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Original article

Trends in the skewness of the body mass index distribution among urban Australian adults, 1980 to 2007

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ABSTRACT

Purpose: We analyzed the changes in the body mass index (BMI) distribution for urban Australian adults between 1980 and 2007.
Methods: We used data from participants of six consecutive Australian nation-wide surveys with measured weight and height between 1980 and 2007. We used quantile regression to estimate mean BMI (for percentiles of BMI) and prevalence of severe obesity, modeled by natural splines in age, date of birth, and survey date.
Results: Since 1980, the right skew in the BMI distribution for Australian adults has increased greatly for men and women, driven by increases in skew associated with age and birth cohort/period. Between 1980 and 2007, the average 5-year increase in BMI was 1 kg/m^2 (0.8) for the 95th percentile of BMI in women (men). The increase in the median was about a third of this, and for the 10th percentile, a fifth of this. We estimated that for the cohort born in 1960 around 31% of men and women were obese by age 50 years compared with 11% of the 1930 birth cohort.
Conclusions: There have been large increases in the right skew of the BMI distribution for urban Australian adults between 1980 and 2007, and birth cohort effects suggests similar increases are likely to continue.

Introduction

We and others have demonstrated that the increases in body mass index (BMI) seen in Australia, New Zealand, and the United States over the past decades have occurred across the entire distribution of BMI, such that even those with the lowest BMI today are heavier than those with the lowest BMI in previous decades [1–3]. However, it is also true that the degree of increase in BMI has been positively correlated with the level of BMI, such that the increase in the prevalence of severe obesity has been greater than that of mild obesity [2–5].

In Australia, between 1980 and 2000, we previously described that, as the prevalence of obesity approximately doubled, the prevalence of class III obesity (BMI $\geq$ 40 kg/m^2) increased fourfold [3]. Similarly, in the United States, between 2000 and 2005, as the prevalence of obesity increased by around one quarter, prevalence of class III obesity increased by around half [4]. Although these observations have been described for the United States and Australia, there has been no direct estimation of the trends in the shape of distribution of BMI over time across different periods or birth cohorts.

Here, we extend on our previous analyses by analyzing changes in the distribution of BMI in more detail. We aimed to estimate the changes in percentiles of BMI for the period 1980 to 2007 and birth cohorts between 1920 and 1980 and to estimate the increase in prevalence of class II and III obesity for these birth cohorts.

Methods

Approach

We combined individual level data from six nationally representative Australian cross-sectional surveys of urban adults with measured height and weight. We used the information on individuals' date of birth and survey dates to construct persons' age at survey. We analyzed trends in the distribution of BMI for Australian adults according to age, calendar time (between 1980 and 2007), and birth cohort.

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Data source

This analysis compares data from six Australian cross-sectional surveys between 1980 and 2007: the National Heart Foundation Risk Factor Prevalence Surveys, 1980 [6], 1983 [7], and 1989 [8]; the National Nutrition Survey (NNS), 1995 [9]; the Australian Diabetes, Obesity, and Lifestyle Study (AusDiab), 2000 [10]; and the National Health Survey (NHS), 2007 [11].

The Risk Factor Prevalence Surveys were conducted on a random selection of 25-to 64-year-olds (extended to 20- to 69-year-olds in 1989) residing in capital cities and listed on state electoral rolls. They aimed to determine the prevalence of ischemic heart disease risk factors in the Australian population. Total number of participants and response rate was 5603 (67%), 7615 (75%), and 6097 (65%) in 1980, 1983, and 1989, respectively. The NNS was conducted on a random subsample of the 57,633 participants aged more than 2 years from urban and rural Australia who had participated in the 1995 NHS. The NNS is used here because unlike the 1995 NHS, participants' height, weight, and waist circumference were measured. Total number of participants (response rate) was 13,858 (61%). AusDiab was conducted in 42 randomly selected sites around Australia in a target population aged 25 years or older to explore the prevalence of diabetes, obesity, hypertension, and kidney disease. Baseline data included 11,247 participants (37% response rate). The 2007 NHS was conducted in one randomly selected adult (18+ years old) and child (2 to 18 years old) from a random sample of 17,426 inhabited private dwellings across Australia from August 2007 to June 2008 to capture the health status of Australians, including their lifestyle and utilization of health services and facilities. Total number of participants (response rate) was 15,792 (91%).

