Original Article

Secular changes in growth among Japanese children over 100 years (1900-2000)

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Human growth is associated with complex interactions between genetic and environmental factors. While research has reported increased body size and body mass index (BMI) of Japanese children, few studies have compared the magnitude of increments in growth before and after World War II (WW II) and also considered other social and economical events that may have influenced the growth of children. The current study assessed the secular change in growth in Japanese children and adolescents aged between 6 and 17 years using data from the School Health Statistics Survey conducted between 1900 and 2000 with consideration of key social changes during the 20th Century. Over the 100-year period, Japanese boys had height and weight increments of 1.0-2.0 cm per decade and 0.4-1.7 kg per decade whereas girls had rates of 1.1-1.9 cm and 0.4-1.5 kg per decade, respectively. The rates of height increment were significantly (p<0.05) different between pre-, during and post-WW II periods. While Japanese children were considerably larger in 2000 compared to 1900, increments between 1950 and 1960 reflected catch-up growth to restore physical size seen in children prior to WW II. The increments in body size continued after 1960 with greatest changes seen across the pubertal years. While increments in BMI were evident in most age groups, the BMI of 17-year-old girls was consistent over the 100 years. Results clarified secular changes in growth in Japanese school children across the 20th Century and possible factors contributing to these changes.

Key Words: secular change, Japan, children, height, BMI

INTRODUCTION

Human growth is governed by a complex set of interactions between genetic and environmental factors.[1] Genes are responsible for biochemical and hormonal regulations governing optimum height, and mechanisms of puberty including the tempo of growth, changes in body composition[2,3] and regulation of body weight. A previous study has suggested that genetic factors explain as much as 90% of individual variability in body mass index (BMI).[4] However, environmental factors interact with genetic influences on growth; for example, insufficient nutritional intake restricts growth and the onset of puberty. At the same time, being obese during childhood is an important risk factor for the development of adult obesity regardless of having obese parents.[5] Prenatal nutritional status also contributes to physical growth and the onset of puberty.[6-8] Other studies have reported that environmental factors are associated with both maternal nutritional status as well as the growth of offspring.[9] Since low birth weight infants have higher risk of developing chronic diseases at later stage of life,[10] it is important to consider social and environmental factors when discussing growth and health status of children.

Earlier growth studies reported that Japanese children showed the greatest height increment amongst 17 nations compared[11] and others reported increases in body size (ie, height) and leg length.[12,13] On the other hand, a limited number of studies have examined secular changes before World War II (WW II). Previous studies that compared differences in growth between pre- and post-WW II suggested greater rates of height and weight increments in

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the post-WW II period and concluded a significant effect of the war on the growth pattern of children and adolescents.[14,15] On the other hand, these studies utilized a selected set of pre- and post-war data, insufficient to take into account the influence of other social and economic events during the last century. Apart from WW II, the Japanese also experienced WW I (1914-1918), the Showa financial crisis (1927), and the subsequent crisis stemming from the Great Depression in the US in 1929. Each may have also influenced food availability and therefore the nutritional status of the population (Figure 1). In addition to the abovementioned social events, the growth of Japanese children may have been influenced by the nation-wide school lunch program which was commenced from 1932. Although the program was interrupted during WW II and until 1947 (resumed in Tokyo and the surrounding area from 1946 and in complete form from 1950), it is likely to have influenced nutritional status and thereby growth of Japanese children. Accordingly, it is important to compare secular changes in growth observed in both the pre- and post-WW II periods, as well as considering major social/financial events which occurred in Japan. The aim of the current study was to observe the secular change in growth in Japanese children and adolescents aged 6 to 17 years using data from the School Health Statistics Survey (SHSS) from 1900 to 2000.

MATERIALS AND METHODS

The current study utilized the SHSS conducted under the auspices of the Ministry of Education (presently, the Ministry of Education, Science, Culture and Sports; MEXT), Japan. The Survey was first conducted in the 1890's to establish growth standards and a growth monitoring system in Japan. By law, the annual health survey measures all kindergarten and schoolchildren in the country aged 5 to 17 years. Measurements of height and weight are taken by school nurses between April and June every year. Data were randomly extracted to analyze health status and the growth trends of Japanese children and adolescents. In 2008, data from 3,322,441 children and adolescents from 7,755 schools (22.6% of the students measured) was used to determine health status and of these, data from 695,600 children (4.7% of the total) was used to assess growth trends.[16]

The 1900-2000 datasets were extracted from the SHSS archive, and gender- and age-specific mean height and weight for 6 to 17-year-old groups at every decade were generated.[17] Since the SHSS was not published during the 1940-1947 period due to WW II, the 1939 dataset (the last dataset prior to the WW II) was utilized in the current study. In addition, because regular measurements of five-year-old children did not commence until 1948, the current study excluded this age group.

