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Ecological analysis of secular trends in low birth weight births and adult height in Japan

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ABSTRACT

Background Japan, which currently maintains the highest life expectancy in the world and has experienced an impressive gain in adult height over the past century, has suffered a dramatic twofold increase in low birth weight (LBW) births since the 1970s.

Methods We observed secular trends in birth characteristics using 64 115 249 live births included the vital statistics (1969–2014), as well as trends in average height among 3 145 521 adults born between 1969 and 1996, included in 79 surveys conducted among a national, subnational or community population in Japan.

Results LBW rates exhibited a U-shaped pattern showing reductions until 1978–1979 (5.5%), after which it increased. Conversely, average adult height peaked for those born during the same period (men, 171.5 cm; women, 158.5 cm), followed by a reduction over the next 20 years. LBW rate and adult height showed a strong inverse correlation (men, r=−0.98; women, r=−0.88). A prediction model based on birth and economical characteristics estimated the national average of adult height would continue to decline, to 170.0cm (95% CI 169.6 to 170.3) for men and 157.9cm (95% CI 157.5 to 158.3) for women among those born in 2014.

Conclusions Adult height in Japan has started to decline for those born after 1980, a trend that may be attributed to increases in LBW births over time. Considering the known association between shorter adult height and adverse health outcomes, evidence of population-level decline in adult health due to long-term consequences of increasing LBW births in Japan is anticipated.

INTRODUCTION

Understanding the determinants of adult height is of keen interest, as numerous epidemiological studies have shown robust associations between being shorter and a shorter life expectancy,[1 2] as well as higher risk of various cardiovascular diseases.[3] The link is suggested to be due to a combination of causal effects of adult height altering blood pressure and body mass index,[3] as well as adult height acting as a proxy of early life factors (eg, undernutrition, infection and social factors) that inhibit childhood growth and alter metabolism, which in turn increases the risk of major non-communicable diseases later in life.[4–6]

Globally, adult height has increased in all countries over the past century.[7] Most high-income countries have experienced a monotonic increase before reaching plateau[1 4 7]; economically thriving low-income and middle-income countries are still experiencing a rapid secular growth,[7] while other countries experiencing economic hardships have experienced a recent decrease in average adult height.[7 8] As serial cross-population assessments of height are not affected by genetic factors (unless the population experienced a large influx of migrant populations), such changes have been interpreted to be reflecting the improved nutritional status and sanitation in wealthier countries and its lack of improvement in other parts of the world.[7 8]

Japan, which currently maintains the highest life expectancy in the world,[9] has experienced an impressive 15 cm gain in adult height over the past century.[7 10 11] While previous reports suggested it has plateaued since births in the 1970s,[7] detailed analysis of recent trends has not been conducted. As Japan has experienced a twofold increase in low birth weight (LBW) births since the 1970s,[12] it is possible that such changes in birth characteristics have influenced secular trends in adult height.

Thus, in this study we aimed to observe trends in average adult height by year of birth using nationally representative serial cross-sectional data. We further examined how trends in birth characteristics are associated with trends in adult height.

METHODS

Calculation of average adult height using population-based data in Japan

Trends in mean adult height for those born between 1969 and 1996 were examined using data from 79 surveys conducted among a national, subnational or community population in Japan. The methodology of this large pooled analysis conducted by the non-communicable diseases (NCD) Risk Factor Collaboration, a network of health scientists around the world, has been previously reported in detail.[7] In brief, multiple routes for identifying and accessing data, including a systematic review, were used to identify all available population-based measurement studies of human anthropometry, after which summary statistics (sample mean and SE by age and sex) were obtained from all relevant studies. Studies were strictly limited to those collected using a probabilistic sampling method with a defined sampling frame and were representative of the general population. All data sources on population subgroups whose anthropometric status may have systematically differed from the general population due to health, ethnic or socioeconomic characteristics were excluded, as well as studies with self-reported height instead of measured height. As a result, 1472 data sources, including 79 data