Participants' height and weight were measured in each survey using a stadiometer and digital scales, and these values were used to calculate participants' BMI in kilogram per square meter. Measurements were averaged where multiple readings were taken to improve accuracy.

Selection criteria

Participants were excluded from the present study if they were recorded as pregnant (or women whose pregnancy status was unknown or not stated at the time of the survey), were missing BMI, or had a BMI outside the 15 to 50 kg/m^2 range. As participants in the NNS and NHS with extreme height or weight data (height outside the range of 145–200 cm and weight outside range of 40–140 kg) were excluded from the data set to preserve confidentiality of the data, we excluded participants with these measurements from all surveys to maintain comparability. Furthermore, we restricted the analysis to urban adults ($\geq$20 years) as rural participants and persons under 20 years were not available in all surveys. The final sample size in the analysis was 42,618.

Combined data

The analysis data set consisted of one record per person with complete information on date of birth, date of examination (and hence age at examination), and measured height and weight (and hence BMI [weight [kilogram]/height^2 [square meter]). For the National Health Surveys where no individual date of examination was available, we assigned a random date in interval during which survey data was collected. Figure 1 shows the distribution of age and date of examination in the final analysis data set.

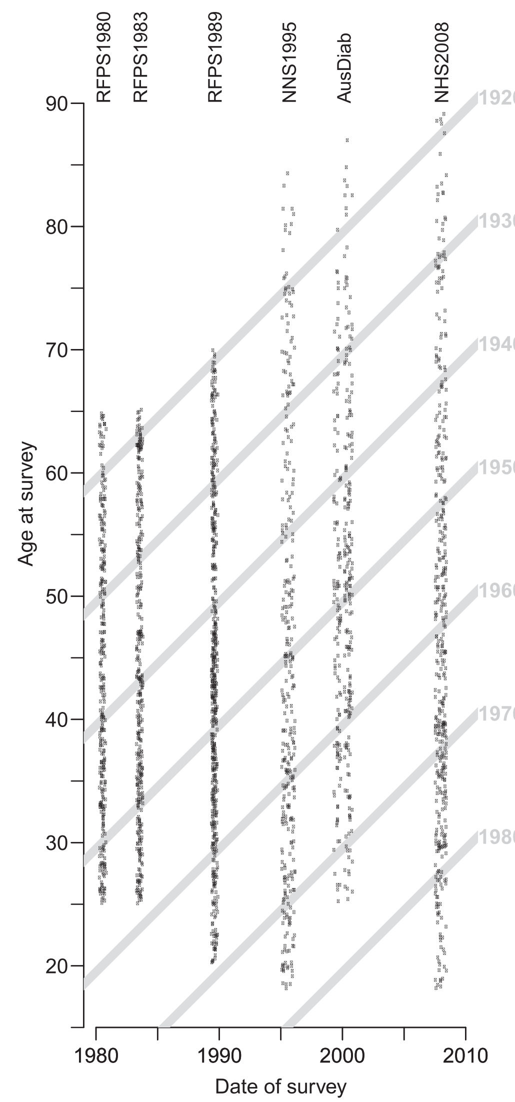

Fig. 1. Age and date of survey for a random 5% sample of persons in the analysis. The *gray lines* indicate the birth cohorts (from the *top*) 1920, 1930, ..., 1980.

Ethics

We received ethics approval for this study from the Alfred Hospital Ethics Committee (approval number 55/12).

Data analysis

Analyses were conducted separately for men and women. The basic assumption was that the distribution of BMI varies smoothly by age and date of birth, so although the distribution is only recorded at six narrow calendar time intervals, we assumed that the surveys represent the overall smooth variation of BMI distribution for birth cohorts over time.

Initially we modeled mean log-BMI by a linear model with normal errors, but found that this approach violated assumptions about variance homogeneity and assumptions about normality (primarily symmetry) of the residual distribution, in particular among women.

As it was of primary interest to analyze the distribution of BMI as it evolved over time, we used quantile regression for the BMI percentiles 5, 10, 25, 50, 75, 90, and 95. Each of the seven quantiles were modeled separately in an age–period–cohort model [12] by natural splines in age and date of birth, both with six knots (and hence five parameters) and date of survey with three knots (one nonlinear parameter).

