

Changes in body mass index by birth cohort in Japanese adults: results from the National Nutrition Survey of Japan 1956–2005

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Background The National Nutrition Survey, Japan (NNS-J) provides annual anthropometric information for a whole nation over 50 years. Based on this survey, the mean body mass index (BMI) of Japanese men and elderly women has increased in recent decades, but that of young women has decreased. We examined the effect of birth cohort on this phenomenon.

Methods We analysed data from the NNS-J for subjects aged 20–69 years. BMI during 1956–2005 and the prevalence of overweight and obesity ($\text{BMI} \geq 25 \text{ kg/m}^2$) during 1976–2005 were estimated.

Results The BMI increased with age in every birth cohort, with similar increments, and did not peak until 60–69 years of age. However, with cross-sectional age, the BMI usually peaked before 60–69 years of age. The differences among cohorts already existed at 20–29 years of age, and slightly increased in men between 20–29 and 30–39 years of age. The BMI in all male age groups increased from the 1891–1900 through 1971–80 cohorts. However, in women, the figure increased until the 1931–40 cohorts, but later decreased. Changes in prevalence were generally consistent with changes in BMI. The recent increase (decrease in young women) in the mean BMI is attributable to birth cohort, indicating that thinner (fatter) and less recent birth cohorts have been replaced by fatter (thinner) ones.

Conclusions A cohort effect was quantitatively demonstrated based on a repeated annual survey. In Japan, the differences in BMI among cohorts were already established by young adulthood.

Keywords Aging, body mass index, cohort effect, cross-sectional studies

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Introduction

The obesity epidemic has become a worldwide phenomenon in recent years.^{1,2} In Japan, the mean body mass index (BMI) has consistently increased in every age category of men from 1976 to 1995.³ However, the trend differs in women; although the mean BMI has increased in older women (over 60 years of age), it has decreased in younger women (20–49 years of age).³ These results are based on nationwide data from the

National Nutrition Survey, Japan (NNS-J), which has been conducted annually since 1948. A similar trend has been confirmed using other nationwide data from the National Cardiovascular Survey of Japan, which was conducted in 1971, 1980 and 1990.^{4,5}

In addition to the international criteria for metabolic syndrome,^{6,7} the Joint Committee of Eight Major Societies of Internal Medicine defined criteria for metabolic syndrome in Japanese people in 2005.⁸ The healthcare policy of the Japanese government recognizes that a systematic reduction in the prevalence of obesity is a top-priority issue.⁹ However, excessive thinness in young women is also regarded as a public health concern in Japan.^{9,10}

These increasing and decreasing trends in BMI suggest that the time courses differ among birth cohorts. However, the time courses for BMI and other anthropometric measurements by birth cohort in representative samples of Japanese adults have not been assessed quantitatively. Recently, some studies have reported the time course of BMI or the prevalence of obesity by birth cohort.^{11–16} Most of these studies were conducted for short durations of ~10 years,^{14,16} with 30 years being the longest.¹⁵ However, it takes several decades to observe changes in BMI over the adult life of a cohort. Furthermore, it takes additional decades to compare changes in BMI among multiple cohorts born in different decades. Only cumulative data from the NNS-J provide an opportunity to examine this issue.

When cohort differences are considered, three time-related factors are involved: age, period and cohort.^{17–19} There are three types of comparison for these three factors. Time trends at a fixed age and changes with cross-sectional age at fixed periods have been reported previously from NNS-J data.^{3,20–23} However, changes in BMI with age in fixed birth cohorts and differences in these changes among birth cohorts have not been described from NNS-J data. Thus, our aim was to analyse the time course of BMI by birth cohort in Japanese adults to assess quantitatively the bimodal phenomenon of increased BMI in men and elderly women and decreased BMI in young women. To address this issue, we used nationwide data from the NNS-J gathered between 1956 and 2005. We further analysed the time course of the prevalence of overweight and obesity ($\text{BMI} \geq 25 \text{ kg/m}^2$) based on data gathered between 1976 and 2005.

Materials and methods

Study population

The NNS-J is a cross-sectional annual survey carried out for large random samples of the Japanese population. Since 1948, it has been the only data source for the nutritional status of Japanese adults, including anthropometric measurements such as height and weight. The survey has been conducted

under the Nutrition Improvement Law since 1952, and under the Health Promotion Law since 2003, with a change in its name to the National Health and Nutrition Survey. The NNS-J covers ~5000 households in 300 randomly selected census units, as defined by the Ministry of Health and Welfare (MHW), Japan, until 2000, and by the Ministry of Health, Labor, and Welfare (MHLW), Japan, since 2001. Summary tables, such as means by age group, were calculated by the MHW for the 1955–98 surveys and by the National Institute of Health and Nutrition since the 1999 survey. The results of surveys have been published in a timely manner as annual reports by the MHW or MHLW. Details of the survey have been described elsewhere.^{24–26} The data are regarded as representative of the Japanese population.²⁵ Subjects were gathered locally, and heights and weights were measured.