The datasets were divided into before WW II (pre-WW II: 1900-1939), during (1939-1950), and after WW II (post-WW II: 1950-2000) to determine the impact of the war on the growth of children as well as differences in secular growth change before and after the event. In addition, based on key social events which occurred in Japan during this period (Figure 1), time points were grouped into the following periods to examine the impact of key events: 1) the period of stable economy (1900-1920); 2) the period during the depression (1920-1930); 3) the period after commencement of the school lunch program (1930-1939); 4) the wartime period (1939-1950); 5) the period after the resumption of the school lunch program (1950-1960); 6) the period of economic growth (1960-1990); 7) the period during the lost decade after the "bubble economy" (1990-2000). Dots in Figure 1 indicate key time points for the abovementioned periods. Values were expressed in absolute and percentage (%) terms as well as a rate per decade using following equations:

$\text{Difference}_{(X1 - X2 \text{ period})}$=(value in X_2) – (value in X_1)

$\%\text{difference}_{(X1 - X2 \text{ period})}$=(value in X_2 – value in X_1)/(value in X_1) x 100

$\text{Rate per decade}_{(X1 - X2 \text{ period})}$=(value in X_2 – value in X_1)/number of decades

In addition, BMI (kg/m^2) for each age group was calculated from the population mean height and weight values reported each year and gender differences in secular changes in BMI were observed. Although BMI values calculated from the population mean height and weight cannot reflect individual variability in health status or growth, observation of the population BMI is still useful in understanding the secular changes in growth and changes in physique of this population.

All statistical analyses were conducted using SPSS for Windows (version 17.0.0, SPSS Inc., Chicago, IL, 2008). Differences in rates of increment for height, weight and BMI between the tested periods were assessed using ANOVA with Bonferonni post hoc test for each gender. In addition, influences of age, gender and the sub-periods on the rates of increment were examined using stepwise regression analyses. A significant level of 0.05 was used unless otherwise stated.

RESULTS

Figures 2 and 3 show secular changes in height and weight for Japanese children over the 100–year period. Using the 1900 data as a reference, both genders showed an increment in height and weight in 2000 in all age groups. The figures also illustrate consistent secular changes in both genders with gradual increments in height and weight from 1900 until 1939, followed by a significant ($p<0.05$) decline in 1950 and dramatic and continuous increment from 1960 onwards. Using the rate of increment during the 1900-1910 period as a reference (0.2 cm per decade for boys and 0.8 cm per decade for girls), boys showed a

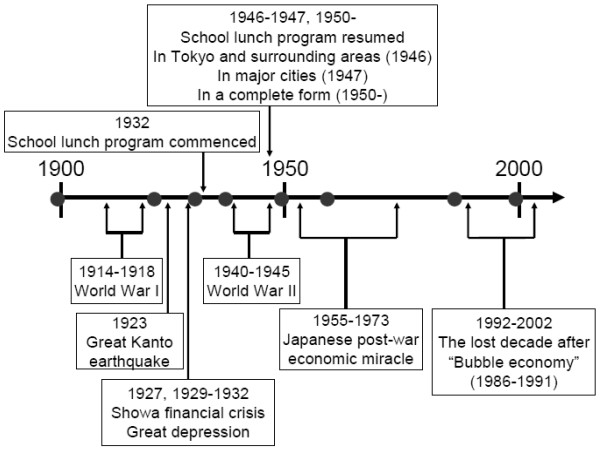


Figure 1. Time line of Japan with social and health events related to nutrition and growth in Japanese children.

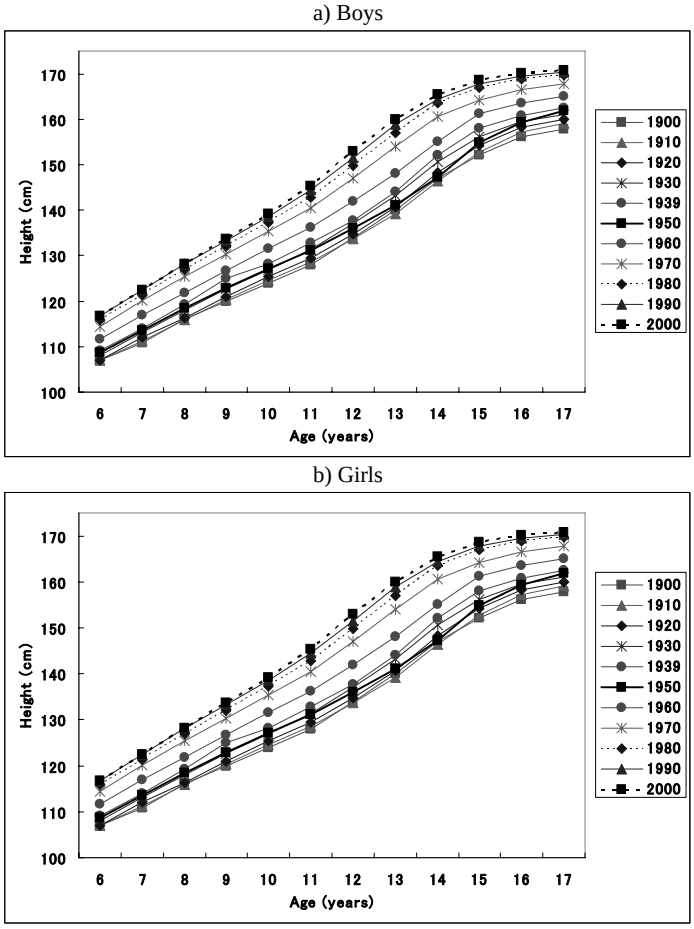


Figure 2. Pseudo distance curves for height for Japanese a) boys and b) girls between the 1900-2000 sub-periods