The age–period–cohort models for the BMI quantiles were parameterized by an age-specific BMI for the 1950 (reference) cohort, an additive cohort effect relative to this, and a residual period effect constrained to be 0 on average with a 0 slope; all allowing nonlinearity. Estimated age effects were derived for each of seven BMI percentiles, allowing age-specific BMI percentiles to be interpreted as how the development would be in a particular birth cohort. Note that we are not considering mortality in this study, so we are modeling the development of BMI with age for a given birth cohort among survivors at a given age. A simplified model assuming a linear trend by date of birth (and hence by date of survey too) was also fitted to provide overall figures of trends in BMI percentiles in more detail. This analysis was made both for absolute and relative changes in BMI percentiles, the latter by using the log transform.

To show the absolute levels of BMI over time, results from the models were shown as the age-specific percentiles in cohorts 1920, 1930, …, 1980 and for the survey dates 1980, 1985, …, 2010.

Finally, we inverted the fitted models to estimate the fraction of persons at a given age and time that exceeded a BMI of 30, 35, or 40 kg/m^2. Confidence intervals for these fractions were computed using bootstrap.

All analyses were done in R [13], version 3.0.2 with the quantreg package, version 4.98 [14]. A complete account of all data reading, transformation and all statistical analyses is available as http://BendixCarstensen.com/IDI/BMI/BMI-APC.pdf.

Results

There were a total of 43,631 persons in the analysis surveyed between May 1980 and May 2009. Overall, there were slightly fewer men than women in the surveys (Table 1). The six surveys had similar distributions of men and women, Australian-born participants, smoking status, and education status, but the age range varied (Table 1). The response fraction was similar across the surveys, apart from AusDiab, which had a lower response fraction.

Age–period–cohort modeling of the 5, 10, 25, 50, 75, 90, and 95 percentiles of BMI showed that the spread in BMI was very skewed, with skewness increasing with both age and birth cohort (Fig. 2). We found that the distribution of BMI has spread out over time, with the increase by cohort in the higher percentiles of BMI steeper than among the lower percentiles (Fig. 2) We found no substantial deviation from linearity by period although the effect was formally statistically significant, but the cohort trends for women were steeper in the later cohorts for the 90th and 95th percentiles.

When assuming the effects of cohort and calendar time to be linear, the increase in the 95th percentile was around 1 kg/m^2 per 5 years for women and 0.8 kg/m^2 for men, whereas the increase for the median was only about a third of this and for the 10th percentile a fifth of this (Fig. 3). It was noticeable that even the leanest 5% of the population saw a small increase of about 0.15 kg/m^2 per 5 year. There was a small tendency that the increases were higher for men than women in the lower percentiles and vice versa for the higher percentiles, so there seems to be a tendency that the distribution of BMI among women at the higher end of the BMI scale is spreading more over time than the distribution for men (Fig. 3).

This tendency was further demonstrated when analyzing the development of BMI with age for successive birth cohorts (Fig. 4). Although there is not yet enough overlapping empirical data to enable firm conclusions regarding changes across birth cohorts for a specific age, there was a clear increase in all BMI percentiles by birth cohort; in particular, increases were greater for higher BMI percentiles, such that the 90th percentile of BMI for men and women aged 50 years increased from 28 kg/m^2 and 29 kg/m^2 in the 1920 birth cohort to 37 kg/m^2 and 40 kg/m^2 in the 1980 birth cohort, respectively, whereas the corresponding increases in the 10th percentiles were from 22 to 19 kg/m^2 to 24 and 22 kg/m^2 (Fig. 4).

When inverting the model to estimate the fraction of the population exceeding BMI 30, 35, or 40 kg/m^2 over time (Fig. 5) and with successive birth cohorts (Fig. 6), we found as previously reported, that in the latest period more than 30% of middle-aged men and women had a BMI more than 30 kg/m^2, with around 10% at the peak age exceeding a BMI of 35 kg/m^2 (Fig. 5). This compares to around 10% (exceeding a BMI 30 kg/m^2) and less than 5% (exceeding a BMI of 35 kg/m^2) in 1980.

