for each month for the first 12 mo of life, as well as the month when solid foods were introduced) were collected by interview from the mothers.

Pre-pregnancy BMI was calculated using data on maternal height and pre-pregnancy weight. We calculated birth weight and birth length z-scores based


doi: 10.1297/cpe.31.2021-0041

on the current parity, sex, and gestational age-specific Japanese birth weight reference (17), and defined small-for-gestational age (SGA) as birth weight and birth length both below the 10% reference line. We did not use results on pregnancy-induced hypertension and gestational diabetes as the clinical definition, and the screening process has changed over the years. We defined those for whom only breastfeeding was reported for months 0–5 as "No use of formula until 6 months", and those for whom introduction of solid foods was reported to be after month 6 to be "No use of solid food until 6 months".

### Analysis

First, distributions of maternal, infant, and feeding characteristics for 1990, 2000, and 2010 were compared using the chi-square test. Next, as we were interested in how the difference in children's height between waves could be explained by the difference in maternal and infant characteristics, we proposed the following causal model, where the change in height over the years (the total effect) could be separated into changes that could be attributable to changes in maternal and infant characteristics (the indirect effect) and those due to other factors (the remaining direct effect).

For this, we estimated the difference in children's height between children in the 1990 and 2000 waves, the 2000 and 2010 waves, and the 1990 and 2010 waves, after sequential adjustment by maternal characteristics (maternal height, parity, age, smoking, and anemia during pregnancy), infant characteristics (infant sex, multiplicity, gestational age, birth weight, and birth length SD scores), and feeding practices (use of formula and solid foods before 6 mo).

To statistically calculate the direct and indirect total effects using these results, we applied the method proposed by Baron and Kenny (18) which uses two models: 1) estimating the total effect (c) of X on Y, and 2) estimating the direct effect (c') of X on Y with M included as a covariate, to calculate the indirect effect c-c' (18), using multivariate linear regression to calculate effect estimates. For each potential mediator, the difference in children's height calculated from the model not containing the variable would be the total effect, while the difference in children's height calculated from the model containing the variable would calculate the direct effect, and their resulting difference would be the indirect effect. This indirect effect was calculated for only the characteristics that showed a positive mediation (estimated indirect effect and total effect were in the same direction).

All descriptive and statistical analyses were performed using STATA version 14 (STATA Corp, College Station, TX), with mediation analysis conducted using the command "paramed" available in the program. Statistical significance was set at 0.05, and all statistical tests were two-tailed.

The protocol for this study was approved by the Institutional Review Board of the National Center for Child Health and Development on December 22, 2016 (number 1356).

## Results

The maternal and infant characteristics, as well as the child's measurements in the survey for waves 1990, 2000, and 2010 are described in **Table 1**. Mothers of children in later waves were taller, older, and more likely to be primiparous and diagnosed with anemia during pregnancy. The mothers of children in wave 2010 had a lower BMI compared to those in 2000. The proportion of mothers who smoked during pregnancy was highest in wave 2000 compared to the waves in 1990 and 2010. Children in later waves included more multiple births, with shorter average gestational age (less post-term deliveries and more pre-term deliveries), more infants born small for gestational age, and lower average SD scores of birth weight and birth length, while no change was observed in sex. The proportion of children who reported no use of formula up to 6 months and who reported no use of solid foods until 6 mo, was the highest in 2010. Children's height and height SD scores were shorter, and BMI was lower in later waves. **Table 2** shows the difference in children's height between waves 1990 and 2000, as well as between waves 2000 and 2010, after sequential adjustment by maternal and child factors.