We used data from the 1956–2005 surveys for men and women aged 20–69 years. The survey was not conducted in 1974; therefore, 49 surveys have been conducted over the last 50 years. Ages are grouped in 10-year intervals, i.e. 20–29, 30–39, 40–49, 50–59 and 60–69 years. We used mean values of height and weight for each gender and age group because there are no individual data for the early survey years. The subjects aged 20–29 years in 2005 were defined as the 1980 birth cohort. The birth cohorts were grouped by decade, giving nine cohort groups from the 1891–1900 to the 1971–80 cohorts. The first cohort group (1891–1900) contained only data for people aged 60–69 years; the second group (1901–10) had data for those aged 50–59 and 60–69 years; and the last group (1971–80) had data only for those aged 20–29 years. Only the fifth group (1931–40) had all data for the five age groups from the 20–29- to 60–69-year age groups. The periods were grouped into five 10-year periods: 1956–65, 1966–75, 1976–85, 1986–95 and 1996–2005. The total sample sizes of the 1972–2005 surveys were 128 274 men and 167 142 women. However, the sample size information for the 1956–71 surveys is missing. The average number of subjects in each age group by cohort group during 1976–2005 was 7542 (range: 4557–10 720) in men and 9771 (range: 5297–15 539) in women. The participation rate for anthropometric measurement among subjects in the NNS-J (or subjects in the lifestyle survey in NNS-J) was 80.3% in men and 86.5% in women during 1993–2005.

The prevalence of overweight and obesity ($\text{BMI} \geq 25 \text{ kg/m}^2$) for the last 30 years, 1976–2005, were analysed, but there is no information of the prevalence for the early surveys. The annual prevalence during 1980–2005²⁴ and the 5-year prevalence during 1976–80³ for each age group were used.

Statistical analysis

The BMI for each survey year was calculated as the mean weight divided by the square of the mean height. The mean values of height, weight and BMI according to gender, age and birth cohort group

were estimated. The mean values of height and weight for 20–29 years of age were estimated as the weighted mean of the mean values for 20, 21, 22, 23, 24, 25 and 26–29 years of age, with equal weight for each age. Two different models, the age-cohort and age-period,²⁷ were fitted to the data. The age-cohort model included age and cohort effects and their interactions to examine differences in changes with age among the cohorts. The age-period model included age and period effects and their interactions to examine differences in cross-sectional age effects among periods. Men and women were analysed separately. The percentage of the Type I sum of squares divided by the total sum of squares was calculated. This showed the percentage that the age effect explained the total variance, the percentage that the cohort or period effect explained the total variance in addition to the age effect and the percentage that the interaction term explained the total variance in addition to the two main effects. The general linear model procedure of the SAS 9.1 statistical software (SAS Institute, Cary, NC, USA) was used for the analyses.

The mean values of prevalence of overweight and obesity according to gender, age and birth cohort group were estimated. The mean prevalence during 1976–85 was estimated as a weighted mean, with equal weight for each survey year. The relationship between BMI and prevalence was examined visually using a scatter diagram and summarized by Spearman's correlation coefficient based on the data by gender and age groups for each survey year during 1981–2005.

Results

We examined changes in height, weight and BMI with age by birth cohort and also by survey year for each gender (Figures 1–3). Table 1 shows average changes in height, weight and BMI across birth cohorts during the successive 10 and 40 years for each gender. As expected, height in each cohort was almost constant between 20–29 and 50–59 years of age and then decreased slightly, especially in women (Figure 1A and C). Height gradually increased as the birth cohorts became more recent in men and women (Figure 1A and C). Then, height decreased with cross-sectional age (Figure 1B and D), so the change in each survey year differed qualitatively from the change in each cohort.

Weight in each cohort increased between 20–29 and 50–59 years of age and then reached a plateau in men and women (Figure 2A and C). Weight gradually increased as the birth cohorts became more recent especially in men, although the increments were very small in women after the 1931–40 cohort (Figure 2A and C). The weight in each survey year reached a peak at approximately age 30–49 years and then decreased (Figure 2B and D), so the change in each period differed qualitatively from the change in each cohort.