Using a cohort perspective, we estimated that for the cohort born in 1960 around 31% of men and women were obese by age 50 years compared with 11% of the 1930 birth cohort (Fig. 6). The proportion reaching a BMI of 35 kg/m^2 or greater by age 50 years increased from around 2% for the 1930 birth cohort to around 11% for the 1960 birth cohort. Although empirical data for this age are not yet available for birth cohorts beyond 1960, the data from younger ages suggest that the prevalence will continue to increase in the 1970 and 1980 birth cohorts.

Discussion

In this analysis of changes in the distribution of BMI across a series of six national cross-sectional biomedical surveys between

Table 1
Demographic information from the six surveys

	1980 Risk Factor Prevalence Survey	1983 Risk Factor Prevalence Survey	1989 Risk Factor Prevalence Survey	1995 National Nutrition Survey	2000 Australian Diabetes, Obesity and Lifestyle Survey	2007 National Health Survey
N	5572	7569	9134	6184	6758	7401
Men (%)	50	49	49	48	46	48
Response fraction (%)	67	75	65	61	37	91
Age distribution, y (%)						
20–25	—	—	8	12	—	10
25–35	28	27	22	21	13	19
35–45	24	27	27	20	22	21
45–55	25	23	19	17	28	17
55–65	23	23	16	13	19	15
≥65	0	0	7	18	18	18
Australian born (%)	71	71	73	69	71	67
Current smokers (%)	32	30	24	24	15	20
Attained high school or higher education (%)	51	58	57	41	51	56

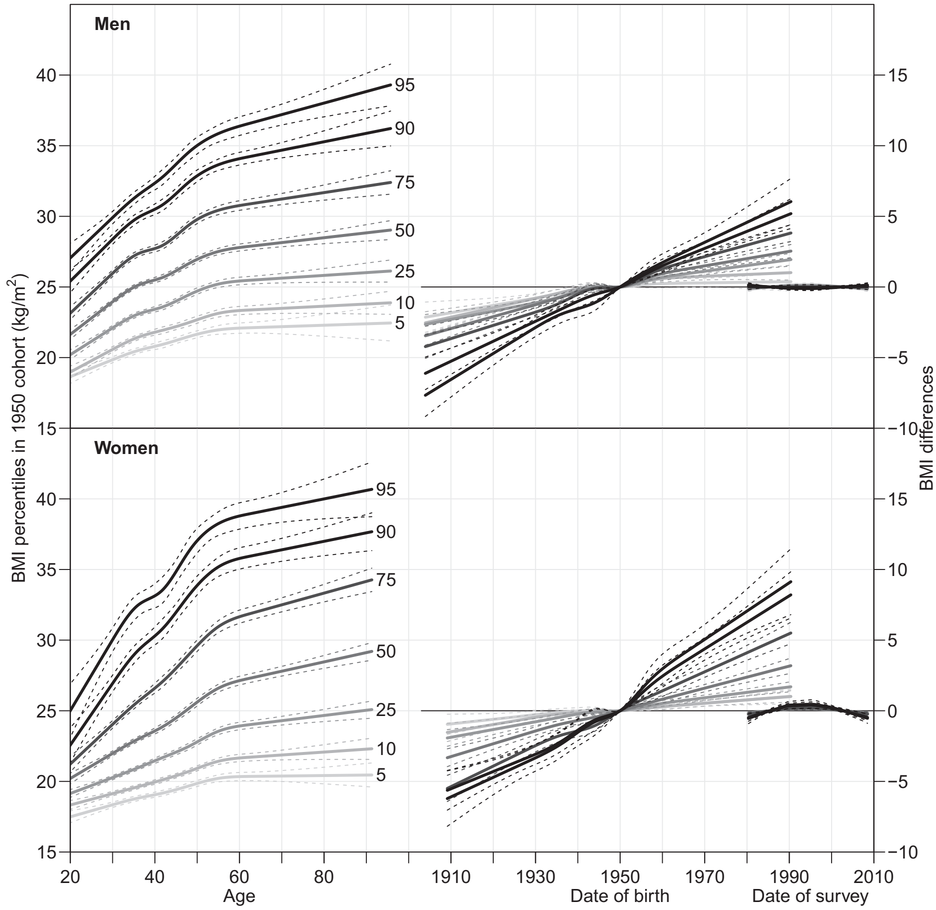

Fig. 2. Body mass index percentiles by age for the 1950 birth cohort and differences by birth cohort and survey period (men *top panel*; women *bottom panel*).

