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Original Research

Age-dependent changes in the risk of weight gain in Chinese adults: results from the Kailuan cohort study

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ABSTRACT

Objectives: Over the past decades, China has seen a dramatic epidemic of overweight and obesity. However, the optimal period for interventions to prevent overweight/obesity in adulthood remains unclear, and little is known regarding the joint effect of sociodemographic factors on weight gain. We aimed to investigate the associations of weight gain with sociodemographic factors, including age, sex, educational level, and income.
Study design: This was a longitudinal cohort study.
Methods: This study included 121,865 participants aged 18–74 years from the Kailuan study who attended health examinations over the period 2006–2019. Multivariate logistic regression and restricted cubic spline were used to evaluate the associations of sociodemographic factors with body mass index (BMI) category transitions over two, six, and 10 years.
Results: In the analysis of 10-year BMI changes, the youngest age group had the highest risks of shifting to higher BMI categories, with odds ratio of 2.42 (95% confidence interval 2.12–2.77) for a transition from underweight or normal weight to overweight or obesity and 2.85 (95% confidence interval 2.17–3.75) for a transition from overweight to obesity. Compared with baseline age, education level was less related to these changes, whereas gender and income were not significantly associated with these transitions. Restricted cubic spline analyses suggested reverse J-shaped associations of age with these transitions.
Conclusions: The risk of weight gain in Chinese adults is age dependent, and clear public healthcare messaging is needed for young adults who are at the highest risk of weight gain.

Introduction

Overweight and obesity have become a major global public health problem,[1,2] with more than 1.9 billion adults having overweight and more than 650 million adults having obesity worldwide in 2016.[3] Between 1975 and 2016, the global prevalence of obesity in adults increased from 3% to 11% in men and from 6% to 15% in women.[4] Alongside the rapid economic and demographic shifts that have occurred in China, the prevalence of obesity has been increasing, rising from 3.1% in 2004 to 8.1% in 2018.[5,6] It is predicted that the prevalence of overweight/obesity in Chinese adults will reach 65.3% by 2030.[7] Obesity is a recognized risk factor for major non-communicable diseases,[8] including cardiovascular disease, diabetes, and cancer,[9,10] and is also associated with higher risks of osteoarthritis, sleep apnea, kidney disease, hepatobiliary disease, and depression.[11,12] This emphasizes the importance of identifying and modifying the factors that determine the onset and progression of overweight and obesity.

A large number of studies have shown that the risk factors for overweight and obesity include an unhealthy diet, physical inactivity, certain medications, and inadequate sleep, which interact

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with genetic susceptibility to cause weight gain and ultimately lead to overweight and obesity.[13–15] However, the critical period for controlling risk factors for overweight and obesity in adulthood remains unclear. Although preliminary observations suggest that young adults are at a higher risk of weight gain than older people,[16] available evidence is lacking from Asian countries accounting for the majority of the global population. In addition, there have been no large-scale cohort studies analyzing the associations of weight gain with age and other important sociodemographic characteristics in China.

In the present study, we used longitudinal data from a large population-based cohort study to examine the joint effect of age, sex, educational level, and income on the risk of weight gain in China.

Material and methods

Study population

The Kailuan study is an ongoing community-based prospective cohort study in Tangshan, China. The detailed study design and procedures have been described previously.[17,18] From 2006 to 2007, employees of the Kailuan Group were recruited to participate in comprehensive biennial health examination at 11 hospitals affiliated with the Kailuan Group. Data were obtained by questionnaire interview, physical examination, and laboratory tests. Participants were eligible for inclusion in this study if they attended at least two health examinations in Kailuan between 2006 and 2019. The exclusion criteria were a diagnosis of pregnancy or viral hepatitis during the follow-up period, age ≥75 years, and missing body mass index (BMI) values at the beginning or end of all three follow-up intervals.

The Ethics Committee of Kailuan Hospital approved this cohort study, and written informed consent was provided by all the participants.