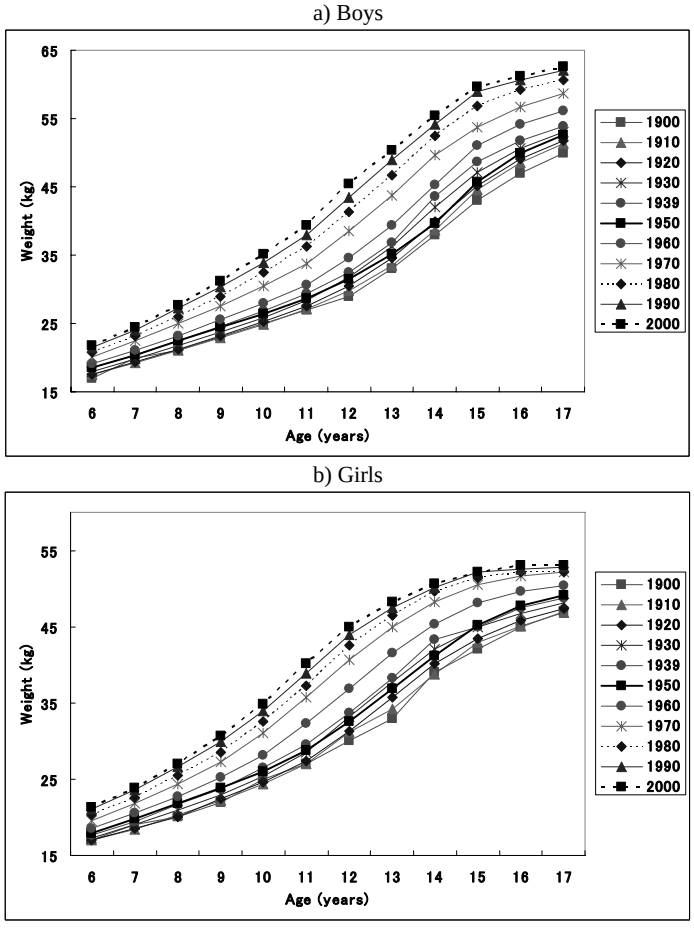


Figure 3. Pseudo distance curves for weight for Japanese a) boys and b) girls between the 1900-2000 sub-periods

significant increment in height during 1920-1930 (1.7 cm per decade) as well as 1950-1980 periods (ranging from 2.1-4.8 cm per decade). Girls showed significant height increments during 1950-1960 and 1960-1970 (3.9 and 3.4 cm per decade, respectively). For weight, increments observed from 1900-1910 for boys (0.51 kg per decade) and girls (0.18 kg per decade) were significantly (p<0.05) different from the 1950-1980 periods (ranging from 2.0-2.7 kg per decade) in boys and 1950-1970 periods in girls (2.4 kg per decade), respectively.

Height and weight increments between 1900 and 2000 are presented in Tables 1 and 2. Increments in height during the pre-WW II period ranged from 2.1 cm to 6.0 cm in boys and 2.9 cm to 6.1 cm in girls, depending on age. This is equivalent to an increment per decade in boys from 0.5 to 1.5 cm, and 0.7 to 1.6 cm in girls. This secular change was reversed during WW II. Using the 1939 data as a reference, boys showed greater reduction in height in 1950 (ranging from -0.3 cm to -4.8 cm or from -0.3% to -3.2%) compared to girls (ranging from -0.1 cm to -2.1 cm or from -0.1% to -1.4%). Height was restored after WW II and the rate of increment over the following five decades (1950-2000) was greater in boys (1.6 cm to 3.8 cm per decade) compared to girls (1.1 cm to 3.1 cm per decade). Over the 100-year period, Japanese boys and girls experienced height increments of 9.7 to 20.0 cm (1.0-2.0 cm per decade) and 11.0 to 19.2 cm (1.1-1.9 cm per decade) respectively, depending on age. The rates of height increment were significantly (p<0.05) different between pre-, during and post-WW II periods.

A similar pattern was observed for weight. Both boys and girls showed comparable rates of increment during the pre-WW II period (0.1-1.4 kg per decade in boys and 0.1-1.3 kg per decade in girls) followed by a decrease in weight gain during wartime. While boys experienced a greater decrease in weight than girls (as much as 3.9 kg or 8.9% in boys compared to 2.1 kg or 4.8% in girls), boys also recovered considerably during the post-WW II period (rate of increment: 0.7-3.1 kg per decade in boys and 0.7-2.5 kg per decade in girls). Over the 100 years, weight increments were 4.4-17.4 kg or 0.4-1.7 kg per decade in boys and 4.3-15.3 kg or 0.4-1.5 kg per decade in girls. As observed for height, the rates of weight increment were significantly (p<0.05) different between pre-, during and post-WW II periods.

In addition to an assessment of secular changes in growth between pre-, during and post WW II, the impact of other social and economic events were examined. As shown in Figures 4 and 5, both genders experienced greatest increments in height and weight during the 1950-1960 period (boys: 4.8 cm per decade and 2.7 kg per decade; girls: 3.9 cm per decade and 2.4 kg per decade), which was significant compared to the 1900-1920 subperiod (p<0.05) in both genders. In contrast, a deceleration in growth was observed during the 1939-1950 period (boys: -1.8 cm per decade and -1.2 kg per decade; girls: -0.8 cm per decade and -0.4 kg per decade) which was significant in boys for both height and weight and only