BMI in each cohort increased between 20–29 and 60–69 years of age (Figure 3A and C). The increments were generally similar among the birth cohorts, except the increments between 20–29 and 30–39 years of age in men, when the difference in BMI increased slightly; the difference in the increment was 0.36 kg/m² (95% confidence interval 0.12–0.61) between the 1921–30 and the 1961–70 cohorts. Between 20–29 and 60–69 years of age, the increase in BMI was 2.26 kg/m² in men and 2.13 kg/m² in women (Table 1). The increments were large between 20–29 and 40–49 years of age in men and women. Specifically, the increase between 20–29 and 30–39 years of age was prominent in men, but the increase in women occurred at a later age. The BMI of men steadily increased as the birth cohorts became more recent (Figure 3A). The BMI of women increased until the 1931–40 birth cohort, but decreased as the birth cohorts became more recent (Figure 3C). The changes in BMI with cross-sectional age varied across survey years and gender (Figure 3B and D), and differed qualitatively from the change in each cohort.

Table 2 shows the age, period and cohort effects and their interactions on height, weight and BMI, using the age-cohort and age-period models by gender. The percentage of the total variance in BMI explained by the age effect was low in men (24.5%) and much higher in women (78.6%). The percentage that the cohort effect explained in addition to the age effect was 69.0% in men and 17.6% in women. The percentage that the age-cohort interaction additionally explained was small, 0.5% in men and 0.7% in women, and no qualitative difference among birth cohorts was obvious (Figure 3A and C). These findings indicated that while the time courses of BMI differed among birth cohorts, especially in men, they were almost parallel. In the age-period model, the age-period interactions were high for all three variables. In particular, the figures were high for BMI and weight in women. These results indicated that changes with cross-sectional age varied considerably among periods (Figures 2D and 3D).

Figure 4 shows the changes in prevalence of overweight and obesity with age by birth cohort for each gender. Changes in prevalence were generally consistent with changes in BMI. The prevalence in each cohort increased between 20–29 and 60–69 years of age. The prevalence in men increased as the birth cohorts became more recent. The prevalence in women increased until the 1921–40 birth cohorts, but then decreased as the birth cohorts became more recent. The difference among cohorts was more prominent in men than in women. Figure 5 shows the relation between the prevalence and BMI. The prevalence increased monotonically, but nonlinearly, as BMI increased. The increase in prevalence per unit increase in BMI at a low level of BMI was smaller than that at a higher level of BMI. Spearman's correlation coefficient was 0.979 ($P < 0.001$).

Table 1 Average changes in height, weight and BMI across birth cohorts by gender from the National Nutrition Survey, Japan, 1956–2005

Age (years)	<i>n</i> ^a	Height (cm) Mean (95% CI)	Weight (kg) Mean (95% CI)	BMI (kg/m ²) Mean (95% CI)
Men				
20–29 vs 60–69 ^b	10	0.13 (–0.11 to 0.36)	6.10 (5.72 to 6.48)	2.26 (2.09 to 2.42)
20–29 vs 30–39	38	0.43 (0.26 to 0.60)	3.87 (3.62 to 4.11)	1.26 (1.18 to 1.34)
30–39 vs 40–49	38	0.12 (–0.03 to 0.28)	2.12 (1.99 to 2.25)	0.74 (0.69 to 0.79)
40–49 vs 50–59	38	–0.30 (–0.44 to –0.15)	0.68 (0.55 to 0.80)	0.34 (0.29 to 0.39)
50–59 vs 60–69	38	–0.57 (–0.76 to –0.37)	–0.14 (–0.37 to 0.09)	0.10 (0.02 to 0.18)
Women				
20–29 vs 60–69	10	–1.17 (–1.39 to –0.96)	4.06 (3.90 to 4.22)	2.13 (2.05 to 2.20)
20–29 vs 30–39	38	0.24 (0.15 to 0.33)	2.04 (1.91 to 2.17)	0.78 (0.72 to 0.84)
30–39 vs 40–49	38	0.01 (–0.09 to 0.10)	2.21 (2.09 to 2.32)	0.94 (0.88 to 1.01)
40–49 vs 50–59	38	–0.54 (–0.65 to –0.44)	0.50 (0.32 to 0.67)	0.39 (0.30 to 0.47)
50–59 vs 60–69	38	–1.15 (–1.27 to –1.02)	–0.36 (–0.50 to –0.22)	0.19 (0.13 to 0.26)

^aNumber of birth cohorts. The survey was not conducted in 1974.

^bThe value at the age of 60–69 years minus that at the age of 20–29 years for each birth cohort was used.