1980 and 2007, we demonstrate large increases in the skew of the distribution in urban Australian adults across age and time. Along with confirming that BMI has increased across the entire distribution of BMI, we show that the rate of increase in BMI in the 90th percentile is between three and four times greater than that in the 10th percentile. The strong birth cohort effect suggests that the prevalence of obesity and severe obesity in middle-aged adults may continue to increase, with the proportion of the 1980 birth cohort

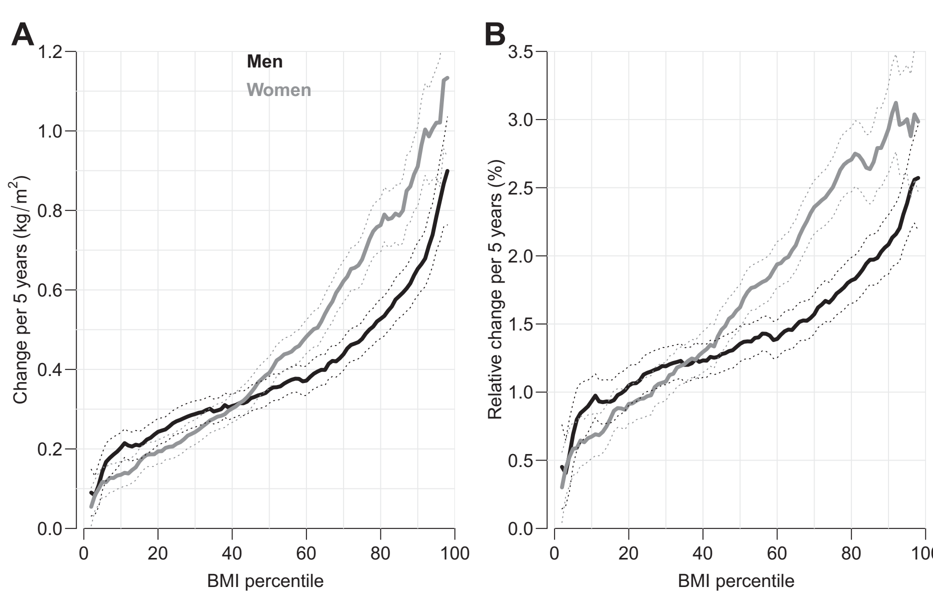

Fig. 3. Absolute (A) and relative (B) 5-year (date of birth/calendar time) changes in BMI across quantiles of the body mass index distribution.