Assessment of sociodemographic variables

Sociodemographic characteristics used in these analyses, including age, sex, family monthly income, and educational level, were obtained using data from the questionnaires at each health examination. We regarded the time at which each participant first attended for a medical examination as the baseline, and according to the ages of the participants at baseline, they were placed into six age groups: 18–24, 25–34, 35–44, 45–54, 55–64, and 65–74 years. With respect to socio-economic status, the educational level of the participants was categorized as primary or below, secondary, or tertiary or above; and family monthly income was categorized as <¥1000, ¥1000–¥3000, or >¥3000.

Assessment of BMI status

For each participant, height and body weight are measured by trained medical staff according to standardized methods. The measurements of height and body mass were made to precisions of 0.1 cm and 0.1 kg, respectively. BMI was calculated as body weight (kilogram) divided by height (meter) squared. The classification of BMI was based on the World Health Organization guidelines (underweight, BMI <18.5 kg/m^2; normal weight, BMI 18.5–24.9 kg/m^2; overweight, BMI 25.0–29.9 kg/m^2; and obesity, BMI ≥30 kg/m^2).[19] We used the baseline BMI and the BMI measurements made at subsequent visits two, six, and 10 years after initial physical examination for the assessment of transitions between BMI categories.

Assessment of covariates

Data regarding covariates were collected using questionnaires and laboratory tests at a health examination and updated every two years. These included smoking status, alcohol consumption status, physical activity, the use of antidiabetic drugs or diuretics, self-reported medical history (of hypertension, diabetes, atherosclerotic cardiovascular disease [ASCVD], chronic kidney disease, and cancer), and total serum cholesterol and triglyceride concentrations. Participants who currently smoked (smoked cigarettes in the past 30 days) or with a history of smoking (smoked ≥100 cigarettes in lifetime) were defined as smokers (i.e. ever-smokers), and those who currently drank (alcohol consumption at least three times per week and more than one cup of alcohol each time during the last month) or who had a history of drinking (alcohol consumption a month ago) were defined as drinkers (i.e. ever-drinkers).[20] Physical activity was defined using a frequency of exercise of more than three times a week, with a duration of >30 min on each occasion. ASCVD was defined using a history of myocardial infarction or stroke. Participants were evaluated after an eight hour fast using calibrated equipment, and the total cholesterol and triglyceride concentrations were measured using an automated analyzer (Hitachi 747, Hitachi, Tokyo, Japan).

Statistical analysis

We summarized baseline characteristics of the participants by follow-up interval and presented them as mean (standard deviation) or median (interquartile range) for continuous variables and number (percentage) for categorical variables. While the longitudinal transitions of BMI status are diverse, the focus of our study is on the onset and progression of overweight and obesity, diseases with shared pathophysiology and adverse long-term clinical consequences. Thus, two unhealthy BMI transition statuses in each time interval were examined in our study: transition from underweight or normal weight to overweight or obesity and transition from overweight to obesity. We used multivariate logistic regression models to calculate odds ratios (ORs) and corresponding 95% confidence intervals (CIs) for the relationships of age and other sociodemographic factors (sex, educational level, and income) with transition to higher BMI categories over two year, six year, and 10 year periods, with adjustment for the potential confounders. In addition to mutual adjustments for sociodemographic factors, the covariates that were also included in the model were baseline BMI, smoking status, drinking status, physical activity, myocardial infarction, stroke, hypertension, diabetes, chronic kidney disease, cancer, the use of diuretics and antidiabetic drugs, and the total cholesterol and triglyceride concentrations. To further illustrate the correlation between age and BMI status transitions in the three time intervals, we also used a restricted cubic spline with four knots located at the 5th, 35th, 65th, and 95th percentiles to flexibly model the possible non-linear relation. The maximum age was chosen as a reference.