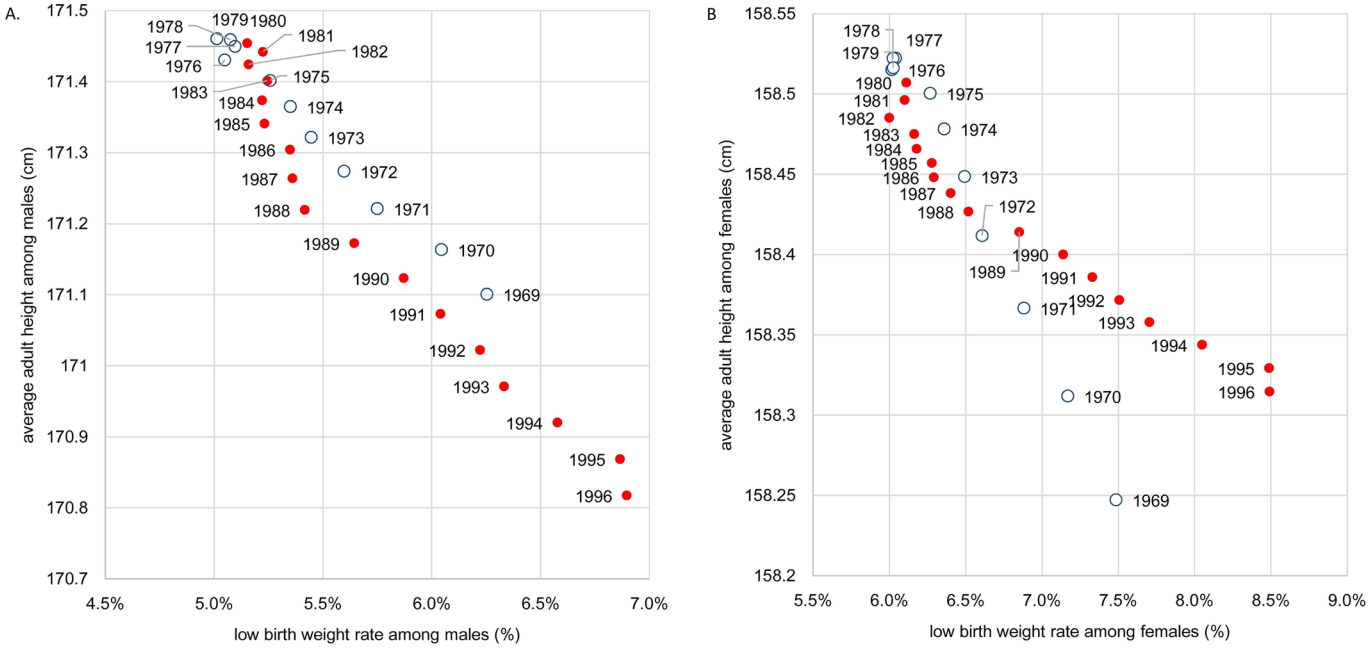

Figure 1 Scatter plot of proportion of low birth weight and average height at adulthood by year of birth (1969–1996) among men (A) and women (B).

sources (39 national-based, 1 subnational-based and 39 community-based) in Japan, were identified, which included 3 242 415 measurements of Japanese adults.

A Bayesian model fitted using the Markov chain Monte Carlo algorithm was used to estimate the mean height and 95% credible intervals (2.5th–97.5th percentiles of the posterior distribution) for each year in men and women separately. This model included a hierarchical structure in which mean height was estimated for each year of birth while accounting for the fact that subnational and community studies may have larger variation and may systematically differ from nationally representative studies. Overall trends in adult height among 200 countries between 1896 and 1996 have been presented previously,[7] with average height among Japanese men and women increasing by 14.5 cm and 16.0 cm over the century, respectively. Mean height and their 95% credible intervals by sex and year of birth as used in this study are available online (http://ncdrisc.org/downloads/height/individual-countries/Japan.csv).

Calculation of birth characteristics using vital statistics

The Japanese national vital statistics database of the Ministry of Health, Labour and Welfare started to collect information on multiplicity and birth weight, as well as maternal characteristics including age, number of previous live births and previous stillbirths, for all registered live births since 1969. For years 1969–1991, birth weight was recorded in categories (every 500 g during 1969–1974; every 100 g during 1975–1991) and since 1992 onwards has been reported in grams. For years 1969–1974, the number of births below 2500 g (exclusive) was not calculable, while the number of births 2500 g or below was calculable. Therefore, we defined LBW as birth weight 2500 g or less (inclusive). We defined primiparous women as those in their first pregnancy, teenage women as maternal age less than 20 at delivery, and advanced maternal age as 35 years and older at delivery. After excluding 277 083 (0.4%) with unknown sex and birth weight, we calculated annual rates of LBW, as well as rates of teenage pregnancies, advanced age pregnancies and primiparous pregnancies, among 64 115 249 births (32 967 335 men and 31 147 914 women) born between 1969 and 2014 by each year of birth.