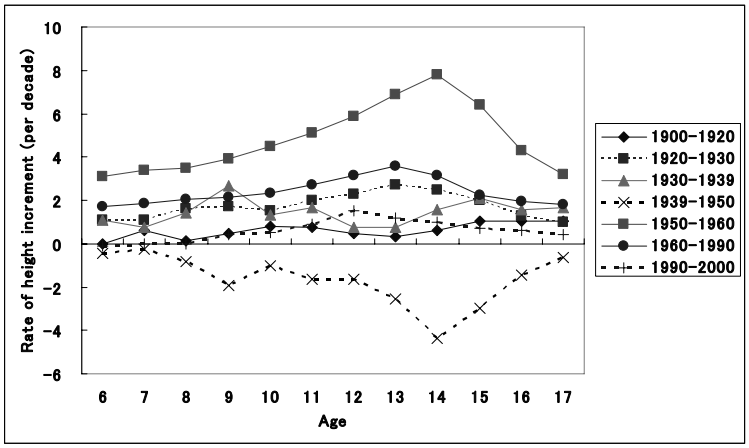
Table 1. Secular change in height in Japanese children and adolescents (6-17 years) between 1900 and 2000

		Age (yrs)											
		6	7	8	9	10	11	12	13	14	15	16	17
Boys													
Difference, cm	1900-1910	0.0	0.3	-0.3	0.3	0.6	0.6	-0.3	-0.9	-0.6	0.6	1.2	1.2
	1910-1920	0.0	0.9	0.6	0.6	1.0	0.9	1.2	1.5	1.8	1.5	0.9	0.9
	1920-1930	1.1	1.1	1.6	1.7	1.5	2.0	2.3	2.7	2.5	2.0	1.3	1.0
	1930-1939	1.0	0.7	1.3	2.4	1.2	1.5	0.7	0.7	1.4	1.9	1.4	1.5
	1939-1950	-0.5	-0.3	-0.9	-2.1	-1.1	-1.8	-1.8	-2.8	-4.8	-3.3	-1.6	-0.7
	1950-1960	3.1	3.4	3.5	3.9	4.5	5.1	5.9	6.9	7.8	6.4	4.3	3.2
	1960-1970	2.8	3.2	3.6	3.6	3.7	4.3	5.2	5.9	5.4	3.1	3.0	2.8
	1970-1980	1.3	1.2	1.4	1.6	2.0	2.4	2.7	2.9	3.1	2.7	2.3	1.9
	1980-1990	1.0	1.1	1.2	1.2	1.3	1.5	1.6	1.9	0.9	0.9	0.6	0.7
	1990-2000	-0.1	0.0	0.0	0.4	0.5	0.9	1.5	1.2	1.0	0.7	0.6	0.4
	1900-2000	9.7	11.6	12.0	13.6	15.2	17.4	19.0	20.0	18.5	16.5	14.0	12.9
Rate (/decade)	Pre-WW II	0.5	0.8	0.8	1.3	1.1	1.3	1.0	1.0	1.3	1.5	1.2	1.2
	During	-0.5	-0.3	-0.8	-1.9	-1.0	-1.6	-1.6	-2.5	-4.4	-3.0	-1.5	-0.6
	Post-WW II	1.6	1.8	1.9	2.1	2.4	2.8	3.4	3.8	3.6	2.8	2.2	1.8
	1900-2000	1.0	1.2	1.2	1.4	1.5	1.7	1.9	2.0	1.9	1.7	1.4	1.3
Girls													
Difference, cm	1900-1910	1.0	0.0	0.6	-0.3	-0.3	0.6	0.6	1.2	0.6	2.2	2.1	1.8
	1910-1920	0.0	0.3	0.7	0.9	0.6	1.2	2.5	2.4	2.8	1.2	0.9	0.9
	1920-1930	1.1	1.6	1.5	1.6	1.8	1.6	2.3	2.0	1.3	1.4	1.5	1.0
	1930-1939	1.2	1.0	1.0	1.8	1.7	1.4	0.4	0.5	1.0	1.1	1.5	1.8
	1939-1950	-0.3	-0.1	-0.1	-1.0	-1.1	-1.0	-1.5	-1.5	-2.1	-0.5	-0.3	0.2
	1950-1960	2.8	3.1	3.5	4.2	5.4	6.4	6.7	5.6	4.1	2.5	1.5	1.0
	1960-1970	3.0	3.4	3.5	3.8	4.2	4.8	4.4	4.0	3.5	2.4	2.1	1.9
	1970-1980	1.3	1.3	1.6	1.8	2.1	2.0	2.2	1.9	1.8	1.5	1.5	1.4
	1980-1990	1.1	1.2	1.2	1.2	1.2	1.4	0.9	0.7	0.4	0.6	0.7	0.9
	1900-2000	11.0	11.7	13.6	14.4	16.4	19.2	19.1	17.2	13.8	12.5	11.6	11.1
Rate (/decade)	Pre-WW II	0.8	0.7	1.0	1.0	1.0	1.2	1.5	1.6	1.5	1.5	1.5	1.4
	During	-0.3	-0.1	-0.1	-0.9	-1.0	-0.9	-1.4	-1.4	-1.9	-0.5	-0.3	0.2
	Post-WW II	1.6	1.8	2.0	2.3	2.7	3.1	3.0	2.5	2.0	1.4	1.2	1.1
	1900-2000	1.1	1.2	1.4	1.4	1.6	1.9	1.9	1.7	1.4	1.3	1.2	1.1

Table 2. Secular change in weight in Japanese children and adolescents (6-17 years) between 1900 and 2000