Moreover, we performed subgroup analyses according to smoking status (smoker vs non-smoker), drinking status (drinker vs non-drinker), and physical activity (physical activity vs physical inactivity). To assess the robustness of our findings, we performed a series of sensitivity analyses. First, we did a complementary analysis using classification of BMI based on the Chinese criteria (underweight, BMI <18.5 kg/m^2; normal weight, BMI 18.5–23.9 kg/m^2; overweight, BMI 24.0–27.9 kg/m^2; obesity, BMI ≥28 kg/m^2).[21] Second, we excluded individuals with ASCVD at baseline. Third, we excluded individuals with diabetes or hypertension at baseline. Fourth, we excluded individuals with chronic kidney disease at baseline. Fifth, we excluded individuals with cancer. Sixth, to maximize statistical power and minimize bias that might occur if participants who attend only one health examination were excluded from analyses, we repeated our analyses with the data sets with imputed variables from multiple imputation by chained equations. Finally, we also conducted a sensitivity analysis without excluding participants aged ≥75 years. Data analyses were conducted using SAS software (version 9.4, SAS Institute, Cary, NC, USA). Two-sided statistical testing was performed, and $P < 0.05$ was considered to represent statistical significance.

Results

Participant characteristics

Of the 132,540 participants who attended at least two health examinations in Kailuan between 2006 and 2019, a total of 121,865 individuals of age 18–74 years were finally included in the study (Fig. 1). The demographic and clinical characteristics of participants are presented in Table 1. Participants for whom an assessment of the change in BMI status over 10 years could be made had a mean (standard deviation) age of 48.30 (11.42) years, and there was a higher proportion of men (61,891 [82.40%]) than women (13,216 [17.60%]). The mean (standard deviation) BMI of the participants was 24.92 (3.35) kg/m^2. Most of them had secondary education (63,308 [84.29%]), 30,656 (40.82%) had hypertension, and 5999 (7.99%) had diabetes.

Sociodemographic factors and the BMI status transitions

In multivariate logistic regression analyses, we found that the transition to higher BMI categories was most strongly associated with age (Fig. 2). Young participants aged 18–24 years were at the highest risk of transitioning to the higher BMI categories. Over the 10-year follow-up period, the adjusted OR for the transition from the underweight or normal weight to the overweight or obesity in the youngest group (18–24 years) was 2.42 (95% CI, 2.12–2.77) in comparison with individuals aged 65–74 years. The absolute risk of the transition from the underweight or normal weight BMI category to the overweight or obesity BMI category increased from 21.16% for the 65–74 years age group to 40.62% for the 18–24 years age group. In addition, we observed the weak obesity-depressing