Statistical analysis

For each sex, we plotted the average height and LBW rates by year of birth and examined the relationship using the Pearson's correlation coefficient. Next, using aggregate annual data for a total of 28 birth years (1969–1996), we conducted linear regression to model average adult height as a function of various birth characteristics (ie, rates of LBW, multiple births, teenage pregnancies, advanced age pregnancies and primiparous pregnancies) and an economic indicator (gross domestic product (GDP) per capita) of each birth year stratified by sex. Using this model, future adult height was predicted for those born between 1997 and 2014, representing individuals who have not yet turned 18 years of age by the time of data collection. To avoid overfitting, the model was bootstrapped 100 times.

All descriptive and statistical analyses were performed using Stata V.13. Statistical significance was set under 0.05, and all statistical tests were two-tailed. 95% CI for outcome prediction using the prediction model was estimated with error set at 2.110 × (SE) reflecting 17 df of the model.

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

RESULTS

For both sexes, the average adult height peaked for births between 1978 and 1979, and a reduction was observed over the next 20 years (figure 1). In contrast, LBW rates reduced monotonically until 1978–1979, after which it increased until 2007 and plateaued at around 9.6%–9.7% for the recent 8 years. The lowest LBW rate and tallest adult height were 5.5% (1979) and 171.5 cm (1979 births) for men, and 6.0% (1978) and 158.5 cm (1978 births) for women, respectively. Correlation

Table 1 Ecological analysis of the association between birth characteristics and average adult height in Japan for those born in 1969–1996

	Among men	Among women
	Effect on height (95% CI) in mm	Effect on height (95% CI) in mm
LBW births† (per +1%)	−2.6 (−2.9 to −2.3)***	−1.5 (−2.19 to −1.0)***
Primiparous births (per +1%)	−0.1 (−0.29 to 0.0)*	0.1 (0.09 to 0.2)*
Multiple births (per +1%)	3.2 (1.79 to 4.8)***	1.1 (−0.69 to 2.8)
Teenage pregnancies (per +1%)	0.4 (−0.59 to 1.3)	−0.9 (−2.19 to 0.3)
Advanced age pregnancies‡(per +1%)	−0.3 (−0.59 to −0.1)***	0.0 (−0.39 to 0.2)
GDP per capita (/US$100 000)	−4.6 (−8.69 to −0.1)*	3.6 (−0.29 to 7.4)

Results have been bootstrapped 100 times.
*p<0.05, **p<0.01, ***p<0.001.
†LBW low birth weight (birth weight 2500 g or less).
‡Maternal age at delivery ≥35.
GDP, gross domestic product; LBW, low birth weight.

between annual LBW rate and average adult height of individuals born in the same year was very strong for both sexes (men: 0.98; women: 0.88), while annual rates of birth characteristics (trends shown in online supplementary appendix 1) and GDP per capita (trends shown in online supplementary appendix 2) were not significantly correlated with average adult height by year of birth. Large changes over time were observed for advanced age pregnancy rate increasing from 4.8% in 1969 to 27.1% in 2014, and GDP per capita increasing from US$1692 in 1969 to US$36 161 in 2014. Teenage pregnancy rate and multiple birth rate increased until the 2000s and then decreased, and primiparous pregnancy has stayed fairly stable over the 45 years.

The prediction model using data from 1969 to 1996 and assuming a linear association between birth characteristics and average adult height showed good fit (model R^2=0.99 for men; R^2=0.96 for women). Association between rates of birth characteristics and average adult height was strongest for LBW and multiple births (table 1), showing a reduction in average adult height of 2.5 mm (95% CI 2.2 to 3.0) in men and 1.5 mm (95% CI 1.0 to 2.1) in women for each 1% increase in LBW; an average increase in adult height of 3.2 mm (95% CI 2.0 to 4.5) in men and 1.1 mm (95% CI −0.6 to 2.8) in women was observed for each 1% increase in multiple births. Using this model to predict average adult height for births 1997–2014 based on annual rates of LBW, multiple births, teenage pregnancies, advanced age pregnancies, primiparous pregnancies and GDP per capita, a continued reduction in adult height is expected, with average height for those born in 2014 estimated to be 170.0 cm (95% CI 169.6 to 170.3) for men and 157.9 cm (95% CI 157.5 to 158.3) for women (figure 2).

DISCUSSION

This is the first study to show that in Japan, after continuous rise in average adult height for over 80 years, secular trend shows a decrease beginning from births that occurred after about 1980. We found average adult height was strongly associated with LBW rates for the corresponding year of birth in both men and women, suggesting that increases in LBW births may have affected the observed decrease in height. According to our estimates, men born in 2014 will be 1.5 cm shorter than those born 40 years ago, and women will be 6 mm shorter. Our findings implicate that Japan may experience increased disease burden among adults, beyond those caused by an ageing population, due to the long-term consequences of increasing LBW birth rates in Japan.