Differences in height after adjusting for child age were –1.2 (95% CI –3.0, 0.7) mm between wave 1990 and wave 2000. Increase in multiple births [–0.1 (95% –0.2, –0.0) mm], increase in smoking during pregnancy [–0.2 (95% –0.4, –0.1) mm], and decrease in birth weight SD scores [–1.5 (95% –2.0, –1.2) mm] showed significant indirect effects explaining part of the difference. The increase in anemia during pregnancy [–0.0 (95% –0.1, 0.0) mm], decrease in gestational age [–0.0 (95% –0.1, 0.1) mm], decrease in birth length SD score [–0.2 (95% –0.4, 0.1) mm], and decrease in the use of solid foods before 6 mo [–0.1 (95% –0.2, 0.0) mm] had non-significant indirect effects. On the other hand, several changes in maternal characteristics (increase in maternal height, increase in primiparous pregnancies, and increase in age at delivery) had opposite effects, i.e., as these changes contributed to increasing children's height, by adjusting for these factors, the difference between waves expanded.

Differences in height after adjusting for child age were –1.3 (95% CI –3.9, 1.0) mm between wave 2000 and wave 2010. The reduction in gestational age [–0.2 (95% –0.4, –0.0) mm], decrease in birth weight SD scores [–1.2 (95% –2.0, –0.8) mm], and decreased use of formula before 6 mo [–0.5 (95% –0.8, –0.2) mm] showed significant indirect effects explaining part of the difference. Reduction in maternal pre-pregnancy BMI [–0.2 (95% –0.4, 0.1) mm], increase in anemia [–0.0 (95% –0.1, 0.0) mm], decrease in birth length SD scores [–0.3 (–0.7, 0.1) mm] and decrease in use of solid foods before 6 mo [–0.3 (95% –0.8, 0.3) mm] had non-significant


doi: 10.1297/cpe.31.2021-0041

**Table 1.** Maternal and child characteristics among children age three to six and participated in the National Growth Survey on Preschool Children (n = 8,692)

| | 1990 (n = 3,684) | | 2000 (n= 2,981) | | 2010 (n=2,027) | | |
|---|---|---|---|---|---|---|---|
| **Maternal characteristics** | | | | | | | |
| | mean | SD | mean | SD | mean | SD | Chi-square p-value |
| Age at delivery (yr) | 28.4 | 4.1 | 28.9 | 4.3 | 30.2 | 4.6 | < 0.001 |
| Mother height (cm) | 156.3 | 4.9 | 157.6 | 5.1 | 158 | 5.3 | < 0.001 |
| Pre-pregnancy BMI (kg/m$^2$) | - | - | 20.9 | 2.9 | 20.8 | 3.1 | |
| | No. | % | No. | % | No. | % | p-value |
| Primiparous | 1,555 | 41.70% | 1,413 | 46.30% | 1,051 | 48.80% | < 0.001 |
| Smoked during pregnancy | 161 | 4.40% | 269 | 9.00% | 129 | 6.40% | < 0.001 |
| Diagnosed anemia during pregnancy | 908 | 24.60% | 790 | 26.50% | 555 | 27.40% | 0.05 |
| Teenage pregnancy (< 20 yr) | 37 | 1.00% | 35 | 1.20% | 11 | 0.50% | 0.08 |
| Advanced age pregnancy (> 35 yr) | 278 | 7.50% | 266 | 8.90% | 367 | 18.10% | < 0.001 |
| **Infant characteristics** | | | | | | | |
| | mean | SD | mean | SD | mean | SD | Chi-square p-value |
| Gestational age (wk) | 39.2 | 1.5 | 39 | 1.5 | 38.9 | 1.6 | < 0.001 |
| Birth weight (g) | 3,163 | 421 | 3,081 | 422 | 3,013 | 431 | < 0.001 |
| Birth weight SD score | 0.34 | 1.08 | 0.19 | 1.05 | 0.06 | 1.03 | < 0.001 |
| Birth length (cm) | 49.5 | 2.1 | 49.1 | 2.3 | 48.9 | 2.3 | < 0.001 |
| Birth length SD score | 0.26 | 1.05 | 0.15 | 1.07 | 0.04 | 1.02 | < 0.001 |
| BMI at birth | 12.9 | 1.3 | 12.7 | 1.4 | 12.6 | 1.3 | < 0.001 |
| | No. | % | No. | % | No. | % | p-value |
| Multiple births | 34 | 0.90% | 51 | 1.70% | 39 | 1.90% | 0.003 |
| Male infant | 1,854 | 50.30% | 1,533 | 51.40% | 1,044 | 51.50% | 0.58 |
| SGA | 83 | 2.20% | 83 | 2.80% | 80 | 3.90% | 0.001 |
| Preterm delivery | 116 | 3.10% | 144 | 4.80% | 94 | 4.60% | 0.001 |
| Postterm delivery | 120 | 3.30% | 45 | 1.50% | 10 | 0.50% | < 0.001 |
| **Feeding characteristics** | | | | | | | |
| | No. | % | No. | % | No. | % | Chi-square p-value |
| No use of formula until 6 months | 1,292 | 35.10% | 872 | 29.30% | 883 | 43.60% | < 0.001 |
| No use of solid food until 6 months | 893 | 24.20% | 847 | 28.40% | 1,113 | 54.90% | < 0.001 |
| **Measurements at the Survey** | | | | | | | |
| | mean | SD | mean | SD | mean | SD | Chi-square p-value |
| Child age (mo) | 57.1 | 12 | 56.8 | 12 | 56.7 | 12 | 0.22 |
| Child height (cm) | 104.81 | 7.72 | 104.54 | 7.74 | 104.36 | 7.77 | < 0.001 |
| Child height SD score | 0.39 | 1.02 | 0.37 | 1.05 | 0.33 | 1.07 | < 0.001 |
| Kaup score (BMI) | 15.6 | 1.5 | 15.5 | 1.5 | 15.3 | 1.5 | < 0.001 |