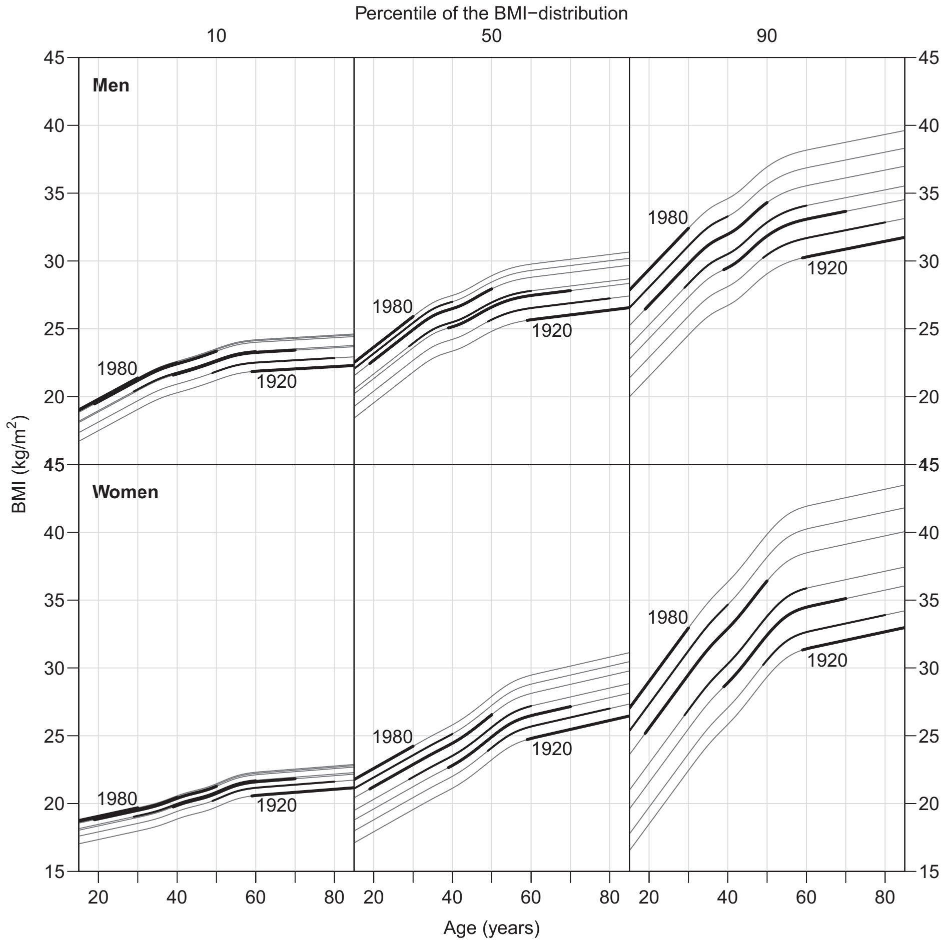

Fig. 4. Predicted percentiles of BMI for birth cohorts 1920, 1930, …, 1980, by age (men *top panel*; women *bottom panel*). The *solid line* sections are the ages represented in the observed data.

obese at age 25 years already threefold higher than for the 1960 birth cohort.

The trends we observed were apparent in both men and women, with some sex-specific differences, suggesting a greater increase in skew over time for women. We observed strong BMI trends across both age and time. Although it is well recognized that the three elements of an age–period–cohort model are not uniquely distinguishable, this pertains to the parameterization of the model. However, there are no problems in relation to the fitted values from the models, they will be the same regardless of the chosen parameterization.

Allman-Farinelli et al [5] similarly demonstrated using data from the Australian National Health Surveys in 1990, 1995, and 2000 that age, period, and cohort were independent contributors to increases in BMI in Australian adults. They estimated changes in the prevalence of overweight and obesity; here we extend this and model the entire BMI distribution from survey data at six times between 1980 and 2007. We also see that each of age, period, and cohort are independent predictors of increases in BMI. Although the three effects cannot be disentangled, our findings suggest the nonlinear component of calendar time is limited, and that nonlinear cohort effects are most prominent among women, where in particular the upper percentiles seem to increase faster for cohorts born after 1950. In particular, we found an increasing spread by birth cohort; the later birth cohorts have a wider spread of the BMI distribution, leading to considerably more right skew, and this was most pronounced among women. Broadly speaking, the leanest half of the population has seen a moderate increase in BMI, whereas the top 10%–25% most obese part of the population has seen a dramatic increase in BMI from generation to generation. The period of observation (1980–2007) is however too short to see whether this is a continuing trend or if the observed increases in the younger ages of the more recent birth cohorts will continue in the same ways as among the older cohorts. If the latter is the case, we can expect to see more than 10% men and 15% women with a BMI more than 35kg/m^2 in middle age.

Other studies have also used national cross-sectional survey series to estimate age and birth cohort effects on BMI. They have similarly demonstrated increases in mean BMI with increasing age and birth cohort, but none have analyzed the entire BMI distribution [15,16]. The major strength of this study is the availability of measured height and weight from seven national surveys spanning the period 1980 to 2007. This enables a detailed description of the nature of the trends across the BMI distribution, allowing a description of not only the trends in mean, but also other key distribution characteristics; in this case, in particular, the spread and the skew of the distribution. This has enabled us to describe the large increases in severe obesity observed over the past decades. These data, extending previous Australian analyses to 2007, also give no suggestion of a slowing of the rate of increase in BMI or obesity prevalence in the most recent period. Although this is different to a number of countries where there are suggestions of a slowing in the increase in obesity prevalence in adults [17], it is