Globally, average height has increased over the century (1896–1996) in all countries, most likely reflecting improved nutritional status and sanitation.[7 8] It was widely understood that changes in average adult height for most Asian and European countries have plateaued after experiencing a monotonic increase over the last century.[7] In contrast, countries experiencing economic hardship such as many of those in Sub-Saharan Africa have experienced a recent deterioration in height. However, careful observation of recent trends for those born in 1980–1996 revealed that average adult height has started to decline (http://ncdrisc.org/), even in some high-income countries such as the USA, Sweden, Norway

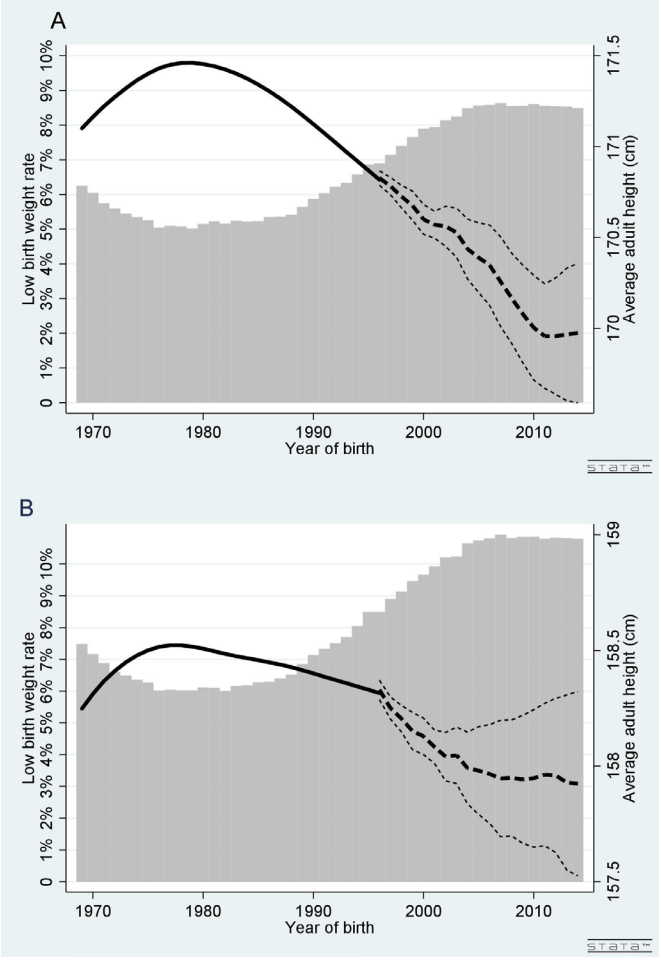

Figure 2 Low birth weight rate (1969–2014, grey bars), average adult height (1969–1996, solid black line) and predicted adult height (1997–2014, dotted black line) by year of birth among men (A) and women (B).

and Japan. While many environmental factors (eg, economical changes, immigration, changes in children's nutritional status) could have contributed to this trend, and the extent of contribution of each factor may differ between countries, the marked patterns observed in our study strongly suggest that the phenomenon is likely attributable to increases in LBW births for Japan. With the current LBW rate (9.6%) nearly twofold higher than that of 1980[12] and among the highest in high-income countries, we estimate that adult height among Japanese is expected to continue to decrease for at least another 10 years.

Japan is uniquely positioned to evaluate population trends in birth characteristics and effects on adult height since it has been experiencing drastic decreases in both gestational length and fetal growth for over 20 years.[13] But recent studies show evidence that other countries as well, such as the USA[14 15] and other regions of the world,[16] are on track to experience similar secular trends into the future regarding reductions in gestational length and fetal growth. Epidemiological studies have repeatedly shown that children born with reduced fetal growth[17] and/or reduced gestational length[18] have shorter height at the individual level. While the majority of infants born small experience catch-up growth, with shorter gestational length, the risk of failing to catch up increases. It has been shown that those who do not catch up by 2–3 years of age tend to have short stature in adulthood.[19 20] Our study not only supports these individual level epidemiological associations, but strikingly for the first time, the results show markedly noticeable population-level effects of changes in LBW rates on adult height. The public health implications of this may potentially be enormous assuming that results from previous studies linking adult height to health status in later life are true. While these findings may be considered a Japan phenomenon for now, it is possible that other countries may experience similar trends in the future.