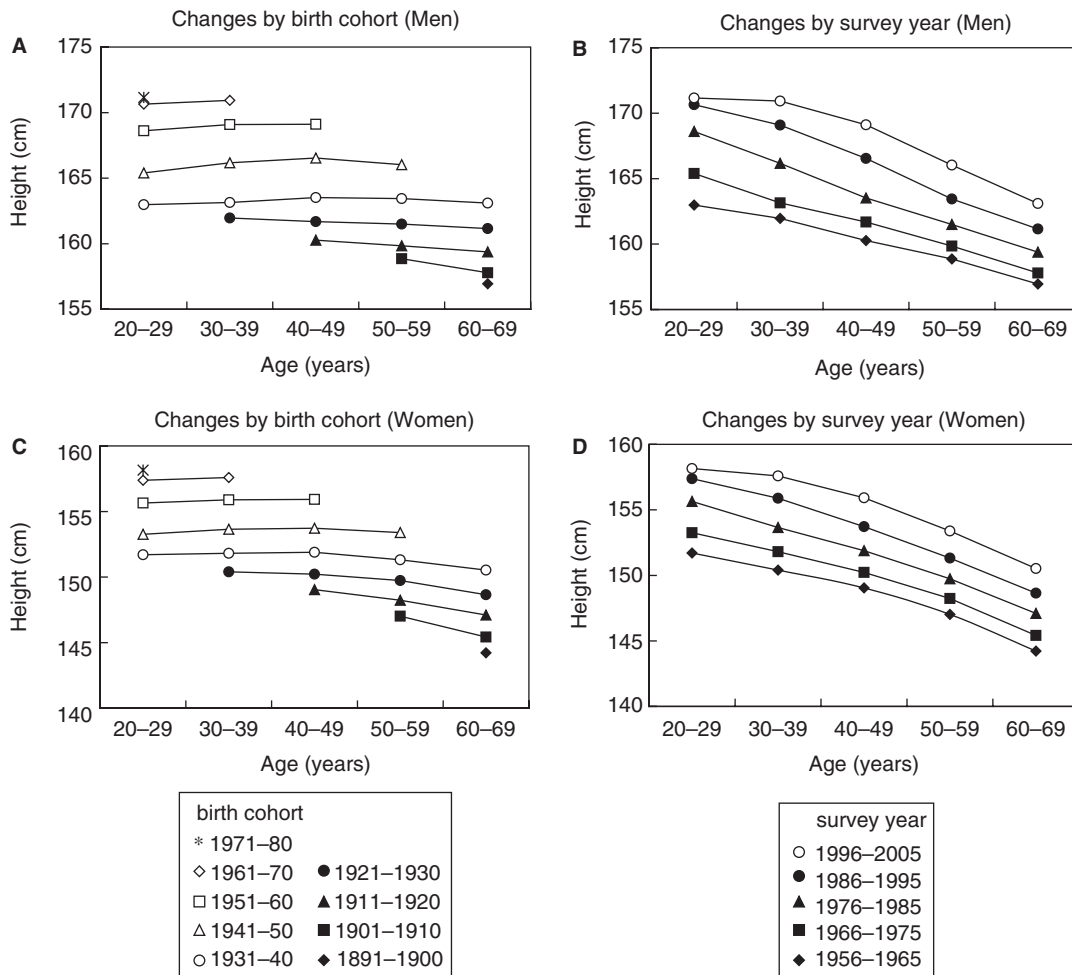


Figure 1 Changes in height with age by birth cohort (1891–1900 to 1971–80) and by survey year (1956–65 to 1996–2005) for each gender from the National Nutrition Survey, Japan, 1956–2005