* Calculated for 8,635 children as 57 did not have measurements. BMI, body mass index; SGA, small for gestational age.

indirect effects. An increase in maternal height, increase in primiparous pregnancies, and an increase in age at delivery, had reverse effects.

**Table 3** shows the difference in children's height between 1990 and 2010, after sequential adjustment by maternal and child factors. Differences in height after adjusting for child age were –2.5 (95% CI –5.4, 0.5) mm between wave 1990 and wave 2010. Increase in multiple births [–0.1 (95% –0.4, –0.0) mm], increase in smoking during pregnancy [–0.2 (95% –0.4, –0.0) mm], decrease in gestational age [–0.3 (95% –0.5, –0.0) mm], decrease in birth weight SD scores [–2.9 (95% –3.6, –2.4) mm], decrease in birth length SD score [–0.4 (95% –0.6, –0.0) mm], and decrease in use of formula before 6 mo [–0.3


doi: 10.1297/cpe.31.2021-0041

**Table 2.** Difference in children's height between measurements at 1990, 2000, and 2010 after sequential adjustment for secular changes in maternal and child factors. Analysis of 8,692 children aged 3 to 6

| Maternal and child factors | Difference after adjustment (remaining direct effect) | Difference explained by added factor (natural indirect effect) |
|---|---|---|
| A) Measurements at year 2000 vs at year 1990 (in millimeters) | | |
| Crude model (adjusted for child age) | –1.2 (–3.0, 0.7) | |
| Maternal characteristics | | |
| + increase in maternal height | –4.9 (–6.8, –3.2) | 3.8 (3.2, 4.5) |
| + increase in primiparous pregnancies | –5.1 (–7.2, –3.4) | 0.1 (0.0, 0.3) |
| + increase in age at delivery | –5.4 (–7.3, –3.4) | 0.3 (0.2, 0.5) |
| + increase in smoking during pregnancy | –5.2 (–7.0, –3.1) | –0.2 (–0.6, –0.0) |
| + increase in anemia during pregnancy | –5.1 (–7.0, –3.4) | –0.0 (–0.1, 0.0) |
| Infant characteristics | | |
| + increase in male births | –5.3 (–7.4, –3.6) | 0.1 (–0.0, 0.3) |
| + increase in multiple pregnancies | –5.2 (–7.0, –3.4) | –0.1 (–0.2, –0.0) |
| + decrease in gestational age | –5.2 (–6.8, –3.5) | –0.0 (–0.1, 0.1) |
| + decrease in birth weight SD score | –3.6 (–5.3, –1.6) | –1.5 (–2.0, –1.2) |
| + decrease in birth length SD score | –3.4 (–4.8, –1.6) | –0.2 (–0.4, 0.1) |
| Feeding practices | | |
| + decrease in use of formula before 6 mo | –3.5 (–5.1, –1.5) | 0.1 (–0.0, 0.2) |
| + decrease in use of solid foods before 6 mo | –3.4 (–5.3, –1.2) | –0.1 (–0.2, 0.0) |
| B) Measurements at year 2010 vs at year 2000 (in millimeters) | | |
| Crude model (adjusted for child age) | –1.3 (–3.9, 1.1) | |
| Maternal characteristics | | |