		Age (yrs)											
		6	7	8	9	10	11	12	13	14	15	16	17
Boys													
Difference, kg	1900-1910	0.5	-0.8	0.1	-0.1	-0.1	0.1	0.8	0.5	0.6	1.6	1.5	1.4
	1910-1920	0.1	0.2	0.1	0.3	0.4	0.4	0.7	1.1	1.3	0.6	0.6	0.4
	1920-1930	0.3	0.4	0.6	0.6	0.6	0.9	1.3	1.6	2.1	1.9	1.5	1.2
	1930-1939	0.6	0.5	0.7	0.8	1.0	0.9	0.7	0.7	1.6	1.5	1.2	0.9
	1939-1950	0.0	0.1	-0.1	-0.2	-0.5	-0.6	-1.0	-1.8	-3.9	-2.9	-1.9	-1.3
	1950-1960	0.6	0.6	0.8	1.1	1.6	2.0	3.1	4.2	5.6	5.3	4.2	3.5
	1960-1970	1.0	1.4	1.8	2.1	2.5	3.1	3.9	4.4	4.3	2.7	2.6	2.6
	1970-1980	0.7	0.8	1.0	1.3	1.9	2.4	2.9	3.0	2.8	3.2	2.5	1.9
	1980-1990	0.7	0.8	1.2	1.4	1.5	1.8	2.1	2.3	1.8	2.1	1.5	1.4
	1990-2000	0.3	0.4	0.5	0.9	1.2	1.4	1.9	1.4	1.2	0.7	0.5	0.6
	1900-2000	4.8	4.4	6.7	8.2	10.1	12.4	16.4	17.4	17.4	16.7	14.2	12.6
Rate (/decade)	Pre-WW II	0.4	0.1	0.4	0.4	0.5	0.6	0.9	1.0	1.4	1.4	1.2	1.0
	During	0.0	0.1	-0.1	-0.2	-0.5	-0.5	-0.9	-1.6	-3.5	-2.6	-1.7	-1.2
	Post-WW II	0.7	0.8	1.1	1.4	1.7	2.1	2.8	3.1	3.1	2.8	2.3	2.0
	1900-2000	0.5	0.4	0.7	0.8	1.0	1.2	1.6	1.7	1.7	1.7	1.4	1.3
Girls													
Difference, kg	1900-1910	0.0	-0.6	0.3	0.2	-0.7	0.0	1.2	1.2	-0.2	0.9	0.1	-0.2
	1910-1920	0.0	0.2	-0.3	0.2	0.3	0.4	0.1	1.5	1.3	0.5	0.7	0.6
	1920-1930	0.3	0.4	0.9	0.6	0.8	1.1	1.9	2.0	2.0	1.6	0.9	0.7
	1930-1939	0.4	0.4	0.8	0.7	1.1	1.0	0.5	0.5	1.2	0.0	0.8	0.7
	1939-1950	0.2	0.4	0.1	0.1	-0.5	-0.7	-1.1	-1.3	-2.1	0.2	0.2	0.3
	1950-1960	0.6	0.7	0.9	1.4	2.2	3.5	4.3	4.6	4.1	2.9	1.9	1.3
	1960-1970	1.0	1.3	1.7	2.0	2.8	3.4	3.7	3.4	3.0	2.4	2.1	1.7
	1970-1980	0.8	0.8	1.1	1.3	1.6	1.6	2.0	1.6	1.3	0.9	0.5	0.0
	1980-1990	0.8	1.0	1.1	1.4	1.4	1.6	1.3	1.0	0.6	0.7	0.4	0.7
	1900-2000	4.3	4.8	7.0	8.7	9.9	13.1	15.0	15.3	11.7	10.1	8.0	6.1
Rate (/decade)	Pre-WW II	0.2	0.1	0.4	0.4	0.4	0.6	0.9	1.3	1.1	0.8	0.6	0.5
	During	0.2	0.4	0.1	0.1	-0.5	-0.6	-1.0	-1.2	-1.9	0.2	0.2	0.3
	Post-WW II	0.7	0.8	1.0	1.4	1.8	2.3	2.5	2.3	1.9	1.4	1.1	0.8
	1900-2000	0.4	0.5	0.7	0.9	1.0	1.3	1.5	1.5	1.2	1.0	0.8	0.6

a) Boys



b) Girls

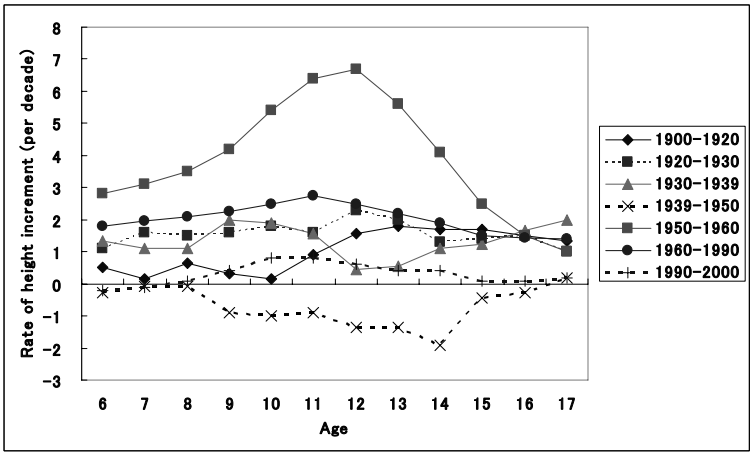


Figure 4. Rate of increment in height (per decade) for Japanese a) boys and b) girls between the 1900-2000 sub-periods