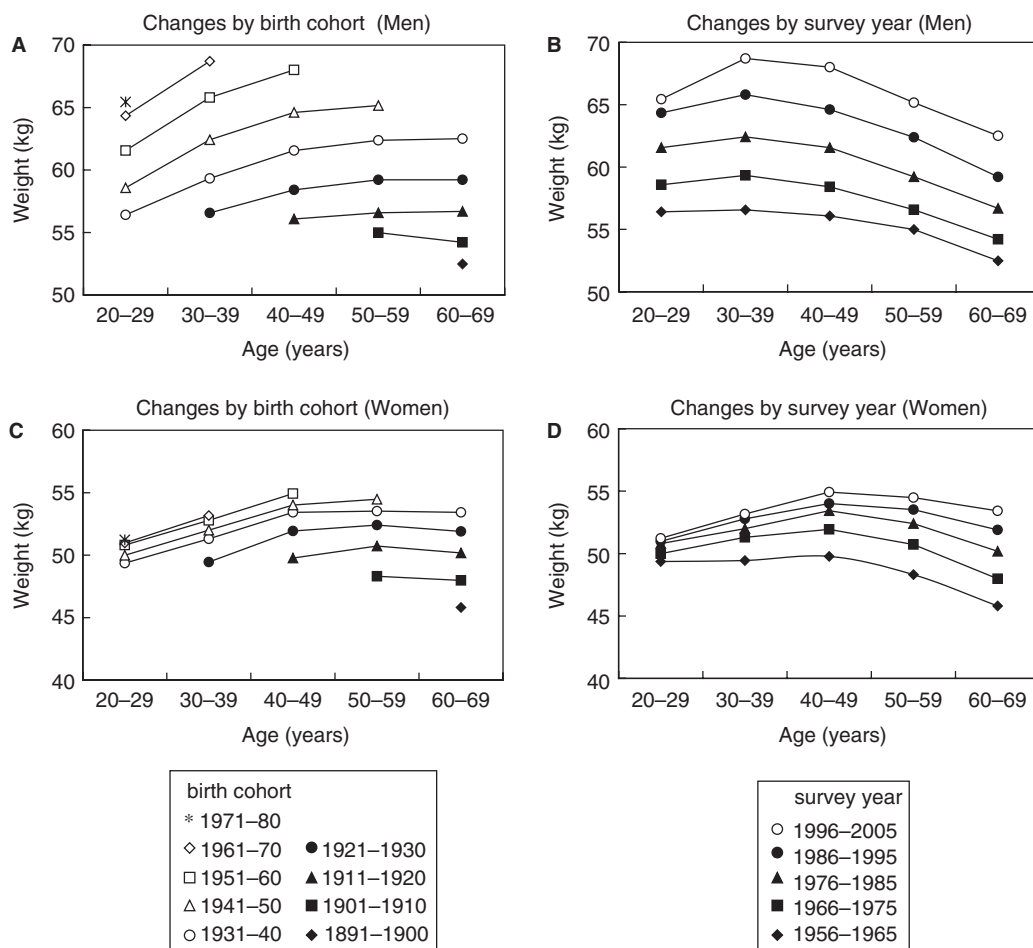


Figure 2 Changes in weight with age by birth cohort (1891-1900 to 1971-80) and by survey year (1956-65 to 1996-2005) for each gender from the National Nutrition Survey, Japan, 1956-2005

Discussion

We focused on changes with age by birth cohort, rather than on changes with cross-sectional age at a fixed time or the time trend at fixed ages. The latter two effects have been used to discuss the results of surveys in previous studies.^{3,20-23} The changes with age by birth cohort were qualitatively different from the changes with cross-sectional age. For example, in men, the BMI increased with age by birth cohort, but decreased with cross-sectional age. Furthermore, the relationship between cross-sectional age and BMI will change dynamically over the years (Figure 3D). In contrast, changes with age by birth cohort were relatively consistent (Figure 3C), and easy to interpret. The analysis that focused on changes with age by birth cohort provides new insights.

Focusing on changes with age by birth cohort, the BMI consistently increased with age in all birth cohorts in men and women. This finding is consistent with those of other studies that have investigated the time course of BMI or the prevalence of obesity by birth cohort.¹¹⁻¹⁶ Furthermore, this finding is consistent with the phenomenon that longitudinal studies in older people

suggest little change or only small decreases in BMI, although BMI reaches a peak at 50-59 years of age according to cross-sectional studies.^{28,29} Thus, it seems to be biologically plausible that BMI increases with age, at least until 60-69 years. More specifically, BMI increased nonlinearly, with large increases between 20-29 and 40-49 years of age. The increment between 20-29 and 60-69 years of age were almost the same in men and women, although the tempos differed. The increase between 20-29 and 30-39 years of age was prominent in men, although the increase in women was seen at a later age. Changes in BMI depend on relative changes in height and weight, and these two variables showed different nonlinear curves. Height tended to be flat between 20-29 and 50-59 years of age and then decreased slightly, especially in women, but weight tended to increase until age 50-59 years and then reach a plateau. Thus, the rapid increase in BMI between 20-29 and 40-49 years of age was largely attributable to the increase in weight. Between 50-59 and 60-69 years of age, the BMI increased because the decrease in height was more influential than the change in weight. This finding of a greater increase at a younger age is consistent with several other studies.^{11,13,15,16}