Numerous reports have shown that adult height is associated with early life experiences and long-term cognitive, educational, economic and health outcomes.[5] Shorter adult height has been associated with increased risk of shorter life expectancy,[1 2] higher risk of various cardiovascular diseases[3] as well as various pregnancy disorders.[21–24] Mendelian randomisation studies[3 25] suggest such associations to be causal, and based on their estimates there will be approximately 3% more cardiovascular disease-related deaths (approximately 6000 cases) among Japanese men born in 2014 as compared with if LBW rates had stayed at the level of 1980. Thus, while long-term adverse effects of LBW reflected through shorter height is yet to be reported (since those born after 1980 are still in an age range not considered to be at high risk of developing chronic diseases or dying) in Japan, our study suggests that the increase in LBW rate is likely to substantially affect population health in the near future. As ecological analyses have shown that gains in mean population height are associated with lower mortality in middle and older ages,[7] this may also affect Japanese life expectancy.

Interestingly, we observed large sex differences in the association between birth characteristics and average height at adulthood. The estimated effect of LBW rate on height was twice as large among men compared with women, and the inverse association between rates of primiparous women and women of advanced age and height was observed only among men. Our findings follow previous reports showing secular change in height to be larger among men compared with women,[7] a finding that is likely explained by larger environmental influences on men compared with women.[26–28] Given the already higher incidence of cardiovascular diseases, strokes and hypertensive disorders and a shorter life expectancy in men, our result of a larger effect of rising LBW rates on height skewed towards this gender implies that we may observe an increase in health discrepancy by gender in the future.

It is important to note the limitations of our study. First, to maximise the number of subjects available for analysis, data from national studies with measurements on adult height were supplemented with estimates from subnational and community studies as well. However, to overcome possible systematic bias and uncertainty of estimates, a statistical model accounting for these uncertainties was applied; estimated 95% credible intervals were narrow (0.5–1.5 mm). Second, while we adjusted for maternal characteristics and other possible confounders reported in previous studies,[18] additional unmeasured factors may have influenced the association between secular trends in LBW and adult height. For example, we were not able to incorporate the effect of changes in foreign resident population, but at most these residents comprised only less than 2% of the Japanese population over time. Additional confidence in our interpretation of these ecological findings is due to the strength of association observed, as well as strong biological plausibility supported by longitudinal studies of both preterm delivery[18] and small for gestational age,[29] the two components of LBW, showing increased risk of shorter adult height. Third, as reporting of gestational length was in months and unreliable until 1979 and birth weight was only reported in crude categories rather than grams until 1992, we were not able to calculate preterm birth rates and small for gestational age rates in all years of interest; thus, we were unable to separately evaluate the effects of these two components of LBW on adult height. While previous studies suggest both decrease in fetal growth (likely due to low maternal nutrition[12 30]) as well as decrease in gestational length (likely due to increased obstetric interventions[13 31]) have contributed to the rise in LBW rates in Japan, future studies are needed to further understand the respective roles of these two mechanisms in affecting adult height.

CONCLUSION

Taking advantage of Japan's chronic pattern of rising LBW rates over the last few decades, our study provides strong evidence of a population-level effect of LBW on decreasing adult height. While understanding causal pathways linking LBW and adult height exceeds the scope of this study, as LBW is a modifiable

What is already known on this subject

- Numerous studies show robust associations between taller height and longer life expectancy. Japan has experienced an impressive gain in adult height over the past century and maintains the highest life expectancy in the world, however has suffered a twofold increase in low birth weight births since the 1970s.

What this study adds

- Adult height in Japan has started to decline significantly for those born after 1980, likely due to the long-term consequences of increasing low birth weight birth rates. Our findings implicate a level of public health urgency for addressing the possible long-term consequences of changes in birth characteristics.

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Contributors NM initiated the concept, designed and conducted the study, wrote the initial manuscript and approved the final manuscript as submitted. KY conducted literature review, provided important comments on the interpretation of the results and approved the final manuscript as submitted. SY and KYU oversaw the process and provided important intellectual context to the study design as well as interpretation of results, and approved the final manuscript as submitted. SVS provided important intellectual context to the study design as well as interpretation of the results, and approved the final manuscript as submitted.

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Competing interests None declared.

Ethics approval The protocol for this study was approved by the Institutional Review Board of the National Center for Child Health and Development on 22 December 2016.

Provenance and peer review Not commissioned; externally peer reviewed.

Data sharing statement Annual rates of birth characteristics (in aggregated form) are available from the authors.

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