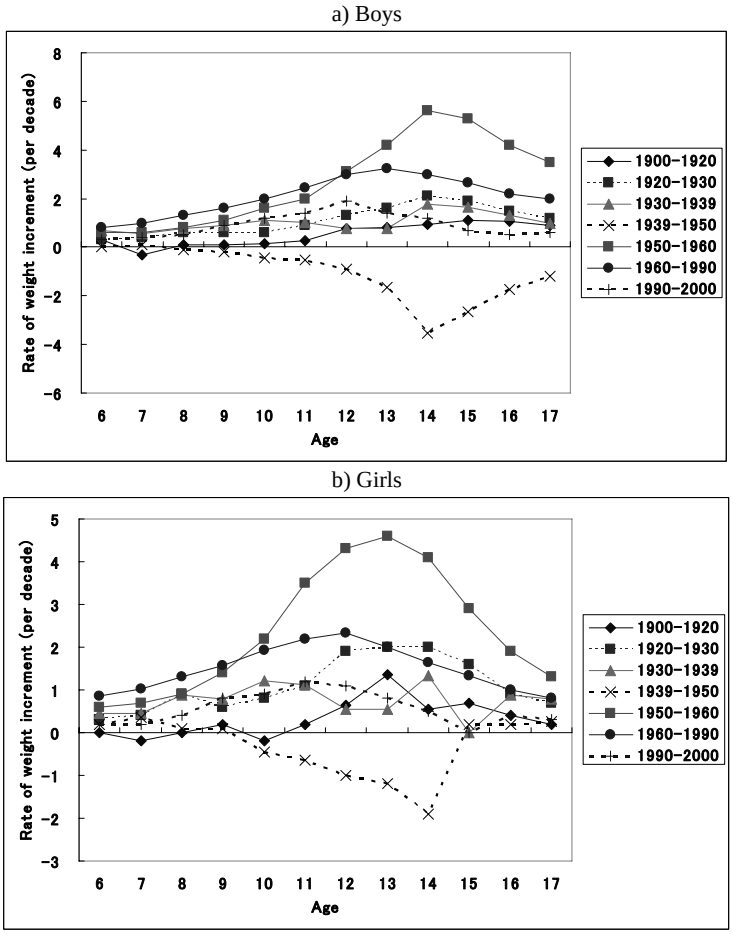


Figure 5. Rate of increment in weight (per decade) for Japanese a) boys and b) girls between the 1900-2000 sub-periods

height in girls (p<0.05). The rates of increment varied between age groups. While boys showed greatest variability for both height and weight in the 14-year-old group, greatest deceleration in growth during wartime was observed around the age of 14 but the greatest recovery was observed in the 12-year-old group. There were no significant differences in the average rate of increment between the 1900-1920 period (boys: 0.6 cm per decade for height and 0.5 kg per decade for weight; girls: 1.0 cm per decade for height and 0.3 kg per decade for weight) and other pre-WW II sub-periods (i.e. 1920-1930 and 1930-1939). In addition, the rate in the 1900-1920 period was comparable to that of the 1990-2000 period for both height and weight regardless of gender. Figures also show a deceleration of growth rate to the 1900-1939 level in the later years of the 20th Century (i.e., 1960 onwards). The regression analyses also confirmed significant differences in the rate of increment between sub-periods. Using age, gender and sub-periods as covariates, rates of increment for height and weight were described as follows:

Rate of height increment = 0.731 + 0.179 x (sub-periods), (R_{adj} = 0.043, SEE = 1.71)

Rate of weight increment = -0.601 + 0.201 x (sub-periods) + 0.073 x (age), (R_{adj} = 0.146, SEE = 1.17)

where the variable (sub-periods) is the 1900-1920 = 1, 1920-1930 = 2, 1930-1939 = 3, 1939-1950 = 4, 1950-1960 = 5, 1960-1990 = 6, 1990-2000 =7.

The secular change in BMI from 1900 to 2000 is presented in Figure 6. Based on pseudo distance curves, BMI in Japanese boys increased gradually from 1900 until 1950. While both boys and girls showed a slight decline in BMI in 1950 compared to 1939, boys restored their BMI back to 1939 level by 1960 and continued to increase in all age groups until 2000. In girls, on the other hand, a greater recovery in their BMI was seen in 1960 compared to their 1939 values with a continued increase until 2000. However, after the 1970's, the distance curve started to plateau at around 15-years and as a result, unlike boys, 17-year-old girls showed a consistent BMI score across the century.

DISCUSSION

The current study examined secular changes in growth among Japanese children and adolescents across the 20th Century to better understand the impact of social events including WW II, and other economic as well as health promotion strategies. The study confirmed that the body size of Japanese children and adolescents changed dramatically over this period.

In comparison with data collected in 1900, absolute body size (height and weight) of Japanese children and adolescents has increased considerably over the last century regardless of gender. However, the present study clarified a difference in the rate of increment in height and weight between pre-, during, and post-WW II periods. From 1900 until 1939, the body size of Japanese children and adolescents increased gradually. The growth rate declined in the wartime (1939-1950) but recovered by 1960