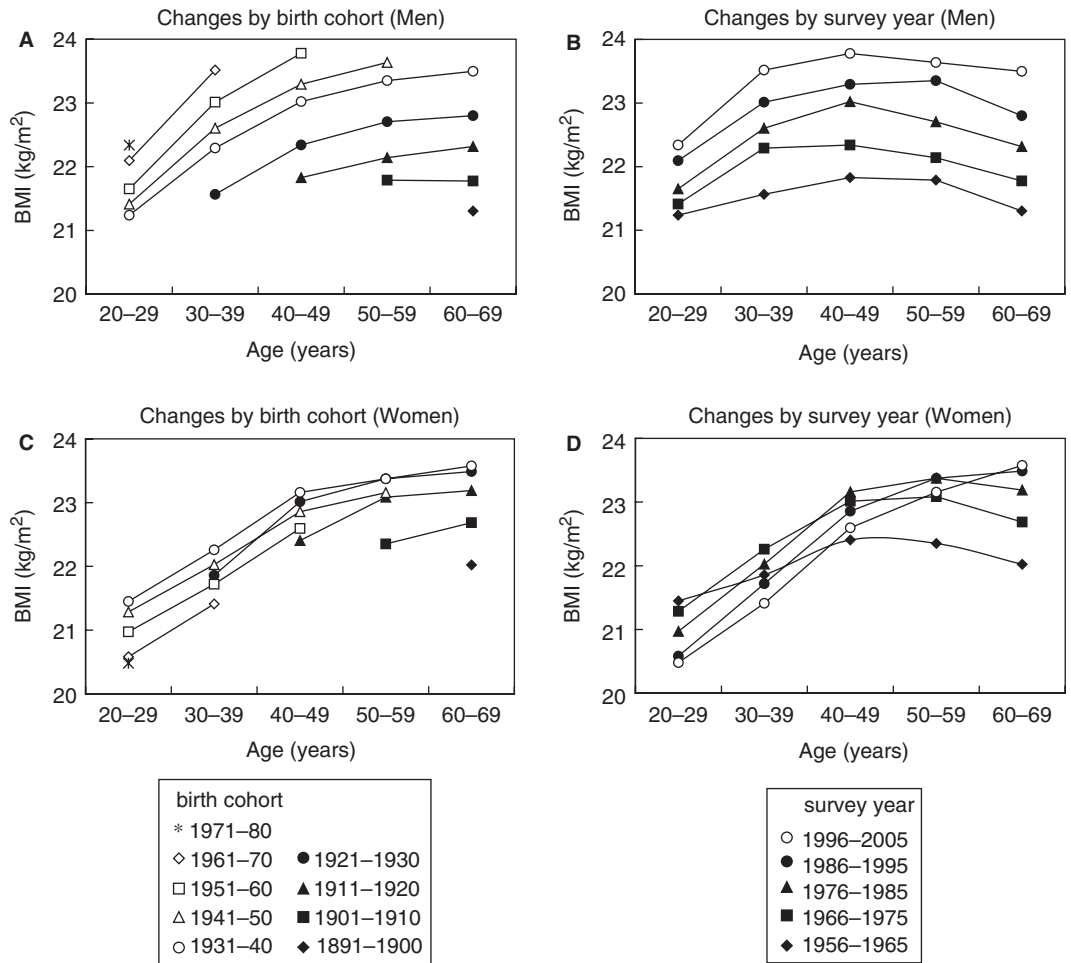


Figure 3 Changes in BMI with age by birth cohort (1891–1900 to 1971–80) and by survey year (1956–65 to 1996–2005) for each gender from the National Nutrition Survey, Japan, 1956–2005

Table 2 Age, cohort and period effects and interactions on mean height, weight and BMI by gender, the National Nutrition Survey, Japan, 1956–2005

	Percent of sum of square (%) ^a				
	Age-cohort model			Age-period model ^b	
	Age df ^c = 4	Cohort df = 8	Interaction df = 12	Period df = 4	Interaction df = 16
Men					
Height	48.2	49.5	0.1	47.6	2.1
Weight	19.5	76.6	0.2	75.7	1.2
BMI	24.5	69.0	0.5	66.1	3.3
Women					
Height	57.3	40.7	0.1	40.4	0.5
Weight	22.5	72.3	0.3	62.0	10.5
BMI	78.6	17.6	0.7	4.1	14.1

^aPercent of Type I sum of squares divided by the total sum of squares.

^bAge effect in the age-period model is identical to that in the age-cohort model.

^cdf, degrees of freedom.