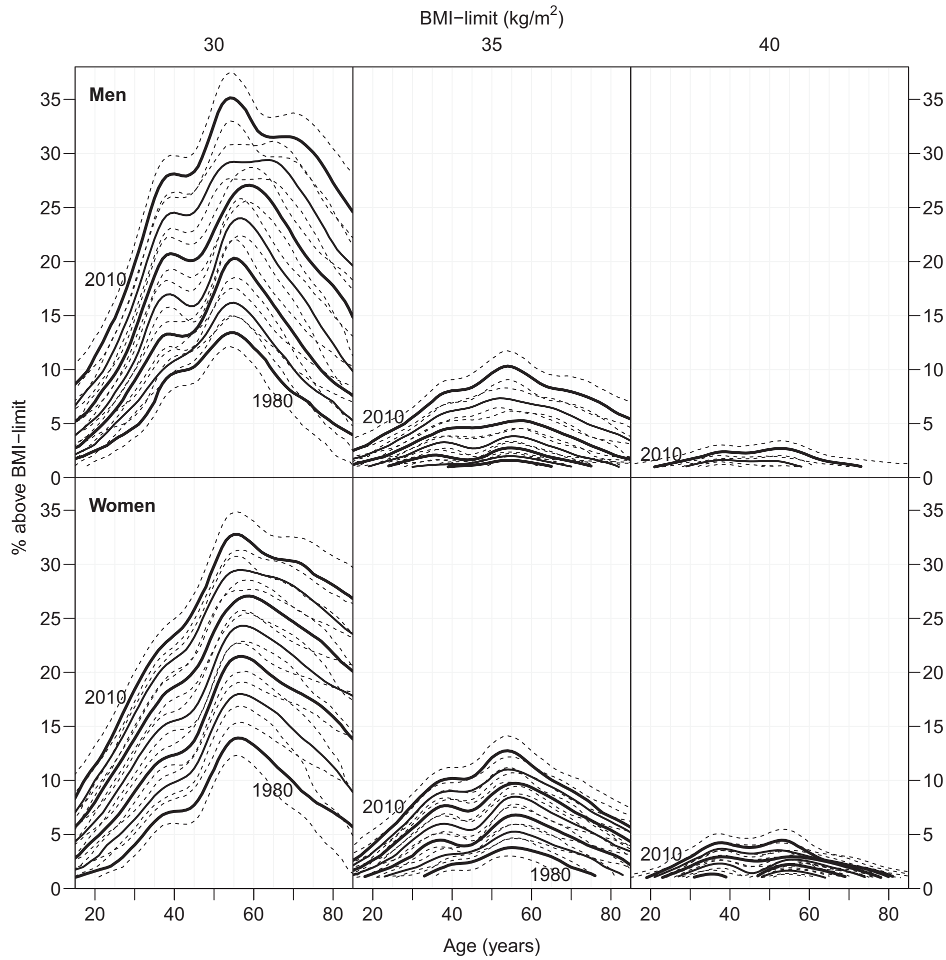

Fig. 5. Age-specific prevalence of BMI in excess of 30, 35 or 40 kg/m^2 at the dates 1980, 1985, …, 2010 (men *top panel*; women *bottom panel*). *Solid lines* represent the median from a bootstrap sample of 1000, with *dotted lines* representing the 95% confidence intervals.

supported by the latest data released by the Australian Bureau of Statistics in 2012 [18].

A study such as this does, however, not provide causative explanations for the observed trends. The survey populations were broadly similar according to country of birth and educational status, with large decreases in smoking status over time. However, we are unable to determine potential differences in ethnicity and other markers of socioeconomic disadvantage such as income. Consequently, we cannot use these data to predict future changes in the distribution of BMI or prevalence of obesity and severe obesity. However, it is clear from the available data that the continued aging of the current population is likely to lead to increases in the prevalence of both obesity and severe obesity in coming decades.

The response fractions of the surveys ranged from 37% to 91%. However, the known healthy responder bias means that any trend and prevalence reported from these national surveys is likely to be an underrepresentation. In addition, we restricted this analysis to urban adult Australians as the first three surveys were only conducted in capital cities. Once again, this is likely to lead to our analysis being an underestimation of the true increases in BMI and right skew as the prevalence of obesity is known to be higher in rural areas. Finally, we confined our analysis to BMI, as waist circumference has only been measured since 1989 in national surveys. As we have demonstrated that a substantial proportion of those with abdominal obesity are not identified through a BMI of 30 kg/m^2 an age–period–cohort analysis of BMI and waist circumference combined would be of interest [19].