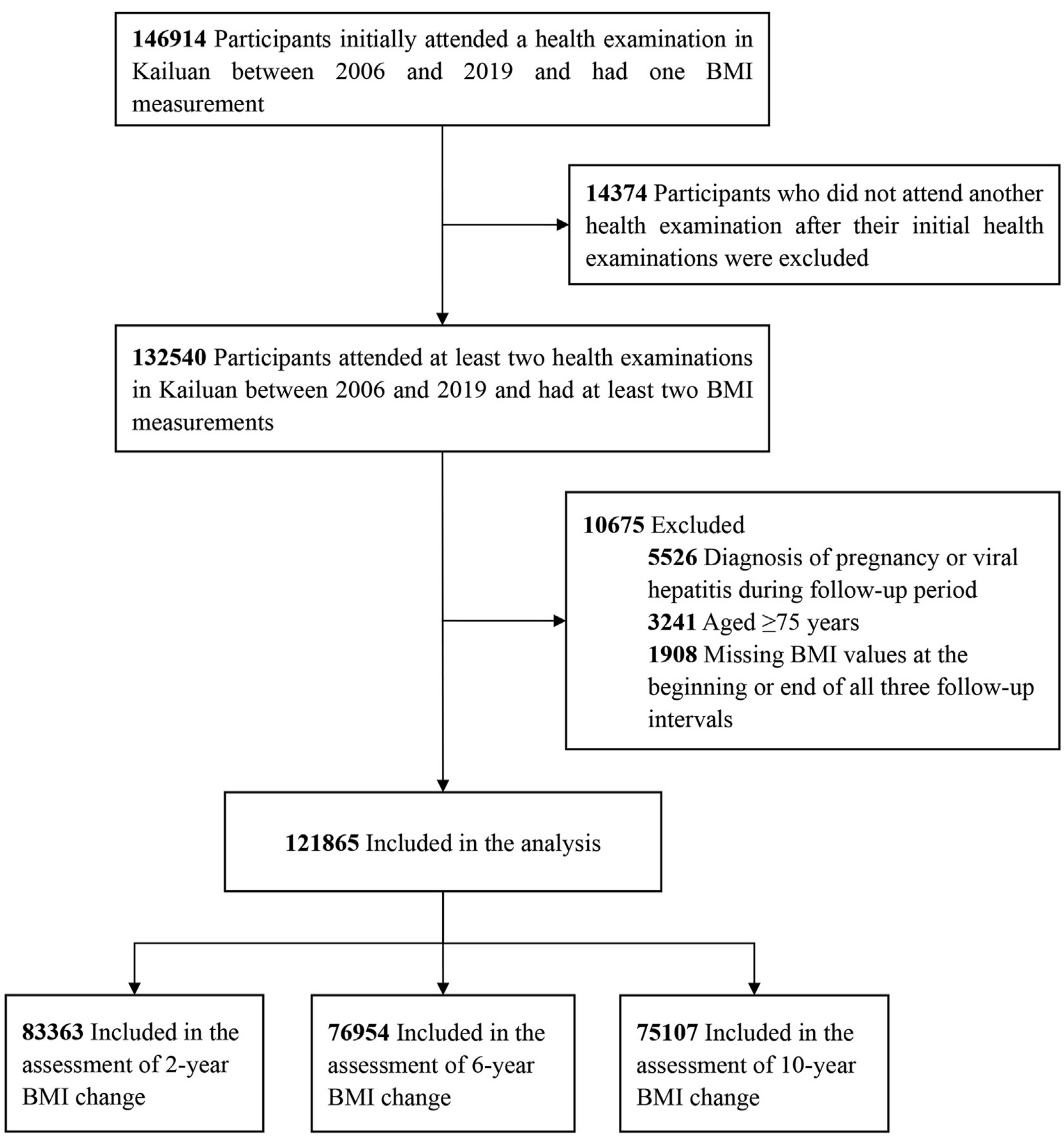


Fig. 1. Flowchart of enrollment of participants in this study. We regarded the time at which each participant first attended for a medical examination as the baseline and respectively included individuals with follow-up intervals of 2, 6, and 10 years since their initial medical examinations.

Table 1
Characteristics of the participants at baseline.

Characteristics	2-year BMI change (n = 83,363)	6-year BMI change (n = 76,954)	10-year BMI change (n = 75,107)
Age (years)	46.73 (12.12)	47.25 (11.95)	48.30 (11.42)
18–24	3882 (4.66)	3299 (4.29)	2612 (3.48)
25–34	11,462 (13.75)	9739 (12.66)	7764 (10.34)
35–44	20,034 (24.03)	18,431 (23.95)	16,617 (22.12)
45–54	27,441 (32.92)	24,713 (32.11)	26,425 (35.18)
55–64	14,718 (17.66)	15,677 (20.37)	16,808 (22.38)
65–74	5826 (6.99)	5095 (6.62)	4881 (6.50)
Sex			
Female	12,642 (15.17)	12,581 (16.35)	13,216 (17.60)
Male	70,721 (84.83)	64,373 (83.65)	61,891 (82.40)
BMI (kg/m^2)	24.85 (3.36)	24.91 (3.36)	24.92 (3.35)
<18.5	2019.0 (2.42)	1785.0 (2.32)	1688.0 (2.25)
18.5–24.9	42,222 (50.65)	38,550 (50.09)	37,517 (49.95)
25.0–29.9	33,452 (40.13)	31,186 (40.53)	30,639 (40.79)
≥30.0	5670.0 (6.80)	5433.0 (7.06)	5263.0 (7.01)
Education level			
Primary or below	5690 (6.83)	5856 (7.61)	5925 (7.89)
Secondary	69,364 (83.21)	64,606 (83.95)	63,308 (84.29)
Tertiary or above	8309 (9.97)	6492 (8.44)	5874 (7.82)
Family monthly income, ¥			
<1000	21,204 (25.44)	18,738 (24.35)	19,013 (25.31)
1000–3000	40,226 (48.25)	37,908 (49.26)	36,398 (48.46)
>3000	21,933 (26.31)	20,308 (26.39)	19,696 (26.22)
Lifestyle			
Smoke	33,239 (39.87)	29,568 (38.42)	28,311 (37.69)
Drink	34,859 (41.82)	31,707 (41.20)	30,764 (40.96)
Physical activity	12,225 (14.66)	11,659 (15.15)	11,515 (15.33)
Prevalence of chronic diseases			
Myocardial infarction	655 (0.79)	684 (0.89)	683 (0.91)
Stroke	997 (1.20)	936 (1.22)	875 (1.17)
Hypertension	32,415 (38.88)	30,874 (40.12)	30,656 (40.82)
Diabetes	6734 (8.08)	6069 (7.89)	5999 (7.99)
Chronic kidney disease	83,444 (10.13)	8977 (11.67)	8952 (11.92)
Cancer	227 (0.27)	199 (0.26)	213 (0.28)
Antidiabetic drugs	1607 (1.93)	1546 (2.01)	1509 (2.01)
Diuretics	676 (0.81)	659 (0.86)	721 (0.96)
TC (mmol/L)	4.89 (1.11)	4.91 (1.12)	4.93 (1.12)
TG (mmol/L)	1.27 (0.87–1.94)	1.27 (0.89–1.94)	1.28 (0.90–1.95)