Although the increments and decrements in height, weight and BMI were similar among the birth cohorts, the mean values of these variables at a fixed age differed among them. Thus, the differences among the cohorts already existed at 20–29 years of age and almost did not change until 60–69 years, except that the difference in BMI slightly increased between 20–29 and 30–39 years of age in men. Height and weight increased as the birth cohorts became more recent in both men and women, whereas the BMI increased only in men. The larger BMI in more recent cohorts at a fixed age in men is consistent with results from several studies.^{11,16} The BMI increased in women until the 1931–40 birth cohorts and decreased thereafter. In particular, the increase in weight from the 1931–40 to the 1971–80 cohorts in women was smaller than that in men. It was also smaller compared with the increase in their height. One reason for the difference between men and women may be a preference for leaner appearance in young women. A misconception regarding self body image was determined from the NNS-J data, which

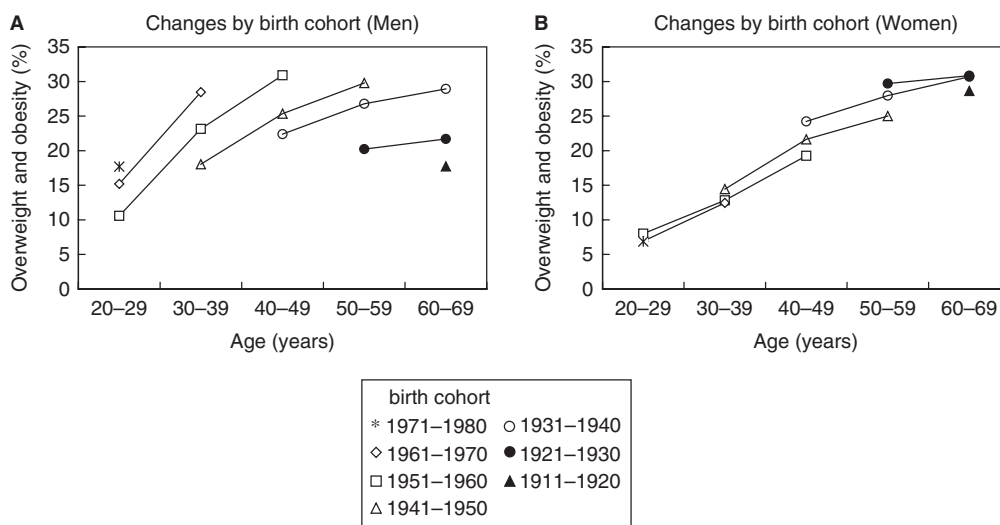


Figure 4 Changes in prevalence of overweight and obesity ($BMI \geq 25 \text{ kg/m}^2$) with age by birth cohort (1911–20 to 1971–80) for each gender from the National Nutrition Survey, Japan, 1976–2005

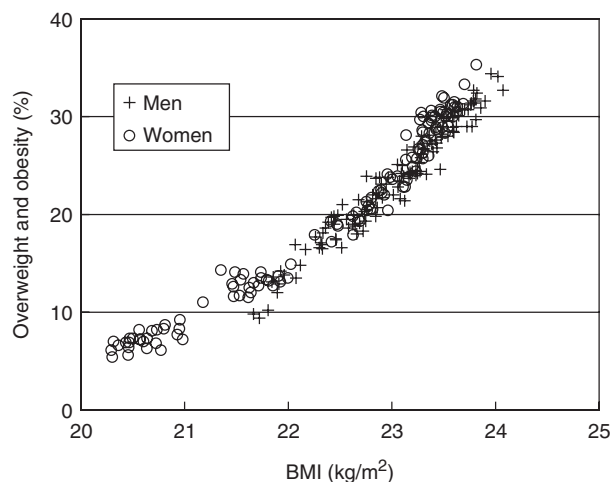


Figure 5 Relation between body mass index (BMI) and prevalence of overweight and obesity ($BMI \geq 25 \text{ kg/m}^2$) across gender, age (20–29 to 60–69 years) and survey year (1981–2005) from the National Nutrition Survey, Japan, 1981–2005

indicated that young women who were actually below normal weight often regarded themselves as being overweight.³⁰

The recent increases in BMI in men and elderly women were attributable to birth cohort, indicating that thinner and less recent birth cohorts have been replaced by fatter ones. The bimodal phenomenon of increased BMI in elderly women and decreased BMI in young women can be explained by focusing on the peak 1931–40 birth cohort. After these cohorts, fatter and less recent birth cohorts have been replaced by thinner ones. This was not likely to have been caused by differences in patterns of change among the birth cohorts. However, the exact reason for the biphasic shift is unclear. In Japan, men born between 1925

and 1939 (the early Showa Era in the Japanese calendar) are known to have high mortality rates from diabetes mellitus, ischaemic heart disease, peptic ulcers, cirrhosis of the liver and suicide.³¹ They were born in the same years as the birth cohort with the peak BMI in women in the present study, and a common factor may be present.