| + increase in maternal height | –2.4 (–5.2, –0.1) | 1.1 (0.3, 1.8) |
| + increase in primiparous pregnancies | –2.5 (–4.9, 0.8) | 0.1 (0.0, 0.3) |
| + increase in age at delivery | –2.9 (–4.6, –0.8) | 0.4 (0.1, 0.8) |
| + decrease in pre-pregnancy BMI | –2.7 (–4.4, 0.1) | –0.2 (–0.4, 0.1) |
| + decrease in smoking during pregnancy | –2.8 (–5.1, –0.5) | 0.1 (–0.0, 0.3) |
| + increase in anemia during pregnancy | –2.8 (–5.3, –0.4) | –0.0 (–0.1, 0.0) |
| Infant characteristics | | |
| + increase in male births | –2.8 (–5.6, –0.9) | 0.0 (–0.2, 0.3) |
| + increase in multiple pregnancies | –2.8 (–5.0, 0.3) | 0.0 (–0.1, 0.1) |
| + decrease in gestational age | –2.7 (–4.7, 0.1) | –0.2 (–0.4, –0.0) |
| + decrease in birth weight SD score | –1.4 (–3.6, 0.8) | –1.2 (–2.0, –0.8) |
| + decrease in birth length SD score | –1.2 (–3.5, 0.7) | –0.3 (–0.7, 0.1) |
| Feeding practices | | |
| + decrease in use of formula before 6 mo | –0.6 (–2.6, 1.3) | –0.5 (–0.8, –0.2) |
| + decrease in use of solid foods before 6 mo | –0.3 (–2.6, 1.9) | –0.3 (–0.8, 0.3) |

BMI, body mass index. –0.0 represents absolute values below 0 that become 0.0 when rounded to the first digit, while 0.0 represents absolute values at or above 0 that become 0.0 when rounded to the first digit.

(95% –0.5, –0.0) mm] showed significant indirect effects explaining part of the difference. The increase in anemia during pregnancy [–0.0 (95% –0.2, 0.0) mm] and decrease in the use of solid foods before 6 mo [–0.3 (95% –1.0, 0.2) mm] had non-significant indirect effects.

## Discussion

In this study, we demonstrate that the height among children aged 3 to 6 years decreased from 1990 to 2010. The only factor that consistently contributed to the reduction in children's height for both 1990–2000 and 2000–2010 was the reduction in birth weight SD score. In this regard, one interesting finding is that we failed to consider it as a large contributor to the reduction in children's height, although gestational age has been reported to be a key factor in the decrease in average birth weight in Japan. Two analyses based on birth certificate data from 1980–2004 (19) and 2000–2010 (20) reported that changes in gestational age explained nearly half the reduction in birth weight with other factors, such as parity, multiplicity, maternal age, and gender contributing only little. However, in our study, reduction in gestational age did not contribute

 doi: 10.1297/cpe.31.2021-0041

**Table 3.** Difference in children's height between measurements at 1990 and 2010 after sequential adjustment for secular changes in maternal and child factors. (in millimeters)