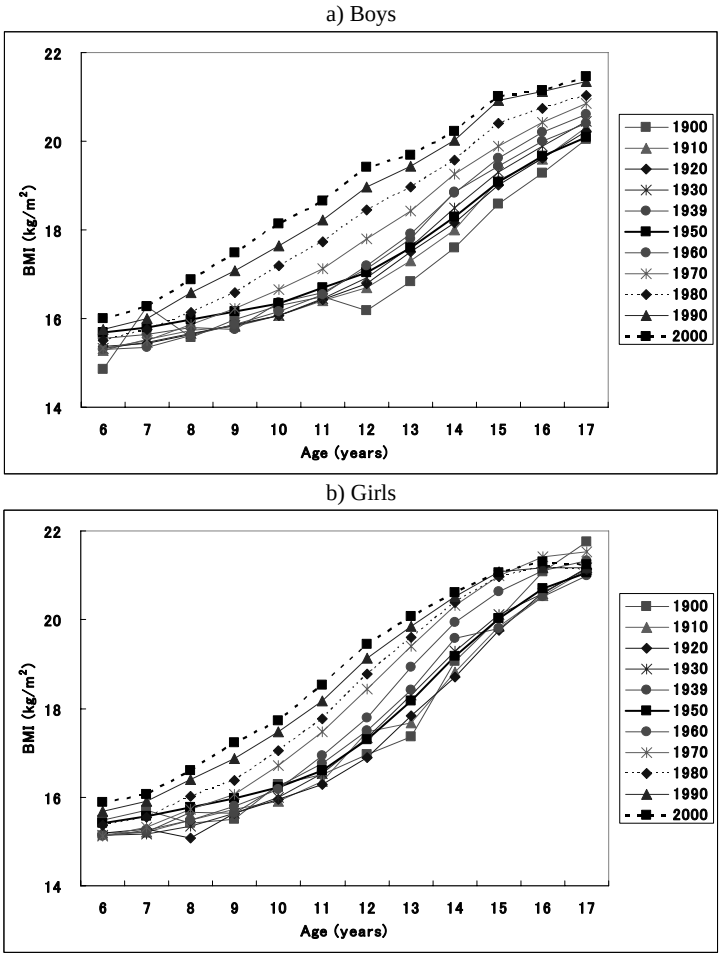


Figure 6. Pseudo distance curves for BMI for Japanese a) boys and b) girls between the 1900-2000 sub-periods

then increased continuously until 2000. This observation of complete recovery by 1960 was consistent to a previous study that reported complete recovery of height and weight in both genders of all ages by 1956 for height and 1957 for weight.[14]

Apart from WW II, Japan experienced a number of national and international events that might have influenced food availability and indirectly, the growth of children and adolescents. The current study grouped datasets into seven sub-periods – three during the pre-WW II period (1900-1920, 1920-1930, 1930-1939), the WW II period (1939-1950), and three during the post-WW II period (1950-1960, 1960-1990, 1990-2000). Due to a natural disaster (Great Kanto earthquake) in 1923 and financial crises (Showa financial crisis and Great depression) in the late 1920s to early 1930s, it was hypothesized that the growth of children may have been affected during this period. However, comparable increment rates of height and weight were see compared to the 1900-1920 sub-period indicating the minimum impact of these events on growth. In addition, there was no significant difference in the rates of increment in 1930-1939, even though previous literature reported an annual economic growth of 4.5% between 1930-1940, with a 9% industrial production rate and also the commencement of the school lunch program in 1932.[18,19] This may reflect that the Japanese economy was sufficient to provide a constant food supply compared to 1900 with a lack of severe health conditions that may have caused deterioration in growth with catch-up growth at a later stage.

A deceleration in growth observed in 1939-1950 is likely related to food shortages during WW II. In addition, malnutrition and poor growth may also be attributed to poor hygiene and increased risk of infections. A previous study reported that the rate of parasite infection increased to 73.1% in 1949 from 58.1% in 1945.[20] The recovery in growth observed in the 1950-1960 sub-period is likely a reflection of catch-up growth from an improvement in nutritional status and dietary pattern as reported in previous studies.[21, 22] From the end of 1946, the Japanese government resumed the school lunch program at selected sites (i.e., Tokyo and nearby regions) and with food supplied from General Headquarters (GHQ) and the United Nations Children's Fund (UNICEF), the program resumed at major cities in January 1947. The program provided lunch in a complete form (including bread, milk and a side dish) in 1950, and by February 1951, approximately four million school children across the country had access to the program.[19] As this lunch provided adequate energy for growth as well as essential nutrients, particularly calcium, it is likely that the nationwide program contributed to the rapid recovery of children' growth. In addition, the year 1960 in Japan was within a dramatic economic growth period known as the "Japanese post-war economic miracle." The current study clarified that adolescent age groups (14-year-old boys and 12-14-year-old girls) were most affected during the 1940-1950

period and showed the greatest recovery during the 1950-1960 period. Puberty is the time of greatest growth as well as physiological change that requires appropriate interactions between biological and environmental factors.[23] Although the current study did not observe strong evidence in support of a direct influence of the economy on the growth of children, it might have assisted indirectly in the achievement of an optimum catch-up growth rate in children and adolescents. Rates of increment for both height and weight started to drop after 1960 regardless of gender and the rate in the 1990-2000 sub-period was comparable to that of the 1900-1920. This pattern of secular change in growth provides additional support for the theory that the rapid growth Japanese children and adolescents experienced during the 1950-1960 sub-period was, at least until late 1950's,[14] a reflection of catch-up growth rather than an increase in body size *per se*.