BMI, body mass index; TC, total cholesterol; TG, triglyceride.
Data are presented as mean (standard deviation), median (interquartile range), or n (%).

effect of education. Education level (most educated vs least educated OR, 0.75; 95% CI, 0.66–0.84) was less associated with this transition. However, sex (men vs women OR, 1.05; 95% CI, 0.98–1.12) and income (most affluent vs least affluent OR, 0.99; 95% CI, 0.93–1.05) were not significantly associated with this change.

In terms of the progression from overweight to obesity, the adjusted OR for the transition from the overweight to the obesity in the youngest group (18–24 years) was 2.85 (95% CI, 2.17–3.75) compared with the 65–74 years age group. The absolute risk of the transition from the overweight to the obesity category increased from 6.22% for the 65–74 years age group to 21.34% for the 18–24 years age group. As expected, the age-related patterns to the transition to higher BMI categories over two and six years were broadly similar to that identified over 10 years, except for the transition from the underweight or normal weight to the overweight or obesity category over two years (Supplementary Table S1 and Table S2). Furthermore, the restricted cubic spline model showed a reverse J-shaped or U-shaped dose–response relationship between age and the risk of the transition to higher BMI categories across the three time intervals (all P-non-linearity <0.001; Fig. 3, Supplementary Figure S1 and Figure S2).