| Maternal and child factors | Difference after adjustment (remaining direct effect) | Difference explained by added factor (natural indirect effect) |
|---|---|---|
| Crude model (adjusted for child age) | –2.5 (–5.4, 0.5) | |
| Maternal characteristics | | |
| + increase in maternal height | –7.2 (–9.8, –5.2) | 4.8 (3.8, 5.5) |
| + increase in primiparous pregnancies | –7.6 (–11.1, –5.4) | 0.4 (0.2, 0.6) |
| + increase in age at delivery | –8.3 (–10.2, –6.3) | 0.7 (0.4, 1.2) |
| + increase in smoking during pregnancy | –8.2 (–10.2, –6.4) | –0.2 (–0.4, –0.0) |
| + increase in anemia during pregnancy | –8.1 (–10.2, –5.9) | –0.0 (–0.2, 0.0) |
| Infant characteristics | | |
| + increase in male births | –8.3 (–10.4, –6.1) | 0.2 (–0.2, 0.4) |
| + increase in multiple pregnancies | –8.2 (–10.9, –5.8) | –0.1 (–0.4, –0.0) |
| + decrease in gestational age | –7.9 (–10.9, –6.2) | –0.3 (–0.5, –0.0) |
| + decrease in birth weight SD score | –5.0 (–7.5, –3.0) | –2.9 (–3.6, –2.4) |
| + decrease in birth length SD score | –4.6 (–6.9, –2.6) | –0.4 (–0.6, –0.0) |
| Feeding practices | | |
| + decrease in use of formula before 6 mo | –4.3 (–6.5, –2.5) | –0.3 (–0.5, –0.0) |
| + decrease in use of solid foods before 6 mo | –4.0 (–6.2, –1.6) | –0.3 (–1.0, 0.2) |

BMI, body mass index. –0.0 represents absolute values below 0 that become 0.0 when rounded to the first digit, while 0.0 represents absolute values at or above 0 that become 0.0 when rounded to the first digit.

to explaining the reduction in height from 1990 to 2000, while a significant only explained 0.2 mm of the reduction from 2000 to 2010.

The inconsistencies between these previous studies on birth weight and our study suggest that among the two mechanisms leading to lower birth weight in the population, i.e., lower gestational age and slower intrauterine growth, the latter seems to have a more lingering effect on children's growth compared to the former. This is understandable upon the consideration of the growth curve; children born slightly earlier but with appropriate fetal growth would likely follow the curve and by preschool age grow as large as other children born with slightly longer gestational age, while an infant born at term but with slower intrauterine growth would have to "catch-up" or move up the growth curve to reach its peers. Studies on pre-term children show that while growth spurts are often observed in children who experienced intrauterine growth restriction, 10% to 20% fail to enter the normal height range for their corrected age, and even when they reach the normal range, they are still shorter than those born with no intrauterine growth restriction (21–23).

Factors other than reduction in fetal body weight that showed significant contributions to reduction in children's height were reduction in gestational age (2000–2010, 1990–2010), increased smoking during pregnancy (1990–2000, 1990–2010), increase in multiple pregnancies (1990–2000, 1990–2010), and reduction in use of formula before 6 mo (2000–2010, 1990–2010). Lower pre-pregnancy BMI, smoking during pregnancy, and an increase in multiple births are also well-known risk factors for reduced birth weight (12, 19). In contrast, an increase in the percentage of mothers with primiparity, which is a known factor of reduced birth weight, was found to slightly contribute to increasing children's height in our study, which is in line with a study that showed that firstborn children grow taller despite being born smaller (24). These findings suggest that lower birth weight, which in itself is a risk of shorter stature, does not always share common causes with risks of shorter height in childhood. In our study, the reduction in the use of formula and solid foods before 6 mo may be related to decrease in children's height. This finding matches results from observational studies in other countries where formula-fed infants are found to be generally larger than those who were exclusively breastfed (25). However, the interpretation of our results should be taken with caution, as the many benefits of exclusively breastfeeding for the infant and mother are widely known (26, 27).

Our study is the first to report the secular trend in children's height in Japan, as well as its potential causes. The strength of this study is its national representativeness, large sample size, uniformity in body measurement methods, and accuracy in perinatal data transcribed from maternal handbooks.