Consistent with the changes in physical size, the current study also confirmed an increase in BMI over the last 100 years. The increase in BMI appears minimal until 1939 and after a slight decrease in 1950, it started to increase again, particularly after 1960 (ie, during the post-WW II period). This rapid increase in BMI after WW II is consistent with the global trend in the second half of the 20th century.[24-26] A number of studies have reported that the onset of puberty and physical development in Japanese school children is about two years earlier.[15,21,27] Since the level of body fat is associated with the early onset of puberty,[28,29] it can be suggested that an improvement in nutritional status plus an increase in adipose tissue deposition caused the early onset of puberty. This allowed Japanese children an extended period in which to increase their height, mainly due to increases absolute and relative leg lengths.[12,13] As others have suggested in relation to BMI,[30] body proportion is related to body weight. While an increment in absolute height and subsequent increase in frame size will increase weight, an increment in relative leg length will decrease weight compared to those with shorter relative leg length. Therefore, it may be suggested that the observed BMI secular change in the post-WW II period is a result of a balance between 1) the rate of weight increment relative to height (due to an increase in fat-free mass [FFM] and fat mass [FM]), and 2) the rate of leg length increment relative to height.

During the post-WW II period, particularly after 1960, both genders showed a considerable increase in BMI from 6 years of age and except for 17-year-old girls, values were greater than the previous sub-periods of the same age groups. This may partially reflect a previous study that found an increase in the proportion of overweight and obese children in Japan (based on age- and gender-specific 95th percentile cut-off points).[31] As the Japanese are likely to develop obesity-related metabolic problems at a lower BMI compared to Caucasians regardless of their age,[32,33] the increasing trend of BMI is considered a health concerns in Japan. While there report of reduced levels of physical activity between 1981 and 1992,[21] it is also true that, based on the adult data, the average total energy consumption among Japanese has been declining in the past several years.[34] In addition, a previous study reported that Japanese children and adolescents underwent a change in body proportion until 1980's and those with comparable body proportion showed minimum increment in their upper body mass.[35] Therefore, despite the fact that a number of Japanese children are overweight or obese, it may be inappropriate to conclude that an increase in BMI in this population over the last 100 years is solely due to an energy imbalance.

Unlike boys, girls aged 15 to 17 years showed consistent BMI values across the century. This finding suggests a small increment rate of weight relative to height which is likely to be due to increased awareness of the "ideal" thin female body image and prevalence of weight management practices after 1960. In support of this hypothesis, Takimoto *et al.*[36] reported that the proportion of young females whose BMI was below 18.5 kg/m^2 as well as those with BMI below 17 kg/m^2 has been increasing over the last 30 years (1976-2000). In addition, girls may require further health promotion strategies to prevent health problems associated with a distorted body image (e.g. disordered eating behaviour, eating disorders, osteoporosis, and anaemia) as well as to prevent them becoming thin and malnourished mothers and subsequently delivering low birth weight infants.

CONCLUSION

The current study confirmed secular changes in height and weight among Japanese school children over the last 100 years. Compared to during and post-WW II, the rate of growth during the pre-WW II was constant and was not affected by social events, including a natural disaster and financial crisis. Despite a deterioration in growth during wartime, Japanese children and adolescents experienced rapid catch-up in growth during the post-WW II period. The rate of growth varies between age groups and the pubertal years were most affected by environmental factors.

The current observation indicated that the secular changes among Japanese children and adolescents occurred predominantly due to catch-up growth. However, after complete recovery, improved nutritional status led to increased adipose tissue deposition. This may accelerate the onset of puberty and affect both absolute size and body proportions. It is difficult to clarify the exact cause of BMI increment during the post-WW II period due to the potential for combined effects of weight increment relative to height and leg length increment relative to height and growth. As BMI is only a crude measure of heaviness relative to height, it may be inappropriate to conclude that an 'observed' increase in BMI over the last 100 years was solely due to energy imbalance. However, a limitation of the current study was that BMI values were calculated using population means rather than individual values. Further studies are warranted to better understand the prevalence of overweight/obesity as well as metabolic health problems with consideration of both lifestyle and biological factors in order to develop/implement health promotion strategies appropriate for each gender.

AUTHOR DISCLOSURES

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Original Article

Secular changes in growth among Japanese children over 100 years (1900-2000)

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日本兒童在 20 世紀期間生長情況之變化

基因與環境因子複雜的交互作用與人類生長息息相關。過去研究曾報告日本兒童體型與身體質量指數的增加，然而較少的研究比較二次世界大戰前後兒童之生長，並且較少考慮其他社會及經濟因子對日本兒童生長之衝擊。本研究使用 1900 至 2000 年所進行的學童健康統計調查(School Health Statistics Survey)資料，以 6 至 17 歲之日本兒童與青少年為目標族群，同時考慮主要的社會變遷，評估在 20 世紀間目標族群之生長變化。在 20 世紀的 100 年間，男生平均每 10 年身高增加 1.0-2.0 公分，體重增加 0.4-1.7 公斤；而女生平均每 10 年身高增加 1.1-1.9 公分，體重增加 0.4-1.5 公斤。在二次世界大戰前、戰爭期間及戰後，身高增加的速率有顯著差異。雖然 2000 年的日本孩童比上 1900 年的孩童，體型明顯較大，但是在 1950 至 1960 年間，增加的幅度可能只是補長，回復至二次大戰前的體型大小。在 1960 年後，體型仍繼續增長，以青春期學生的體型增加最大。雖然身體質量指數在大部分年齡層都增加，但 17 歲的女生在那 100 年間都維持一致的身體質量指數。本篇結果釐清 20 世紀日本學童生長情況的長期變化，以及可能造成影響之因素。

關鍵字：長期性變化、日本、兒童、身高、身體質量指數