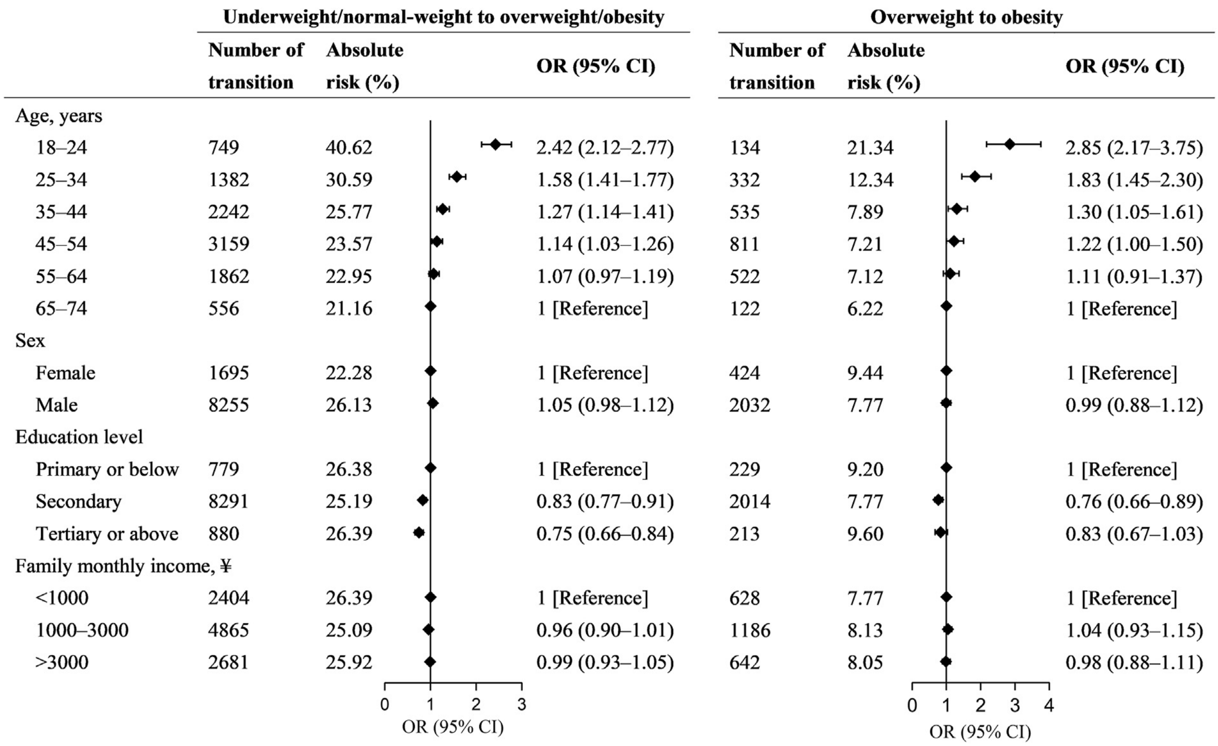
Subgroup and sensitivity analysis

The subgroup analyses performed according to smoking status, drinking status, and physical activity generated similar results to the main analysis (Supplementary Table S3–Table S5). Sensitivity analyses showed no substantial changes in the findings. Compared with our main model, similar results were obtained when BMI was classified according to the Chinese criteria (Supplementary Table S6). In addition, the estimated associations did not alter dramatically when individuals with several chronic diseases were excluded separately (Supplementary Table S7–Table S10). The results were generally consistent with the main analysis when the missing data were imputed using multiple imputation by chained equations (Supplementary Table S11). The inclusion of participants aged ≥75 years did not significantly alter the results (Supplementary Table S12).

Discussion

In the longitudinal cohort study of Chinese adults, we found age-dependent changes in the risk of weight gain and the youngest adults (aged 18–24 years) had the highest relative and absolute risk of shifting to higher BMI categories. Compared with age, education level was less related to these transitions, whereas sex and income were not significantly associated with these changes. Therefore, community and healthcare strategies for the prevention and management of overweight and obesity should target young adults who are at the highest risk of weight gain.

The association between demographic factors and weight change has been extensively researched in several cohort studies. Consistent with our findings, other previous studies have also



	Underweight/normal-weight to overweight/obesity			Overweight to obesity		
	Number of transition	Absolute risk (%)	OR (95% CI)	Number of transition	Absolute risk (%)	OR (95% CI)
Age, years						
18–24	749	40.62	2.42 (2.12–2.77)	134	21.34	2.85 (2.17–3.75)
25–34	1382	30.59	1.58 (1.41–1.77)	332	12.34	1.83 (1.45–2.30)
35–44	2242	25.77	1.27 (1.14–1.41)	535	7.89	1.30 (1.05–1.61)
45–54	3159	23.57	1.14 (1.03–1.26)	811	7.21	1.22 (1.00–1.50)
55–64	1862	22.95	1.07 (0.97–1.19)	522	7.12	1.11 (0.91–1.37)
65–74	556	21.16	1 [Reference]	122	6.22	1 [Reference]
Sex						
Female	1695	22.28	1 [Reference]	424	9.44	1 [Reference]
Male	8255	26.13	1.05 (0.98–1.12)	2032	7.77	0.99 (0.88–1.12)
Education level						
Primary or below	779	26.38	1 [Reference]	229	9.20	1 [Reference]
Secondary	8291	25.19	0.83 (0.77–0.91)	2014	7.77	0.76 (0.66–0.89)
Tertiary or above	880	26.39	0.75 (0.66–0.84)	213	9.60	0.83 (0.67–1.03)
Family monthly income, ¥						
<1000	2404	26.39	1 [Reference]	628	7.77	1 [Reference]
1000–3000	4865	25.09	0.96 (0.90–1.01)	1186	8.13	1.04 (0.93–1.15)
>3000	2681	25.92	0.99 (0.93–1.05)	642	8.05	0.98 (0.88–1.11)

Fig. 2. Absolute risks and odds ratios of shifting to higher BMI categories over 10 years. Odds ratios were additionally adjusted for baseline BMI, smoking status, drinking status, physical activity, myocardial infarction, stroke, hypertension, diabetes, chronic kidney disease, cancer, the use of diuretics and antidiabetic drugs, total cholesterol, and triglycerides. BMI, body mass index.