However, our study presents some limitations. First, while the survey participants were randomly chosen based on the census, one-fifth did not participate, with the participation rate declining from 10% to 30% over the years. As children with lower socioeconomic status or severe diseases or disabilities may have been less likely to participate, this selection bias may have led to an underestimation of children with short stature in the more recent years and also caused bias in the


doi: 10.1297/cpe.31.2021-0041

estimation of the mediation analysis. Second, while missing information was filled based on interviews in cases where the maternal and child handbook was not available, we did not have information on for which children missing information was filled as suche. Third, while our analysis considered many variables and was comprehensive compared to previous studies, we still could not evaluate many important variables that may influence children's height, such as physical activity, nutritional intake, or time of measurement (as measured height tends to be shorter towards the end of the day). This is the likely reason why we could not explain half of how children's height have declined over the years, and it is worth considering the possibility of unmeasured confounding.

In conclusion, we found that height among children aged 3 to 6 yr decreased from 1990 to 2010, with a reduction in fetal body weight likely attributed to a decrease in child height, while the contribution of reduction in gestational length and other maternal and child characteristics may be limited.

**Conflicts of Interests:** The authors declare that they have no conflicts of interest.

## Acknowledgements:

This study was funded by a grant from the Ministry of Health, Labor, and Welfare (21DA2001, H30-SUKOYAKA-SHITEI-001) to the National Center for Child Health and Development.

## References

1. Tanner JM, Hayashi T, Preece MA, Cameron N. Increase in length of leg relative to trunk in Japanese children and adults from 1957 to 1977: comparison with British and with Japanese Americans. Ann Hum Biol 1982;9: 411–23. [Medline] [CrossRef]
2. NCD Risk Factor Collaboration (NCD-RisC). A century of trends in adult human height. eLife 2016;5: 5. [Medline]
3. Cole TJ. The secular trend in human physical growth: a biological view. Econ Hum Biol 2003;1: 161–8. [Medline] [CrossRef]
4. Emerging Risk Factors Collaboration. Adult height and the risk of cause-specific death and vascular morbidity in 1 million people: individual participant meta-analysis. Int J Epidemiol 2012;41: 1419–33. [Medline] [CrossRef]
5. Perkins JM, Subramanian SV, Davey Smith G, Özaltin E. Adult height, nutrition, and population health. Nutr Rev 2016;74: 149–65. [Medline] [CrossRef]
6. Nüesch E, Dale C, Palmer TM, White J, Keating BJ, van Iperen EP, *et al*. EPIC-Netherland Investigators UCLEB Investigators IN Day. Adult height, coronary heart disease and stroke: a multi-locus Mendelian randomization meta-analysis. Int J Epidemiol 2016;45: 1927–37. [Medline] [CrossRef]
7. Morisaki N, Urayama KY, Yoshii K, Subramanian SV, Yokoya S. Ecological analysis of secular trends in low birth weight births and adult height in Japan. J Epidemiol Community Health 2017;71: 1014–8. [Medline] [CrossRef]
8. Silventoinen K. Determinants of variation in adult body height. J Biosoc Sci 2003;35: 263–85. [Medline] [CrossRef]
9. Ministry of Health Law. http://www.mhlw.go.jp/toukei/list/73-22.html (accessed May 18, 2021).
10. Kato N, Sato K, Takimoto H, Sudo N. BMI for age references for Japanese children--based on the 2000 growth survey. Asia Pac J Public Health 2008;20(Suppl): 118–27. [Medline]
11. Kato N, Takimoto H, Yokoyama T, Yokoya S, Tanaka T, Tada H. Updated Japanese growth references for infants and preschool children, based on historical, ethnic and environmental characteristics. Acta paediatrica (Oslo, Norway : 1992) 2014;103(6):e251-e261.
12. Takimoto H, Yokoyama T, Yoshiike N, Fukuoka H. Increase in low-birth-weight infants in Japan and associated risk factors, 1980-2000. J Obstet Gynaecol Res 2005;31: 314–22. [Medline] [CrossRef]
13. Isojima T, Kato N, Ito Y, Kanzaki S, Murata M. Growth standard charts for Japanese children with mean and standard deviation (SD) values based on the year 2000 national survey. Clin Pediatr Endocrinol 2016;25: 71–6. [Medline] [CrossRef]
14. Mori R, Yonemoto N, Noma H, Ochirbat T, Barber E, Soyolgerel G, *et al*. The Maternal and Child Health (MCH) handbook in Mongolia: a cluster-randomized, controlled trial. PLoS One 2015;10: e0119772. [Medline] [CrossRef]
15. Knop MR, Geng TT, Gorny AW, Ding R, Li C, Ley SH, *et al*. Birth weight and risk of type 2 diabetes mellitus, cardiovascular disease, and hypertension in adults: a meta-analysis of 7, 646, 267 participants from 135 studies. J Am Heart Assoc 2018;7: e008870. [Medline] [CrossRef]
16. Goldenberg RL, Gravett MG, Iams J, Papageorghiou AT, Waller SA, Kramer M, *et al*. The preterm birth syndrome: issues to consider in creating a classification system. Am J Obstet Gynecol 2012;206: 113–8. [Medline] [CrossRef]
17. Itabashi K, Miura F, Uehara R, Nakamura Y. New Japanese neonatal anthropometric charts for gestational age at birth. Pediatrics international: official journal of the Japan Pediatric Society 2014;56(5):702–8.
18. Chen W, Chang MH. New growth charts for Taiwanese children and adolescents based on World Health Organization standards and health-related physical fitness. Pediatr Neonatol 2010;51: 69–79. [Medline] [CrossRef]
19. Kato N, Sauvaget C, Yoshida H, Yokoyama T, Yoshiike N. Factors associated with birthweight decline in Japan (1980-2004). BMC Pregnancy Childbirth 2021;21: 337. [Medline] [CrossRef]
20. Yoshida H, Kato N, Yokoyama T. Current trends in low birth weight infants in Japan. Hoken Iryou Kagaku 2014;63: 2–16.
21. Itabashi K, Mishina J, Tada H, Sakurai M, Nanri Y, Hirohata Y. Longitudinal follow-up of height up to five years of age in