One of the largest events that affected anthropometric measurements in recent Japanese history is of course World War II. The NNS-J was started just after World War II to assess nutritional conditions in the population. Restrictions in the food supply started around 1940 in Japan. The height of children decreased, with the estimated worst period being 1944–45; the most damaged age was the 14-year-old.³² People born between 1925 and 1939 experienced food shortages from 1940 to 1945 during their childhood and early adult life (1–20 years of age). Some studies have suggested that this early period of life may be important in the susceptibility to develop obesity.^{2,33} Changes in early life may result in an increase in obesity or thinness at later ages.

Changes in the prevalence of overweight and obesity over the last 30 years were generally consistent with changes in BMI, although the overlapping periods among birth cohorts were longer in BMI due to the longer duration of observation over 50 years. The scatter diagram (Figure 5) showed a monotonic, but nonlinear, relationship between BMI and prevalence. This nonlinear relationship is consistent with another study.³⁴ The prevalence of overweight and obesity decreased in women after the 1921–40 birth cohorts. In contrast, the prevalence of thinness ($BMI < 18.5 \text{ kg/m}^2$) increased in young women aged 20–29 years from 12.4% in 1980 to 22.6% in 2005.²⁴ These results suggest that the opposite trend in young women accompanied both the increase in thinness and the decrease in overweight and obesity.

The NNS-J data are based on repeated random samples from multiple, large birth cohorts. Random sampling assures the reliable estimation of changes in BMI by birth cohorts at the population level, and an advantage of our study is that we were able to infer whether the changes differed among birth cohorts from different decades. This study is the first to report the effect of birth cohort, based on the longest term observations available, and it would be difficult to infer our results from a longitudinal study with a closed cohort. The disadvantage is that all the inferences are described in terms of population averages, and the variability of time courses among individuals and the effects of covariates cannot be inferred. Changes in BMI with age by birth cohort were studied in Denmark¹⁵ over 30 years and in eastern Finland¹² over 25 years. The absolute values of BMI and its increase with age were varied, with the largest in Finland and the lowest in Japan, but similar gender-specific patterns of increases with age described before were seen. The differences among birth cohorts in BMI were seen in Danish men and Finnish men before about the 1930 cohorts at older ages, but the differences were not clear in more recent, younger cohorts. The differences among birth cohorts in women were not clear in either study. In contrast, the differences were clearly seen in Japanese men and women. Our study appeared to have a higher power to detect cohort differences because of the large number of times the survey was repeated, the large sample size and the large number of overlapping periods among the birth cohorts. The NNS-J was started in 1948 and has been conducted for more than 50 years, allowing us to assess changes over decades in multiple birth cohorts born in different decades.

The BMI was calculated using mean values of height and weight for each gender, age group and survey year because individual data were not available for early survey years. Preliminarily, we assessed differences from the mean BMI calculated from the BMI for each individual. The root mean squared differences based on data from the 1996–2005 surveys ($n = 100$) was 0.037 kg/m^2 . Thus, the difference is small and likely negligible, at least in the Japanese surveys. Some researchers may be interested in more details

such as results according to 5-year age groups and results stratified by major confounders, although this information does not exist for the early survey years.

The analysis of age, period and cohort effects has received considerable attention in analyses of incidence and mortality.^{35–38} The concept has been applied to quantitative data from longitudinal studies of total cholesterol level³⁹ and especially pulmonary function.^{27,40,41} Fitting statistical models with age, period and cohort effects to estimate each effect separately is fraught with difficulty because of linear dependency. Xu *et al.*²⁷ have proposed two-factor models to examine longitudinal and cross-sectional age effects. This method avoids the problem of the lack of identifiability and provides a straightforward interpretation for the estimated parameters. We used this method to analyse data from a series of cross-sectional annual surveys.

In conclusion, we showed an increase in BMI with age in every birth cohort. The differences in BMI among cohorts were already established by young adulthood. This is the first quantitative analysis that demonstrates a cohort effect based on an annual survey repeated over 50 years. Birth cohort should be emphasized in understanding the origins of the obesity epidemic. Some increase in BMI seems inevitable with aging, and men in more recent cohorts require swift intervention to slow their current rate of weight gain.

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Conflict of interest: None declared.

KEY MESSAGES

- This is the first quantitative analysis that demonstrates a cohort effect based on the National Nutrition Survey, Japan (NNS-J), which is the longest cross-sectional annual nationwide survey repeated over 50 years.
- The BMI increased with age in every birth cohort, with similar increments, and did not peak until 60–69 years of age.
- The difference in BMI among cohorts already established by young adulthood.
- In Japanese men and elderly women, thinner and less recent birth cohorts have been replaced by fatter ones. The opposite holds for young women, in which fatter and less recent birth cohorts have been replaced by thinner ones.
- Changes in BMI with age by birth cohort were qualitatively different from those by survey year.

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