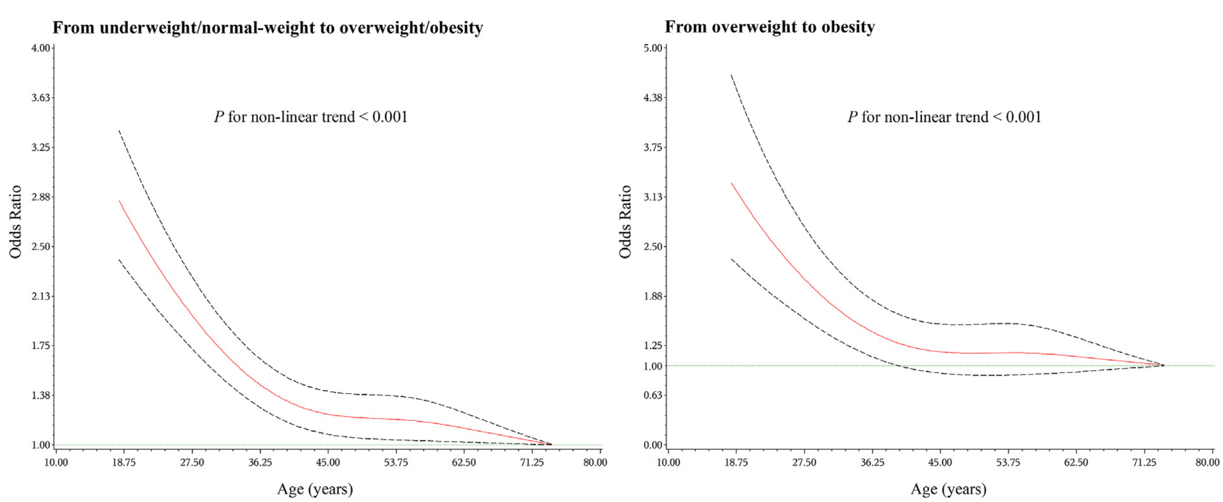


Fig. 3. Restricted cubic spline of the association between age and BMI status transition over 10 years. Solid lines indicate odds ratios, and dashed lines indicate 95% CIs from restricted cubic spline regression. The association was adjusted for gender, educational level, income, baseline BMI, smoking status, drinking status, physical activity, myocardial infarction, stroke, hypertension, diabetes, chronic kidney disease, cancer, the use of diuretics and antidiabetic drugs, total cholesterol, and triglycerides. The maximum age (74 years) was chosen as a reference. CI, confidence interval.

shown that young people are at a higher risk of weight gain than older people. An epidemiological study of the US CARDIA cohort revealed that weight gain is greatest among people in their 20s.[22] Caman et al.[23] showed in a Swedish cohort that the increase in BMI with increasing age is higher in younger individuals than in older individuals. A longitudinal study of an Austrian cohort by Peter et al.[24] showed that body weight increases between 20 and 70 years of age, with the largest increase occurring in men aged 20–25 years. However, most of these previous studies that focused on only one or a limited number of sociodemographic factors did not involve the collection of information necessary to assess several risk factors or use self-reported weight which is associated with the risks of reporting or recall bias. The present study, conducted in a large Chinese population–based cohort and involving long-term follow-up, has the strength that numerous accurate and reliable BMI measurements were made, and this has extended previous findings by evaluating the joint effect of four significant sociodemographic factors (age, sex, educational level, and income) on the change in BMI category.