 doi: 10.1297/cpe.31.2021-0041

infants born preterm small for gestational age; comparison to full-term small for gestational age infants. Early Hum Dev 2007;83: 327–33. [Medline] [CrossRef]
22. Taine M, Charles MA, Beltrand J, Rozé JC, Léger J, Botton J, *et al*. Early postnatal growth and neurodevelopment in children born moderately preterm or small for gestational age at term: A systematic review. Paediatr Perinat Epidemiol 2018;32: 268–80. [Medline] [CrossRef]
23. Karlberg J, Albertsson-Wikland K. Growth in full-term small-for-gestational-age infants: from birth to final height. Pediatr Res 1995;38: 733–9. [Medline] [CrossRef]
24. Savage T, Derraik JG, Miles HL, Mouat F, Cutfield WS, Hofman PL. Birth order progressively affects childhood height. Clin Endocrinol (Oxf) 2013;79: 379–85. [Medline] [CrossRef]
25. Kramer MS, Guo T, Platt RW, Shapiro S, Collet JP, Chalmers B, *et al*. PROBIT Study Group. Breastfeeding and infant growth: biology or bias? Pediatrics 2002;110: 343–7. [Medline] [CrossRef]
26. Kramer MS, Kakuma R. Optimal duration of exclusive breastfeeding. Cochrane database of systematic reviews (Online) 2012;2012(8):CD003517.
27. Koletzko B, von Kries R, Closa R, Escribano J, Scaglioni S, Giovannini M, *et al*. Can infant feeding choices modulate later obesity risk? Am J Clin Nutr 2009;89: 1502S–8S. [Medline] [CrossRef]

 doi: 10.1297/cpe.31.2021-0041