The implications of these results are to further underscore the need to intervene to prevent weight gain across the life course and for the entire population. At the same time, the more rapid increase in BMI with increasing BMI demonstrates the need to increase our efforts to prevent further weight gain in those living already with overweight or obesity. It is also important to continue to understand the cause of the increasing right skew. The implications of the rapid increases in severe obesity for our health care system are substantial. It is well recognized that weight loss maintenance is difficult and in severe obesity requires intensive intervention, through a combination of behavioral, medical, and surgical methods. Finally, these results suggest that monitoring of trends in healthy weight, overweight, and obesity will not be a good proxy for likely increases in severe obesity. It is important to ensure that trends in severe obesity are also routinely analyzed.

In conclusion, in this analysis of a series of national surveys spanning 1980 to 2007 we demonstrate large increases in the right skew of the BMI distribution for urban Australian adults, and birth cohort effects suggest that similar increases are likely to continue. These results underscore the need to prevent weight gain across the life course at the same time as working to prevent further weight gain in those already living with overweight and obesity. It is

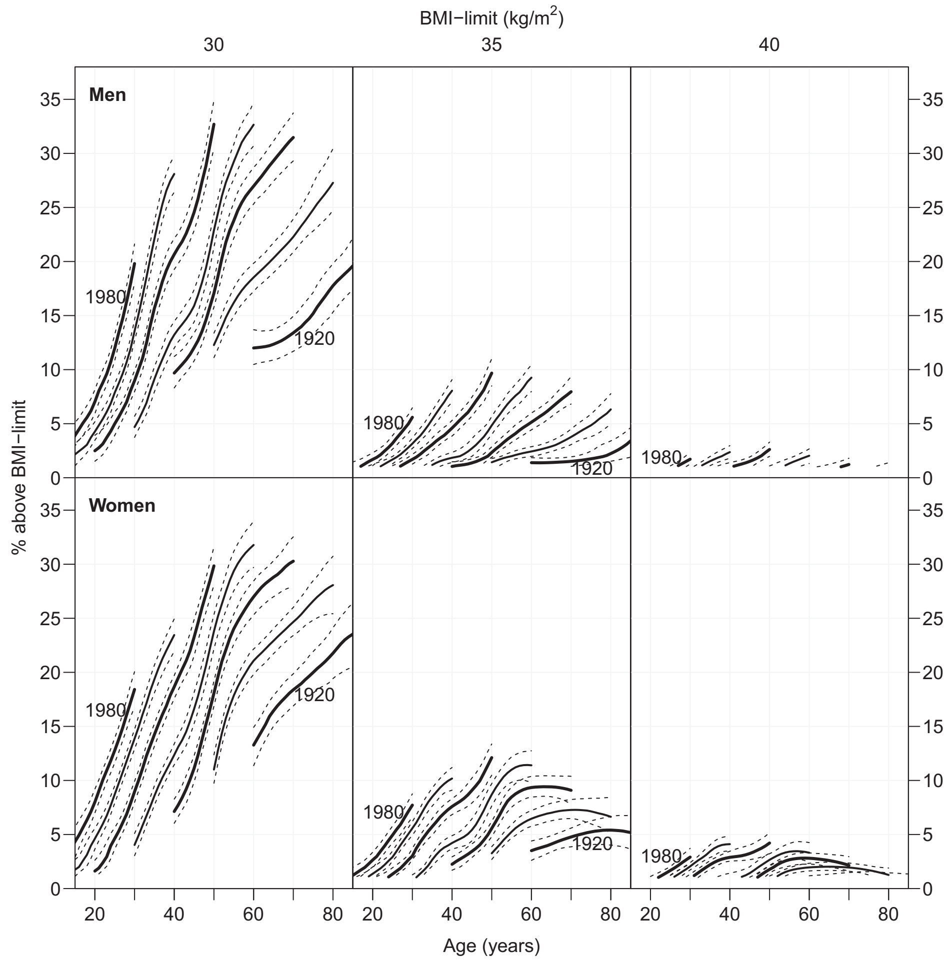

Fig. 6. Age-specific prevalence of BMI in excess of 30, 35 or 40 kg/m^2 in the birth cohorts 1920, 1930, …, 1980 (men *top panel*; women *bottom panel*). *Solid lines* represent the median from a bootstrap sample of 1000, with *dotted lines* representing the 95% confidence intervals.

important that the rapid increase in severe levels of obesity is not overlooked through the use of overly simplistic descriptions of changes in the prevalence of healthy weight, overweight, and obesity as our sole monitoring tools.

Acknowledgments

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