The population-based longitudinal study conducted in the United Kingdom, similar in design to the present study, has reported similar findings.[16] However, we did not identify evident associations between age and the transition from underweight or normal weight to the overweight or obesity category over the two year follow-up period. This may be attributed to the short-term changes in weight being more susceptible to multiple factors.[13] Additional studies are warranted to better elucidate the short-term effects of age on weight gain in Chinese population. Although the magnitude of the decrease in OR associated with weight gain with increasing age appears to differ according to discrepancies in geographical region and demographic characteristics of study population, both the present study and the UK study have demonstrated that young adults are at the highest risk of weight gain, which emphasizes that future prevention strategies for overweight and obesity should focus on young adults.

The mechanisms underlying the higher risk of weight gain in young adults remain unclear, but there are several possible explanations. First, at the population level, obesity is primarily driven by environmental effects that diminish the ability of people to make decisions regarding their own behavior.[25] Young adults confront unique challenges in their living environment, and numerous beverage and fast-food companies target young people, increasing their access to high-calorie foods.[26] In contrast, older people may follow more traditional lifestyles and have higher dietary fiber consumption. In addition to the physical environment, interpersonal relationships have an impact on the weight status of young adults and their willingness to lose weight.[27] Young adults with overweight or obesity tend to have more overweight friends, relatives, and romantic partners than their peers who are not overweight.[28] When living in these obesogenic environments, it may be challenging to maintain a healthy weight. Furthermore, at the individual level, a poor lifestyle with respect to diet and physical activity contributes to weight gain in an increasing number of individuals. Most young people have unhealthy dietary habits, including substantial consumption of fast food and sugary drinks and more frequent binge eating.[29–31] In addition, physical inactivity by young people because of a lack of time, motivation, and social support would further increase this weight gain.[32–34]

The findings of the present study have important clinical and public health implications. Data obtained during the Global Burden of Overweight and Obesity Study show that the prevalence of overweight and obesity is lower in young people than in older adults, but that weight gain is most rapid in those aged 20–40 years.[35] Our findings also show that the risk of weight gain is higher in young people than in older people. Thus, most adults are at high risk for overweight and obesity in early adulthood (18–44 years) rather than in late adulthood. Clinical studies have shown that the use of various weight loss interventions, including lifestyle interventions, medication, and bariatric surgery, are associated with huge challenges to the maintenance of this weight loss over time, despite good short-term outcomes.[36–38] Therefore, the prevention of obesity is particularly important in early adulthood before the onset of obesity. Moreover, weight gain between early and mid-adulthood is associated with higher risks of morbidity and mortality related to several chronic diseases in later life, including type 2 diabetes, cardiovascular disease, cancer, and non-traumatic death.[39,40] Our findings advocate for efforts to prevent overweight and obesity to extend to younger people to reduce the lifetime risk for developing major non-communicable diseases.

This study has several limitations. First, although many potential confounders were adjusted for in our analysis, we were unable to directly adjust for psychological disorders because those important covariates were not available in the Kailuan study. These and other unmeasured factors may cause residual confounding. Second, an additional limitation was the lack of consideration of dietary patterns. However, many obesogenic drivers could have distal effects on obesity.[41] For example, income inequality and chronic diseases might convert to higher obesity prevalence through a number of pathways, such as through changes in dietary patterns and psychosocial effects. Hence, dietary patterns might be mediators rather than confounders of age-dependent changes in BMI increase, which merit further study. Finally, the participants were all employees and retirees of the Kailuan Group and were mostly male. The homogeneity of geographical region and ethnicity may help minimize confounding and enhance the internal validity, but this would limit the generalizability of the findings.

Conclusions

The risk of weight gain in Chinese adults is age dependent. Young adults were found to be at significantly higher risk of weight gain than older age groups. Early adulthood may be the optimal timing for overweight and obesity prevention interventions. These findings underscore the importance of providing young adults with clear public health information because they may underestimate their risk of weight gain and imply that young adults should adhere to obesity prevention strategies and individual weight management interventions.

Author statements

Acknowledgments

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Ethical approval

The Ethics Committee of Kailuan Hospital approved this cohort study, and written informed consent was provided by all the participants. This study was conducted in accordance with Helsinki Principles. Data obtained from all participants were kept confidential.

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Competing interests

None declared.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhe.2023.03.004.

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